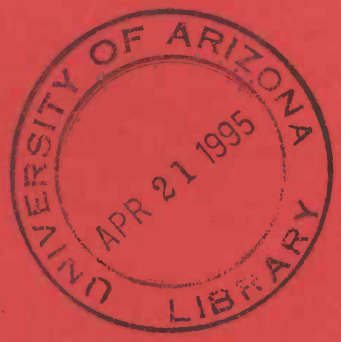
VOLUME 36 / NUMBER 3 / 1994

Radiocarbon

An International Journal of Cosmogenic Isotope Research



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ISSN: 0033-8222

RADIOCARBON
An International Journal of Cosmogenic Isotope Research

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Published by
Department of Geosciences
The University of Arizona

Published three times a year at The University of Arizona, Tucson, AZ 85712 USA.

Subscription rate (1995): $115.00 (for institutions), $85.00 (for individuals), $42.50 (for students with proper identification). Foreign postage is extra. A complete price list, including Proceedings of International Conferences, special publications and 1995 subscription categories, appears in the back of this issue. Back issues may be obtained by contacting *RADIOCARBON*.

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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.

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FROM THE EDITORS

TO OUR FRIENDS (CONTINUED)

With reserved euphoria, we report the success of our subscription and fund-raising campaign. The added income combined with cost-cutting reductions have eliminated our short-term deficit. An upward trend has begun and we are determined to keep it that way. We sincerely appreciate the warm words of encouragement and generous financial support in terms of new subscriptions, laboratory packages, purchases of books and full sets of *RADIOCARBON*, lifetime subscriptions and donations. We are indebted to our Associate Editors for their commitment, and to our Board of Governors, especially outgoing Chair, Clement G. Chase, whose "gentle persuasion" and support yielded positive results.

Although we can report that our short-term deficit of $26,000 has been turned into a short-term surplus of some $22,000, caution still needs to be exercised. Our projections indicate that revenue will remain at a healthy rate, which will allow us to commit salaries for one year in advance, as our institution prefers. Taking these encumbrances into account, the journal will break even. We will continue to monitor our budget and approach new endeavors with discretion.

With much regret, we were forced to replace Kimberley Tanner with a part-time student employee. A capable person such as she is, Kim was able to find an excellent position elsewhere on campus. We wish her well and will miss her.

The reason for the reservation is that we must continue our efforts to serve the radiocarbon community, and the community must continue its support. Here are some of what you can expect from us soon:

- Glasgow ^{14}C Conference issue
- Glasgow Liquid Scintillation Conference volume
- Tree-Ring Conference volume
- Expanded Internet Resources, including, if funding permits, a ^{14}C soil database
- PAGES Workshop issue
- ^{14}C Dynamics in Soils issue
- Carbon in the Oceans issue

Finally, despite many years of publishing research articles, and an amendment to the journal's name, we are still laboring under a stigma of being only a repository of ^{14}C dates. We feel the only way to shed this image, yet maintain the journal's momentum, is to publish only peer-reviewed research articles. Beginning with Volume 37, 1995, future issues will contain only research articles, as we will publish date lists electronically. Date lists will still be available, however, in journal format, upon request. With our new Consulting Editor, Tim Jull, to whom we owe much gratitude for helping save our "sinking ship", and a new tool kit for Associate Editors, we will more aggressively solicit papers that deal with new trends in applications and techniques of cosmogenic isotopes.

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

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RADIOCARBON recognizes the following for their generous contributions beyond their regular subscription orders:

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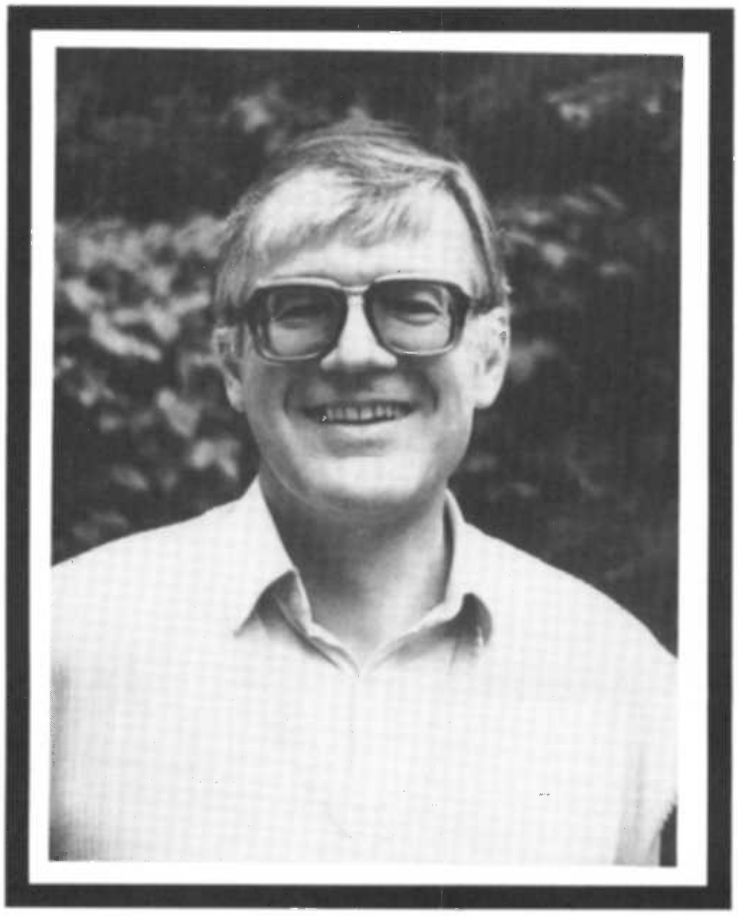

ULRICH SIEGENTHALER, 1941–1994

On 15 July 1994, Ulrich Siegenthaler, Professor at the Physics Institute in Bern, Switzerland, died at the age of 53. We lost an excellent scientist and a good friend and colleague.

His research may be characterized by the two words, *interdisciplinarity* and *quality*. He was an expert in various fields. He was, for example, interested in the global carbon cycle and the greenhouse effect, in climate change and the role of the ocean and the biosphere, in the global water cycle and in isotope hydrology. In some of these fields, he was active in an experimental way, and in other fields, in a theoretical way, as a modeler.

The high quality of Uli Siegenthaler's research is visible in:

- his many publications in reputed journals. One example is the famous article on the box diffusion model that he wrote with Hans Oeschger in 1975;
- his engaged activity in various national and international committees. He participated in JGOFS, SCOPE, IGBP, IPCC and others;
- his shared knowledge as an advisor for journals such as *Tellus* and *Climate Dynamics*. For many years, he was an Associate Editor of *RADIOCARBON;*
- his election as a Fellow of the American Geophysical Union for the year 1994.

One consequence of his broad and active research interests were the many friends gathered all over the world. I think that the friendships are even more important than the number of papers that he had published. Uli was welcome in many universities and institutes in Switzerland and abroad. Twenty years ago, he was the guest, for one year, of Joel Gat at the Weizmann Institute in Rehovot, where he worked on isotopic fractionation during the evaporation of precipitation. He later visited Karl Otto Münnich in Heidelberg for several months, and Jorge Sarmiento, at Princeton. Uli collaborated with other physicists, as well as biologists, botanists, chemists, oceanographers and geologists. And he was not only appreciated by scientists from far and wide; everybody within his group and in the Institute liked him as a partner in discussions. Students also liked his quiet, kind and friendly manner.

We, who all lost a good friend, will remember mainly these characteristics of friendly discussions. Although his scientific scale was at a high level, and he could be critical, his advice was always constructive and helpful. Therefore, we will remember Uli Siegenthaler as a brilliant scholar, and at the same time, as a very dear colleague. Let's hope that we, ourselves, may continue in his style, and always take the time, besides our work, for friendship among colleagues in a peaceful atmosphere.

Heinz Hugo Loosli

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Radiocarbon

1994

ON THE ^{14}C AND ^{39}Ar DISTRIBUTION IN THE CENTRAL ARCTIC OCEAN: IMPLICATIONS FOR DEEP WATER FORMATION[1]

PETER SCHLOSSER,[2,3] BERND KROMER,[4] GOTE ÖSTLUND,[5] BRENDA EKWURZEL,[2,3] GERHARD BÖNISCH,[2] H. H. LOOSLI[6] and ROLAND PURTSCHERT[6]

ABSTRACT. We present $\Delta^{14}C$ and ^{39}Ar data collected in the Nansen, Amundsen and Makarov basins during two expeditions to the central Arctic Ocean (RV *Polarstern* cruises ARK IV/3, 1987 and ARK VIII/3, 1991). The data are used, together with published $\Delta^{14}C$ values, to describe the distribution of $\Delta^{14}C$ in all major basins of the Arctic Ocean (Nansen, Amundsen, Makarov and Canada Basins), as well as the ^{39}Ar distribution in the Nansen Basin and the deep waters of the Amundsen and Makarov Basins. From the combined $\Delta^{14}C$ and ^{39}Ar distributions, we derive information on the mean "isolation ages" of the deep and bottom waters of the Arctic Ocean. The data point toward mean ages of the bottom waters in the Eurasian Basin (Nansen and Amundsen Basins) of *ca.* 250–300 yr. The deep waters of the Amundsen Basin show slightly higher ^{3}H concentrations than those in the Nansen Basin, indicating the addition of a higher fraction of water that has been at the sea surface during the past few decades. Correction for the bomb ^{14}C added to the deep waters along with bomb ^{3}H yields isolation ages for the bulk of the deep and bottom waters of the Amundsen Basin similar to those estimated for the Nansen Basin. This finding agrees well with the ^{39}Ar data. Deep and bottom waters in the Canadian Basin (Makarov and Canada Basins) are very homogeneous, with an isolation age of *ca.* 450 yr. $\Delta^{14}C$ and ^{39}Ar data and a simple inverse model treating the Canadian Basin Deep Water (CBDW) as one well-mixed reservoir renewed by a mixture of Atlantic Water (29%), Eurasian Basin Deep Water (69%) and brine-enriched shelf water (2%) yield a mean residence time of CBDW of *ca.* 300 yr.

INTRODUCTION

Measurements of the radioactive isotope of carbon, ^{14}C, have frequently been used for determining circulation patterns and mean residence times of the deep and bottom waters in the world ocean (see, *e.g.*, Broecker *et al.* 1960, 1985; Münnich and Roether 1967; Stuiver, Quay and Östlund 1983). The application of ^{14}C in oceanographic studies is based on the conversion of the activity gradient between surface waters and deep waters into a mean *age* of the deep waters (see, *e.g.*, Broecker *et al.* 1991). During the past decades, a fairly good ^{14}C data set has been assembled for most major ocean basins. However, due to the limited access to ice-covered regions, the database for the Arctic Ocean has been comparably sparse for a long time, during which the only platforms for collection of ^{14}C data have been ice camps (see, *e.g.*, Östlund, Top and Lee 1982; Östlund, Possnert and Swift 1987). Only since the mid-1980s have we been able to collect ^{14}C data with good spatial resolution in the Arctic Ocean (for first results, see Schlosser *et al.* 1990, 1995).

The purpose of this contribution is to combine new ^{14}C data collected during two cruises of the German research icebreaker *Polarstern* to the central Arctic Ocean with those available in the literature to describe the ^{14}C distribution in the central Arctic Ocean. In addition, we present an ^{39}Ar data set

[1]This paper was presented at the 15th international Radiocarbon Conference, 15–19 August 1994, Glasgow, Scotland.

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from the Nansen, Amundsen and Makarov Basins, which we use to strengthen the conclusions drawn from the $\Delta^{14}C$ data; we also derive mean ages of the deep and bottom waters in the Arctic Ocean. Due to the limited data sets, some of our conclusions are preliminary. The final evaluation of the data, in combination with other steady-state and transient tracers, is beyond the scope of this paper, and will be presented in a follow-up study.

Description of the Data Set

The data set used in this paper consists of three parts: 1) A ^{14}C section collected during the 1987 crossing of the Nansen Basin by RV *Polarstern* (Fig. 1). These data, as well as the methods used for collection and measurement of large volume (LV) ^{14}C, accelerator mass spectrometry (AMS) ^{14}C and ^{39}Ar samples, have been described previously (Schlosser *et al.* 1990, 1995); 2) ^{14}C profiles and ^{39}Ar samples collected in the Nansen, Amundsen and Makarov Basins during the ARCTIC 91 expedition on board RV *Polarstern* (Fig. 1). The ^{14}C data from this cruise are exclusively high-precision

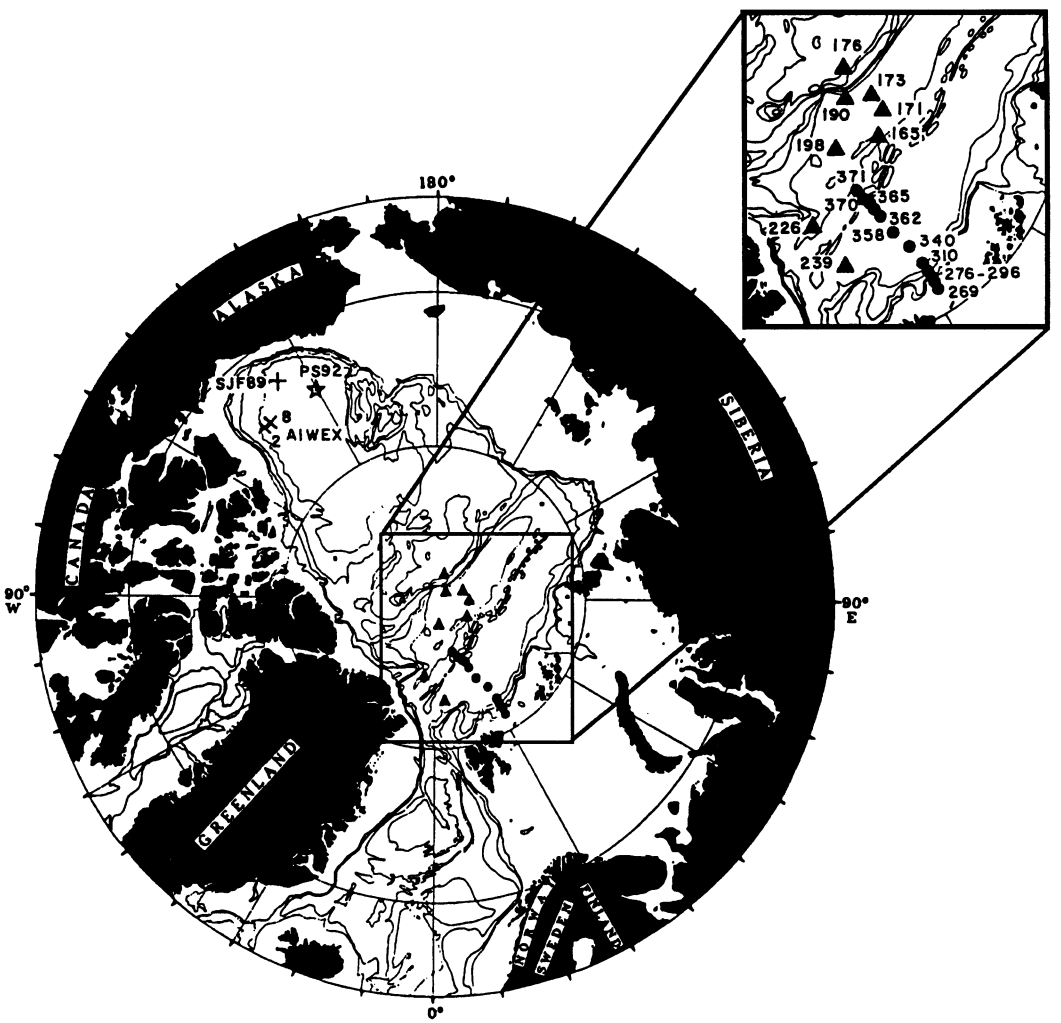

Fig. 1. Geographical position of the ^{14}C and ^{3}H stations in the Amundsen, Nansen, Makarov and Canada Basins

LV measurements performed in the ^{14}C laboratory of the University of Heidelberg. Sample collection and measurement procedures are identical to those used for the LV samples collected during the 1987 expedition and are described by Schlosser *et al.* (1995); 3) Three published ^{14}C profiles from the Canadian Basin (Makarov Basin: one profile (Östlund, Possnert and Swift 1987); Canada Basin: two profiles (Macdonald and Carmack 1991; Jones *et al.* 1994)). The ^{14}C data from the Makarov Basin are from the 1979 Lomonosov Ridge Experiment (LOREX) ice camp; LV measurements were made at the University of Miami. The data published by Macdonald and Carmack (1991) and by Jones *et al.* (1994) are AMS data collected during the 1989 CCGS *Sir John Franklin* cruise (SJF) and the 1992 USCG *Polar Star* cruise (PS 92). They were measured at the IsoTrace AMS laboratory of the University of Toronto and at the Woods Hole Oceanographic Institution National Oceanographic AMS facility, respectively. Figure 1 summarizes geographical positions of all stations.

The ^{3}H measurements used to indicate the penetration of bomb ^{14}C into the water column were measured at the University of Heidelberg (ARK IV) and at the University of Miami (ARK VIII and Canada Basin Station SJF; Fig. 1). It is evident from Figure 1 that presently we have the best coverage for the Nansen and Amundsen Basins, whereas the database for the Canadian Basin is still fairly sparse. However, the new data from the ARCTIC 91 expedition presented below allow us, for the first time, to compare ^{14}C data from all major deep basins of the Arctic Ocean. Additionally, it provides the first ^{39}Ar data from the Canadian Basin.

Hydrographic Background

To provide background for the discussion of the ^{14}C data, we briefly summarize the main hydrographic features of the Arctic Ocean, following the work of Aagaard, Swift and Carmack (1985). We use their section of potential temperature, salinity and potential density across the Iceland-Greenland-Norwegian Seas and the Arctic Ocean (for geographic position of the stations in this section, see Fig. 2). The focus of the description will be on the Arctic Ocean portion of the section.

The hydrographic section across the Arctic Ocean (north of Fram Strait) is dominated by three water masses: 1) upper waters; 2) Atlantic-derived water; and 3) deep water. The upper waters are divided into the Polar mixed layer (PML; 30–50 m deep) and the halocline (*ca.* 30–50 to *ca.* 200 m deep; Fig. 3). The PML is cold (temperatures close to the freezing point) and fresh due to the impact of Arctic river runoff. The halocline consists of water advected into the interior basins from the Arctic shelves where it is preconditioned by sea-ice formation during winter (see, *e.g.*, Aagaard, Coachman and Carmack 1981). Jones and Anderson (1986) used nutrient measurements in addition to T/S considerations to distinguish between upper halocline waters (UHW: $S \approx 33.1$) originating in the Bering and Chukchi Seas, and lower halocline waters (LHW: $S \approx 34.2$) produced most likely in the Barents and Kara Seas.

The Atlantic-derived water underlies the halocline waters. It is defined as the layer with temperatures above 0°C, and is typically found at depths ranging from *ca.* 200–800 m. The deep waters below the Atlantic derived waters are relatively low in potential temperature (≈ -0.95°C in the Eurasian Basin and ≈ -0.5°C in the Canadian Basin) and high in salinity (≈ 34.945 at 3000 m depth in the Eurasian Basin and ≈ 34.955 at the same depth in the Canadian Basin). Smethie *et al.* (1988) divide the deep waters of the Nansen Basin into Eurasian Basin Deep Water (EBDW: $32.921 < S < 34.927$; -0.96°C $< \Theta < -0.70$°C) and Eurasian Basin Bottom Water (EBBW: $34.930 < S < 34.945$; -0.95°C $< \Theta < -0.94$°C). The reason for the freshness of the Eurasian Basin deep waters is probably linked to exchange of deep waters with the Norwegian and Greenland Seas. The density gradient in the Arctic Ocean water column is strongest in the halocline and weakest in the deep waters of the Canadian Basin (see σ_3 section in Fig. 3).

Fig. 2. Geographical position of the stations used to construct the section plotted in Fig. 3 (from Aagaard *et al.* 1985; © by the American Geophysical Union).

Results

Nansen Basin

The $\Delta^{14}C$ profiles from the 1987 Nansen Basin section are divided into three groups representing the southern, central and northern Nansen Basin, respectively (Fig. 4). Each group of profiles is further divided into a plot displaying the entire water column (Figs. 4A–C) and a plot of the deep waters (depth >1500 m; Figs. 4D–F). The $\Delta^{14}C$ profiles show several characteristic features: 1) The surface water $\Delta^{14}C$ values increase from south (≈ 50–80‰; Figs. 4A–B) to north (≈ 120‰; Fig. 4C). This increase reflects the higher fraction of river runoff in the surface waters of the northern part of the section (Schlosser *et al.* 1994; Bauch, Schlosser and Fairbanks 1995); 2) The average $\Delta^{14}C$ values in the core of the Atlantic-derived layer (maximum in potential temperature located at ≈ 200–300 m

depth) are fairly constant throughout the section (≈ 50‰); Figs 4A–C). The Atlantic-derived layer is eroded toward the north, which is reflected in the fairly thin water layer with $\Delta^{14}C$ values close to 50‰ (Fig. 4C); 3) Between the core of the Atlantic-derived water marked by the temperature maximum and the deep water (here defined as water below 1500 m depth), the $\Delta^{14}C$ values drop fairly

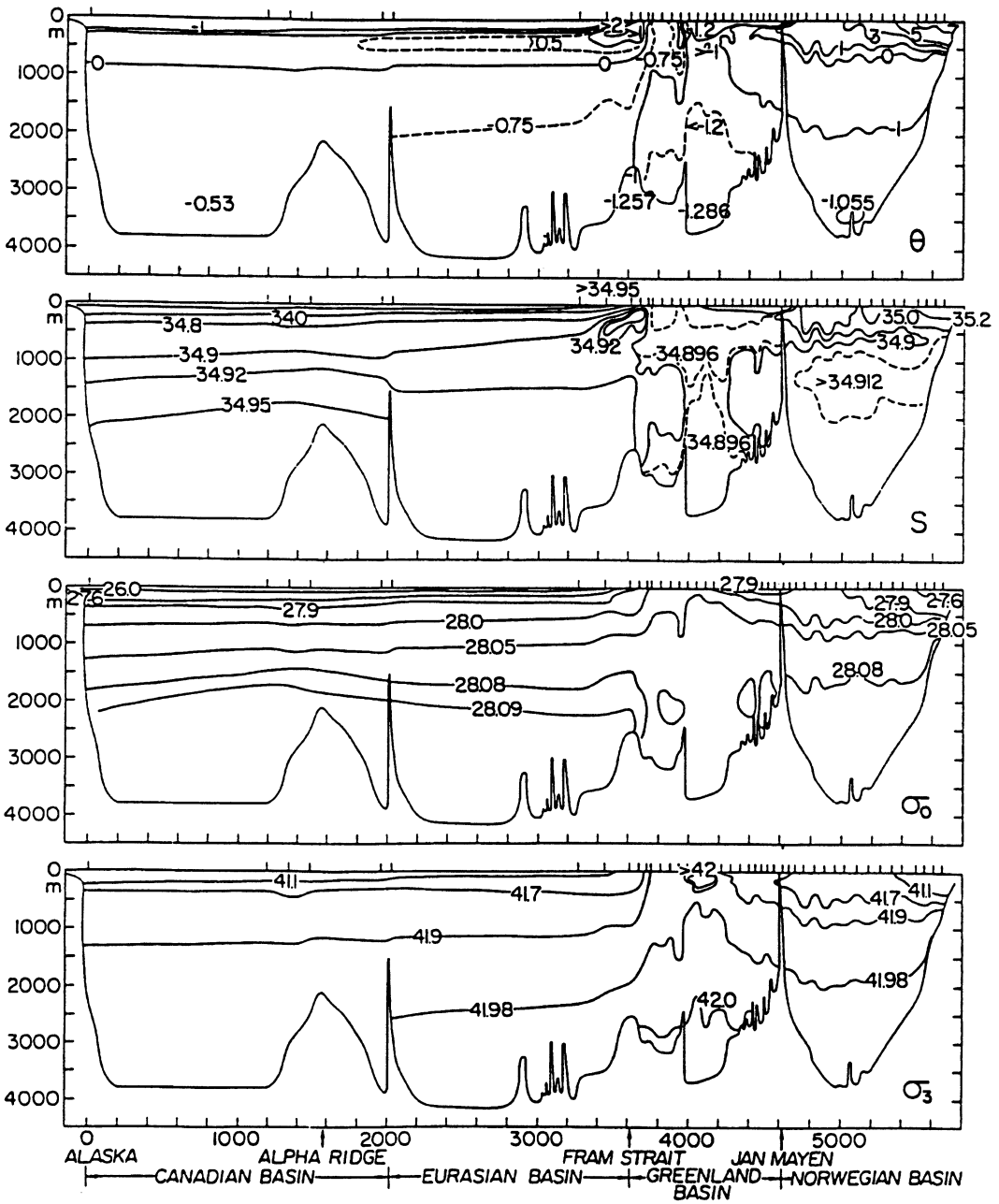

Fig. 3. Section of potential temperature (θ), salinity (S) and density (σ_0 and σ_3) along a section across the Greenland-Iceland-Norwegian Seas (from Aagaard *et al.* 1985; © by the American Geophysical Union).

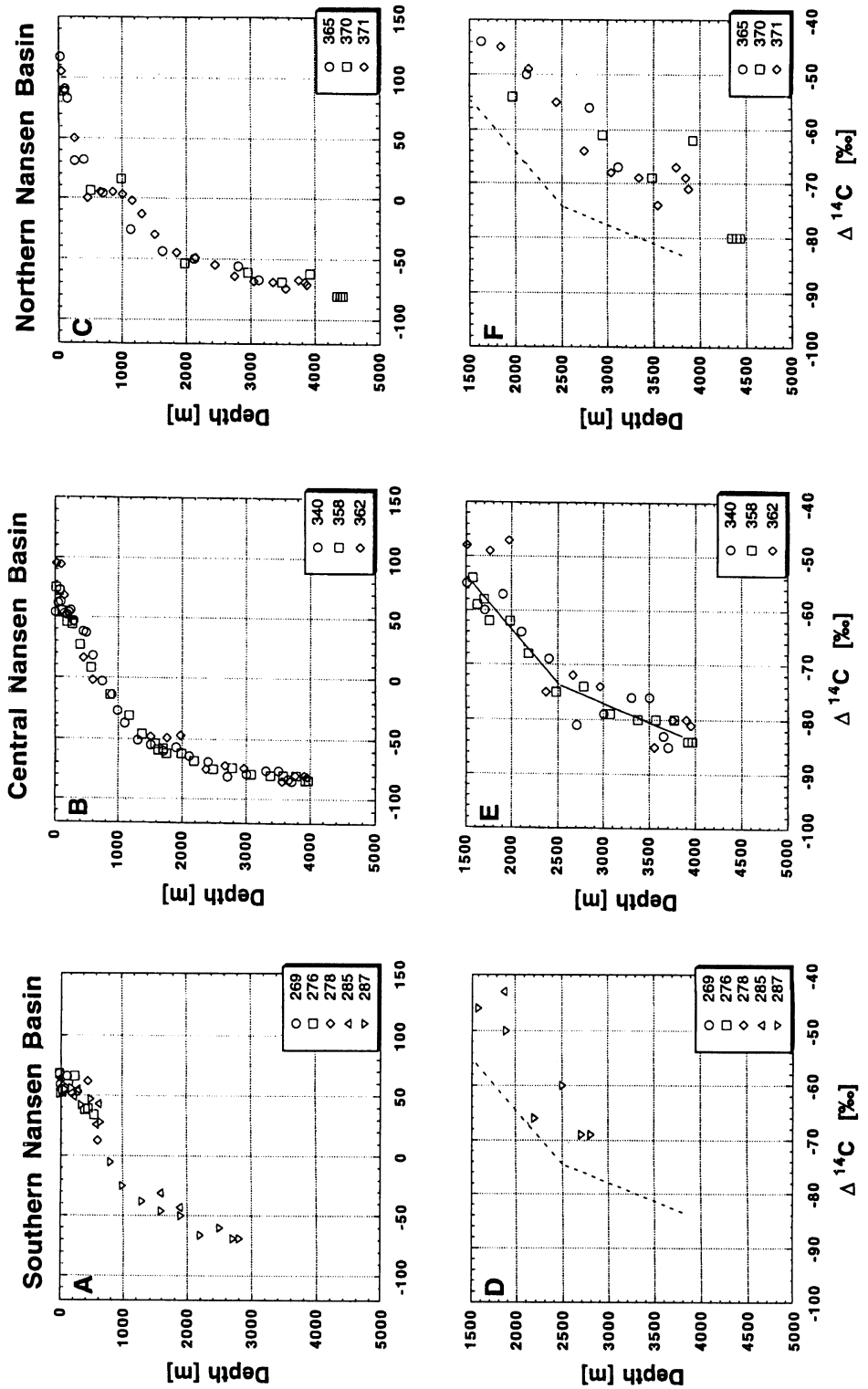

Fig. 4. A. $\Delta^{14}C$ profiles from the Southern; B. Central; C. Northern Nansen Basin (for geographical position of the stations, see Fig. 1); D–F. Deepwater column (≥1500-m depth) shown on an extended scale. - - - = shape of the $\Delta^{14}C$ profile in the Central Nansen Basin.

monotonically to values of *ca.* −50‰ in the southern and central Nansen Basin (Figs. 4A, B), whereas a clear inflection of water with somewhat higher $\Delta^{14}C$ values in the northern Nansen Basin centers at *ca.* 1000 m (Fig. 4C); 4) The $\Delta^{14}C$ profiles in the deep and bottom waters show a distinct break at *ca.* 2500 m in the central Nansen Basin (Fig. 4E). This depth coincides with the sill depth of Fram Strait. The break is not observed in the southern and northern Nansen Basin (Figs. 4D, F). The lowest $\Delta^{14}C$ values of the deep and bottom waters (≈ −80 to −85‰) are observed in the central Nansen Basin (Fig. 4E), whereas $\Delta^{14}C$ values in the bottom waters of the southern and northern parts of the section (Figs. 4D, F) are slightly higher (≈ −70‰). However, the bottom waters at Station 370 located in the trough of the Gakkel Ridge have $\Delta^{14}C$ values close to those in the central Nansen Basin.

The ^{3}H profiles (Fig. 5) from corresponding stations show features similar to those observed in the $\Delta^{14}C$ profiles. They are used as indicators of the penetration of bomb ^{14}C into the water column. The concentrations of ^{3}H in the bottom waters are higher in the northern and southern Nansen Basin (≈ 0.3 TU; Figs. 5D, F; 1 TU means a ^{3}H-to-hydrogen ratio of 10^{-18}) than in the central Nansen Basin (≈ 0.05 TU; Fig. 5E).

The ^{39}Ar data collected in the Nansen Basin show a constant decrease between surface waters (92% modern at Station 269) and bottom waters (46% modern at Station 358; Fig. 10). Resolution is not sufficient in the ^{39}Ar distribution to resolve potential lateral gradients in the Nansen Basin.

Amundsen Basin

The $\Delta^{14}C$ profiles available from the Amundsen Basin (Fig. 6) have the closest similarity to those of the northern Nansen Basin: 1) They show basically the same surface $\Delta^{14}C$ values of ≈ 120‰; 2) $\Delta^{14}C$ values are ≈ 50‰ in the Atlantic layer at *ca.* 250–300 m depth; 3) an inflection of waters with relatively high $\Delta^{14}C$ values is observed at *ca.* 1000 m depth (most pronounced at Station 190, located closest to the Lomonosov Ridge); and 4) $\Delta^{14}C$ values in the bottom waters are significantly higher (5–7‰) than those observed in the central Nansen Basin (Fig. 6B). Station 239 included in Figure 6 is actually located in the southern Nansen Basin just north of Fram Strait (Fig. 1). The $\Delta^{14}C$ values of this station are close to values observed in the deep central Nansen Basin. The $\Delta^{14}C$ profiles of the Amundsen Basin show a distinct break at a depth of *ca.* 3000 m. This feature is very similar to that observed in the central Nansen Basin, although at a slightly lower depth (3000 m compared to ≈ 2500 m; Fig. 6B). Only one full ^{3}H profile is available from the Amundsen Basin (Sta. 173; Fig. 7). It shows penetration of significant levels of bomb ^{3}H into the bottom waters (≈ 0.2 TU).

^{39}Ar concentrations in the deep Amundsen Basin range from 71% modern (Station 173; 1900-m depth) to 55% modern (Station 173; 4300-m depth; Fig. 10).

Makarov Basin

The only high-resolution $\Delta^{14}C$ profile available from the Makarov Basin is Station 176, occupied during the ARCTIC 91 expedition (Figs. 6A and 8A). In the upper 200 m, the structure is similar to that observed in the Nansen and Amundsen Basins. Below this depth, the $\Delta^{14}C$ values in the Makarov Basin are much lower throughout the water column than those in the Eurasian Basin (Nansen and Amundsen Basins). Below 2000 m depth, the $\Delta^{14}C$ values of the deep waters in the Makarov Basin are constant within the analytical precision of the ^{14}C measurement with a mean value of (−104 ± 3)‰. This value is in excellent agreement with the $\Delta^{14}C$ value of −104‰ obtained by from the 1979 LOREX ice camp at 2500 m depth (Östlund, Possnert and Swift 1987). The ^{3}H

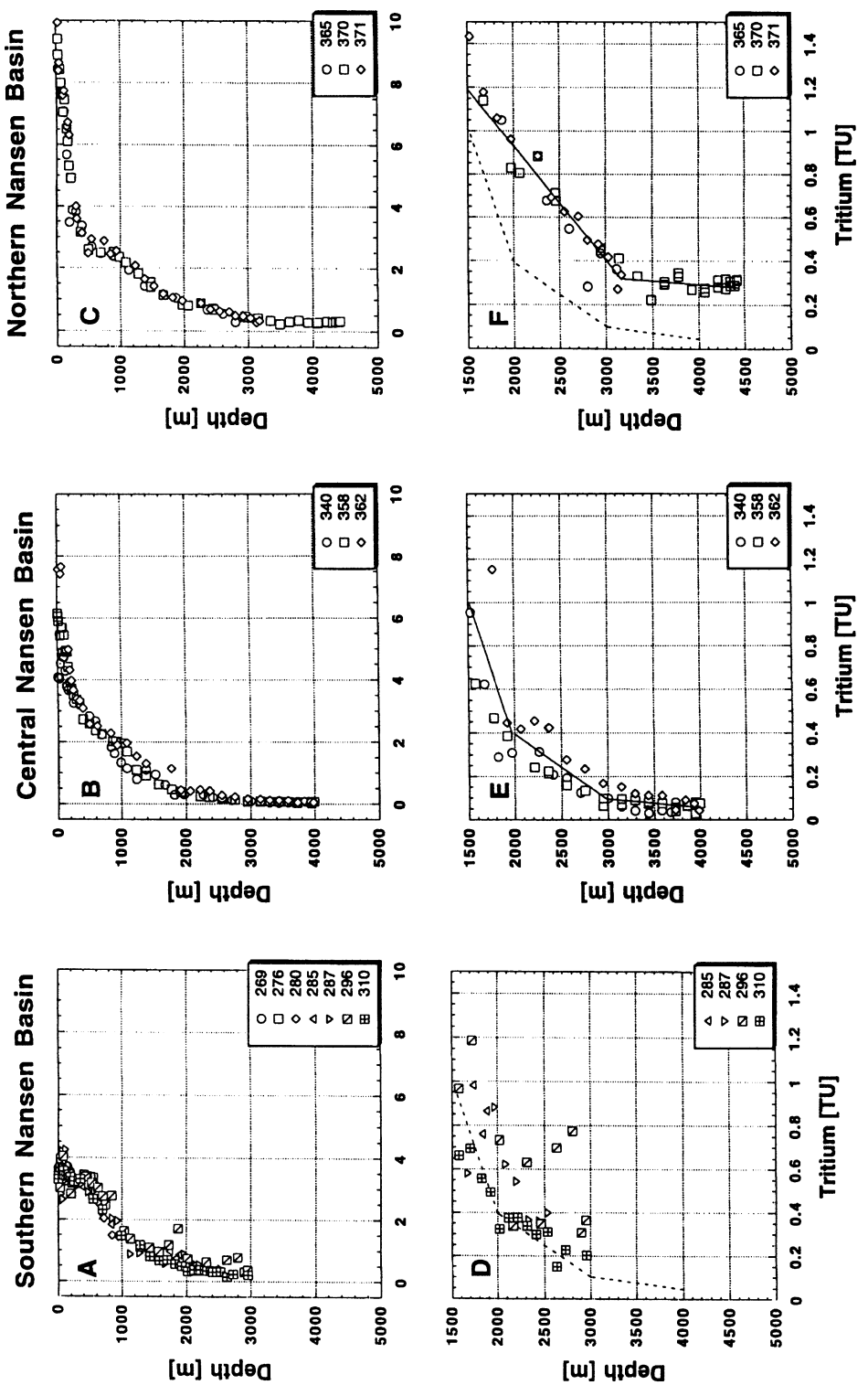

Fig. 5. ^{3}H profiles from the Southern (A), Central (B) and Northern (C) Nansen Basin (for geographical position of the stations, see Fig. 1); D–F. Deepwater column (≥1500 m depth) shown on an extended scale. —— in Figs. E and F = a subjective fit of the data; - - - in D and F = shape of the ^{3}H profile in the Central Nansen Basin.

profile from Station 176 (Fig. 7) indicates that no bomb ^{3}H penetrated below *ca.* 2000 m depth in the Makarov Basin.

^{39}Ar data from the deep Makarov Basin (Fig. 10) are close to 43% modern (range: 50 ± 5 to 35 ± 7% modern). These concentrations are the lowest observed in the Arctic Ocean (≈ 24% modern lower than those in the Eurasian Basin).

Canada Basin

The two $\Delta^{14}C$ profiles from the (southern) Canada Basin (Macdonald and Carmack 1991; Jones *et al.* 1994) show significantly lower surface $\Delta^{14}C$ values compared to the Eurasian and Makarov Basins (≈ 25‰ *vs.* ≈ 120‰; Fig. 8A). Below the surface waters, the $\Delta^{14}C$ values in the Atlantic-

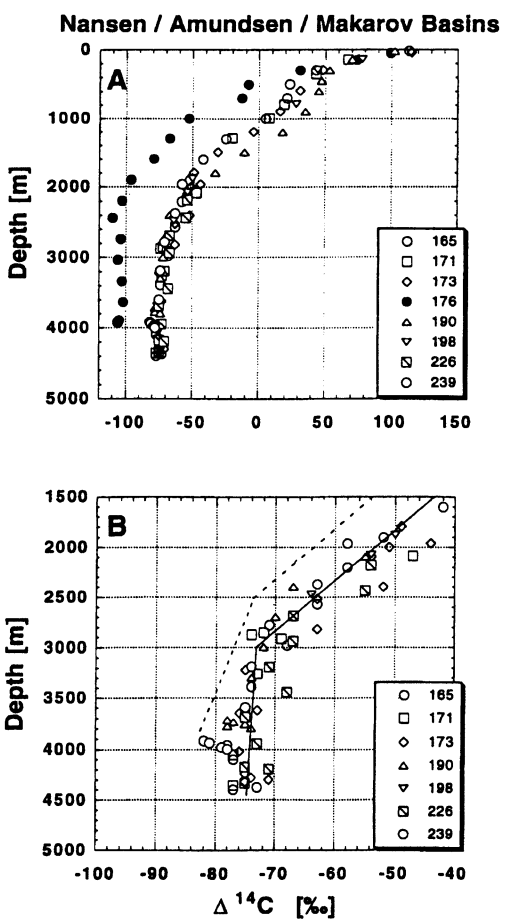

Fig. 6. A. $\Delta^{14}C$ profiles from the Nansen (Sta. 239), Amundsen (Stas. 165, 171, 173, 190, 198, 226) and Makarov (Sta. 176) basins of the Arctic Ocean (for geographical position of the stations, see Fig. 1); B. Deepwater column (≥1500-m depth) shown on an extended scale. —— = subjective fit of the data; - - - = mean $\Delta^{14}C$ profile observed in the Central Nansen Basin.

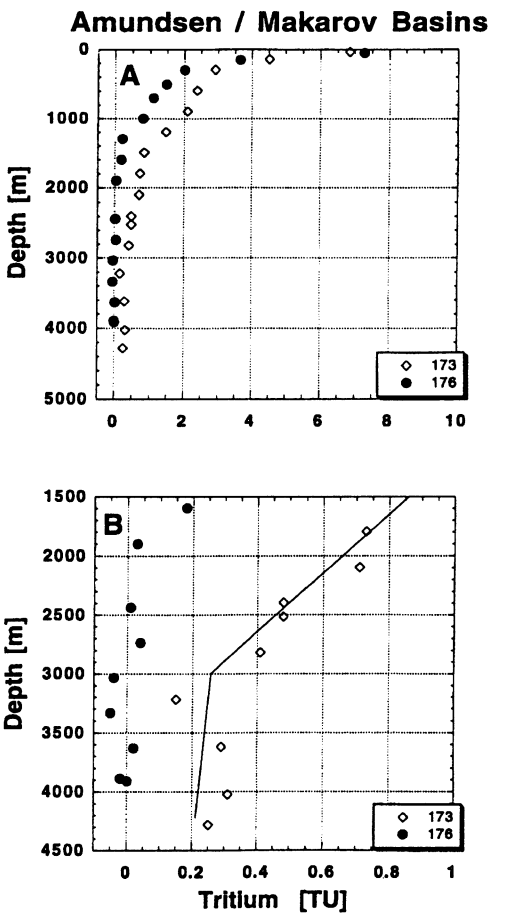

Fig. 7. A. ^{3}H profiles of two stations representative for the Amundsen (Sta. 173) and Makarov (Sta. 176) Basins of the Arctic Ocean (for geographical position of the stations, see Fig. 1). B. Deepwater column (≥1500-m depth) is shown on an extended scale.

derived layer are similar to those observed in the other basins of the central Arctic Ocean (≈ 50‰). Below the core of the Atlantic-derived water (≈ 200–300 m depth), the $\Delta^{14}C$ values in the Canada Basin are higher than those in the Makarov Basin. As in the case of the northern Nansen and the Amundsen Basins, an inflection of water with relatively high $\Delta^{14}C$ values seems to center at *ca.* 1000–1500 m depth. Below 2500 m depth, the $\Delta^{14}C$ values are constant throughout the water column with a mean $\Delta^{14}C$ value of *ca.* (−107 ± 5)‰ (Fig. 8B). This value changes to (−105 ± 2)‰, if one value of the SJF profile with an error of ± 18‰ (Macdonald and Carmack 1991) is omitted in the data set used for calculation of the mean value. The mean value for the waters below 2500 m in the Canada Basin is in excellent agreement with that observed in the waters below 2000 m in the Makarov Basin (−104 ± 3)‰ (see above). The few ^{3}H data available from the deep Canada Basin (Fig. 9) are consistent with those of the Makarov Basin, although the scatter around 0 TU is significantly higher in the Canada Basin than in the Makarov Basin.

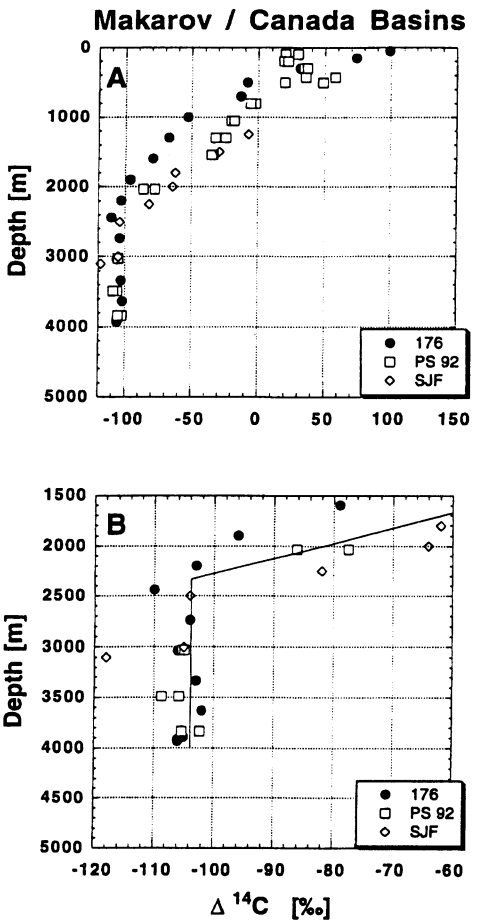

Fig. 8. A. $\Delta^{14}C$ profiles from the Makarov (Sta. 176) and the Canada Basin of the Arctic Ocean (for geographical position of the stations, see Fig. 1). B. The deepwater column (≥1500-m depth) is shown on an extended scale.

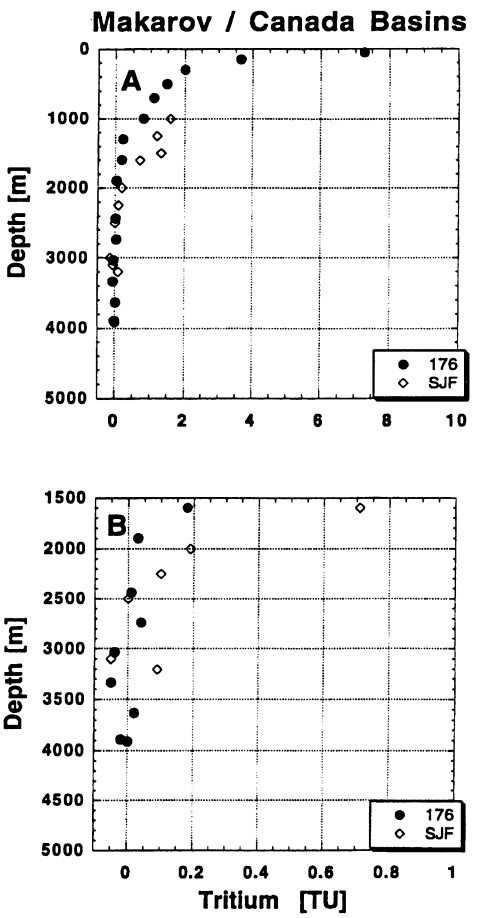

Fig. 9. A. ^{3}H profiles from the Makarov (Sta. 176) and the Canada Basin of the Arctic Ocean. The data from the Canada Basin are from a 1989 cruise of the SJF (Macdonald and Carmack 1991). For geographical position of the stations, see Fig. 1. B. Deepwater column (≥1500-m depth) is shown on an extended scale.

Discussion

Upper Waters

The upper waters are dominated by bomb ^{14}C. According to Östlund, Possnert and Swift (1987), pre-bomb $\Delta^{14}C$ values reached from *ca.* −48‰ in the shelf waters to −55‰ in the intermediate waters of the Arctic Ocean. Therefore, the water column contains significant fractions of bomb ^{14}C down to depths of *ca.* 1500–2000 m in all major basins (Figs. 4A–C, 6A, 8A). In the Eurasian Basin, traces of bomb ^{14}C can actually be found all the way to the bottom, as indicated by the presence of bomb ^{3}H (Figs. 5, 7, 9). The separation of the bomb ^{14}C signal from the natural ^{14}C signal in these waters is fairly difficult, and will not be attempted in the context of this contribution. We rather focus our effort on a purely descriptive treatment of the main features observed in the upper water column. However, for the deep waters, we present a semi-quantitative evaluation of the ^{14}C data below.

There is a pronounced $\Delta^{14}C$ gradient in the surface waters with a transition from low values in the southern Nansen Basin (≈ 50–70‰; Fig. 4A) to higher values in the northern Nansen Basin (≈ 80–120‰; Fig. 4C), the Amundsen Basin (≈ 100–120‰; Fig. 6A), and the Makarov Basin (≈ 120‰; Fig. 6A). The gradient reverses toward the southern Canada Basin, where surface $\Delta^{14}C$ values of only *ca.* 20–40‰ are observed (Fig. 8A).

The increase in surface $\Delta^{14}C$ in the Nansen, Amundsen and Makarov Basins is correlated with an increasing fraction of river runoff in the surface waters of those basins (see, *e.g.*, Schlosser *et al.* 1995; Bauch, Schlosser and Fairbanks 1995). The river runoff is also marked by high carbonate concentrations (see, *e.g.*, Anderson *et al.* 1989). A somewhat speculative interpretation of the high $\Delta^{14}C$ values in the river-runoff-tagged water is ^{14}C exchange of the surface and groundwaters feeding the Siberian Rivers with soil carbonates. Such a process would delay the input of ^{14}C from the bomb peak into the river runoff compared to open ocean surface waters, and would result in the observed high $\Delta^{14}C$ values in waters with high river runoff fractions.

$\Delta^{14}C$ values in the core of the Atlantic-derived water underlying the surface and halocline waters are fairly uniform (≈ 50‰) throughout the Arctic Ocean (Figs. 4, 6, 8). This feature seems to indicate that the bomb ^{14}C signal has been spread fairly homogeneously throughout this water layer during the past 25 yr, *i.e.*, the mean residence time of water in the Atlantic layer seems to be significantly faster than this time span.

Below the core of the Atlantic layer centered at *ca.* 300-m depth and the deep waters, $\Delta^{14}C$ values decrease monotonically in all basins to values of *ca.* −50‰ at depths of *ca.* 1500 m (central Nansen Basin) to *ca.* 2000 m in all other basins except the Makarov Basin, where the −50‰ isoline is at a much shallower depth of *ca.* 1000 m. This observation, together with the ^{3}H data, suggests that waters that have recently been in contact with the atmosphere penetrate less deeply in the Makarov Basin and the central Nansen Basin than in the other basins of the Arctic Ocean. The highest fraction of those recently ventilated waters at intermediate depth (1000–2000 m) is observed in the southern Canada Basin followed by the northern Nansen Basin and the Amundsen Basin. However, the ^{3}H data coverage of the Amundsen Basin is still very sparse, and firm conclusions have to wait until the $^{3}H/^{3}He$ data set has been completed. One might speculate that the recently ventilated intermediate waters correlated with a salinity maximum at *ca.* 600-m depth observed by Smethie *et al.* (1994) over the continental slope of the Laptev Sea are the source of the intermediate waters with relatively high $\Delta^{14}C$ and ^{3}H values found in the northern Nansen Basin, the Amundsen Basin and the southern Canada Basin. Such a scenario seems to be consistent with the circulation scheme that Rudels, Jones and Anderson (1994) proposed for the intermediate waters of the Arctic Ocean.

Deep Waters

Most of the deep waters of the Eurasian Basin contain a significant fraction of bomb ^3H ($\approx$ 0.05 TU in EBBW of the central Nansen Basin to $\approx$ 0.2–0.3 TU in EBBW of the Amundsen and Northern Nansen Basins; Figs. 5E, 5F, 7B). These waters then also contain a trace of bomb ^{14}C, preventing a straightforward conversion of their measured $\Delta^{14}C$ values into age information. However, $^3H/^{14}C$ correlations can be used to subtract the bomb ^{14}C from the observed $\Delta^{14}C$ values. The corrected $\Delta^{14}C$ values can then be converted into *isolation ages*. We define isolation age as the average time elapsed since the waters producing the deep waters have been isolated from exchange of ^{14}C with the atmosphere. The isolation age should not be confused with the *mean residence time* of a body of water. The mean residence time is a measure for the average time a water parcel spends in a certain reservoir of a deep basin, whereas the isolation age reflects the average time needed for surface waters to reach this deepwater reservoir. Consequently, the isolation age of a deep water reservoir can be significantly higher than its mean residence time.

Schlosser *et al.* (1995) have applied the above concept to the Nansen Basin. Here we summarize the main results of this study, which yielded isolation ages of *ca.* 150 yr for EBDW and *ca.* 250–300 yr for EBBW. These ages agree well with ^{39}Ar data and box model calculations tuned by transient and steady-state tracers (for details, see Schlosser *et al.* 1995; Bönisch and Schlosser 1995).

The deep waters of the Amundsen Basin have slightly higher $\Delta^{14}C$ values than those of the Nansen Basin ($\approx$ −72 to −75‰ compared to $\approx$ −75 to −83‰; Fig. 6B) which, if taken at face value, would translate into lower isolation ages. However, the higher ^3H concentrations of the deep waters in this basin require subtraction of a higher bomb ^{14}C component from the observed $\Delta^{14}C$ values. Using a $^3H/^{14}C$ correlation for the bottom waters of the Amundsen Basin extrapolated to a ^3H concentration of zero leads to a corrected $\Delta^{14}C$ value of *ca.* −85‰. This value is almost identical to that obtained for the bottom waters of the Nansen Basin, which means that the *old* component of EBBW in the Amundsen Basin, *i.e.*, the water free of surface water added during the past *ca.* 25 yr, has about the same isolation age as the EBBW in the central Nansen Basin. This is more-or-less free of bomb ^3H (Fig. 5E). The main difference between the two deep basins is the higher rate of addition of near-surface water tagged by transient tracers such as ^3H or bomb ^{14}C to the deep and bottom waters in the Amundsen Basin. This seems to result in slightly younger overall isolation ages (and mean residence times) of EBDW and EBBW in the Amundsen Basin compared to the Nansen Basin. This finding agrees well with the ^{39}Ar data. Quantification of this effect is beyond the scope of this contribution and will be done in combination with other tracer fields in a follow-up paper.

The deep waters of the Canadian Basin are practically ^3H-free at depths below *ca.* 2000 m (Makarov Basin) to 2500 m (southern Canada Basin; Fig. 9B). From this observation, we conclude that the contribution of bomb ^{14}C to these waters is negligible. Another remarkable feature of the ^{14}C distribution in the deep Canadian Basin is the homogeneous $\Delta^{14}C$ values. No detectable gradient in $\Delta^{14}C$ is present in the deep waters of the Makarov and southern Canada Basins, both vertically, at depths below 2000–2500 m, and laterally (Fig. 8B). The boundary below which the distribution of $\Delta^{14}C$ is extremely homogeneous coincides with the transition to a very weakly stratified water body (see σ_0 and σ_3 sections in Fig. 3). Assuming a mean $\Delta^{14}C$ value of −105‰ for the deep waters and a prebomb surface water $\Delta^{14}C$ value of −55‰ (Östlund, Possnert and Swift 1987), we calculate an isolation age for the deep waters of the Canadian basin of *ca.* 450 yr. ^{39}Ar data from the deep Makarov Basin (below 2500 m; Fig. 10) also suggest a higher isolation age compared to the Eurasian Basin. However, the straightforward estimate of the isolation age based on an ^{39}Ar concentration of *ca.* 40% yields only *ca.* 350 yr, a value significantly lower than that obtained from the ^{14}C data.

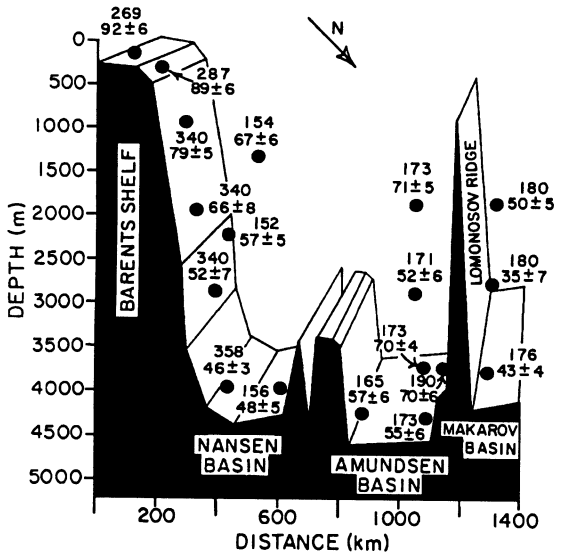

Fig. 10. ^{39}Ar concentrations observed in the Nansen, Amundsen, and Makarov basins of the Arctic Ocean. The numbers indicate the station number and the average ^{39}Ar concentration (in % modern; the uncertainty is the error of the mean value of up to three replicate measurements).

In light of the new data from the deepest waters in the Canada Basin, the age estimates of Östlund, Possnert and Swift (1987) were probably a few hundred years too high (they obtained mean isolation times of *ca.* 700–800 yr). Those measurements were made at an early stage of development of the AMS facility at Uppsala and, as stated by Östlund, Possnert and Swift (1987), had larger uncertainties than the radiometrically determined ^{14}C data reported in the same paper. Thus, the disagreement with the newer results in this contribution has a reasonable explanation.

^{14}C data have already been used to estimate the age of the deep water in the Canadian Basin. These estimates assumed different scenarios for the deepwater formation process. Inspired by the high ages of Canadian Basin deep waters derived by Östlund, Possnert and Swift (1987), Macdonald and Carmack (1991) and Macdonald, Carmack and Wallace (1992) assumed that the deep waters of the Canadian Basin are the remnant of a deepwater renewal event several hundred years ago. They further assume that the deepwater body formed in this way is now only eroded from the top by vertical turbulent exchange (eddy diffusion). Using the shape of the SJF $\Delta^{14}C$ profile (Fig. 8A), they calculated an exchange coefficient of $3.9 \times 10^{-5} m^2 sec^{-1}$ (Macdonald, Carmack and Wallace 1992). However, the few ^{14}C data points in the SJF profile probably misled these authors to believe that the deep $\Delta^{14}C$ profile has the shape of a quasi-exponential function consistent with a one-dimensional diffusion profile. New data points from a site close to the SJF station (PS 92; Jones *et al.* 1994) and from our Makarov Basin Station (176) clearly show no measurable $\Delta^{14}C$ gradient in the deep waters of the Canadian Basin. Therefore, the Macdonald and Carmack scenario does not seem to be consistent with the data. A turbulent exchange coefficient of $3.9 \times 10^{-5} m^2 sec^{-1}$ would lead to an erosion of the profile with a mean penetration depth of *ca.* 800 m. Such a feature is not consistent with the strictly constant $\Delta^{14}C$ profile below 2000 m in the Makarov Basin and below 2500 m in the southern Canada Basin (Fig. 8).

Jones *et al.* (1994) assumed a different scenario of a continuous renewal of the deep waters by shelf waters ($\Delta^{14}C$ value: –55‰) at a rate of *ca.* 0.01 Sv. They explain the vertical homogeneity of the $\Delta^{14}C$ profile below 2500 m as caused by a thick benthic boundary layer maintained by convection in a weakly stratified water body in analogy to the observations in the Black Sea by Murray, Top and Ozsoy (1991). Using this scenario, Jones *et al.* (1994) calculate an isolation age of the deep Canada Basin waters of 430 yr, a value practically identical with our estimate (≈ 450 yr) and that of Östlund, Possnert and Swift (1987) for the Makarov Basin (≈ 450 yr; this estimate was based on a single data point below 2000 m depth).

To estimate the mean residence time of CBDW, we apply a simple inverse model calculation based on the circulation scheme proposed by Jones, Rudels and Anderson (ms.). We assume that CBDW is

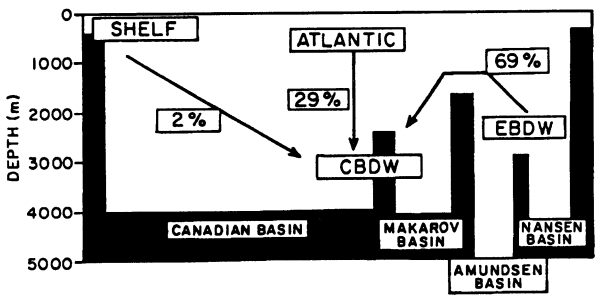

Fig. 11. Schematic view of the box model used to estimate the mean residence time of CBDW

a mixture of Atlantic Water, EBDW flowing over the Lomonosov Ridge into the deep Canadian Basin, and brine-enriched shelf water from the shelf seas surrounding the Canadian Basin. Assuming the salinities and potential temperatures listed in Table 1, we estimate the fractions of Atlantic Water, EBDW and Shelf Water to be *ca.* 29%, 69% and 2%, respectively (Fig. 11). Brine-enriched shelf water is typically low in $\delta^{18}O$ (*e.g.*, Bauch, Schlosser and Fairbanks 1995), and thus, cannot be a major contributor to the deep waters with $\delta^{18}O$ values close to those of Atlantic-derived water (*ca.* 0.3‰). However, the small fraction of shelf water derived from our simple inverse model approach is consistent with the observed $\delta^{18}O$ values in Arctic Ocean Deep Water (Bauch, Schlosser and Fairbanks 1995). After calculating the fractions of the individual water masses contributing to CBDW, we then use ^{14}C and ^{39}Ar data to estimate the mean residence time of CBDW under steady-state conditions. We obtain mean residence times of *ca.* 317 yr (^{14}C) and 293 yr (^{39}Ar), respectively. Within the errors of our estimates, these values are practically identical.

TABLE 1. Parameters used in the simple inverse box-model calculation of the fractions of Atlantic-derived water, EBDW and brine-enriched shelf water contained in CBDW, as well as the mean residence time of CDBW

Water mass	θ [°C]	Salinity	$\Delta^{14}C$ (‰)	^{39}Ar (% modern)
Shelf water	−1.8	36.5	−52	100
Atlantic-derived	0.8	34.9	−65	90
EBDW	−0.87	34.93	−74	66
CBDW	−0.4	34.95	−105	42

Although apparently more sensible than the scenario assuming the existence of a relict water body eroded by turbulent vertical exchange from the top, the continuous renewal hypothesis is not without problems. Continuous renewal at a rate of several per mil per year based on a mean renewal rate of *ca.* 300 yr results in a replacement of *ca.* 8% of deep water by near-surface water over a period of 25 yr, *i.e.*, the period during which bomb ^{3}H was present in these waters. Using the box model described by Bönisch and Schlosser (1995), we estimated the ^{3}H concentration of CBDW for steady-state conditions. The results indicate that CBDW collected during the 1980s should have ^{3}H concentrations close to the detection limit (≈ 0.05 TU; Fig. 12). However, the observed ^{3}H concentrations fall around *ca.* 0 TU, and might indicate discontinuous renewal from the surface. Therefore, we conclude that either deepwater formation in the Canadian Basin was discontinous (no deepwater formation during at least the past several decades), or that the newly formed deep water is confined to a boundary current from which it slowly mixes into the interior of the basin and has not yet reached Stations SJF and PS 92. Unfortunately, no ^{3}H data are available from Station PS 92, which is very close to the continental slope and should have detectable ^{3}H concentrations if the continuous renewal scenario is correct.

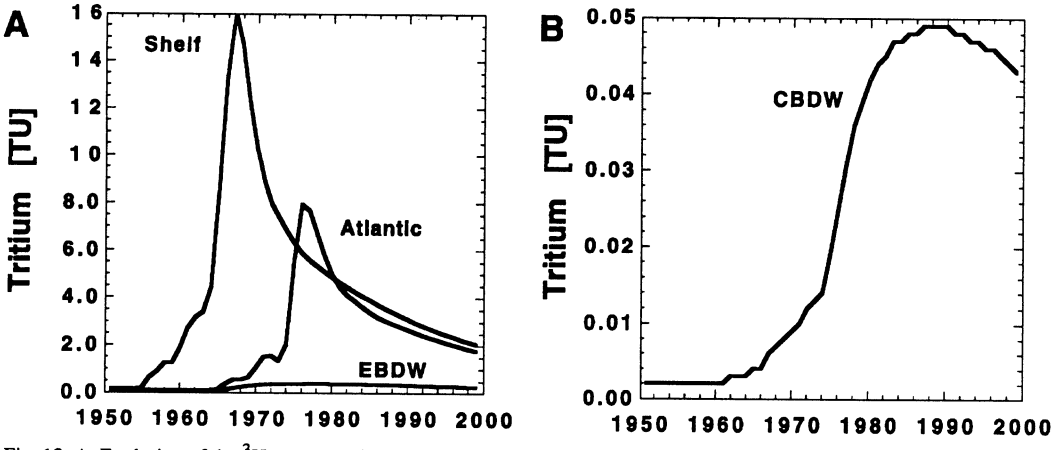

Fig. 12. A. Evolution of the ^{3}H concentration in Atlantic Water, EBDW and brine-enriched shelf water. B. Evolution of the ^{3}H concentration in CBDW (69% EBDW; 29% Atlantic Water; 2% brine-enriched shelf water) for steady-state conditions.

Conclusion

The data set presented above of all the major basins of the Arctic Ocean allows us to draw the following conclusions:

1. The deep and bottom waters of the Eurasian Basin (Nansen and Amundsen Basins) are significantly younger than those of the Canadian Basin (Makarov and Canada Basins). The mean isolation ages of the deep and bottom waters in the Eurasian Basin range from *ca.* 160 yr (≈ 1500–2600-m depth) to *ca.* 250–300 yr (bottom waters below 2600-m depth). These results are based on a pre-bomb surface $\Delta^{14}C$ value of −55‰ (Östlund, Possnert and Swift 1987) and are in agreement with box-model calculations tuned by transient tracers (^{3}H, CFC-11, CFC-12, ^{85}Kr). They further agree with estimates of the isolation age based on ^{39}Ar measurements (Schlosser *et al.* 1995).
2. The Lomonosov Ridge is an effective barrier for exchange of deep and bottom waters between the Eurasian and Canadian Basins of the Arctic Ocean. This results in significantly higher isolation ages of the deep and bottom waters in the Canadian Basin.
3. There is no measurable ^{14}C gradient between the deep waters of the Makarov Basin (depth ≥2000 m) and the southern Canada Basin (depth ≥2500 m). There is also no detectable vertical gradient in the deep waters of the Canadian Basin. A straightforward estimate of the isolation age of the deep Makarov and Canada Basins yields values of *ca.* 450 yr (pre-bomb surface $\Delta^{14}C$ value: −55‰). A straightforward estimate based on ^{39}Ar yields an isolation age of *ca.* 350 yr.
4. ^{3}H concentrations in the deep Canadian Basin are very close to or below the detection limit. If the renewal of deep water in the Canadian Basin were continuous, we would expect ^{3}H levels of ≈ 0.05 TU. From this observation, we conclude that the renewal of deep water in the Canadian Basin might be variable in time, and that it might have been reduced during the past few decades. Variability in deepwater formation has been observed in other parts of the coupled system Greenland-Norwegian Seas and Arctic Ocean (see, *e.g.*, Schlosser *et al.* 1991; Rhein 1991; Meincke, Jonsson and Swift 1992). An alternative explanation of our observations is renewal of deep water through narrow, confined boundary currents that have not yet been sampled for transient tracers. Input of CCl_4 to the oceans reaches further back in time. CCl_4 data from the Canadian Basin should therefore provide a better test of the hypotheses outlined above.

ACKNOWLEDGMENTS

This work profited from the contributions of numerous individuals and institutions. The Alfred-Wegener-Institut for Polar and Marine Research and the crew of RV *Polarstern* provided invaluable logistical assistance for the ARK IV and ARK VIII field programs. Andrea Ludin, Peter Marian, Matthias Meder and Jose Rodriguez helped to collect and degas the large volume ^{14}C samples at sea. The careful preparation of the ^{14}C sampling equipment by the workshop of the Institut für Umweltphysik under the leadership of Reiner Fletterer guaranteed two successful sampling campaigns. Jörn Thiede and Dieter Fütterer, chief scientists during ARK IV and ARK VIII, respectively, provided generous ship time for the collection of *ca.* 300 LV ^{14}C samples. Financial support was provided by the Office of Naval Research (Grant N00014-90-J-1362), the National Science Foundation (Grant DPP 90-22890) and the Deutsche Forschungsgemeinschaft. This is L-DEO contribution no. 5296.

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[RADIOCARBON, VOL. 36, NO. 3, 1994, P. 345–357]

HUMAN SETTLEMENTS AND THE LAST DEGLACIATION IN THE FRENCH ALPS[1]

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ABSTRACT. According to most geological and geomorphological studies, the maximal advance of the Würmian glaciers in the French Alps occurred at least before 40 ka BP and cannot be dated by ^{14}C. Scientists believed that this dating method could be used for dating the last glacial advance and late deglaciation in the region. The scarce and scattered ^{14}C dating results available from geological samples do not confirm an early (*ca.* 18 or 20 ka BP) age for the total cooling of the ice nor do they prove that residual ice sheets remained at low elevations. Attempting to solve this chronological problem, we compiled current archaeological knowledge of the oldest Late Paleolithic sites. A review of their ^{14}C results shows that no site older than 15 ka BP (with Gravettian, Solutrean or early Magdalenian industries) can be found east of the Saône-Rhône Valley, even at low elevations. Only rare sites, dated to *ca.* 14.5 ka BP, may be found close to the mountain regions that were suddenly occupied around the beginning of the Bølling period (*ca.* 13.5 ka BP). Thus, it seems that the eastern Alps offer no evidence for direct association between glacial retreat and human settlement or simultaneous occurrence in early or late deglaciated areas.

INTRODUCTION

Each year, many new Middle and Upper Paleolithic archaeological sites are discovered in Europe. We could infer from this that *Homo sapiens* wanted to occupy all the available terrain across much of the European land mass, and was limited or driven back only by the developing inland ice sheets of Northern Europe. To test this hypothesis, we decided to study the distribution of human settlements linked with the retreat of the glaciers. A quasi-contemporaneity between glacial retreat and new settlements would confirm the likelihood that *Homo sapiens* branched out to every possible location; on the other hand, a delay in the occupation of vacant areas would suggest that factors other than deglaciation may have governed the distribution of settlements.

Conclusions related to widespread human settlement have often been reached for central and eastern Europe in relation to the expansion and recession of the Scandinavian glaciers. To draw the same conclusions for the western European mountains, one must first consider the types of glaciers, the dates of their last retreats, as well as the sources of information. Only then would it be possible to assess the known Paleolithic sites and to evaluate their distance from the corresponding glacial front.

GLACIAL HISTORY OF THE FRENCH ALPS

The French Alps are made up of a central mountain massif with high summits (*ca.* 4000-m elevation) surrounded by several smaller massifs at lower elevations (*ca.* 2000 m), and huge piedmont plains, cut by deep valleys. Because of these contrasting landscapes, the accumulated ice encircled the higher peaks, covered the high plateaus with glacial ice caps and spread long ice sheets over mountain valleys and their extensions.

The shape of the glacial structures of the Alpine massif, often simplified into an ellipse with linear outlines, comparable to the glaciers of Northern Europe or North America, is, in fact much more complex. The ice spread far into the peripheral massifs and into the valleys or onto the plains. Thus, the front of the last major glacial advance of the Würmian can be characterized as an extremely sin-

[1]This paper was presented at the Archaeology Workshop, 15th International ^{14}C Conference, 14 August 1994, Glasgow, Scotland.

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uous line (Fig. 1). To reconstruct this complex scenario, we must make a systematic investigation of the surface evidence. The highly varied topography, differential glacial melting, catchment basins formed to collect the downslope water flow and ice masses accumulated at the bottom of the deeply carved valleys all indicate that glacial movements were complex throughout the region, and may have varied from north to south, and from one valley to another.

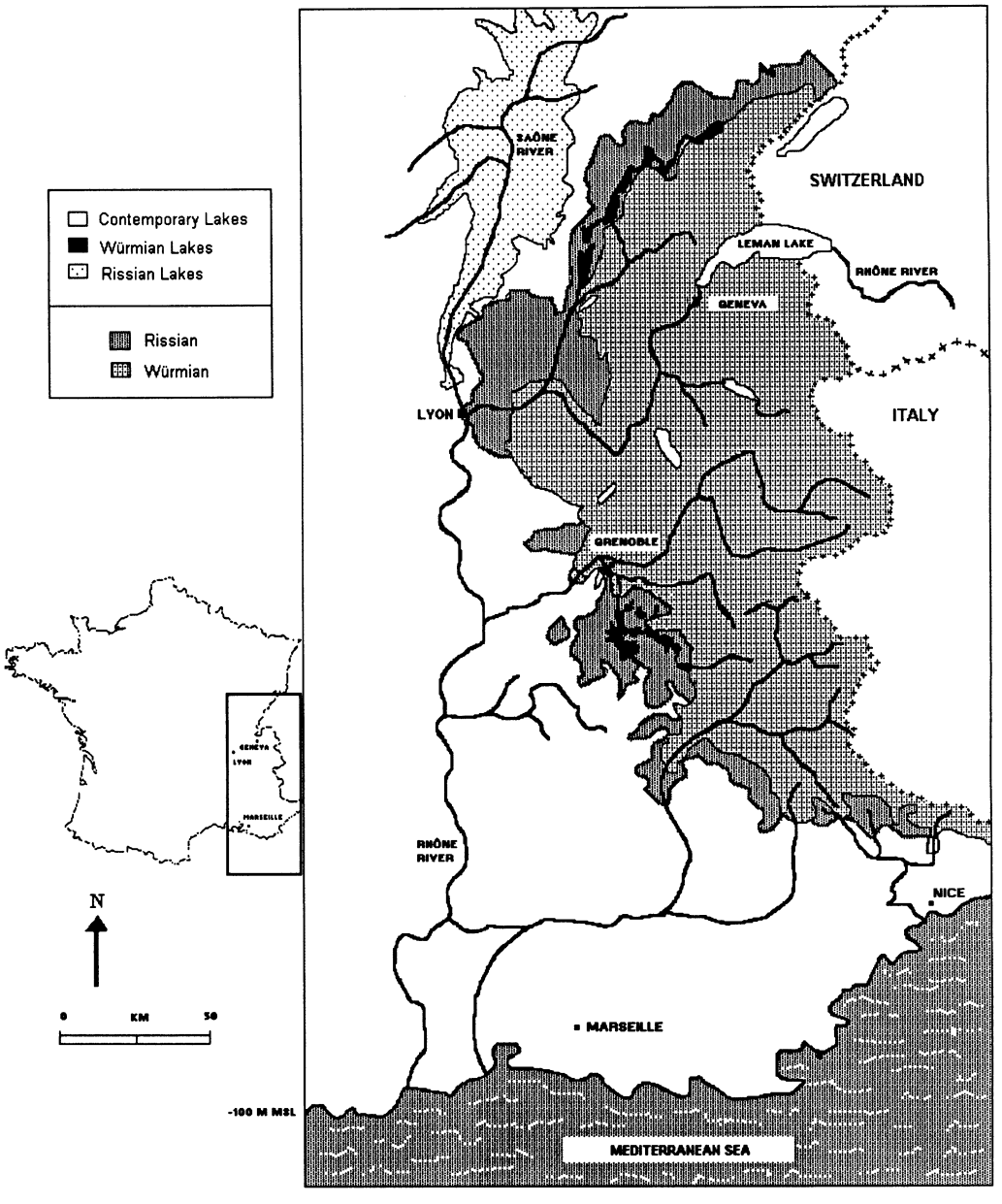

Fig. 1. Maximum of glacial front of the last glaciation in the French Alps

Global climate change influenced Alpine glaciers, with many more fluctuations than boreal ice caps, as their relatively low mass must have rendered them vulnerable to small climate variations. The relief and latitude of the massif affected the rhythm of glacial advances and retreats, which were unrelated to glacial events and behavior in other areas. Perhaps humidity also played a more significant role in the high massif than in lower elevations where precipitation is not blocked by high peaks. Thus, it is difficult to reconstruct the paleogeography of glacial movements and establish their chronology at the same time, both of which are crucial to understanding the process of the first human settlements after deglaciation. We must then turn to all the available geologic and archaeological data.

In the French Alps, the last (Würmian) glaciation was smaller than its predecessor (Rissian) (Mandier 1984; Monjuvent 1971). On the whole western arc, Rissian moraines extended farther than did Würmian moraines (Fig. 1), but neither the precise date of the Rissian maximum, nor the number of major advances and retreats during the Riss is known, despite numerous studies spanning more than a century (Mandier 1984). Figure 1 shows the different maxima of the Rissian and Würmian glaciations. The current landscape was shaped more by the Rissian glaciation than by the Würmian; its great curves are about the same as those of the Riss-Würm interglacial. With the similarity of landscapes, it is not surprising, then, that Middle Paleolithic sites, whose dates are older than the Würmian glaciers, are found where late Magdalenian sites were settled some 80 ka later.

During the Würmian, the earlier of two main glacial advances in the western French Alps, was the most extensive. Yet, in certain frontal regions, as in the vicinity of Lyon, for example, the difference between the two borders of terminal moraines is clearly visible, yet at slightly higher elevations, no difference can be seen between these two stages. Thus, some authors believe that only one long oscillating Würmian advance affected the piedmont area (Monjuvent and Nicoud 1988).

In recent years, much research has been done on the end of the last glacial retreat, in the middle Rhône River Valley and Lac Léman basin (Arn 1984; Mandier 1984; Monjuvent 1988). A rhythmic retreat through numerous stages of halting, abandonment of sheets of stagnant ice and formation of kame terraces and temporary lakes were noted (Fig. 2). The absolute date of the last retreat has not yet been established, but it seems to date from *ca.* 15–18 ka BP in the most meridional parts of the Alps (Jorda, Rosique and Evin 1980) or in the Jura massif (Campy and Richard 1988). Mandier (1984, 1988) argues for a recent age on the basis of the elevations of the fluvioglacial terraces of the central Isère and Rhône glaciers, and from ^{14}C dates from bones found in those terraces (Table 1).

Radiocarbon Dating the Glacial Record

Few possibilities exist for direct ^{14}C dating of glacial or fluvioglacial deposits. The presence of carbon in these landforms is extremely rare. Bones are always absent from moraines, as they are too fragile to withstand the crushing transport of glacial debris. All bone dates at *ca.* 25–40 ka BP are from Ursidae in the karstic networks of Le Bugey, La Chartreuse or Le Vercors massifs (Table 1), but their relation to glaciation is uncertain. Charcoal has never been found, and the rare piece of wood that is found is totally unreliable, because it may have been redeposited by previous interglacial or interstadial activity.

Geological Dating

As direct dating of glacial landforms is impossible, we can date either the interstadial features underlying or adjacent to the moraines, or the fluvial terraces linked with the runoff outlets of the melting glaciers. Table 1 lists two series of dates. The first series, at *ca.* 25 ka BP or older, were

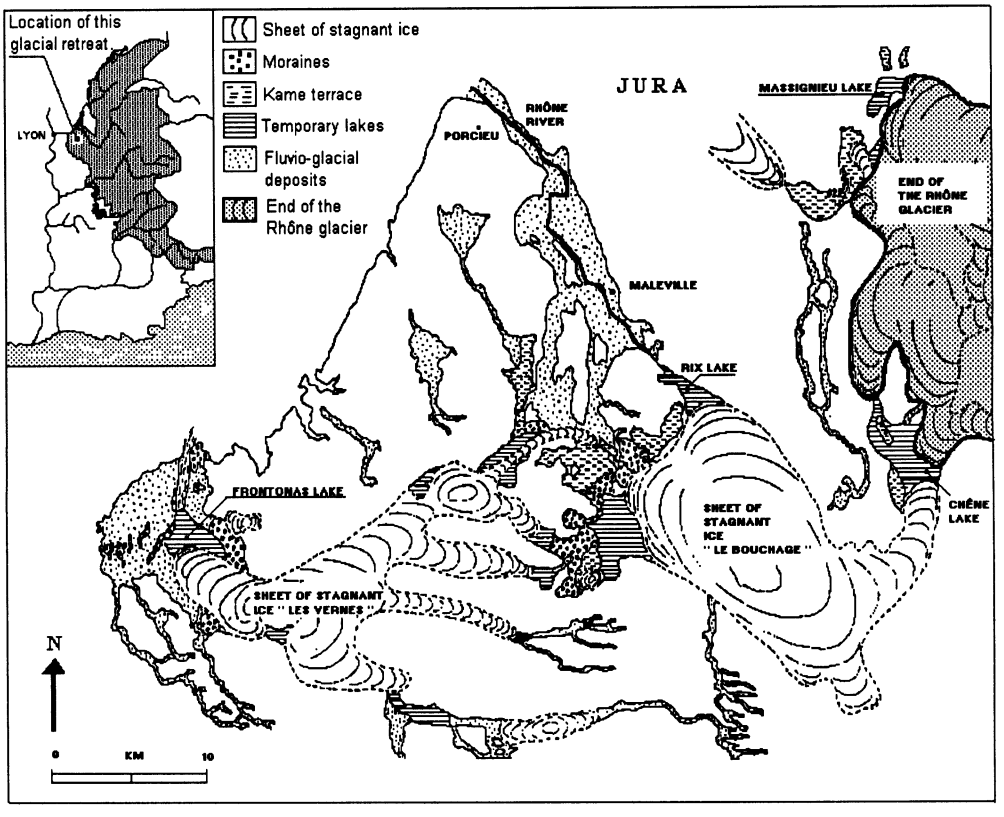

Fig. 2. One phase of the Rhône glacial retreat, showing that several sheets of stagnant ice and fluvioglacial deposits formed temporary lakes

obtained from peat sediments collected in the Chablais region in the Dranse Valley close to Lac Léman, which were associated with the Rhône glacier (Blavoux and Brun 1966). However, these dates cannot confirm, with absolute certainty, the oldest age of the last glacial advance. Another series of dates, between 25 and 17 ka BP, at Pugneux close to Lyon, on peat deposits adjacent to the end moraine of the Würmian Rhône glacial maximum near Lyon (Evin, Marien and Pachiaudi 1976), disagrees with geological evidence placing the maximum earlier than 35 ka BP. Dates between 45 and 60 ka BP from an interstadial occupation underlying a glacial terrace in the region of Chambéry-Grenoble suggest that this Würmian maximum occurred *ca.* 40 ka BP (Hanss 1982). However, these dates are not reliable because the samples were probably contaminated, and some were measured with isotopic enrichment. One date (Ly-3814: 26,470 ± 920) on fragments of wood from a large lakeside terrace at the base of the Rhône River Valley, near Malville (Table 1), indicates a minimal age of several thousand years for the duration of the last retreat, but this can be a matter of redeposited material.

These dating results are contradictory. To date glacial or fluvioglacial landforms, there remains only ^{14}C dating of material uncovered in associated fluviatile terraces. Thus, we obtained a series of dates from low terrace basins of the Rhône River and from alluvial cones to the south of Lyon, on fluvioglacial material related to the last advance of the Rhône glacier. The dates range from 18 to 20 ka BP (Table 1), and they derive from bones or other organic material contained in clays from the first

stage of retreat (Grenay stage). The youngest date: Ly-4818: 14,090 ± 120 BP from Montalieu-Porcieu probably relates to one of the last stages of Rhône glacial retreat (Morestel stage) (Fig. 2) (Mandier and Piegay 1991).

Obtaining a minimum for a terminal age of a glacial retreat can be achieved by dating paludal or lakeside terraces, for example, in the Lac Léman region. Dates from the Allerød period are of little

TABLE 1. Radiocarbon Dates from Geological Sites of the French Alps, Jura Massif and Saône-Rhône Valley from 40–11.5 ka

Region	Lab no.	Site	Material	Layer/Level	^{14}C age (yr BP)
Bugey	Ly-4166	Grotte du Pissoire	Bone	Layer 1	24,360 ± 530
Bugey	Ly-4165	Grotte du Pissoire	Bone	Layer 4	31,000 ± 1000
Bugey	7 Ly dates	Lac de Cerin	Peat	Boring from 691–1048 cm	10,500 ± 180 to 13,680 + 720
Bas Dauphiné	Ly-4184	Montalieu-Porcieu	Bone	Terrace	14,090 ± 120
Bas Dauphiné	Ly-3814	Malville	Wood	Boring –20 m	26,470 ± 920
Bas Dauphiné	7 Ly dates	Le Grand Lemps (Clerc 1988)	Peat	Boring from 4.7–15.1 m	12,150 ± 150 to 14,670 ± 180
Chablais	4 Gif dates	Sionnex (Delibrias *et al.* 1969	Peat	Boring from 31–187 m	23,500 ± 1200 to 26,200 ± 1200
Chablais	Lu-1723	Abri du Salève	Charcoal	Paleosol	13,000 ± 100
Chablais	ETH-4532	Grotte du Barée	Bone	Unknown	38,470 ± 810
Chablais	Ly-2530	Armoy	Peat	Fluviatile sediment	≥35,000
Chartreuse	Ly-5373	Balme à Colomb	Bone	Boring	≥33,000
Chartreuse	Ly-3 / OxA-3946	Balme à Colomb	Bone	Square W4	24,160 ± 370
Chartreuse	Ly-3315	Trou du Glaz	Bone	Single layer	24,300 ± 600
Vercors	Ly-167	Prélétang	Bone	Layer 9	≥32,000
Vercors	Ly-2811	Balme Rousse	Bone	Base of filling	26,000 ± 1500
Oisans	Ly-1647	Chonas	Wood	Middle terrace	11,530 ± 260
Oisans	Ly-2146	Les 2 Alpes-Côtes Brune	Peat	Summit	12,310 ± 150
Oisans	Ly-2147	Les 2 Alpes-Côtes Brune	Peat	Base	12,890 ± 180
Oisans	Ly-2401	La Muzelle II	Clay	Boring –5.4 m	13,460 ± 390
Royans	Ly-2621	St. Hilaire du Rozier	Peat	–2 m	13,980 ± 250
Royans	Ly-2622	St. Hilaire du Rozier	Clay	–3.7 m	15,200 ± 250
Royans	Ly-5014	St. Hilaire du Rozier	Clay	–13 m	22,000 ± 350
Royans	Ly-5197	St. Hilaire du Rozier	Clay	Base	30,000 ± 500
Royans	Ly-3208	St. Julien de Ratz	Peat	–680 cm	13,100 ± 400
Royans	Ly-3210	St. Julien de Ratz	Peat	–710 m	12,580 ± 540
Royans	Ly-2983	St. Julien de Ratz	Peat	–725 cm	12,470 ± 320
Lyonnais	18 Ly dates	Les Echets (Evin *et al.* 1985	Lacustrine sediment	Boring from 4–24 m	11,910 ± 350 to 24,500 ± 500
Lyonnais	5 Ly dates	Pugneux (Evin *et al.* 1985	Plant debris	Fluviatile sediment	17,300 ± 510 to 24,110 ± 900
Lyonnais	Ly-723	Chasse sur Rhône	Bone	Top terrace	12,120 ± 180
Lyonnais	Ly-653	Chasse sur Rhône	Bone	Basal terrace	14,350 ± 290
Lyonnais	Ly-360	Saint Maurice l'Exil	Bone	Middle terrace	18,800 ± 490
Valentinois	Ly-4458	Cône Drôme River	Clay	Boring –8.6 m	11,850 ± 400
Valentinois	Ly-5529	Cône Roubion River	Clay	Boring base	15,550 ± 260
Valentinois	Ly-1689	Salaise sur Sanne	Bone	Boring –16 m	14,110 ± 620
Valentinois	Ly-1690	Salaise sur Sanne	Bone	Boring –17 m	20,370 ± 460
Provence	Ly-6388	La Peyrerie	Wood	Fluvioglacial sediment	18,600 ± 200
Provence	Ly-6387	La Peyrerie	Wood	Fluvioglacial sediment	17,680 ± 130

interest, because they are largely younger than the last ice retreat. Thus, despite much research over a 30-yr period, the date of the last glacial retreat in the French Alps remains inaccurate, based only on geological data.

Archaeological Dating

The rare carbon samples directly linked to glacial formations are most often archaeological remains, which can provide the most precise age information. Lithic artifacts are a stable material, and are important for dating, even if typological dating is often inaccurate. Archaeological sites from the plain are often covered with thick Holocene deposits. In the mountains, rock shelters almost exclusively provide either bone or charcoal samples for dating. Such samples are important, for, generally, they are not subject to major disturbances, and thus, to dating uncertainties arising from redeposited material. Consequently, archaeological material usually offers better guarantees for successful ^{14}C dating than does geological material.

Archaeological Sites in the French Alps

We are aware of *ca.* 100 sites in the French Alps, the Jura Massif and the Saône-Rhône Valley for the Tardiglacial; 31 of them have been ^{14}C-dated (Table 2). The geographical distribution is erratic (Fig. 3). Numerous sites are located in the Saône-Rhône Valley and along the margins of the smaller peripheral mountain massifs (Chartreuse, Vercors, Bugey) adjacent to areas of major erosional tracks such as where the Rhône and Isère River Valleys fan out. A few sites are in the interior of the massifs at medium elevation, but there are no sites in the central massifs and only a few in the south. It is always possible that the absence of sites is due more to lack of knowledge than to lack of settlements; however, the disparity between the west and east of the chain is, in itself, significant. Figure 3 shows that most sites are located in the west, particularly in the southwest, of the Saône and Rhône River Valleys.

TABLE 2. Radiocarbon Dates from Archaeological Sites of the French Alps, Jura Massif and Saône-Rhône Valleys from 25,000–10,500 BP

Lab no.	Material	Site (no. in Fig. 3)	Layer / Level	^{14}C age (yr BP)	Culture
Ly-2161	Bone	Arcis sur Cure (1)	Layer V	20,150 ± 500	Gravettian
BM-1819	Burned bone	Arcis sur Cure (1)	Layer V	22,550 ± 350	Gravettian
Ly-894	Bone	Crest (2)	Single level	12,850 ± 240	Magdalenian
Ly-314	Burned bone	Solutré (3)	Layer L13	16,440 ± 300	Solutrean
Ly-316	Bone	Solutré (3)	Layer L13	17,350 ± 300	Solutrean
Ly-317	Bone	Solutré (3)	Boring C	24,050 ± 600	Perigordian
Ly-312	Bone	Solutré (3)	Boring B, Level 6	28,650 ± 1100	Perigordian
Ly-313	Bone	Solutré (3)	Boring B, Level 6	22,650 ± 500	Perigordian
Ly-392	Charred bone	Solutré (3)	Level P16	13,350 ± 350	Magdalenian
Ly-393	Bone	Solutré (3)	Square P16	12,580 ± 250	Magdalenian
Ly-560	Bone	Solutré (3)	Boring B, Level 6	30,400 ± 0	Magdalenian
Ly-561	Bone	Solutré (3)	Boring B, Level 6	23,200 ± 700	Perigordian
Ly-562	Bone	Solutré (3)	Boring Terre Seve	21,600 ± 700	Perigordian
Ly-1530	Bone	Solutré (3)	−1.65 to −1.70 m	13,680 ± 240	Magdalenian
Ly-1531	Bone	Solutré (3)	−1.70 to −1.75 m	13,710 ± 230	Magdalenian
Ly-1532	Bone	Solutré (3)	−1.80 to −1.90 m	14,360 ± 280	Magdalenian
Ly-1533	Bone	Solutré (3)	−2.40 to −2.50 m	19,590 ± 280	Solutrean
Ly-1534	Bone	Solutré (3)	−2.10 to −2.50 m	17,310 ± 470	Solutrean
Ly-309	Charred bone	Vignes ChateauBeau(4)	Hearth	24,150 ± 550	Perigordian
Ly-310	Charred bone	Vignes ChateauBeau(4)	Hearth	21,100 ± 1300	Perigordian

TABLE 2. (Continued)

Lab no.	Material	Site (no. in Fig. 3)	Layer / Level	^{14}C age (yr BP)	Culture
Ly-311	Bone	Vignes ChateauBeau(4)	Hearth	22,900 ± 600	Perigordian
Ly-2150	Charred bone	Goutte Roffat (5)	Ashy level	10,860 ± 210	Magdalenian
Ly-3092	Charred bone	Goutte Roffat (5)	Level 1	13,530 ± 260	Magdalenian
Ly-3093	Charred bone	Goutte Roffat(5)	Level 2a	12,720 ± 180	Magdalenian
Ly-3094	Charred bone	Goutte Roffat (5)	Level 2b	12,420 ± 320	Magdalenian
Ly-3095	Charred bone	Goutte Roffat (5)	Level 2c	12,090 ± 170	Magdalenian
Ly-3096	Charred bone	Goutte Roffat (5)	Level 3, Pit 1	11,940 ± 280	Magdalenian
Ly-3097	Charred bone	Goutte Roffat (5)	Level 3, Hearth	12,150 ± 200	Magdalenian
Ly-3098	Charred bone	Goutte Roffat (5)	Level 3, Pit 2	12,330 ± 300	Magdalenian
Ly-2152	Charred bone	Vigne Brun (6)	Surface	16,180 ± 250	Magdalenian
Ly-2151	Charred bone	Vigne Brun (6)	Hearth	19,500 ± 480	Perigordian
Ly-2153	Charred bone	Vigne Brun (6)	Hearth	20,840 ± 390	Perigordian
Ly-2637	Charred bone	Vigne Brun (6)	Hearth 010	23,450 ± 690	Perigordian
Ly-2638	Charred bone	Vlgne Brun (6)	Hearth	21,580 ± 600	Perigordian
Ly-2639	Charred bone	Vigne Brun (6)	Hearth 016	23,230 ± 760	Perigordian
Ly-2640	Charred bone	Vigne Brun(6)	Hearth	23,500 ± 1000	Perigordian
Ly-391a	Charred bone	Pré Brun (7)	Hearth	18,520 ± 500	Perigordian
Ly-391b	Charred bone	Pré Brun(7)	Hearth	24,900 ± 2000	Perigordian
Ly-3079	Bone	Cabones (8)	Lower level	11,520 ± 191	Magdalenian
Ly-2296	Bone	Cabones (8)	Lower level	12,620 ± 250	Magdalenian
Ly-1863	Ivory	Mère Clochette (9)	Red level	25,800 ± 700	Perigordian
Ly-440	Bone	Chaumois Boivin (10)	Level C	12,040 ± 270	Magdalenian
Ly-497	Bone	Arlay (11)	Level G	15,320 ± 370	Magdalenian
Ly-559	Bone	Arlay (11)	Level E	15,770 ± 390	Magdalenian
Ly-1509	Bone	Arlay (11)	Level C	14,220 ± 560	Magdalenian
Ly-1510	Bone	Arlay (11)	Layer C	14,820 ± 370	Magdalenian
Ly-1535	Bone	Arlay (11)	Layer C	14,530 ± 290	Magdalenian
Ly-1536	Bone	Arlay (11)	Layer C	14,840 ± 360	Magdalenian
Ly-1798	Bone	La Baume (12)	Layer IV	12,370 ± 460	Magdalenian
Ly-1702	Bone	La Baume (12)	Layer IV	13,620 ± 480	Magdalenian
Ly-1703	Bone	La Baume (12)	Layer V	22,430 ± 500	Magdalenian
Gif-8717	Charcoal	Le Colombier (13)	Layer 15	11,460 ± 310	Magdalenian
Ly-5291	Charcoal	Le Colombier (13)	Layer 16	14,660 ± 660	Magdalenian
Ly-5292	Charcoal	Le Colombier (13)	Layer 17	14,480 ± 360	Magdalenian
Ly-2339	Bone	Les Pêcheurs (14)	Surface F10–F11	23,880 ± 750	Aurignacian
Ly-2342	Bone	Les Pêcheurs (14)	Level 5	24,940 ± 680	Epigraveytian
Ly-321	Charcoal	Les Deux Avens (15)	Level C	12,320 ± 600	Magdalenian
Ly-322	Bone	Les Deux Avens (15)	Level C	12,350 ± 200	Magdalenian
Ly-1984	Bone	Oullins (16)	Level D	20,100 ± 500	Solutrean
Ly-1983	Bone	Oullins (16)	Level 9	20,060 ± 450	Solutrean
Ly-798	Bone	Oullins (16)	Level 6	19,369 ± 420	Solutrean
Ly-799	Bone	Oullins (16)	Level 7	19,710 ± 400	Solutrean
Ly-800	Bone	Ebbou (17)	Layer C1	12,980 ± 220	Magdalenian
Ly-847	Charcoal	La Tête du Lion (18)	Layer E and F	21,650 ± 800	Solutrean
Ly-597	Bone	Chinchon (19)	Layer 15	12,000 ± 420	Tardigravettian
Ly-541	Bone	Adaouste(20)	Layer 12	12,280 ± 190	Magdalenian
Ly-540	Bone	Adaouste (20)	Layer 17	12,760 ± 250	Magdalenian
Gif-2994	Charcoal	Fontbregoua (21)	Layer 70	11,200 ± 150	Magdalenian
Ly-5558	Charcoal	Grotte Cosquer (22)	Surface soil	18,440 ± 440	LatePaleolithic
Gif A-92348	Charcoal	Grotte Cosquer (22)	Surface soil	20,370 ± 250	Late Paleolithic
Gif A-92416	Charcoal	Grotte Cosquer (22)	Painting of horse	18,840 ± 240	Paleolithic
Gif A-92418	Charcoal	Grotte Cosquer (22)	Painting of feline	19,200 ± 220	Paleolithic
Gif A-92409	Charcoal	Grotte Cosquer (22)	Painting of hand	27,110 ± 390	Paleolithic

TABLE 2. (Continued)

Lab no.	Material	Site (no. in Fig. 3)	Layer / Level	^{14}C age (yr BP)	Culture
Ly-357	Bone	La Croze sur Suran (I)	Hearth	14,330 ± 260	Magdalenian
Ly-434	Bone	La Croze sur Suran (I)	Hearth	14,850 ± 350	Magdalenian
Ly-433	Bone	La Colombière (II)	Level D	13 390 ± 300	Magdalenian
L-177	Charcoal	La Colombière (II)	Hearth	14,150 ± 450	Magdalenian
Ly-16	Charcoal	Les Romains (III)	Layer III	14,380 ± 380	Magdalenian
Ly-356	Bone	Les Romains (III)	Level III	12,980 ± 240	Magdalenian
MC-1275	Shells	Les Romains (III)	Level IIb	12,540 ± 400	Magdalenian
MC-1276	Shells	Les Romains (III)	Level III	12,540 ± 230	Magdalenian
ETH-3937	Bone	Etrembieres (IV)	Soil of habitation	12,300 ± 130	Magdalenian
B-3787	Bone	Etrembieres (IV)	Soil of habitation	12,310 ± 140	Magdalenien
Ly-453	Bone	Douattes (V)	Level B	10,680 ± 450	Magdalenian
Ly-435	Bone	Douattes (V)	Level 7	12,480 ± 260	Magdalenian
0xA-538	Bone	Bange (VI)	Layer G	12,080 ± 180	Magdalenian
OxA-540	Bone	Bange (VI)	Layer G	12,200 ± 160	Magdalenian
Ly-3640	Bone	Bange (VI)	Layer G	11,680 ± 190	Magdalenian
Ly-390	Charcoal	Saint Thibaud II (VII)	Hearth	13,300 ± 280	Magdalenian
Ly-925	Bone	Saint Thibaud II (VII)	Layer 3	12,400 ± 240	Magdalenian
Ly-926	Charcoal	Saint Thibaud II (VII)	Layer 3	13,280 ± 290	Magdalenian
Ly-625	Charcoal	Saint Thibaud II (VII)	Layer Theta	10,470 ± 200	Magdalenian
Ly-692	Charcoal	Saint Thibaud II (VII)	Layer Theta	11,590 ± 330	Magdalenian
Ly-693	Charcoal	Saint Thibaud II (VII)	Layer Theta	11,630 ± 240	Magdalenian
Ly-828	Charcoal	Saint Thibaud II (VII)	Layer 3	12,470 ± 200	Magdalenian
Ly-829	Charcoal	Saint Thibaud II (VII)	Layer 9b	12,720 ± 230	Magdalenian
Ly-830	Charcoal	Saint Thibaud II (VII)	Layer Lambda	13,070 ± 210	Magdalenian
Ly-2911	Bone	La Fru (VIII)	Layer 2	12,690 ± 380	Magdalenian
Ly-431	Bone	Le Calvaire (IX)	Layer 3	12,970 ± 300	Magdalenian
Ly-432	Bone	Le Calvaire (IX)	Layer4	13,450 ± 300	Magdalenian

Chronological distribution of the sites is also irregular. Figure 4 shows the duration of ^{14}C-dated settlements of the mountain region, compared with the duration of all the dated sites in the Saône-Rhône basin from the south of Burgundy to the Mediterranean coast. It is clear that, before 14.5 ka BP, there is no trace of human presence to the east of the Saône-Rhône Valley (except, on the western fringe of the Jura, the site of Arlay, with its peculiar *à navette* Magdalenian industry found in rare sites from western France to Poland (Allain *et al.* 1985), dated from 15.5 ka BP). Nor is there a lithic remain prior to the Middle Magdalenian. We sometimes find redeposited Middle Paleolithic material, but never any for the Early or Upper Paleolithic (Aurignacian, Perigordian, Solutrean). On the other hand, a series of settlements or of decorated grottoes from the Perigordian and the Solutrean, in Burgundy (Solutré), Lyonnais (Villerest), Vivarais (Les Pêcheurs) or coastal Provence (Cosquer Grotto) has been found (Fig. 4). The contrast between east and west of the Rhône basin is striking.

The dates of the last retreat remain ambiguous, but it had probably begun as early as 15 ka BP for the whole western Alps. As the first inhabitants of the mountains seem to be contemporaneous with the beginning of the Bølling (*ca.* 13.3 ka BP), a long interval (*ca.* 2 ka) elapsed between the ice retreat and this first human migration.

The irregular distribution of the sites is not the sole proof of this delay in settlement; the general outline and conditions of fill of certain sites also lend supportive evidence for the time of occupation. The site of Saint-Thibaud de Couz, at an elevation of 550 m, at the foot of the Epine massif near Chambéry, is a good example of delayed settlement (Bintz 1994). Although the site is not directly implanted on glacial material, it is in direct relation to the former glacier. Figure 5 shows the various

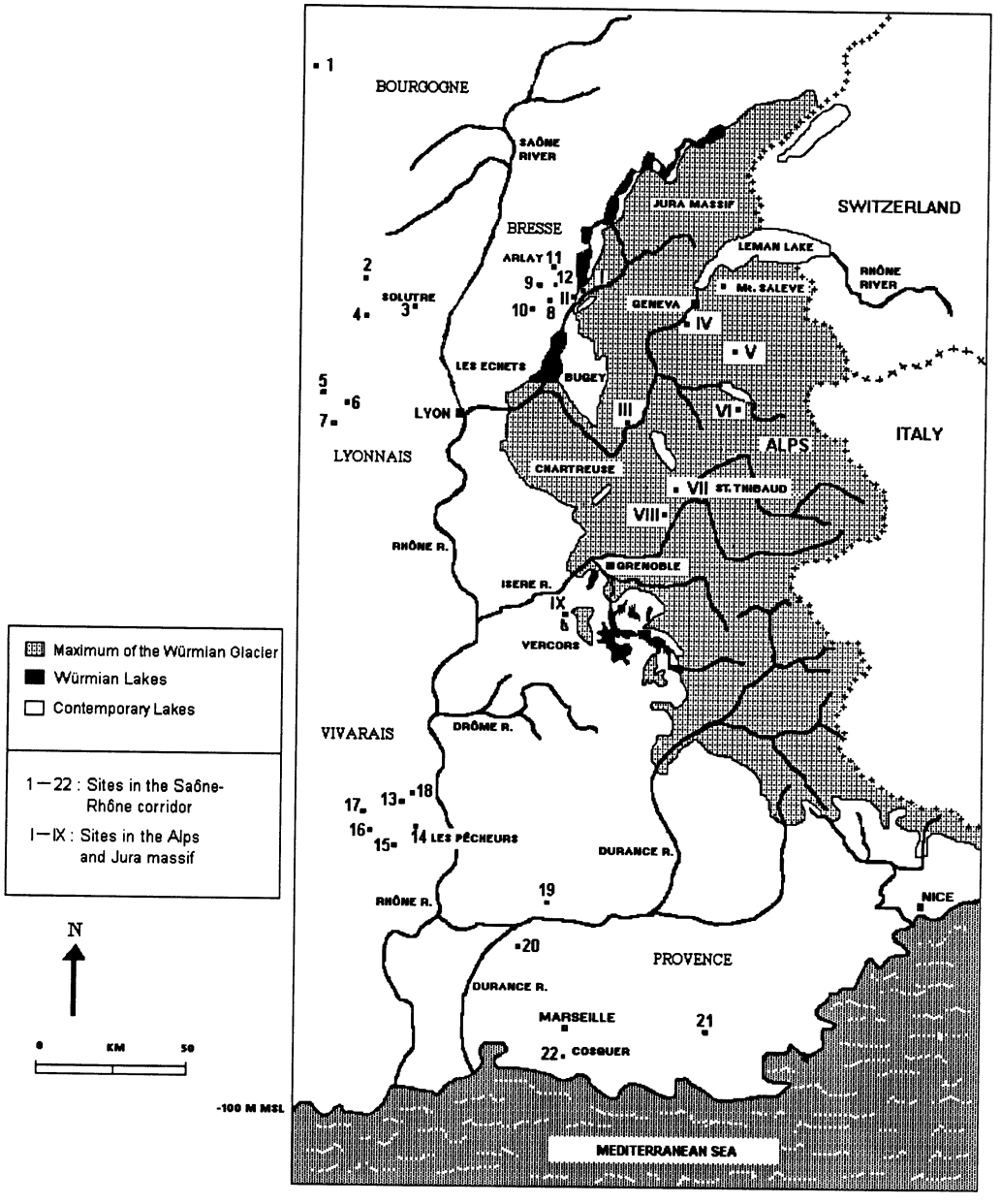

Fig. 3. Location of the Upper Paleolithic sites from the Jura Massif, French Alps and the Saône-Rhône Valley

stages of the development of a site. Although the precise duration between Phase 2 (retreat of the glacier) and Phase 6 (human settlement) cannot be calculated, one may assume it was a very long time, and the glacial front must have been quite remote by the time of settlement. Galay (1992) used the same reasoning for evaluating the site of Etrembières (Veyrier), which was located directly on glacial till on the mountainside of Mt. Salève near Geneva. The first Magdalenians who resided here must have viewed the same landscape as do present-day Genevans. Thus, either Upper Magdalenian

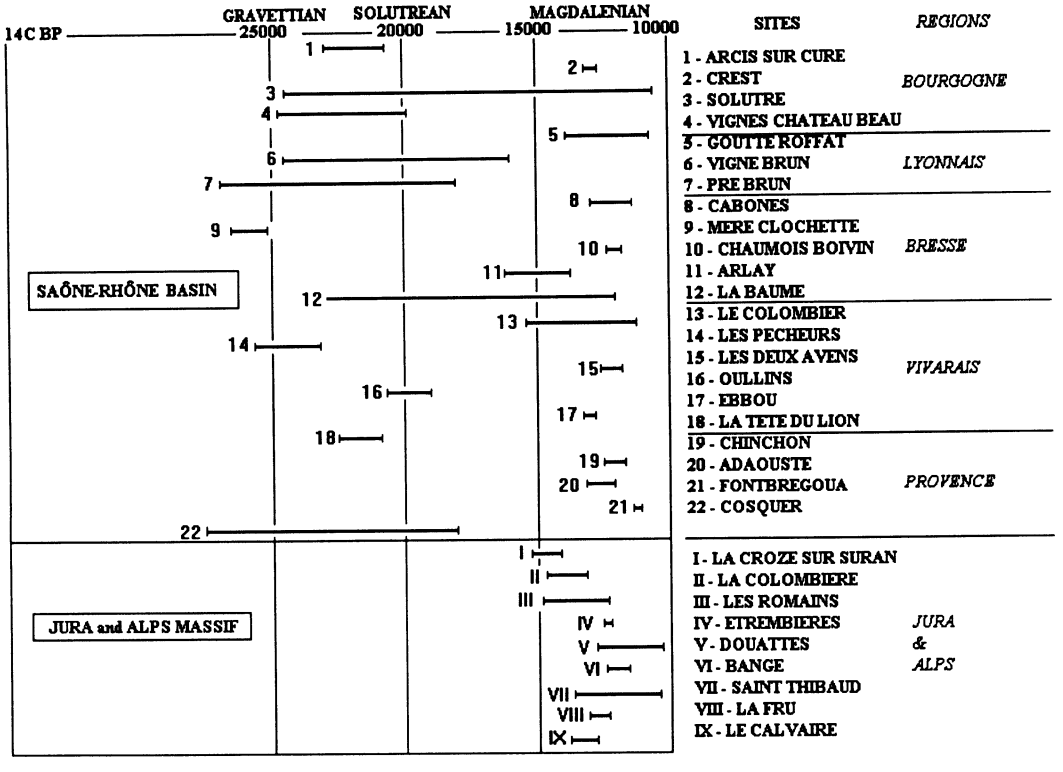

Fig. 4. Duration of human occupation in the sites of the Saône-Rhône basin, the Jura and the French Alps

sites of the French Alps are located where glaciers melted a long time before, or the ^{14}C dates of these sites are too young (12–10 ka BP).

Throughout the pleniglacial and at only 80 km from the extreme advance of the glacial front, a human population left some sites to the west of the Rhône corridor. The pollen diagram of Les Echets swamp, 10 km north of Lyon (de Beaulieu *et al.* 1980) shows that, at this time, large melted patches of sparsely vegetated land covered the piedmont area. Yet, no archaeological sites were found east of the Rhône basin, neither before nor during the last pleniglacial. Further, there is no evidence of human settlement in the mountain zone. Perhaps during the pleniglacial, even after the main glaciers receded (*i.e.,* during most of the Würmian), the deeply eroded valleys dug by the first maximal glacial expansion (at a very early date) remained covered by sheets of stagnant ice. Thus, the landscapes were probably not conducive to habitation. Also, great lakes of melted ice with steep banks in U-shaped valleys could have rendered the intra-Alpine massifs inaccessible (Fig. 6).

Deglaciation spread mainly throughout the northern French Alps (Fig. 1). As for the southern Alps, that is, those south of the Drôme and upper Durance Rivers, the massifs and valleys were not glaciated; the only important glacier was that of the Durance, supplied at a high altitude by the Pelvoux massif. Thus, the southern Alps were cleared and accessible throughout the Würmian. However, they are totally devoid of Upper Paleolithic sites, except near the Rhône River and the Mediterranean Sea.

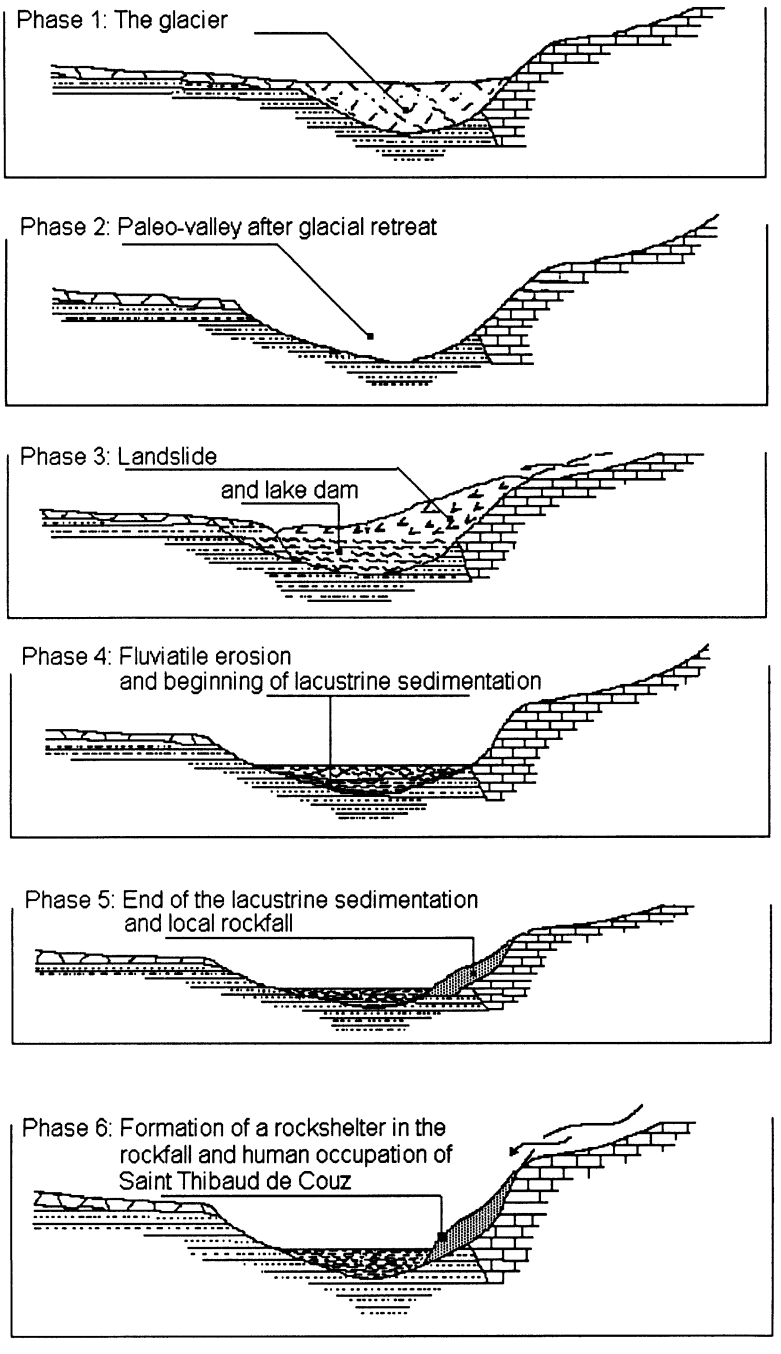

Fig. 5. Assumed phases of land formation around the site of Saint Thibaud de Couz, showing the long transition between glacial retreat and human settlement

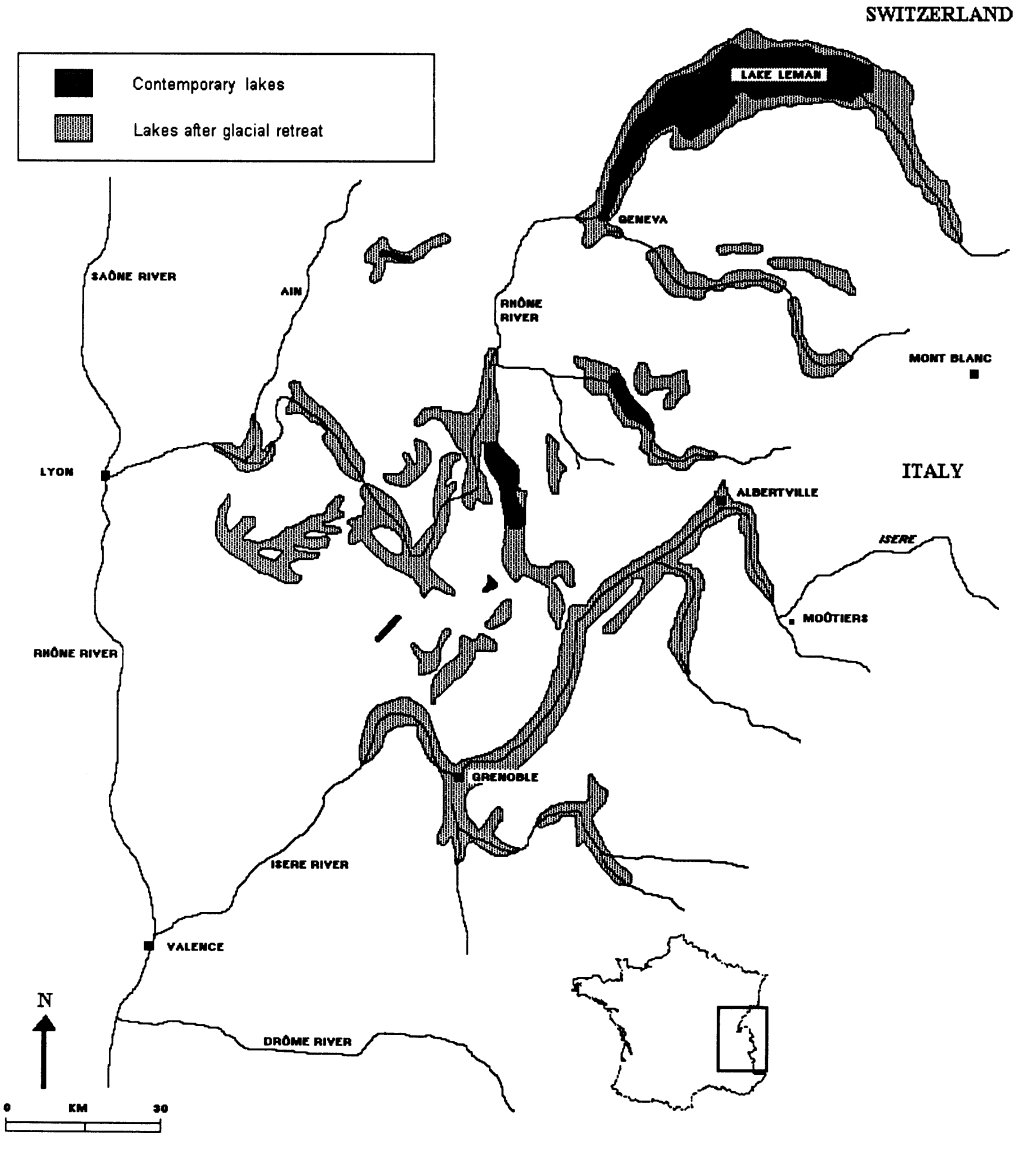

Fig. 6. Lakes in the northern French Alps after the Würmian deglaciation

Conclusion

Little has been written on the chronology of final deglaciation of the French Alps due to the lack of geological and ^{14}C data. However, there seems to be no connection between the first human settlement and the extension of the last glaciation. Indeed, the study of site distribution and glacial deposits shows that, for reasons yet unknown, settlement occurred long after deglaciation, and sites were far distant from the glacial front. More sites will have to be studied before we can understand the motives for population movements toward high elevations and for the apparent non-relation between glaciers and human settlement.

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[RADIOCARBON, VOL. 36, NO. 3, 1994, P. 359–366]

RADIOCARBON DATING OF THE STONE AND BRONZE AGE SITES IN PRIMORYE (RUSSIAN FAR EAST)

YAROSLAV V. KUZMIN,[1] LYOBOV A. ORLOVA,[2] LEOPOLD D. SULERZHITSKY[3] and A. J. T. JULL[4]

INTRODUCTION

The first results of radiocarbon dating of the ancient sites in the Russian Far East were published early in the 1960s (Okladnikov 1964). We now have enough data to establish the main features in the ^{14}C chronology of the Stone and Bronze Age cultures in Primorye, one of the archaeologically well-studied regions of the Russian Far East.

The 49 dates described here were sampled from 19 sites and analyzed at different laboratories at the following institutions: The University of Arizona, Tucson (AA); Institute of Geology, Novosibirsk (SOAN); Geological Institute, Moscow (GIN); Moscow State University (MGU); Institute of Archaeology, St. Petersburg (RUL, LE); Northeastern Complex Research Institute, Magadan (MAG); Institute of Geochemistry and Physics of Minerals, Ukrainian Academy of Sciences, Kiev (Ki); Institute of Geography, Moscow (IGAN). All the Russian laboratories are part of the Russian Academy of Sciences.

The materials dated are mainly charcoal collected during excavations, but we also dated other materials, such as birch bark, wood, bones (both human and animal), humus and seeds. Except for samples indexed AA-, which were dated by accelerator mass spectrometry (AMS), all samples were dated using liquid scintillation counting (LSC). Neolithic and Bronze Age dates were calibrated according to standard tables compiled by Klein *et al.* (1982) and Stuiver and Pearson (1986). Figure 1 shows the locations of sites in this study.

We report here only dates that correspond well to archaeological contexts (Krushanov 1989). Some disagreements of ^{14}C ages with the expected archaeological contexts are discussed in the comments.

THE PALEOLITHIC

1. IGAN-341 **32,570 ± 1510**

Bones of horse and mammoth, from Geographical Society cave (42°52′N, 133°00′E), depth 60–80 cm below surface. Collected and submitted by N. K. Vereschchagin.

Comment (Y.K.): Vasiljevsky (1987) believes that artifacts lie below the dated level. This conjecture remains to be confirmed.

2. Ki-3502 **15,300 ± 140**

Small charcoal fragments from Suvorovo 4 (44°15′N, 135°19′E), from 25–30 cm below surface in Squares KH-9, TS-9, collected August 1989 by S. Gladyishev and A. Tabarev, submitted September 1989 by Y. Kuzmin.

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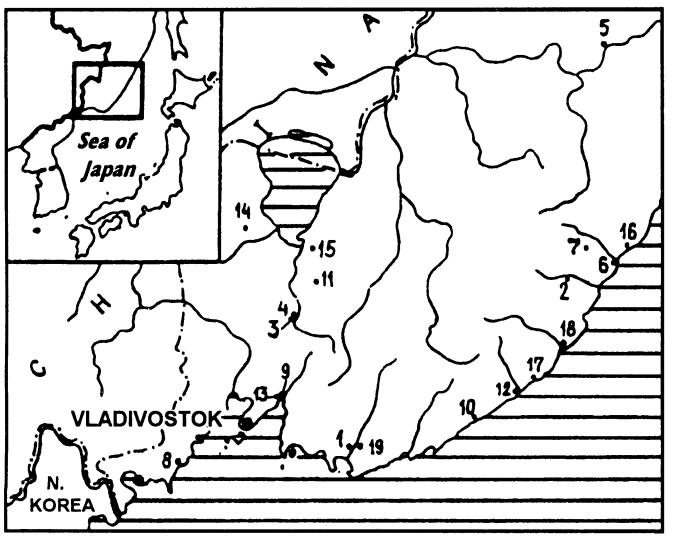

Fig. 1. ^{14}C-dated sites in Primorye. Numbers correspond to those in the text: 1. Geographical Society cave; 2. Suvorovo 4–6; 3. Gorbatka 3; 4. Ilistaya 1; 5. Almazinka; 6. Rudnaya; 7. Chertovy Vorota; 8. Boisman 2; 9. Oleny A; 10. Valentin-Peresheek; 11. Mustang; 12. Phusun; 13. Kirovsky; 14. Novoselischche 4; 15. Sinii Gai; 16. Lidovka 1; 17. Eustaphy-Oleg 1; 18. Sinie Skaly; 19. "Under the Linden".

3. AA-9463 **15,105 ± 110**

Small charcoal fragments from Suvorovo 4, 25–30 cm below surface. Collected August 1990 by S. Gladyishev and A. Tabarev, submitted August 1992 by Y. Kuzmin.

Comment (Y.K.): Although the dates for Ki-3502 and AA-9463 are in remarkable agreement, they contradict pollen data, which show a younger age for this site, of *ca.* 8000–9000 BP (Kuzmin 1992).

4. SOAN-1922 **13,500 ± 200**

Humic acids from Gorbatka 3 (43°57′N, 132°24′E), from a lens of organic-rich sediments in colluvial deposits. Collected and submitted 1980 by A. Kuznetsov.

Comment (Y.K.): the sample was collected below the artifacts at this site, which are slightly younger at 13,500 BP.

5. Ki-3163 **7840 ± 60**

Charcoal from Ilistaya 1 (43°57′N, 132°26′E) at 30–40 cm below surface. Collected July 1987 by A. Kuznetsov, submitted Oct 1987 by Y. Kuzmin.

General Comment: Because of the paucity of dates, the age of the Paleolithic in Primorye is still not well known. The main problem is the lack of charcoal in the Paleolithic cultural layers. The age of the Suvorovo 4 site is under discussion, and more dating of the site sediments is necessary. In general, the ^{14}C dates show that Paleolithic sites existed in Primorye during the Late Pleistocene and Early Holocene, up to 7800 BP. *Editors' note:* The five dates from the Paleolithic reported here also appear in Kuzmin (1994), which follows this article.

THE NEOLITHIC

Rudnaya Series

Charcoal from Tetukhe, Rudnaya Pristan (44°21′N, 135°48′E).

6. GIN-5983 **7690 ± 80**

Charcoal from the lowest layer of site, Dwelling 2, Squares A–YA/12. Collected 1985, submitted 1988 by V. Djakov.

7. GIN-5631 **7550 ± 60**
Charcoal from the lowest layer of site, Dwelling 2, Squares A–YA/10–11. Collected 1985 by V. Djakov, submitted 1987 by Y. Kuzmin.

8. GIN-5984 **7390 ± 100**
Charcoal from the lowest layer of site, Dwelling 2, Squares A–YA/10–11. Collected 1985, submitted 1988 by V. Djakov.

Comment (Y.K.): GIN-5631 and -5984 were collected from the same location.

9. GIN-5980 **4130 ± 40**
Charcoal from the middle layer of site, depth 60 cm below surface, Dwelling 7, Squares ZH–Z/7–8. Collected 1985, submitted 1988 by V. Djakov. Calibrated range: 2910–2435 cal BC.

10. GIN-5630 **4040 ± 40**
Charcoal from the middle layer of site, Dwelling 8, Squares B–V/1–3. Collected 1985 by V. Djakov, submitted 1987 by Y. Kuzmin. Calibrated range: 2870–2405 cal BC.

11. GIN-5982 **4030 ± 40**
Charcoal from the middle layer of site, Dwelling 8, Squares A–D/1–2. Collected 1985, submitted 1988 by V. Djakov. Calibrated range: 2865–2400 cal BC.

12. GIN-598 **4000 ± 40**
Charcoal from the middle layer of site, depth 65 cm below surface, Dwelling 7, Squares I–K/9–10. Collected 1985, submitted 1988 by V. Djakov. Calibrated range: 2785–2330 cal BC.

Almazinka Series

13. AA-9818 **7545 ± 80**
14. AA-9817 **7430 ± 65**
15. AA-9819 **7410 ± 60**
Small charcoal fragments from Almazinka (45°58′N, 135°46′E), depth 80–90 cm below surface, excavation pit 1992. Collected July 1992 by V. Lyinsha, submitted September 1992 by Y. Kuzmin.

Comment (Y.K.): Lyinsha (1992) expected the site to be Paleolithic, but 1992 excavations revealed pottery fragments (V. Lyinsha, personal communication, October 1993); thus, the site may be associated with the Neolithic.

Chertovy Vorota Series

16. SOAN-1212 **6825 ± 45**
Animal bones from Chertovy Vorota (44°29′N, 135°230′E), depth 10–80 cm below surface. Collected and submitted 1973 by V. Tatarnikov. Calibrated range: 6037–5377 cal BC.

17. LE-4182 **6710 ± 105**
Animal bones collected 1986 by Zh. Andreeva, submitted 1987 by Y. Kuzmin. Calibrated range: 5930–5310 cal BC.

18. SOAN-1083 **6575 ± 45**
Charcoal, depth 90 cm below surface. Collected and submitted 1973 by V. Tatarnikov. Calibrated range: 5755–5255 cal BC.

19. MGU-504 **6380 ± 70**
Charcoal collected 1973 by V. Tatarnikov, submitted 1974 by V. Stepanov. Calibrated range: 5565–5095 cal BC.

20. LE-4181 **5890 ± 45**

Animal bones collected 1986 by Zh. Andreeva, submitted 1987 by Y. Kuzmin. Calibrated range: 5070–4560 cal BC.

Boisman 2 series

21. AA-9461 **6355 ± 60**

Small charcoal fragments from the lowest layer of Boisman 2 (42°47′N, 131°16′E), depth 95 cm below surface in Square G14. Collected July 1992 by A. Popov, submitted August 1992 by Y. Kuzmin. Calibrated range: 5545–5077 cal BC.

Comment (Y.K.): The sample was collected from the bottom of the cultural layer, below the shell midden.

22. AA-9460 **5330 ± 55**

Small charcoal fragments from the lower layer of site, depth 50 cm in Square V7. Collected July 1992, submitted August 1992 by Y. Kuzmin. Calibrated range: 4400–3890 cal BC.

Comment (Y.K.): The sample was collected from the center of the shell midden.

23. SOAN-3020 **5300 ± 215**

Animal bones from the lower layer of site in Squares A–B/13–14. Collected July 1991 by A. Popov, submitted Nov 1991 by Y. Kuzmin. Calibrated range: 4530–3685 cal BC.

Comment (Y.K.): The sample was collected from the center of the shell midden.

24. SOAN-3019 **5160 ± 140**

Human bones from Burial 1, depth 130–135 cm below surface. Collected July 1991 by A. Popov, submitted Nov 1991 by Y. Kuzmin. Calibrated range: 4530–3685 cal BC.

Comment (Y.K.): The burial is associated stratigraphically with the middle of the shell midden.

25. GIN-6957 **5030 ± 140**

Animal bones from the lower part of the site in Squares A–B/13–14. Collected July 1991 by A. Popov, submitted Nov 1991 by Y. Kuzmin. Calibrated range: 4120–3545 cal BC.

Comment (Y.K.): GIN-6957 is from the same location as SOAN-3020.

Oleny A Series

26. SOAN-1549 **5370 ± 65**

Charcoal from Layer 3, Oleny A (43°21′N, 132°17′E), 100 cm below surface, Dwelling 9b. Collected 1965 by D. Brodiansky, submitted 1966 by A. Okladnikov. Calibrated range: 4410–3900 cal BC.

27. SOAN-1534 **5010 ± 30**

Charcoal from hearth, layer 3, depth 78 cm below surface, Dwelling 7b. Collected 1965 by D. Brodiansky, submitted 1966 by A. Okladnikov. Calibrated range: 3915–3360 cal BC.

Valentin-Peresheek Series

28. MAG-422 **4900 ± 200**

Charcoal from the lower layer of Valentin-Peresheek (43°07′N, 134°18′E), depth 70-80 cm below surface. Collected and submitted 1975 by A. Garkovik. Calibrated range: 4090–3355 cal BC.

29. MAG-398 **4500 ± 120**

Charcoal from the lower layer of site, depth 70–80 cm below surface. Collected and submitted 1975 by A. Garkovik. Calibrated range: 3505–2925 cal BC.

30. MGU-544 **4320 ± 90**

Charcoal from the lower layer of site, depth 100–130 cm. Collected 1975 by A. Garkovik, submitted 1976 by V. Stepanov. Calibrated range: 3355–2665 cal BC.

Mustang Series

31. Ki-3151 **4660 ± 60**

Charcoal from the lower layer of Mustang (44°09′N, 132°35′E), 80 cm below surface. Collected July 1987 by A. Garkovik, submitted October 1987 by Y. Kuzmin. Calibrated range: 3655–3175 cal BC.

32. Ki-3152 **4050 ± 70**

Charcoal from the lower layer of site, depth 50 cm below surface. Collected July 1987 by A. Garkovok, submitted Oct 1987 by Y. Kuzmin. Calibrated range: 2875–2405 cal BC.

33. RUL-193 **4250 ± 60**

Charcoal from Phusun (Moryak-Rybolov) (43°20′N, 134°48′E). Collected and submitted 1959 by A. Okladnikov. Calibrated range: 3145–2660 cal BC.

Comment (Y.K.): it is still unclear whether the sample was collected from the Neolithic or the Bronze Age (Derevianko 1973: 118–119; Brodiansky 1987: 114; Djakov 1992: 113–119).

34. RUL-177 **4150 ± 60**

Wood from Kirovsky (43°20′N, 132°17′E). Collected and submitted 1959 by A. Okladnikov.

Comment (Y.K.): Okladnikov (1964) associated the dated cultural layer with the Bronze Age. In this layer, the earliest cultivated plant remains—millet (*Setaria italica* L.)—were found. A Neolithic layer is also present at the site. Calibrated range: 2925–2550 cal BC.

"Under the Linden" Series

35. SOAN-1530 **3915 ± 50**

Charcoal from "Under the Linden" (42°56′N, 133°06′E). Collected and submitted 1976 by A. Okladnikov and V. Medvedev. Calibrated range: 2480–2361, 2339–2327 cal BC.

36. SOAN-1532 **3635 ± 30**

Charcoal. Collected and submitted 1976 by A. Okladnikov and V. Medvedev. Calibrated range: 2130–2103, 2092–2073, 2054–2037, 2017–1978, 1962–1946 cal BC.

General Comment: The Rudnaya (basal layer) and the Chertovy Vorota sites are of the earliest Neolithic culture in Primorye, the Rudnaya. Together with the basal layer of the Boisman 2 site (Boisman culture) they can be attributed to the Early Neolithic. Another principal Neolithic culture in Primorye, the Zaisanovskaya, is represented by the Rudnaya (middle layer), Oleny A, Valentin-Pereshhek (basal layer), Mustang (basal layer) and "Under the Linden" sites. The dates of the Phusun and Kirovsky sites are chronologically close to the Zaisanovskaya culture, with which they may be associated.

THE BRONZE AGE

37. GIN-6951 **2980 ± 50**

Charcoal from Novoselischche 4 (44°37′N, 131°47′E), from the middle layer of site, depth 40 cm below surface in Square T3. Collected August 1991 by N. Kluev, submitted Nov 1991 by Y. Kuzmin. Calibrated range: 1335–1254, 1229–1122 cal BC.

Sinii Gai A Series

38. SOAN-1540 **2875 ± 45**

Birch bark from Sinii Gai A (44°28′N, 132°36′E) Layer 3, depth 60–70 cm below surface, Dwelling 29. Collected 1967 by D. Brodiansky, submitted 1967 by A. Okladnikov. Calibrated range: 1125–1002 cal BC.

39. SOAN-1541 **2820 ± 55**

Birch bark from Layer 3, depth 40–60 cm below surface, Dwellings 17–18. Collected 1967 by D. Brodiansky, submitted 1967 by A. Okladnikov. Calibrated range: 1034–915 cal BC.

Lidovka 1 Series

40. SOAN-1390 **2610 ± 45**

Charcoal from Lidovka 1 (44°25′N, 135°53′E), depth 35 cm below surface. Collected and submitted 1975 by V. Djakov. Calibrated range: 806–789 cal BC.

41. SOAN-1388 **2570 ± 60**

Charcoal, depth 35 cm below surface. Collected and submitted 1975 by V. Djakov. Calibrated range: 804–764, 675–662 cal BC.

42. SOAN-1424 **2530 ± 40**

Seeds of foxtail or Japanese millet, depth 40–50 cm below surface. Collected and submitted 1976 by V. Djakov. Calibrated range: 792–759, 685–658 cal BC.

43. SOAN-1389 **2450 ± 50**

Charcoal, depth 30 cm below surface. Collected and submitted 1975 by V. Djakov. Calibrated range: 764–678 cal BC.

Suvorovo 6 Series

44. GIN-7234 **2960 ± 90**

Charcoal from the upper layer of Suvorovo 6 (44°14′N, 135°20′E), depth 30–40 cm below surface in Square K3. Collected July 1991 by A. Krupianko, submitted April 1992 by Y. Kuzmin. Calibrated range: 1370–1345, 1317–1031 cal BC.

45. SOAN-3023 **2935 ± 50**

Charcoal from the upper layer of the site in Square K3. Collected July 1991 by A. Krupianko, submitted November 1991 by Y. Kuzmin. Calibrated range: 1261–1068 cal BC.

46. SOAN-3022 **2320 ± 55**

Charcoal from the upper layer of site, southern part of the 1991 excavation pit. Collected July 1991 by A. Krupianko, submitted November 1991 by Y. Kuzmin. Calibrated range: 405–378 cal BC.

Eustaphy-Oleg 1 Series

47. GIN-6948 **3150 ± 80**

Charcoal from Eustaphy-Oleg 1 (43°28′N, 134°59′E), depth 50–70 cm below surface in Squares V/2–3, G/2–3. Collected August 1991 by A. Garkovik, submitted November 1991 by Y. Kuzmin. Calibrated range: 1519–1394, 1332–1329 cal BC.

48. GIN-6949 **2900 ± 120**

Charcoal from the lower part of the cultural layer, depth 80–90 cm below surface. Collected August 1991 by A. Garkovik, submitted November 1991 by Y. Kuzmin. Calibrated range: 1300–920 cal BC.

49. MGU-542 **2840 ± 170**

Charcoal from the lower layer of the site at Sinie Skaly (43°44′N, 135°14′E), depth 80–100 cm below surface. Collected 1976 by Zh. Andreeva, submitted 1977 by V. Stepanov. Calibrated range: 1260–830 cal BC.

General Comment: Krushanov (1989) subdivided the Bronze Age of Primorye into three cultures: Sinegaiskaya (Sinii Gai, Layer 3; Novoselischche 4), Lidovskaya (Lidovka 1; Suvorovo 6, upper layer) and Margaritovskaya (Sinie Skaly, lower layer; Eustaphy-Oleg 1). All these cultures follow the Neolithic and are close to one another chronologically.

Discussion and Conclusion

We have estimated for these series of dates the weighted mean age (WMA) (Aitken 1990). The WMA of the 3 dates at the Almazinkasite is 7450 ± 40 BP; of the 3 dates for Rudnaya (lower layer), 7560 ± 45 BP; of the 4 dates for the Rudnaya (middle layer), 4050 ± 20 BP, *i.e.*, 2865–2415 cal BC; of the 2 dates for Sinii Gai (layer 3), 2855 ± 35 BP, *i.e.*, 1082–977 cal. BC; and of the 4 dates for Lidovka 1, 2540 ± 25 BP, *i.e.*, 792–765, 677–661, 606–604 cal BC.

Based on the chronological difference between the Rudnaya and Zaisanovskaya cultures, we establish the Zaisanovskaya as a Late Neolithic culture. The ^{14}C age of the oldest shell midden on the Pacific coast of the Russian Far East, Boisman 2 (lower layer), is close to the age of the Early Neolithic shell midden at Tongsamdong in Korea (5890 ± 140 BP; GX-0378) (Nelson 1991).

Using the WMA as a reference point together with all the ^{14}C dates (Fig. 2), one can establish both the boundaries and the duration of archaeological periods and cultures. The transition from the Pale-

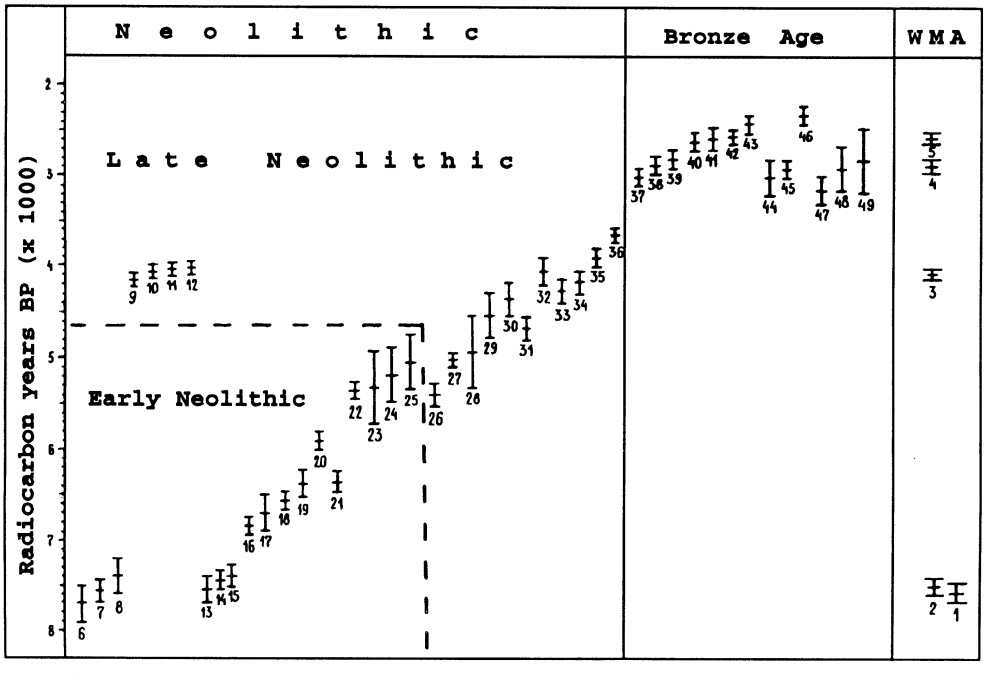

Fig. 2 ^{14}C sequence of the Neolithic and Bronze Ages of Primorye. Numbers correspond to those in the text; dates are plotted with two sigma errors. WMA: 1. Rudnaya (lower layer); 2. Almazinka; 3. Rudnaya (middle layer); 4. Sinii Gai A, Layer 3; 5. Lidovka 1.

olithic to the Early Neolithic occurred *ca.* 7800–7900 BP. The Early Neolithic Rudnaya and Boisman cultures existed up to 5000 BP; the Rudnaya to 7600–5900 BP, and the Boisman to 6400–5000 BP. The Early Neolithic gave way to the Late Neolithic at *ca.* 5300–5000 BP. The Zaisanovskaya culture existed between 5300–3600 BP. We can also place the boundary between the Late Neolithic and Bronze Age at *ca.* 3000 BP, but no known Zaisanovskaya sites are dated between 3600 and 3000 BP. The Bronze Age cultures date from 3000–2300 BP.

The first interpretation of ^{14}C dates of the ancient cultures from Primorye presented here show that we must continue to date these sites and cultures, and establish the age of the Paleolithic/Neolithic transition and the Late Neolithic/Bronze Age boundary.

ACKNOWLEDGMENTS

The authors thank the following individuals for helpful discussions of the results and for providing us with information: Zh. Andreeva, D. Brodiansky, A. Garkovik, S. Gladyishev, V. Djakov, N. Kluev, A. Krupianko, A. Kuznetsov, V. Lyinsha, N. Ovodov, A. Popov, V. Stepanov, A. Tabarev, R. Vasijevsky. The dating of the Arizona AA- samples was partially funded by U.S. NSF Grant EAR 92-03883. We thank L. J. Toolin and A. L. Hatheway for technical assistance in these measurements. We also thank N. Mishchenko for helping to prepare the manuscript.

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[RADIOCARBON, VOL. 36, NO. 3, 1994, P. 367–376]

PREHISTORIC COLONIZATION OF NORTHEASTERN SIBERIA AND MIGRATION TO AMERICA: RADIOCARBON EVIDENCE[1]

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ABSTRACT. This review of radiocarbon dates from northeastern Siberian Paleolithic sites provides data that can be applied to establishing a chronology of human settlement, and that can provide a rough estimate of the timing of the initial peopling of the New World.

INTRODUCTION

Radiocarbon dating of ancient sites is one of the most useful and important aspects of chronometric age determination (Aitken 1990). This method is used extensively to establish the chronologies of both northeast Siberian and northwest North American Paleolithic cultures and migrations to the New World (see, *e.g.*, Morlan 1987; Hoffecker, Powers and Goebel 1993; Whitley and Dorn 1993). Waters (1985) made one of the most appropriate critical overviews of ^{14}C dating for the earliest (pre-Clovis) sites in the Americas. The aim of this review is to present the ^{14}C dates of northeast Siberia, together with a brief discussion of their relevance to an important scientific problem—the peopling of the New World. Because the majority of sources of Siberian ^{14}C dates are in Russian, it is useful to compile an English-language review for the international scientific community.

METHODS

Table 1 lists the ^{14}C dates from Paleolithic sites of northeast Siberia, from Lake Baikal to Chukotka (Figs. 1–3). The list includes dates from published sources through Autumn 1993, but includes no references. Besides the dates, Table 1 includes such information as sample material, context and depth below surface. Dates are grouped into geographical regions of northeastern Siberia.

DISCUSSION

Early Upper Paleolithic (39,000–24,000 BP)

Ancient sites that are associated with the Early Upper Paleolithic have not been ^{14}C dated, except for the Filimoshki site (Table 1). Up to the present, Early Paleolithic and Mousterian sites of northeastern Siberia are unknown in well-defined geological contexts (Yi and Clark 1983; Kuzmin 1992a; Kuzmin and Krivonogov 1994). The earliest Upper Paleolithic sites of the area are Makarovo 4, Arta 2 (Layer 4), Tolbaga (Layer 4), Varvarina Gora (Layer 2), Ust-Kova (Layer 7) and Geographical Society Cave (Fig. 1). Dates of these sites range from 39,000 to 27,200 BP.

Kirillov and Kasparov (1990) assumed that Layer 4 of the Arta 2 site is associated with the cultural stage preceding the Upper Paleolithic. Mochanov (1977) used ^{14}C dates from the Ust-Mil 2 (Layers B, C) and Ikhine 2 (Layers 2 b, c, d) sites to suggest that the beginning of the Dyutkai complex lies between 30,000 and 35,000 BP. Some archaeologists, for example, Abramova (1979) do not accept this viewpoint, and propose that the ages of these sites are between 15,000 and 20,000 BP. One of

[1] *Editors' note:* This paper was scheduled for presentation at the Archaeology Workshop of the 15th International Radiocarbon Conference, 14 August 1994, Glasgow, Scotland, but was not delivered because of the author's absence.

the earliest of Mochanov's key sites – Ezhantsy – was dated, at the end of the 1970s, to 17,150 ± 345 BP: IM-459. In my opinion, the most probable age of the earliest Yakutian sites is *ca.* 24,000–26,000 BP. Thus, the general boundary between the early and late stages of the Upper Paleolithic in northeastern Siberia and may be fixed to *ca.* 29,000–24,000 BP.

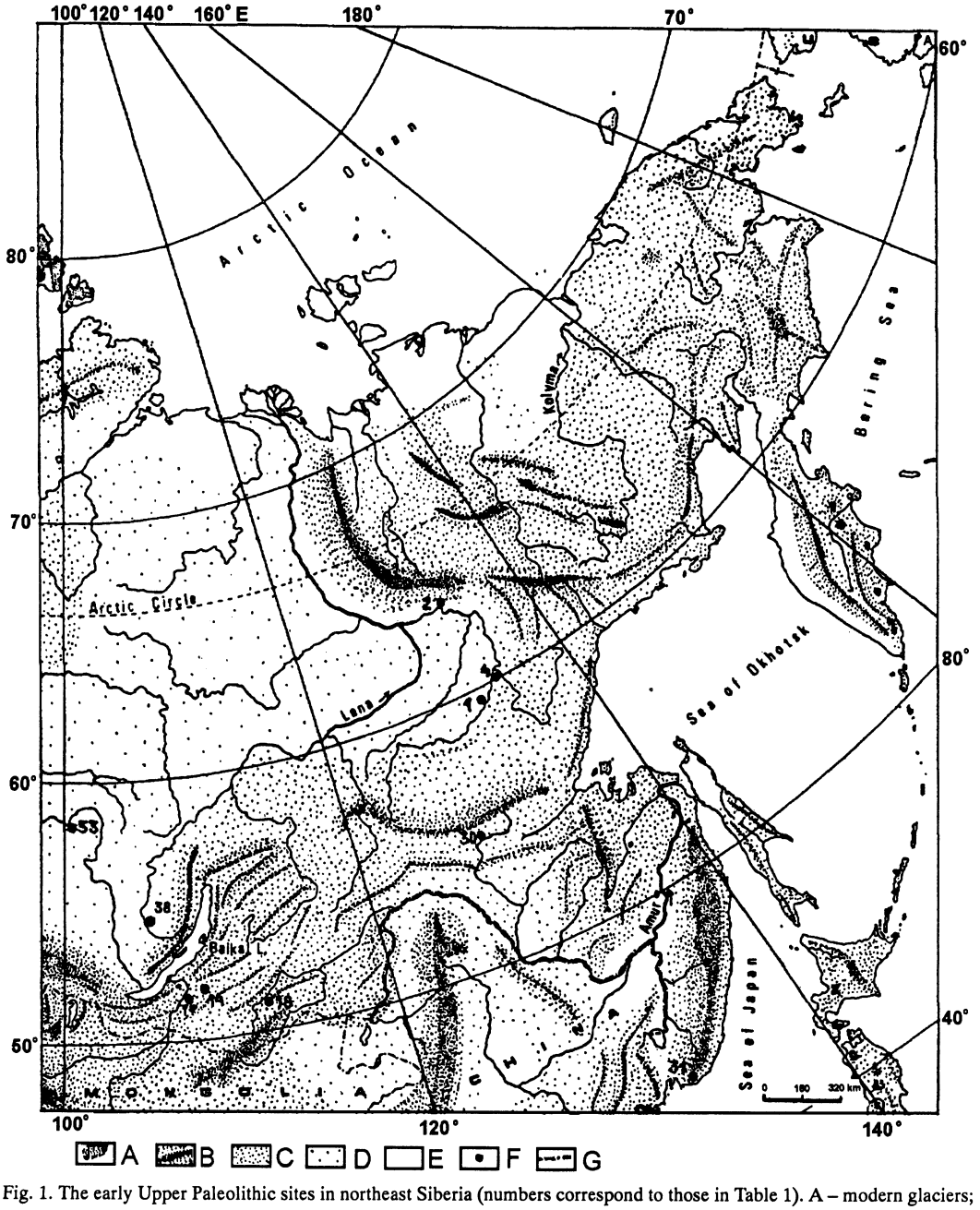

Fig. 1. The early Upper Paleolithic sites in northeast Siberia (numbers correspond to those in Table 1). A – modern glaciers; B – mountain ridges; C – high plains; D – low plains; E – lowlands; F – Paleolithic sites; G – state boundaries.

Late Upper Paleolithic (24,000–10,000 BP)

Many ancient sites in northeastern Siberia relate to the Late Upper Paleolithic, occurring practically all over the study region, except for the Kolyma River basin and Chukotka (Fig. 2). The earliest sites of this cultural stage are Military Hospital 2 and Makarovo 3, containing redeposited material and dating from 31,200–29,700 BP. Most of the dates fall within the period, 24,000–10,000 BP, whereas, in Yakutia, the Ust-Timpton site, Layer 5a is as late as 9400 BP.

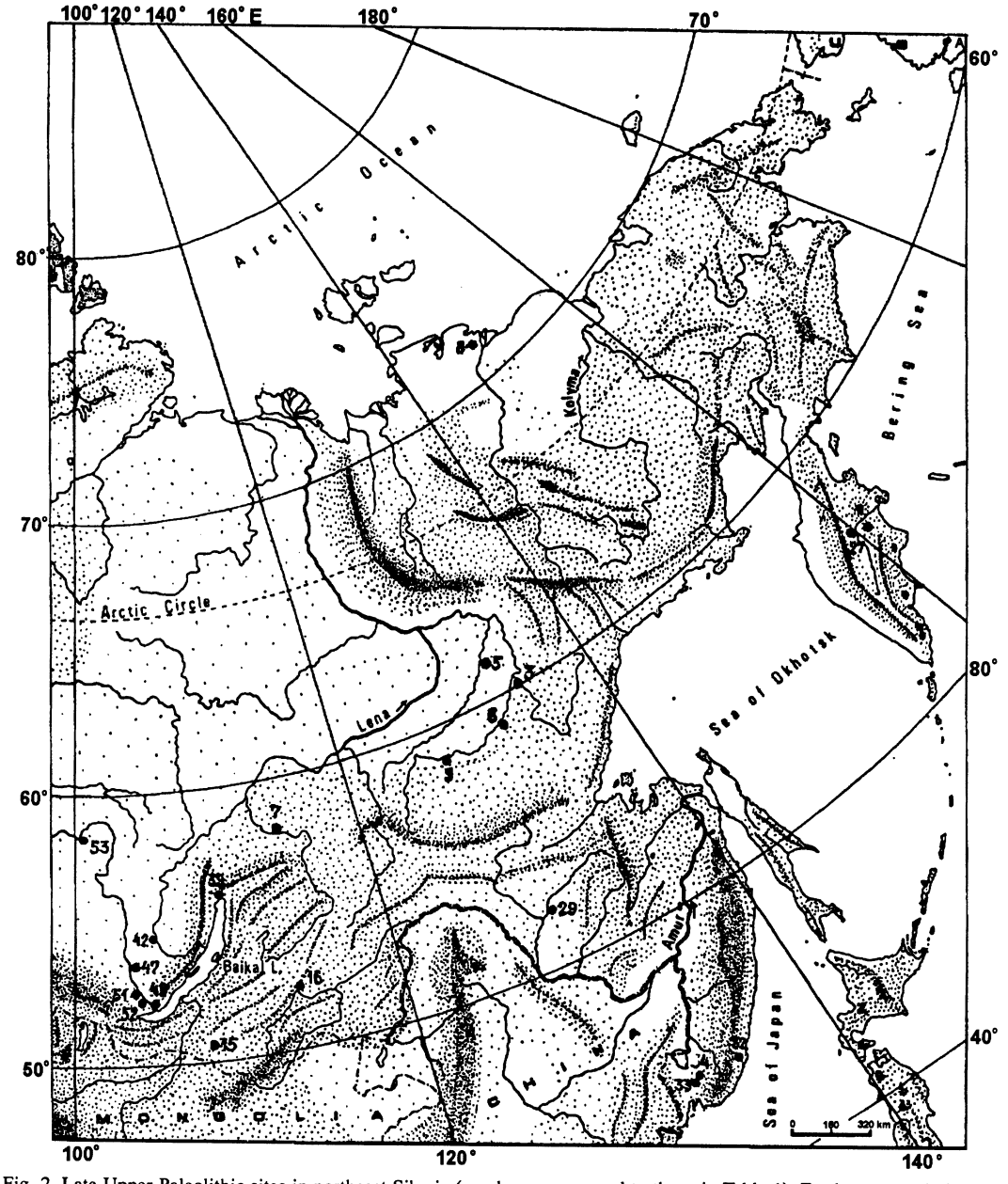

Fig. 2. Late Upper Paleolithic sites in northeast Siberia (numbers correspond to those in Table 1). For key to symbols, see Fig. 1.

Late to Final Paleolithic Transition (15,200–12,400 BP)

The earliest sites associated with the transition from Late to Final Paleolithic are Makarovo 2, Ust-Belaya (Layer 14), Kurla 3 (Layer 1) and Bolshoi Yakor (Layer 7), which range from 15,200 to 12,400 BP.

Final Upper Paleolithic (Mesolithic) (10,000–6000 BP)

Sites of this cultural stage occupy all of northeastern Siberia (Fig. 3).

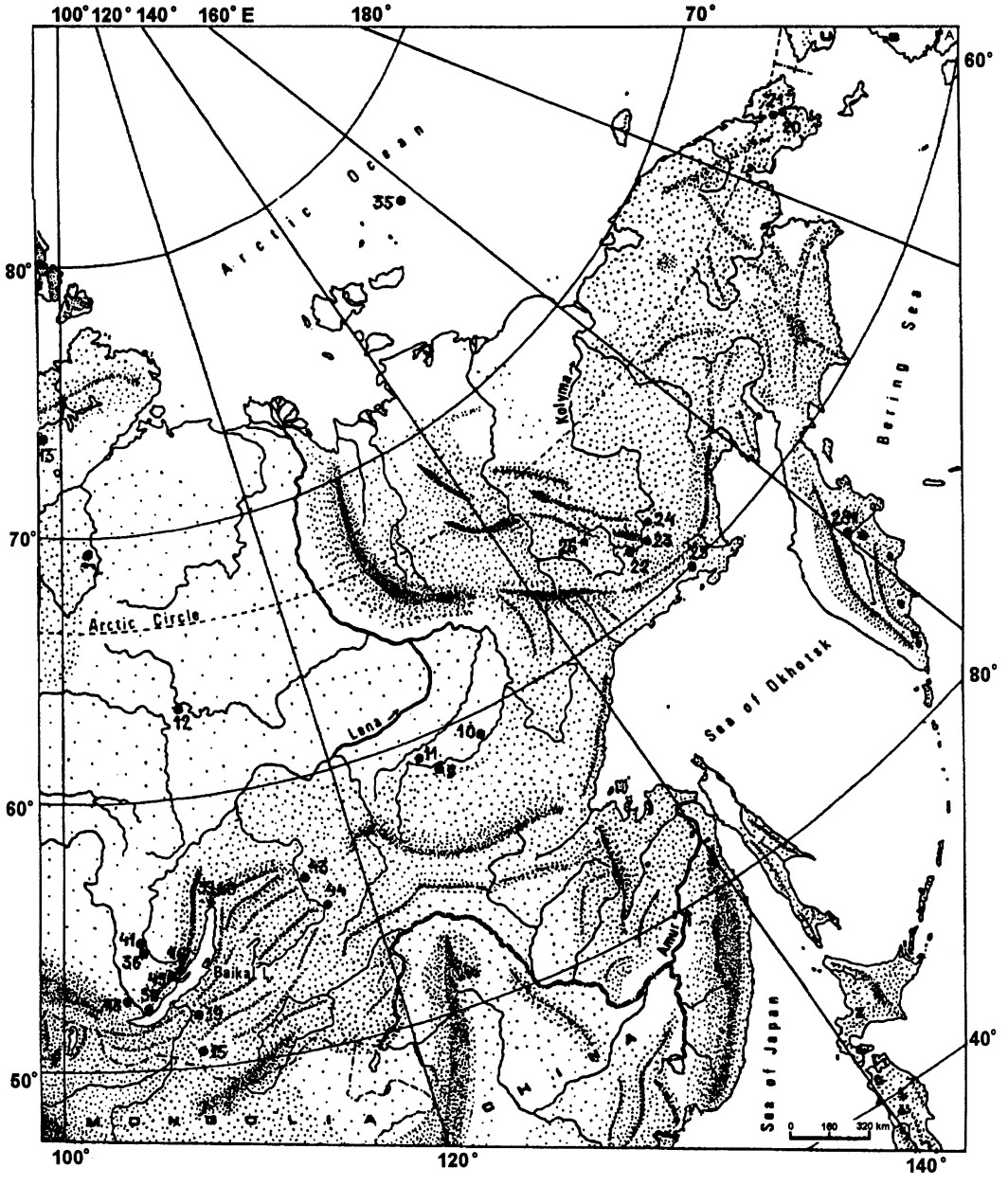

Fig. 3. Final Upper Paleolithic sites in northeast Siberia. For key to symbols, see Fig. 1.

Paleolithic to Neolithic Transition (12,960–5900 BP)

Dating not later than 5900 BP, the younger sites are located in Yakutia, Taimyir Peninsula, and in the High Arctic, are Belkachi, Sumnagin, Tagenar 6 and Zhokhov. The Paleolithic/Neolithic transition in northeastern Siberia is non-synchronous. Taking into account that pottery-making is the most distinctive innovation of the Neolithic, the earliest pottery of the area comes from the Lower Amur River basin – the Gasya site, dating to 12,960 ± 120 BP: LE-1781, and from Trans-baikal, dating to *ca.* 10,000 BP. At *ca.* 8000 BP, pottery appeared for the first time over most of the Russian Far East (Kuzmin 1992a, b). In Yakutia, the Kolyma River basin and Chukotka, the earliest pottery dated to younger than 6000 BP.

TABLE 1. Radiocarbon Dates from the Paleolithic and Mesolithic Sites in Northeastern Siberia

Site no., name*	^{14}C date (yr BP)	Lab no.	Sample material	Context, depth
Yakutia				
1 Ust-Mil 2	12,200 ± 170	LE-953	Wood	Layer A, 1.50 m
	23,500 ± 500	LE-999	Wood	Layer B, 1.80 m
	33,000 ± 500	LE-1000	Wood	Layer C, 2.25 m
	30,000 ± 500	LE-1001	Wood	Layer C, 2.40 m
	35,400 ± 600	LE-954	Wood	Layer C, 2.50 m
	35,600 ± 900	LE-955	Wood	Below artifacts, 4.0 m
2 Ikhine 2	24,330 ± 200	LE-1131	Wood	Layer IIb, 0.95 m
	24,500 ± 480	IM-203	Wood	Layer IIb, 0.90 m
	24,600 ± 380	IM-155	Wood	Layer IIc, 1.40 m
	27,400 ± 800	IM-205	Wood	Layer IIb, 0.90 m
	30,200 ± 300	GIN-1019	Wood	Layer IIb, 0.95 m
	26,600 ± 900	IM-201	Wood	Layer IIc, 1.20 m
	31,200 ± 500	GIN-1020	Wood	Layer IIc, 1.20 m
	26,030 ± 200	IM-239	Bone	Rhinoceros, 1.30 m
	26,500 ± 540	IM-202	Wood	Layer IIc, 1.30 m
	27,800 ± 500	IM-206	Wood	Layer IId, 1.60 m
3 Verkhne-Troitskaya	18,300 ± 180	LE-905	Wood	5.30 m
4 Ezhantsy	17,150 ± 345	IM-459	Bone	Alluvium, 0.60–1.0 m
5 Khaergas	16,000 ± 300	IM-887	Bone	Layer 6
6 Duyktai Cave	12,100 ± 120	LE-907	Wood	Layer VIIa, 1.80 m
	12,520 ± 260	IM-462	Wood	Layer VIIb mammoth, 2.7 m
	12,690 ± 120	LE-860	Charcoal	Layer VIIb, 2.60 m
	13,070 ± 90	LE-784	Charcoal	Layer VIIb, 2.30 m
	13,110 ± 90	LE-908	Wood	Layer VIIc, 3.50 m
	13,200 ± 250	GIN-405	Charcoal	Layer VIIa, 1.60 m
	14,000 ± 100	GIN-404	Charcoal	Layer VIIb, 2.30 m
7 Avdeikha	9200 ± 390	IM-471	?	0.90 m
	12,900 ± 300	GIN-1022	Charcoal	Layer C, 0.90 m
	15,200 ± 300	IM-236	Charcoal	Layer C, 0.80–1.20 m
8 Berelekh	10,600 ± 90	LE-998	Wood	2.53 m
	11,830 ± 110	LU-147	Wood	Above artifacts, 1.6 m
	12,240 ± 160	LU-149	Ivory	2.55 m
	12,930 ± 80	GIN-1021	Wood	2.30 m
	13,420 ± 200	IM-152	Wood	2.53 m
9 Ust-Timpton	6380 ± 80	LE-894	Charcoal	Layer IIIb, 1.20 m
	6570 ± 100	LE-910	Charcoal	Layer IIIb, 1.25 m
	7000 ± 90	LE-895	Charcoal	Layer IVa, 1.50 m
	8900 ± 200	IM-456	Charcoal	Layer Va, 2.00 m

TABLE 1. (Continued)

Site no., name*	^{14}C date (yr BP)	Lab no.	Sample material	Context, depth
	9000 ± 110	LE-832	Charcoal	Layer IVb, 1.75 m
	9400 ± 90	LE-896	Charcoal	Layer Va, 2.00 m
	9450 ± 300	IM-455	Charcoal	Layer Vb, 2.05 m
	10,130 ± 100	LE-897	Wood	Layer VIb, 2.25 m
	10,300 ± 50	LE-920	Charcoal	Between L. V–VI, 2.15 m
	10,340 ± 140	LE-862	Wood	Layer VIa, 2.20 m
	10,650 ± 80	LE-898	Wood	Layer VIb, 2.30 m
	10,740 ± 100	LE-861	Charcoal	Layer VIb, 2.05 m
	11,150 ± 150	IM-454	Charcoal	Layer V (?)
	11,800 ± 200	IM-453	Charcoal	Layer VIII, 2.50 m
10 Belkachi	5900 ± 70	LE-678	Charcoal	Layer 8, 1.80 m
	6250 ± 60	LE-697	Charcoal	Layer 9, 2.00 m
	6720 ± 50	LE-650	Charcoal	Layer 10, 3.00 m
	6750 ± 70	LE-698	Charcoal	Layer 10, 3.10 m
	7430 ± 60	LE-741	Wood	Layer 12, 2.90 m
	7830 ± 150	LE-742	Wood	Layer 13, 3.30 m
	7920 ± 60	LE-743	Wood	Layer 14, 3.70 m
	8060 ± 70	LE-746	Charcoal	Layer 17, 5.10 m
	8110 ± 80	LE-744	Wood	Layer 15, 4.60 m
	8260 ± 80	LE-745	Wood	Layer 17, 4.90 m
	8290 ± 80	LE-760	Wood	Layer 19, 5.50 m
	8360 ± 80	LE-747	Wood	Layer 18, 5.30 m
	8370 ± 80	LE-761	Charcoal	Layer 20, 5.80 m
	8440 ± 80	LE-801	Wood	Layer 21, 5.90 m
	8500 ± 160	LE-740	Charcoal	Close to L. 20, 5.80 m
	8520 ± 80	LE-762	Charcoal	Layer 22, 6.10 m
	9045 ± 210	IM-243	Wood	Layer 23, 6.30 m
	9180 ± 80	LE-763	Wood	Layer 23, 6.30 m
11 Sumnagin	5960 ± 60	LE-795	?	Layer 20, 2.70 m
	6100 ± 50	GIN-296	Wood	Layer 36, 4.45 m
	6200 ± 60	LE-798	?	Layer 36, 4.45 m
	6280 ± 60	LE-797	?	Layer 33, 4.20 m
	6360 ± 60	LE-796	?	Layer 24, 3.10 m
	6900 ± 50	GIN-295	Wood	Layer 20, 2.70 m
12 Ust-Chirkuo	7200 ± 180	IM-475	Wood	Layer 5, 1.20 m
	7600 ± 80	LE-996	?	Layer 6, 0.80 m
	7650 ± 170	IM-481	Charcoal	Layer 8, 1.40 m
	8350 ± 150	IM-476	Wood	Layer 12, 1.80 m
	8740 ± 100	IM-373	?	Layer 10, 1.60 m
	8750 ± 200	IM-479	Charcoal	Layer 10, 1.60 m
13 Tagenar 6	6030 ± 100	LE-884	?	
Transbaikalian				
14 Tolbaga	15,100 ± 520	SOAN-810	Bone	Layer 3
	27,210 ± 300	SOAN-1523	Bone	Layer 4
	34,860 ± 2100	SOAN-1522	Bone	Rhinoceros, Layer 4
15 Studenoye	10,755 ± 140	SOAN-1653	Coal	Layer 13/1
	10,975 ± 135	SOAN-1654	Charcoal	Layer 14
	11,395 ± 100	SOAN-1655	Charcoal	Layer 14
	11,340 ± 180	GIN-2931a	Charcoal	Layer 15
	11,660 ± 400	GIN-2930	Charcoal	Layer 15
	11,340 ± 200	GIN-2932	Charcoal	Layer 16
	11,630 ± 50	SOAN-1656	Charcoal	Layer 16
	12,130 ± 150	GIN-2934a	Charcoal	Layer 17

TABLE 1. (Continued)

Site no., name*	^{14}C date (yr BP)	Lab no.	Sample material	Context, depth
	12,140 ± 150	GIN-2934	Charcoal	Layer 17
	12,110 ± 150	GIN-2935	Charcoal	Layer 18
	12,800 ± 400	GIN-2937	Charcoal	Layer 18
16 Sokhatino 4	11,900 ± 130	SOAN-841	Bone	
	26,110 ± 200	SOAN-1138	Charcoal	
17 Varvarina Gora	17,035 ± 400	SOAN-3053	?	Layer 1
	29,895 ± 1790	SOAN-3054	?	Layer 2
	30,600 ± 500	SOAN-850	Bone	Layer 2
	34,900 ± 780	SOAN-1524	Bone	Layer 2
18 Arta 2	23,200 ± 2000	LE-2966	Charcoal	Layer 3
	37,360 ± 2000	LE-2967	Charcoal	Mousterian(?), Layer 4
19 Oshurkovo	10,900 ± 500	GIN-302	Charcoal	Layer 3
Chukotka				
20 Chelkun 4	8150 ± 450	MAG-719	Charcoal	
21 Ananaiveem	8410 ± 80	LE-2791	Charcoal	
Kolyma River Basin				
22 Siberdik	7865 ± 310	MAG-184	Charcoal	Layer 3, 0.90 m
	8020 ± 80	KRIL-250	Charcoal	Layer 3, 0.80–0.90 m
	8130 ± 100	MAG-606	?	Layer 3, 0.80 m
	8480 ± 200	KRIL-249	Charcoal	Layer 3, 0.80–0.90 m
	9700 ± 500	MAG-1019	?	Layer 3, 1.00 m
	13,225 ± 230	MAG-916	?	Layer 3
23 Kongo	8080 ± 500	MAG-406	?	Layer 1
	8600 ± 220	MAG-196	Charcoal	Layer 1, 1.60 m
	8700 ± 400	MAG-595	?	Layer 3, (?)
	8850 ± 500	KRIL-315	Charcoal	Layer 2, 1.00 m
	9020 ± 510	KRIL-313	Charcoal	Layer 2, 1.00 m
	9470 ± 530	KRIL-314	Charcoal	Layer 2, 1.20 m
24 Maltan	7490 ± 70	MAG-183	Charcoal	Layer 2, 0.40 m
25 Uptar	8260 ± 330	MAG-1262	Charcoal	0.10-0.35 m
26 Zima	7070 ± 60	MAG-1260	Charcoal	
Kamchatka				
27 Ushki 1	9750 ± 100	MAG-637	Charcoal	Layer 7
	10,360 ± 220	MAG-401	Charcoal	Layer 6
	10,360 ± 350	MO-345	Charcoal	Layer 6, 1.70 m
	10,760 ± 110	MAG-219	Charcoal	Layer 6, 1.80 m
	13,600 ± 250	GIN-167	Charcoal	Layer 7, 2.20 m
	14,300 ± 200	GIN-168	Charcoal	Layer 7
	21,000 ± 100	GIN-186	Charcoal	Layer 6 (?)
28 Ushki 5	8790 ± 150	MAG-215	Charcoal	Layer 6
Russian Far East				
29 Ust-Ulma	19,350 ± 65	SOAN-2619	Charcoal hearth	
30 Filimoshki	20,350 ± 850	SOAN-825	Peat	Redeposited
31 Geographical Society Cave	32,570 ± 1510	IGAN-341†	Bone	Horse, mammoth, 0.60–0.80 m
32 Suvorovo 4	15,105 ± 140	AA-9463†	Charcoal	0.25–0.30 m
	15,300 ± 140	Ki-3502†	Charcoal	0.25–0.30 m
33 Gorbatka 3	13,500 ± 200	SOAN-1922†	Humic acids	Below artifacts
34 Ilistaya 1	7840 ± 60	Ki-3163†	Charcoal	
High Arctic				
35 Zhokhov Island	7450 ± 200	LE-4534	Wood	

TABLE 1. (Continued)

Site no., name*	^{14}C date (yr BP)	Lab no.	Sample material	Context, depth
	7850 ± 40	LU-2433	Wood	
	7870 ± 60	LU-2432	Wood	
	7930 ± 40	GIN-6400	Bone	
	7940 ± 170	LE-4533b	Charcoal	
	8020 ± 50	LU-2499	Wood	
	8200 ± 40	GIN-6399	Wood	
	8560 ± 180	LE-3527	Charcoal	
	8790 ± 90	LU-2502	Wood	Below artifacts
Upper Lena River and Lake Baikal				
36 Makarovo 2	11,400 ± 500	GIN-480b	Charcoal	Layer 3
	11,860 ± 200	GIN-480a	Charcoal	Layer 3
	11,950 ± 50	GIN-481	Charcoal	Layer 4
37 Makarovo 3	30,000	GIN-7067a	Bone	Average date
	31,200 ± 500	GIN-7067b	Bone	
38 Makarovo 4	27,005 ± 370	AA-8879a	Bone	Layer 6a
	39,340 ± 1300	AA-8879b	Bone	Layer 6
39 Kurla 3	13,160 ± 350	SOAN-1396k	Bone	Layer 1
	15,200 ± 1250	SOAN-1396	Charcoal	Layer 1
	24,060 ± 5700	SOAN-1397	Charcoal	Layer 2
40 Kurla 6	14,150 ± 960	SOAN-1398	Charcoal	Layer 1
41 Shishkino	7430 ± 230	GIN-303a	Charcoal	
	8000 ± 700	GIN-303b	Charcoal	
	8270 ± 160	GIN-303c	Charcoal	
42 Shishkino 8	21,190 ± 175	AA-8882	Bone	
43 Bolshoi Yakor	10,100 ± 100	IM-920	Charcoal	Layer 3A
	10,070 ± 540	LE-4173A	Charcoal	Layer 4A
	10,320 ± 150	IM-968	Charcoal	Layer 4A
	10,400 ± 650	LE-4172	Charcoal	Layer 6
	12,400 ± 150	LE-4172A	Charcoal	Layer 6
	12,330 ± 250	GIN-6466	Charcoal	Layer 7
44 Nizhnyaya Dzhilinda	6720 ± 80	LE-1957	Charcoal	Layer 4
	7230 ± 40	GIN-4051	Bone	Layer 5A, burial
	7880 ± 80	LE-1955	Charcoal	Layer 5A
	7580 ± 80	LE-1956	Charcoal	Layer 5
	8980 ± 80	LE-1951	Charcoal	Layer 6
	11,280 ± 80	LE-1953	Charcoal	Layer 6
	11,280 ± 120	LE-1952	Charcoal	Layer 6
45 Ityirkhei	7300 ± 290	IM-402	Charcoal	Layer 7
	8010 ± 100	GIN-4882	Bone	Layer 8
46 Sagan-Zaba	7630 ± 45	SOAN-1573	Bone	Layer 4
	8775 ± 40	SOAN-1574	Bone	Layer 5
Upper Angara River Basin				
47 Igeteisky Log	21,260 ± 240	LE-1590	Charcoal	Layer 4
	23,500 ± 250	LE-1592	Charcoal	Layer 4
	23,700 ± 1100	IM-405	Charcoal	Layer 4
	24,400 ± 400	GIN-5327	Bone	Layer 6
48 Ust-Belaya	8960 ± 60	GIN-96	Bone	Layers 3–4
	9850 ± 500	GIN-483	Charcoal	Layer 8
	11,930 ± 230	GIN-5329	Bone	Layer 14
49 Military Hospital 2	29,700 ± 500	GIN-4440	Bone	Redeposited (?)

TABLE 1. (Continued)

Site no., name*	^{14}C date (yr BP)	Lab no.	Sample material	Context, depth
50 Verkholenskaya Gora 1	12,570 ± 180	MO-441	Charcoal	Layer 3
51 Buret	21,190 ± 100	?	Bone	
52 Malta	14,750 ± 120	GIN-97	Bone	Badai horizon
	20,700 ± 150	GIN-7709	Bone	
	21,000 ± 140	GIN-7706	Bone	
53 Ust-Kova	14,220 ± 100	LE-1372	Charcoal	Layer 4
	23,920 ± 310	KRIL-381	Charcoal	Layer 5
	28,050 ± 670	SOAN-1875	Charcoal	Layer 7
	30,100 ± 150	GIN-1741	Charcoal	Layer 7
	> 32,865	SOAN-1874	Charcoal	Layer 7

*Numbers correspond to numbers in Figs. 1–3.
†Also reported in Kuzmin *et al.* (1994), which precedes this article.

CONCLUSION

From the available data, it is possible to draw a preliminary conclusion that ancient people occupied western Beringia (the Indigirka River basin and Kamchatka) *ca.* 12,000–14,000 BP, at which time they could have migrated across the Bering Land Bridge. The data presented here form the foundation for a proposed Radiocarbon Database of Paleolithic sites in Siberia and the Russian Far East. Because of the rapid accumulation of new dates, it is necessary to plan for a sustained supplement to the database. For a detailed discussion of the general database, see Kra (1988).

ACKNOWLEDGMENTS

I am grateful to the following persons who helped me in the preparation of the manuscript and in the discussion of the data: M. P. Aksenov; O. I. Goryunova; E. M. Ineshin; G. I. Medvedev; L. D. Sulerzhitsky; and V. N. Vetrov. My thanks also go to M. R. Waters for the idea to compile this review. I am especially grateful to Dr. A. J. T. Jull and Profs. Robert E. Ackerman and Don E. Dumond for correcting the language and grammar of the draft. Research for this publication was supported by Grant #122-0645 A from the International Research and Exchanges Board, with funds provided by the U. S. Department of State, Title VIII. Neither of these organizations is responsible for the views expressed in the manuscript.

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[RADIOCARBON, VOL. 36, NO. 3, 1994, P. 377–389]

RADIOCARBON DATING SITES OF NORTHWEST RUSSIA AND LATVIA

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ABSTRACT. We describe applications of radiocarbon dating used for establishing a chronology of archaeological sites of the Novgorod region at the end of the first millennium AD. We have ^{14}C-dated known-age tree rings from sites in Latvia and ancient Novgorod, northwest Russia, as well as charcoal and wood from Novgorod. Calendar ages of ^{14}C-dated tree rings span the interval, AD 765–999. We used the Groningen calibration program, CAL15 (van der Plicht 1993) to calibrate ^{14}C ages to calendar years. Comparisons between ^{14}C results and archaeological data show good agreement, and enable us to narrow the calendar interval of calibrated ^{14}C determinations.

INTRODUCTION

Systematic excavations of old cities in northwest Russia, mainly Novgorod, have led to the construction of an archaeological chronology of the 10th–15th centuries. Lesman (1984, 1990) has linked Russian burial sites in northwest Russia with the well-dated dendrochronological scale of ancient Novgorod. This enables us to place the origin of many burial complexes at the beginning to the middle of the second millennium AD.

Pre-Christian Slavic settlement of northwest Russia has attracted much attention since the end of the 19th century. Recently excavated material from related settlements supplements the information retrieved from burial sites of long-barrow and high mound (*sopki*) cultures. However, chronological data are scarce (Popov, Svezhentsev and Zaitseva 1993).

The ancient city of Novgorod provides a well-documented archaeological chronology for northwest Russia. Dendrochronologically dated wood samples (Chernykh 1985) and the reconstruction of pavement-level stratigraphy at the Troitskii-VIII site (Bassalygo, Sorokin and Khoroshev 1988) indicate that the settlement at Novgorod extends from the mid-9th to the early 15th centuries. Our research on ^{14}C-dating tree rings has narrowed the period of occupation to AD 765–1000. Figure 1 shows the archaeological sites of the Novgorod region.

METHODS

We used dendrochronologically dated pine wood samples for ^{14}C-dating 14 samples from the sites of Ushuri and Araishiu, Latvia (which belong to the western European forest zone and are synchronous with some layers of ancient Novgorod), and 25 samples from the Troitskii-VIII excavation in Novgorod (Chernykh 1985a,b, 1987; Urieva 1989).

Wood samples were pretreated by using benzene/alcohol 2:1 for resin removal and acid-alkali-acid (AAA) solutions. The sequence follows: extraction of resins for 5–6 h; 1% HCl solution at room temperature for 1–2 h; 0.5% NaOH solution at 80°C for 1 h; washing with hot water; 1% HCl solution at 80°C for 1 h; and finally, rinsing with hot water to pH 7. The yield of this procedure is *ca.* 60–70% by weight. The samples were then carbonized by the dry distillation method (anoxic). We reacted the carbonized samples with lithium, then used standard procedures to convert Li_2C_2 to C_6H_6. The ^{14}C activity was measured using liquid scintillation spectrometry. We used a two-channel analyzer with quartz vials of 3.2- and 6.8-ml capacities. We did not correct for isotopic fractionation. The ratio of our calibration standard to the international standard, SRM-4990 (Arslanov

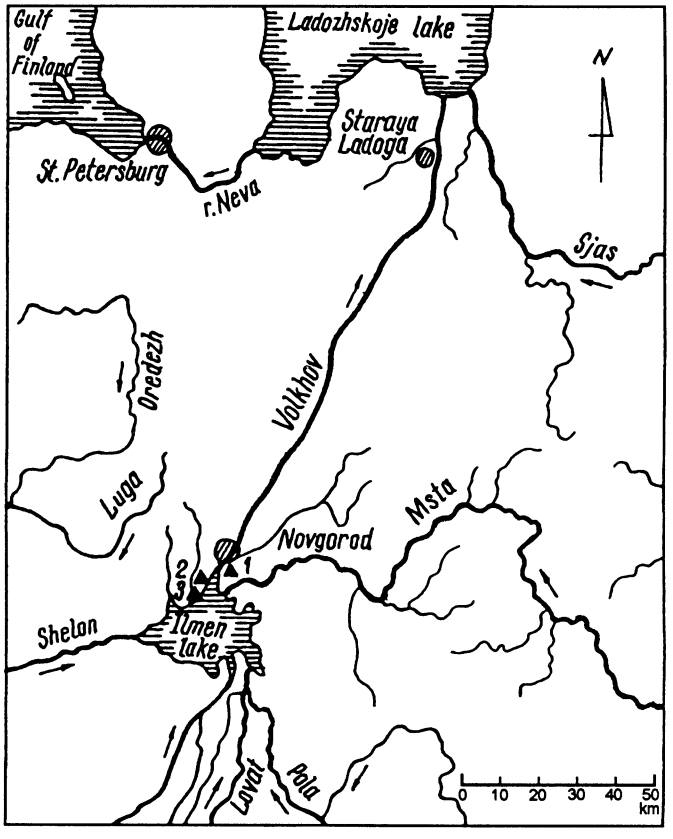

Fig. 1. Map of the Novgorod region and archaeological sites mentioned in the text: 1. Ryurikovo Gorodishche; 2. Gorodishche Georgii; 3. Vasiljevskoe-I settlement

1987) was 4.993 ± 0.011. The statistical error depended on the number of counts accumulated. Generally, the 1 σ error was between 30 and 60 yr, sometimes 70 and 90 yr.

Results

Earlier excavations yielded ^{14}C data sets for dendrochronologically dated wood samples from the 25th level of the Troitskii-VIII site in ancient Novgorod: TC-VIII-25–78, felling date: AD 968; and TC-VIII-25–63, felling date: AD 960 (Table 1, Fig. 2: III–IV). In the three years since we wrote our last report (Popov, Svezhentsev and Zaitseva 1993), we have obtained more data from Layers 22, 26 and 27 of the same excavation: TC-VIII-22–50—wood from the framework, felling date: AD 1002; TC-VIII-26–88—wood from planking, felling date: AD 960; and TC-VIII-27–130—wood from a wall, felling date: AD 958 (Table 1, Fig. 2: V–VII). Further, we have obtained dating results of dendrochronologically dated wood from Latvia: Ushuri—wood from planking, felling date: AD846; and Araishiu—wood from planking, felling date: AD 920–930 (Table 1, Fig. 2: I, II)

We have also reconsidered previous conclusions (Popov, Svezhentsev and Zaitseva 1993) based on new results and recent calibration information (Stuiver and Pearson 1993). We used the calibration program CAL15 (van der Plicht 1993) to convert ^{14}C determinations to calendar ages. We report

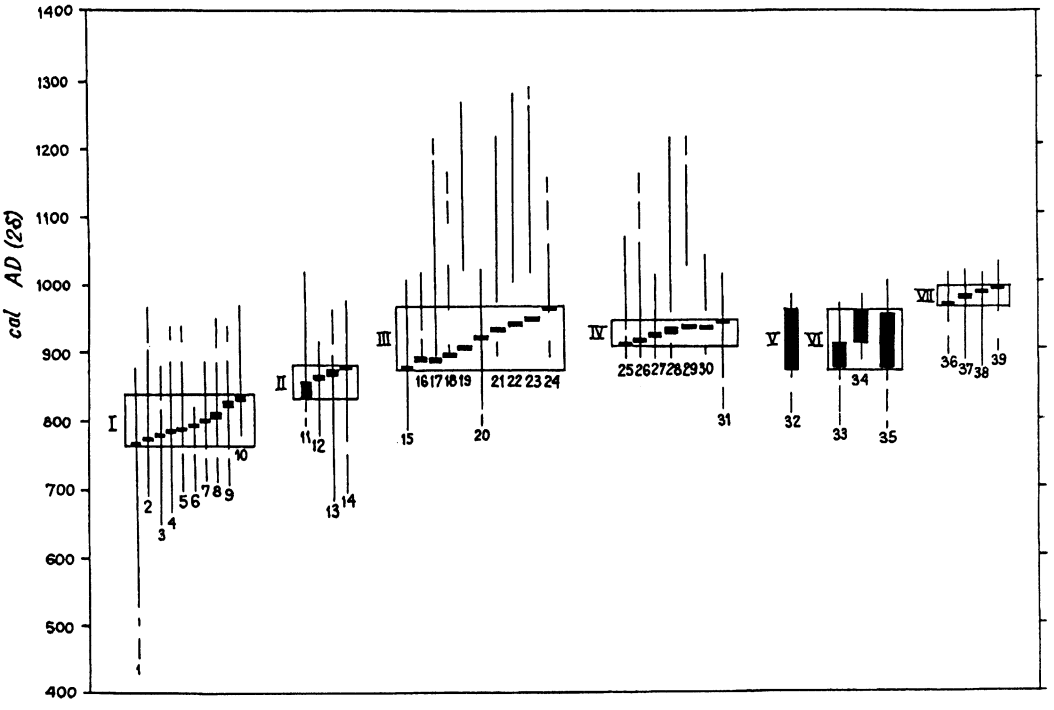

Fig. 2. Calibrated ^{14}C dates (2 σ) of tree-ring-dated wood samples: I–VII = blocks of tree-ring-dated wood samples; ▮ = range of tree-ring dates; Nos. 1–39 = sample numbers correlated to Table 1.

our results in Table 1 and in Figures 2 and 3. Figure 3 shows a rapid decline in ^{14}C concentration in Section 3 of the curve at *ca.* cal AD 900. Some samples of dendrochronologically dated wood lie within this period.

Table 1 compares calendar ages for wood (determined dendrochronologically) with calibrated ^{14}C ages (Fig. 2: Blocks I–VII). Generally, the two data sets agree, particularly where the ^{14}C concentration changes smoothly (Fig. 3: 1, 2, 4). Blocks I, II and IV (Fig. 2) correspond to these sections

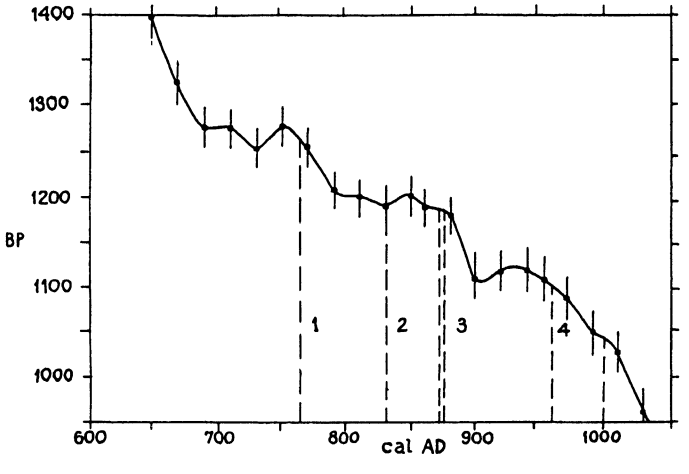

Fig. 3. The Stuiver and Pearson (1993) calibration curve for AD 600–1050 according to the range of ^{14}C-dated tree-ring dates

and tree-ring dates lie inside the calibrated range of ^{14}C ages. Blocks III and IV show some differences between calibrated and tree-ring dates, which may be connected with the section of the calibration curve (Fig. 3: 3), where the ^{14}C concentration quickly changes. It is important to note that the tree-ring samples cover 1–4 rings and have been dated on a bidecadal scale. Measurement may reflect the fine structure of the curve at this point. One cannot fully exclude poorer precision of measurement, on the one hand, and errors in determining tree-ring ages, on the other. In all cases, uncertainties exist in calibrating ages of tree-ring samples; calendar ranges are sometimes wider than tree-ring dates. However, these uncertainties can be smoothed by dating large quantities of tree rings, as Blocks V and VI (Fig. 2) illustrate. We dated Block V as a whole (AD 873–960); we divided VI into 3 samples: the 1st included 35 inner tree rings; the 2nd, 45 external tree rings; and the 3rd included tree rings from AD 879–958.

DATING ARCHAEOLOGICAL SITES OF THE NOVGOROD REGION

Figure 1 shows locations of archaeological sites of the Novgorod region reported here. Of primary importance in studying ancient Novgorod are the complexes of Ryurikovo Gorodishche, the tradecraft and military-administrative center preceding Novgorod. Ryurikovo Gorodishche is the earliest fortified site at the source of the Volkhov River, dating to the 9th century AD (Nosov 1990). The excavation of a moat in 1987–1989 from a depth of 4.5 m from the ancient surface confirmed the presence of the fortification, in contrast to the opinion of some archeologists (Lebedev 1985). Archaeologically, the moat dates to the 9–10th centuries. Table 2 and Figures 4 and 5 show the ^{14}C data sets and corresponding calendar ranges for 1 and 2 σ, respectively. Results obtained on charcoal samples from different levels date the moat to the 7th to the 10th centuries. The moat may have been built between the early 7th and 8th century (LE-3467, 3469). LE-3332 suggests occupation of the site to the Early Iron Age, which also concurs with the presence of pottery typical for this time. The moat was filled in at the time the city was replanned in the 11th century AD (Nosov 1990). A charcoal sample, LE-3333, from a lime-firing kiln, agrees well on stratigraphic, archaeologic and ^{14}C grounds. Erected on the site of the filled-in moat, the kiln is strongly linked to the construction of Blagoveschenje Church in AD 1103 (Nosov 1990). One of the calibrated ranges subsumes this date.

The rich wood buildings with galleries discovered at Ryurikovo Gorodishche are associated with a later period. These buildings must have belonged to royalty (Nosov 1990), as their foundations were dug into the fill of a moat. Artifactual and ceramic assemblages date to the 12th–14th centuries. Three ^{14}C dates (LE-4405, -4411, -3935) from the remains of logs and charcoal at the base of the complex date initial construction to the second half of the 13th century. Six samples (5 charcoal and 1 wood: LE-4406 to -4408a, -4412, -4414) date the destruction of the complexes by fire to the second half of the 15th century.

In the Novgorod area, 34 settlements with cultural layers from the end of the first millennium AD are known from the Ilmen Lake district (Poozerje) and from the upper Volkhov River. Samples from two of these sites, Vasiljevskoe-I and Georgii, on the Veryazha River, yielded two representative ^{14}C data sets. According to the archaeological remains, Vasiljevskoe-I dates fall between the 9th and 10th centuries (Nosov 1990). The calibrated dates (LE-4157, -4388 to -4392 and -3327 to -3329) on charcoal determine the duration of occupation from AD 956–1000(1020) (Table 2, Fig. 5). Beads and Ladoga-type pottery found at the excavation confirm these dates. However, the possibility of earlier habitation cannot be ruled out (Table 2, Fig. 5).

The site of Gorodishche Georgii, situated 0.3 km upstream on the Veryazha River, was dated archaeologically to the 8th–9th centuries (Orlov and Aksenov 1961). Recent excavations (Nosov 1990)

established settlement during the 9th century. Samples LE-3460, and -3937 to -3943, date part of the settlement to *ca.* AD 925–999. Charcoal from Squares 2 and 3 yielded a calibrated range from the end of the 8th to the 9th centuries (LE-3461). Two calibrated dates on charcoal from fortified buildings (LE-3934, -3935) support this interval, but cannot exclude later occupation in the 9th–10th centuries. Archaeological evidence (Nosov 1990) corroborates the synchronic existence of Vasiljevskoe-I and Gorodishche Georgii, at least at one point (LE-3936), during the Early Iron Age.

Historically associated with ancient Novgorod is the famous site of northwest Russia, Staraya Ladoga (Zemlyanoe Gorodishche), which was first excavated in 1909 (Kirpichnikov 1985). Chernykh (1987) combined dendrochronological time scales of Staraya Ladoga with ancient Novgorod. We tree-ring dated two wood samples from Layer E3 (AD 760–830) (Chernykh 1985a). The sample without a tree-ring date was divided into two (1 of sapwood and 1 of heartwood). The calibrated range for samples LE-4158 and -4159 is the same as the dendrochronological period of Layer E3.

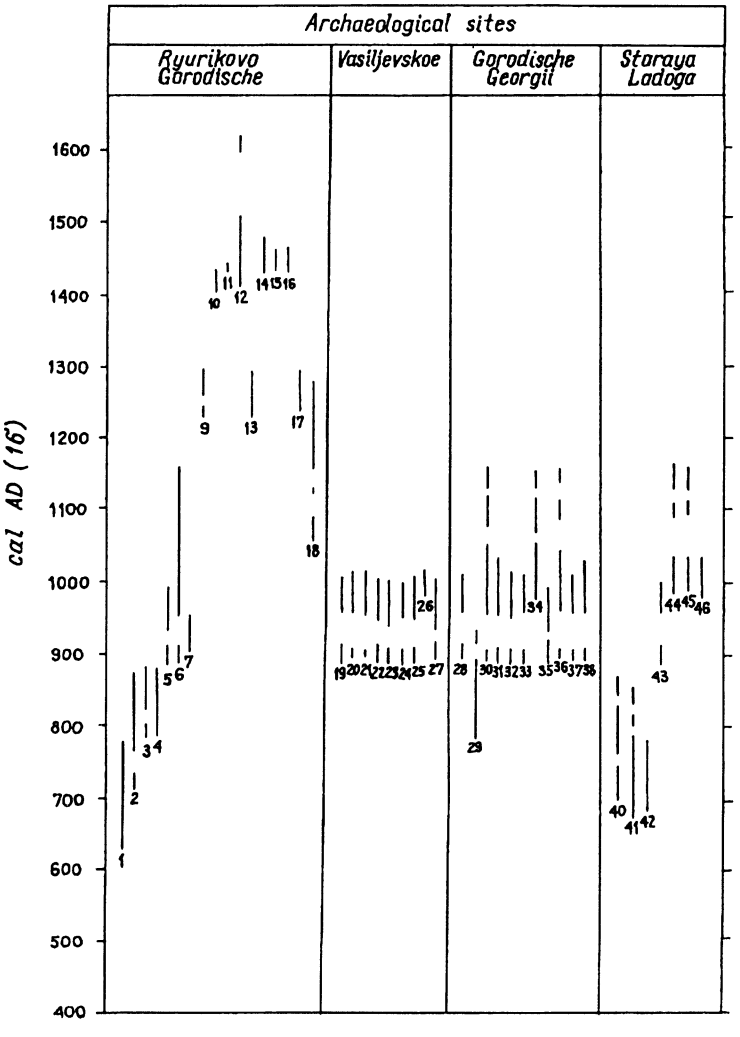

Fig. 4. Calibrated ^{14}C dates (1 σ) on charcoal and wood samples for the Novgorod region. Nos. 1–46 = sample numbers correlated with Table 2.

An oak sample containing 27 rings from a building erected in AD 776–811 (Chernykh 1989) yielded a calibrated ^{14}C date (LE-4795) of AD 680–786, which lies within the dendrochronological range. ^{14}C ages of planks and logs (LE-4416 to -4419) agree with archaeological ages, and date to the second half of the 10th century.

Conclusion

^{14}C dating of archaeological sites of the Novgorod region is effective for time scales requiring high-precision dating. Shorter calendar intervals can be obtained only by serial dating and comparisons with results obtained using other dating methods. Archaeological sites of the Novgorod region of the end of the first millennium AD allow us to compare the ^{14}C data with dendrochronological, archaeological and historical documentation. ^{14}C dating of dendrochronologically dated tree rings demonstrated that uncertainties can result from converting ^{14}C years to calendar years. We have

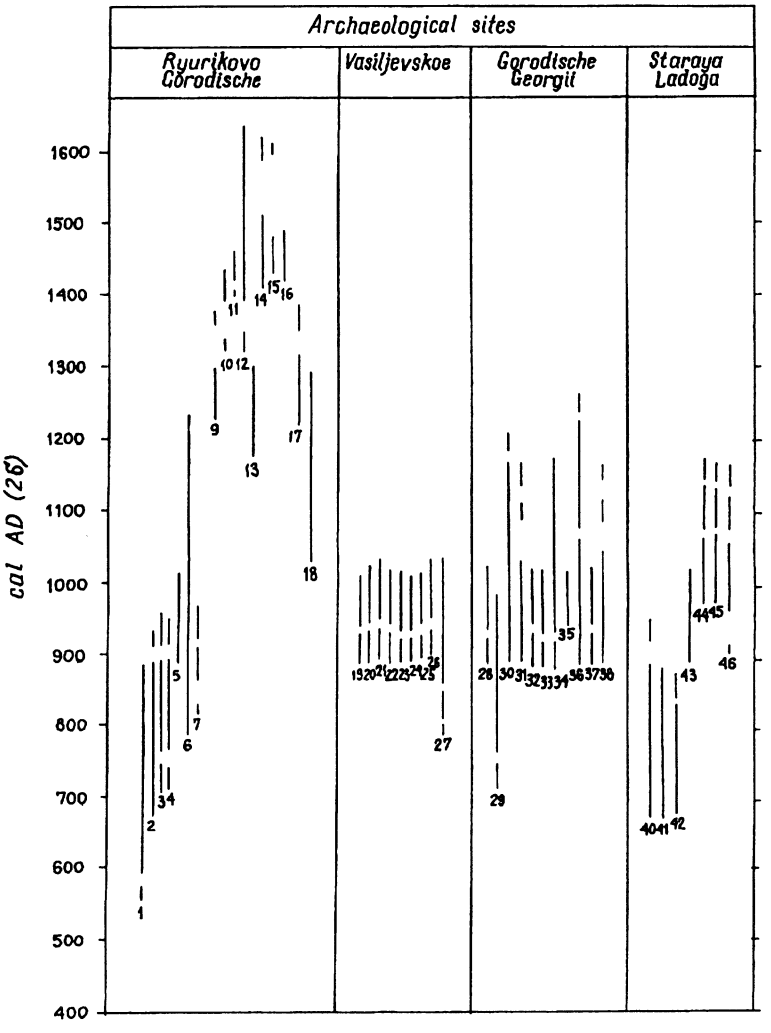

Fig. 5. Calibrated ^{14}C dates (2 σ) for the Novgorod region. For key, see Fig. 4.

found that at least 10–20 tree rings are needed to obtain reliable dates and to show close agreement between calibrated ^{14}C ranges and tree-ring dates.

The ^{14}C data set for archaeological sites of the Novgorod region and Staraya Ladoga is important for studying Slavic history. Staraya Ladoga was the oldest settlement, dating to the 7th–8th century AD; the lower layers of Ryurikovo Gorodishche are also associated with the same period. The sites of Vasilijevskoe-I and Georgii co-existed during the 9th–10th century AD. Future research for this area should link the history of northwestern Russia to the chronology of ancient Novgorod.

ACKNOWLEDGMENTS

We thank N. B. Chernykh and A. F. Urjeva for providing tree-ring-dated wood samples and E. N. Nosov for analyzing archaeological samples; we also appreciate their discussions of Novgorod archaeology.

TABLE 1. Radiocarbon Dates of Tree-Ring-Dated Wood

No.	Lab no.	Tree-ring ages (AD)	Uncalibrated ^{14}C date (BP)	Calibrated range (van der Plicht 1993) (cal AD) 1 σ	2 σ
Latvia – Ushuri, 1964 Excavation (Block 1)					
1	LE-4244	767	1386 ± 90	564–570, 596–726, 732–772	454–480, 540–512, 530–880
2	LE-4243	772	1205 ± 60	724–734, 772–892, 922–941	690–902, 904–968
3	LE-4242	777	1297 ± 50	674–772	658–824, 836–870
4	LE-4241	781	1253 ± 60	694–752, 758–820, 838–866	662–892, 922–942
5	LE-4240	786–787	1217 ± 40	782–876	694–752, 758–892, 920–947
6	LE-3632	796–798	1235 ± 35	774–874	694–752, 758–884
7	LE-4238	798–801	1226 ± 30	780–824, 836–872	714–742, 766–886
8	LE-3633	804–808	1211 ± 40	786–878	706–748, 762–849, 916–957
9	LE-3635	818–828	1216 ± 35	786–828, 832–874	706–748, 762–892, 922–940
10	LE-3636	829–835	1175 ± 40	792–802, 814–846, 853–892, 918–952	780–968

Table 1. (Continued)

No.	Lab no.	Tree-ring ages (AD)	Uncalibrated ^{14}C date (BP)	Calibrated range (van der Plicht 1993) (cal AD) 1 σ	2 σ
Latvia – Araishiu, 1965–1967 Excavation (Block II)					
11	LE-4225	835–855	1109 ± 55	890–988	792–802, 814–848, 852–1022
12	LE-4224	861–865	1182 ± 40	788–892, 924–934	776–968
13	LE-4223	866–872	1210 ± 60	718–738, 770–892, 926–934	684–900, 906–966
14	LE-4222	872–876	1190 ± 60	780–892, 920–951	696–750, 758–980
Ancient Novgorod, Troitskii-VIII, 1987 Excavation					
	TC-Y111-25-78 (Block III)				
15	LE-4571	878	1143 ± 55	824–836, 872–984	784–1006
16	LE-4572	882–884	1084 ± 30	896–910, 963–1008	892–924, 936–1016
17	LE-4573	888	1011 ± 70	972–1058, 1078–1124, 1134–1160	890–1177, 1192–1206
18	LE-4574	892–895	1022 ± 35	988–1030	900–906, 966–1050, 1088–1118, 1138–1158
19	LE-4576	901–902	899 ± 70	1040–1098, 1112–1146	1020–1269
20	LE-4580	923–924	1104 ± 60	890–996	790–806, 812–1026
21	LE-4581	930–935	1014 ± 50	978–1044, 1092–1116, 1142–1156	894–912, 957–1164
22	LE-4582	936–937	919 ± 80	1032–1177, 1190–1208	1002–1275
23	LE-4583	943–950	907 ± 70	1040–1100, 1110–1146, 1152–1212	1016–1260, 1262–1268
24	LE-4586	958–962	1028 ± 40	978–1032	894–916, 956–1054, 1082–1122, 1136–1158
	TC-Y111-25-63 (Block IV)				
25	LE-4589	913–916	1018 ± 60	970–1052,	

Table 1. (Continued)

No.	Lab no.	Tree-ring ages (AD)	Uncalibrated ^{14}C date (BP)	Calibrated range (van der Plicht 1993) (cal AD) 1 σ	2 σ
				1086–1118, 1138–1158	892–922, 936–1166
26	LE-4591	921–922	1046 ± 55	894–918, 956–1034	886–1056, 1082–1122, 1136–1160
27	LE-4592	925-927	1089 ± 40	894–918, 954–1008	890–1016
28	LE-4593	930–932	993 ± 60	996–1058, 1080–1122, 1134–1160	898–910, 963–1210
29	LE-4594	935–937	922 ± 30	1042–1096, 1114–1144, 1154–1164	1030–1177, 1192–1208
30	LE-4595	938–940	1045 ± 30	986–1018	900–908, 966–1030
31	LE-4596	942–945	1126 ± 40	892–968	818–840, 858–1012
	TC-Y111-26-88 (Block V)				
32	LE-4791	873–960	1143 ± 30	886–896, 912–963	820–840, 860–986
	TC-Y111-27-130 (Block VI)				
33	LE-4793	879–913	1157 ± 30	878–898, 910–963	792–804, 814–848, 851–974
34	LE-4792	914–958	1116 ± 30	892–922, 941–976	886–991
35	LE-4794	879–958	1136 ± 40	886–902, 904–966	794–802, 814–846, 853–1002
	TC-Y111-28-50 (Block VII)				
36	LE-3627	971–976	1070 ± 30	970–1014	892–920, 946–1022
37	LE-3628	981–983	1092 ± 45	892–920, 950–1008	884–1020
38	LE-3629	988–990	1113 ± 40	892–924, 936–980	876–1016
39	LE-3620	995–999	1045 ± 30	986–1018	900–908, 966–1030

TABLE 2. Radiocarbon Dates of the Novgorod Region and Staraya Ladoga

No.	Lab no.	Provenience	Material	Uncalibrated date (BP)	Calibrated date (van der Plicht 1993) 1 σ, cal AD/BC	2 σ, cal AD/BC
Rurikovo Gorodishche 1987–1989 Excavation						
	Moat					
1	LE-3467	Sq. 237, depth 3.75 m	Charcoal	1340 ± 80	634–782	558–576, 594–884
2	LE-3469	Sq. 238, depth 5.35 m	Charcoal	1240 ± 50	718–740, 768–876	672–892, 924–934
3	LE-3468	Sq. 237, depth 4.2–4.6 m	Charcoal	1210 ± 40	786–878	708–748, 762–894, 914–957
4	LE-3477	Sq. 195, pit, depth 3.7–3.8 m	Charcoal	1210 ± 40	786–878	708–748, 762–894, 914–957
5	LE-3476	Sq. 241, depth 3.56 m	Charcoal	1100 ± 40	892–920, 946–998	886–1014
6	LE-3475	Sq. 233, pit, depth 2.18 m	Charcoal	1020 ± 100	890–920, 952–1160	790–1230
7	LE-4404	Sq. 184, layers on moat walls	Charcoal	1160 ± 20	882–893, 919–951	821–839, 865–902, 904–967
	Cultural layer					
8	LE-3332	Sq. 201, high layer	Charcoal	2870 ± 40	1114–1094 BC, 1072–986 BC, 960–938 BC	1158–1148 BC, 1126–916 BC
	"Northern" complex					
9	LE-4405	Sq. 165, base of fill: log on step	Wood	740 ± 40	1257–1296	1225–1304, 1362–1378
10	LE-4406	Sq. 165, crude boards	Charcoal	530 ± 30	1406–1430	1322–1334, 1396–1440
11	LE-4407	Sq. 164–171, base	Wood	465 ± 20	1443–1446	1422–1459
12	LE-4408(a)	Posthole in NW	Charcoal	460 ± 75	1406–1508, 1600–1618	1318–1342, 1394–1638
	"Southern" complex					
13	LE-4411	Sq. 179, base	Wood	770 ± 50	1236–1287	1170–1300
14	LE-4412	Sq. 185, base	Charcoal	440 ± 40	1434–1476	1414–1516, 1588–1624
15	LE-4413	Sq. 175, black basal layer	Charcoal	430 ± 25	1442–1466	1434–1486, 1606–1610
16	LE-4414	Sq. 175, 182, base	Charcoal	450 ± 30	1434–1463	1420–1482
17	LE-3935	Sq. 169–176, gray humic layer	Charcoal	740 ± 50	1242–1298	1216–1312, 1350–1390
	Lime-firing kiln					
18	LE-3333	Fill of kiln; depth 2.14 m	Charcoal	850 ± 80	1056–1080, 1122–1134, 1160–1277	1032–1287
	Valilyevskoe-I, 1986–1989 Excavation					
19	LE-4157	Hearth frame (excav. 1986)	Charcoal	1090 ± 30	896–914, 959–1004	892–926, 932–926

TABLE 2. (Continued)

No.	Lab no.	Provenience	Material	Uncalibrated date (BP)	Calibrated date (van der Plicht 1993) 1 σ, cal AD/BC	2 σ, cal AD/BC
20	LE-4388	Sq. 31, 46	Charcoal	1060 ± 40	900–906, 966–1020	892–926, 932–1028
21	LE-4389	Sq. 41, 42, 51, 52	Charcoal	1060 ± 40	900–906, 966–1020	892–926, 932–1028
22	LE-4390	Sq. 51, 54, top	Charcoal	1090 ± 40	892–918, 954–1008	932–1028, 888–1014
23	LE-4391	Sq. 51, 54, bottom	Charcoal	1090 ± 35	894–916, 956–1006	890–928, 930–1012
24	LE-4392	Sq. 55	Charcoal	1090 ± 25	896–912, 963–1000	892–922, 936–1012
25	LE-3327	Sq. 55	Charcoal	1080 ± 40	894–914, 959–1012	890–926, 930–1018
26	LE-3328	Sq. 63	Charcoal	1050 ± 30	984–1018	898–910, 963–1028
27	LE-3329	Sq. 56–61	Charcoal	1090 ± 55	892–922, 944–1010	794–800, 816–844, 854–1032
	Gorodische Georgii, 1988 Excavation					
28	LE-3460	Sq. 6, 7	Charcoal	1070 ± 40	898–910, 963–1016	892–926, 932–1024
29	LE-3461	Sq. 2, 3	Charcoal	1190 ± 50	780–892, 922–938	712–744, 764–976
30	LE-3934	Trench, Sec. ZH, depth 2.5–3.0 m	Charcoal	1020 ± 70	898–908, 965–1054, 1082–1122, 1136–1158	886–1174, 1194–1206
31	LE-3935	Trench, Sec. A–B, dark-gray charcoal layer	Charcoal	1050 ± 50	896–912, 961–1028	886–1046, 1092–1116, 1142–1156
32	LE-3937	Construction in sq. 34, 37, basal charcoal layer	Charcoal	1075 ± 40	896–912, 961–1014	890–926, 930–1020
33	LE-3938	Clay-charcoal layer, sq. 31, 34	Charcoal	1080 ± 30	898–908, 965–1010	892–922, 938–1018
34	LE-3939	Pit, sq. 13, 14, 18, 19, top of fill	Charcoal	1010 ± 60	976–1052, 1084–1120, 1138–1158	892–922, 940–1170
35	LE-3940	Pit, sq. 13, 14, 18, 19, bottom of fill	Charcoal	1100 ± 40	892–920, 946–998	886–1014
36	LE-3941	Pit, sq. 39, 40	Charcoal	1030 ± 50	900–906, 966–1040, 1098–1110, 1146–1152	892–924, 936–1060, 1067–1124, 1130–1160
37	LE-3942	Construction in sq. 24, 25	Charcoal	1080 ± 40	894–914, 959–1012	890–926, 930–1018
38	LE-3943	Cultural layer in sq. 16	Charcoal	1050 ± 50	896–912, 961–1028	886–1046, 1092–1116, 1142–1156

TABLE 2. (Continued)

No.	Lab no.	Provenience	Material	Uncalibrated date (BP)	Calibrated date (van der Plicht 1993) 1 σ, cal AD/BC	2 σ, cal AD/BC
39	LE-3936	Trench, Sec. D, depth 0.1–0.3 m	Charcoal	2350 ± 70	752–730 BC, 714–716 BC, 530–360 BC, 286–254 BC	762–672 BC, 666–628 BC, 596–576 BC, 558–342 BC, 324–200 BC
Staraya Lagoda (Zemlyanoe Gorodishche) Horizon E3						
40	LE-4158	Pillar, external tree rings	Wood	1250 ± 60	704–748, 760–826, 834–872	664–892, 920–945
41	LE-4159	Pillar, inner tree rings	Wood	1275 ± 55	672–792, 804–814, 848–850	666–880
42	LE-4795	Pillar of construction N3 (1982) (sample N105), brown humin (felling date: AD 776–811)	Wood (oak)	1270 ± 40	680–786	672–826, 834–872
43	LE-4416	Remains of 3rd layer, sq. D 30	Wood	1085 ± 40	894–916, 956–1010	890–1016
44	LE-4417	2nd pavement, sq. D28–E28	Wood	1010 ± 40	988–1049, 1093–1112, 1144–1152	970–1064, 1074–1126 1132–1162
45	LE-4418	Top of pavement, sq. D28–E28	Wood	1010 ± 40	988–1049, 1093–1112, 1144–1152	970–1064, 1074–1126 1132–1162
46	LE-4419	Felling frame, sq. Z30	Wood	1020 ± 35	988–1032	902–904, 966–1052, 1086–1120, 1138–1158

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[RADIOCARBON, VOL. 36, NO. 3, 1994, P. 391–398]

DATING THE PREHISTORIC SITE NAHAL ISSARON IN THE SOUTHERN NEGEV, ISRAEL[1]

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ABSTRACT. The prehistoric site Nahal Issaron is located on the alluvial fan of Nahal Issaron, a short wadi draining into Biqat Uvda some 50 km north of Eilat. Excavated in the early 1980s, it constitutes a major Pre-Pottery Neolithic B (PPNB) layer, with continued but sporadic occupation throughout the Late Neolithic to the Chalcolithic period. In the PPNB layer, a dense agglomeration of rounded, polygonal and rectangular structures was found, with courtyards and a variety of features such as hearths and ovens. The upper layer is badly preserved, apart from the hearths and ovens. Thirty samples from the site were ^{14}C-dated in the Rehovot laboratory and five in the Pretoria laboratory. The results enabled a fine temporal resolution between layers and a refinement of the 7th through 5th millennium BC chronology. The dates also placed the sequence of changes in architecture and lithics within a more robust temporal framework, thus making the site a key chronological anchor in the Neolithic of Southern Israel, Sinai and Jordan.

INTRODUCTION

The Neolithic settlement of Nahal Issaron is located at the eastern edge of Biqat Uvda, in the southern Negev Desert, Israel (34°55′E, 29°52′N). Biqat Uvda is a large, shallow syncline situated close to the border with eastern Sinai on one side, and a narrow band of hills forming the steep escarpment of the eastern side of the Rift Valley on the other (Fig. 1). The site is located on and in the center of the alluvial fan where Nahal Issaron, a short wadi draining eastwards from the edge of the escarpment, empties into Biqat Uvda. Precipitation is presently sporadic, averaging <50 mm per year. The Saharo-Arabian vegetation of the area is sparse, and almost entirely restricted to wadi channels. The closest sources of water are *ca.* 10 km away in the Rift Valley, *ca.* 400 m lower than Biqat Uvda.

A. N. Goring-Morris and A. Gopher directed three seasons of excavations at Nahal Issaron from 1980 to 1981, as part of the Emergency Archaeological Survey of the Negev (Goring-Morris and Gopher 1983, 1987; Gopher 1985; Gopher, Goring-Morris and Gordon, in press; Davis 1983; Lipschitz 1986). The systematic excavations completely or partially exposed some 230 m^2 in the central area of the settlement, which appears to have extended over *ca.* 500 m^2.

Given the excellent preservation of charcoal throughout much of the site, we undertook an extensive project of ^{14}C determinations. We chose samples to obtain the following results:

1. A chronological framework for the occupation history of the site.
2. A spatially extensive network of dates from all the excavated areas of the site.
3. Solutions to microstratigraphic problems.

METHODS

Thirty-five ^{14}C determinations were obtained—30 by the Weizmann Institute (Table 1) and 5 by Pretoria (Table 2). Preservation of samples tended to be poorer closer to the surface, with the exception of well-constructed hearths and ovens. Thus it was not always possible to provide samples from areas considered problematic and crucial stratigraphically. Precise locations of the samples are shown on the site plan, which includes the architectural remains from all occupational phases (Fig. 2). All sam-

[1]This paper was a poster presentation at the 15th International ^{14}C Conference, Glasgow, Scotland, 15–19 August 1994.

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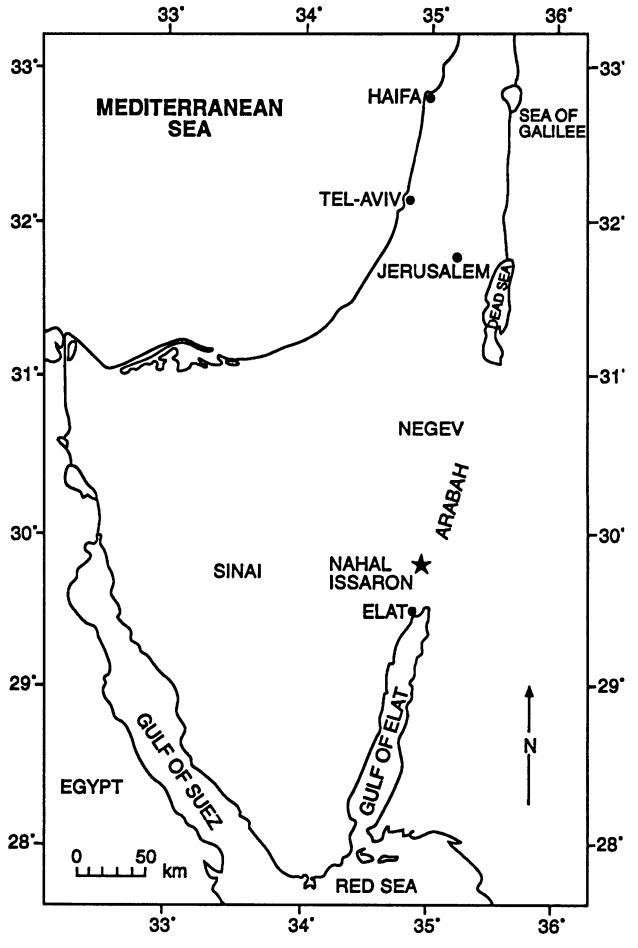

Fig. 1. Map of Southern Levant showing location of Nahal Issaron in the southern Negev

ples were charcoal. We used the acid-alkali-acid (AAA) treatment to clean them, and they were converted to ethane and counted in proportional counters (Carmi 1987).

Results

Most of the dates accord well with and complement the technotypological seriation currently used for the Neolithic in the Levant (Gopher 1985). Only a few results, such as Pta-3000 and RT-1665 from Locus 5, are obviously aberrant in terms of the stratigraphy (Tables 1, 2; Figs. 2, 3). We calibrated the dates to calendar years using the most recent program of Stuiver and Reimer (1993). Most surprising are several dates that considerably antedate the accepted chronology based on arrowhead typologies, *i.e.*, prior to *ca.* 7750 BC. These dates derive from samples at the base of the occupation sequence. This could be explained by 1) a conjectured *founders'* occupation, which left few material remains, or 2) by the use of old wood for construction and fuel during the main phase of occupation, or 3) a combination of both.

TABLE 1. Rehovot ^{14}C dates from Nahal Issaron

Sample RT-no.	Locus*	Grid coordinates†	Depth (cm below surface)	$\Delta^{14}C$ (‰)	$\delta^{13}C$ (‰)	^{14}C age (yr BP)	Calibrated range (cal BC)‡	Probability (%)§
1506	39	W38c	175–185	−504.2 ± 4.2	−21.5	5635 ± 70	4530–4365	100
1507	34	M37c	200–205	−634.4 ± 4.1	−21.5	8080 ± 90	7245–6770	100
1508	12	M35a+b	175–180	−612.6 ± 3.9	−21.4	7620 ± 80	6537–6362	97
1509	12	M35a+d	200–205	−624.5 ± 2.7	−21.6	7870 ± 55	6991–6849	6
							6765–6562	93
1510	17	I37a+b	220–230	−677.9 ± 3.4	−21.0	9100 ± 85	8193–8027	97
1511	17	H37a	150–155	−635.9 ± 3.7	−21.5	8120 ± 80	7262–7002	98
1512	15	S36cd+T35d	175–180	−659.2 ± 3.5	−11.3	8650 ± 85	7869–7817	20
							7707–7543	80
1513	9 (10-1)	N-O/40	174–179	−474.7 ± 1.4	−21.6	5170 ± 55	4039–3940	84
							3851–3821	16
1514	36-5	T33		−629.6 ± 3.9	−21.7	8200 ± 90	7296–7044	100
1515	25	L40a+c	210–215	−665.0 ± 3.4	−21.7	8785 ± 80	7938–7700	100
1516	46	K42a	205–210	−605.0 ± 4.6		7460 ± 95	6373–6187	100
1518	3	S32	145	−462.8 ± 3.2	−17.9	4990 ± 50	3903–3881	14
							3803–3703	86
1520	36A	O35c	--	−630.2 ± 2.5	−20.8	7990 ± 55	7007–6726	100
1521	36	O35	--	−648.1 ± 4.1	−20.9	8390 ± 95	7506–7305	100
1522	36	N35d+N36b	190–200	−646.4 ± 3.3	−21.0	8350 ± 75	7484–7451	100
1606	14?	F37a	165–178	−564.5 ± 4.5	−22.0	6680 ± 85	5610–5450	100
1607	10	M40d	206–210	−681.6 ± 2.8	−22.0	9195 ± 70	8331–8092	100
1608	35?	P31a+b	140–145	−507.5 ± 3.4	−21.8	5690 ± 55	4592–4460	100
1609	28 (36-1)	Q34	156–169	−660.8 ± 2.9	−22.0	8685 ± 70	7881–7810	30
							7719–7576	70
1630	42	U32a	135–140	−503.5 ± 4.2	−22.6	5625 ± 70	4515–4428	100
1638	2	P38c	188–195	−642.7 ± 3.5	−21.8	8265 ± 80	7422–7098	100
1640	8	N31a+d+M32b	178–182	−588.5 ± 4.9	−22.0	7135 ± 95	6046–5854	99
1663	8?	P33a+b	131–136	−511.6 ± 5.1	−21.8	5755 ± 85	4713–4513	100
1664	19	M39d	184–190	−645.4 ± 4.5	−20.9	8330 ± 100	7489–7258	96
1665	5	K37d	210–215	−612.1 ± 5.4	−21.1	7600 ± 110	6533–6240	100
1691	8?	N31b+a	158–165	−586.7 ± 3.7	−21.5	7100 ± 70	5991–5854	100
1692	31 (36-9)	T33d	131–136	−546.5 ± 4.8	−21.1	6350 ± 90	5423–5221	100
1699	41	Q36b	185–190	−656.8 ± 10.2	−21.1	8590 ± 240	7936–7420	100
1700	27	F40b	190–200	−628.1 ± 5.2	−22.7	7950 ± 110	7001–6654	100
1701	38	U33d	180–185	−643.6 ± 3.5	−22.7	8290 ± 80	7472–7102	100

*Loci numbers as designated on plan (Fig. 2); †See border, Fig. 2; ‡Calibrated using CALIB 3.0.3 (Stuiver and Reimer 1993); §Results are given at ±1 σ uncertainty; the probability shows the confidence in percent.

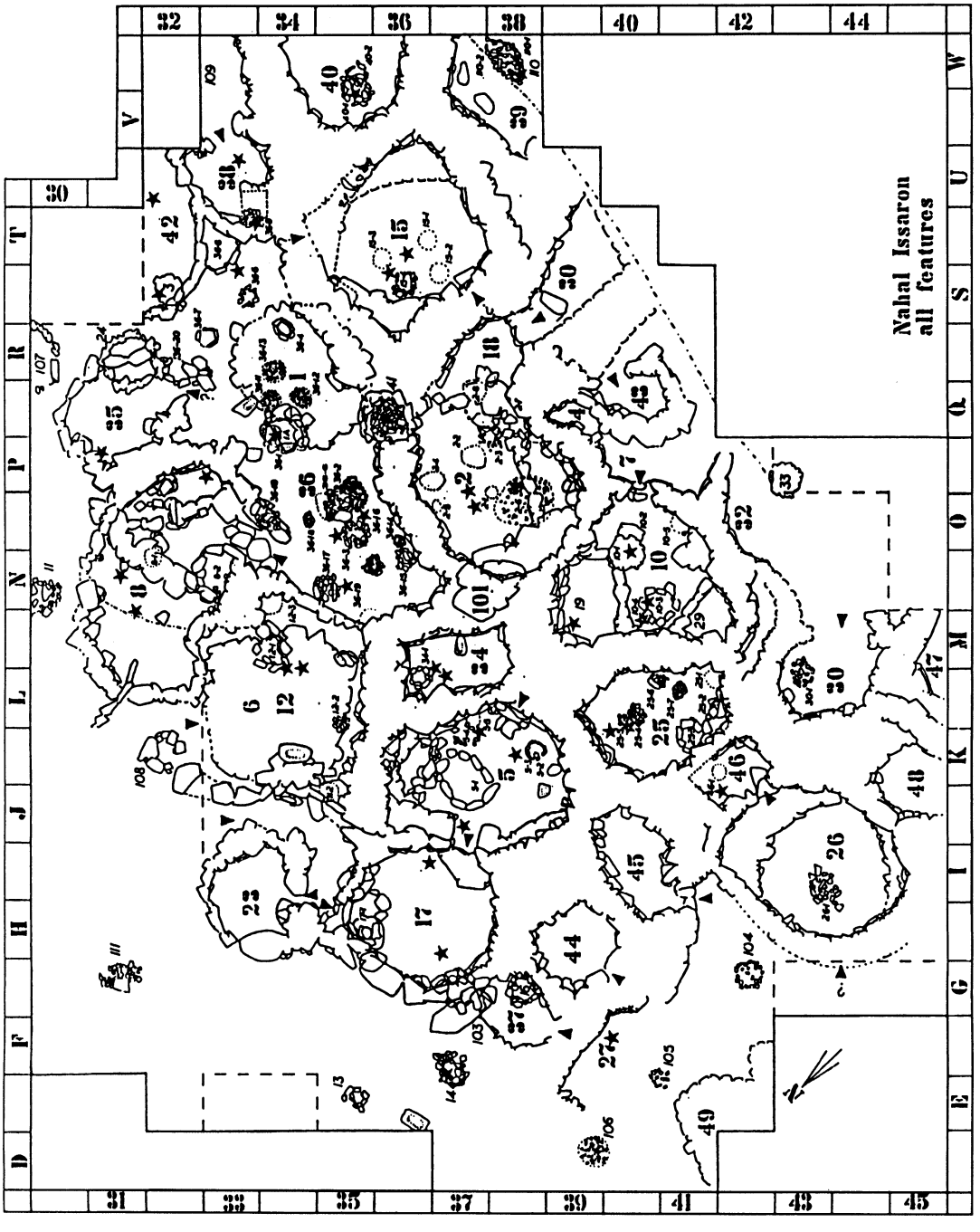

Fig. 2. Plan of the architectural remains from the excavations at Nahal Issaron (all phases). ★ = locations of charcoal samples for dating. ▶ = assumed entrance to the structures. Border represents grid coordinates (see Table 1).

TABLE 2. Pretoria ^{14}C Dates from Nahal Issaron

Sample Pta-no.	Locus	Grid coord.	Depth (cm below surface)	^{14}C age (yr BP)	Calibrated range (cal BC)*	Probability (%)†
2999	5	J37a	158–165	6460 ± 80	5440–5311	100
3000	5		200	8430 ± 80	7539–7418	91
					7345–7325	9
3376	2		160	8050 ± 80	7048–6725	90
3377	40		195	8180 ± 80	7266–7041	95
3486	15		160	6130 ± 80	5203–4944	100

*Calibrated using CALIB 3.0.3 (Stuiver and Reimer 1993)

†Results are given at ±1 σ uncertainty; the probability shows the confidence in percent.

The principal phase of occupation can be securely dated to *ca.* 7500–7000 BC and perhaps even 6750 BC, after which the site continued to be occupied sporadically until *ca.* 4500 BC, or shortly thereafter. Use of the site was probably seasonal and non-continuous, with a series of gaps in occupation. Following a brief hiatus, the latest two dates (RT-1513 and RT-1518) indicate a further brief use of the site at *ca.* 3800 BC.

When arranged sequentially (Fig. 3), the dates correlate well with depth below datum. This is somewhat surprising, given the evidence for differential depths of the various layers over the site, the excavation and construction of later features such as ovens and hearths into the underlying sediments and a general, though hardly marked, slope of the present and pre-occupation surfaces from east to west along the length of the alluvial fan. With few exceptions, the results also correlate well with field observations and subsequent analysis concerning details of the stratigraphic sequence. In certain instances, *e.g.*, in Locus 2 (Pta- 3376 and RT-1638), Locus 8 (RT-1640, -1663, -1691) and Locus 15 (RT-1512 and Pta-3486), the results provide important data on the microstratigraphy. Almost all samples provided consistent $\delta^{13}C$ results, which accord well with the identifications obtained independently on samples analyzed by Lipschitz (1986), namely that the charcoal derives primarily from C_3 vegetation, *i.e.*, indicating somewhat more humid conditions.

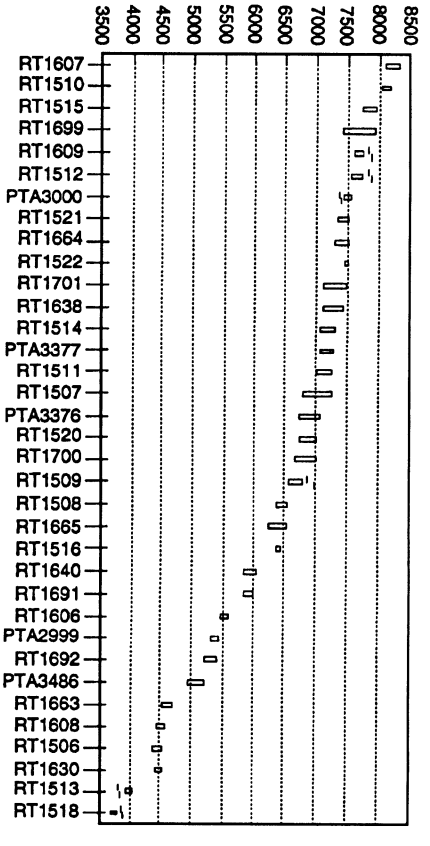

Fig. 3. ^{14}C determinations from Nahal Issaron arranged in chronological order. Dates are calibrated to calendar years BC; when more than one span is possible for a particular sample, the other less likely option is also indicated.

DISCUSSION

The Chronostratigraphy

Findings from the excavation revealed that the site comprises up to 1.5 m of cultural deposits with the following complex stratigraphic sequence of occupation (from the base up):

1. An initial, but major occupation attributable, on the basis of the technotypological characteristics of the chipped stone assemblage, to a late phase of the Pre-Pottery Neolithic B (PPNB) period, *ca.* 8400–8000 BP (uncalibrated).

   Indirect evidence seems to indicate that the earliest use of the site, of short duration, may have been an ephemeral occupation with sparse remains and occasional hearths, though the use of old wood may be another explanation. This was followed almost immediately (?) by the major architectural remains on the site: tightly clustered, small (2–3 m in diameter), interlocking subcircular through polygonal and rectangular structures and features constructed of fieldstones with walls preserved to a maximum height of *ca.* 1.2 m (Fig. 2). Superstructures were seemingly of light perishable materials (brush, skins?). The associated deposits are primarily anthropogenic in origin, with quantities of gray ash and sand in addition to the remains of collapsed walls, directly overlying the poorly sorted boulders, gravels and sands of the alluvial fan. Both within the structures and in the open, courtyard areas in between the structures were numerous hearths of various forms.

   Although analysis is incomplete, the cultural remains include an abundant chipped-stone industry, numerous grinding stones, beads and pendants made of marine mollusks and semiprecious minerals, and a small bone tool assemblage. Faunal remains include *Capra ibex* (ibex), *Gazella* sp. (gazelle), *Equus* sp. (onager), *Bos* sp. (aurochs), *Lepus capensis* (hare), reptiles, avifauna and even fish vertebrae—the Gulf of Eilat is 40 km distant to the south (Davis 1983; L. K. Horwitz, personal communication).

2. An erosional event, perhaps catastrophic in nature (a flash flood?), followed, eroding structures on the southern side of the site. The date of a hearth (RT-1506) from the overlying sediments seems to indicate that this event occurred prior to *ca.* 5600 BP but following the main PPNB occupation, *ca.* 8000 BP (Tables 1 and 2).

3. The erosional event was followed by gradual infilling and aggradation of alluvial fan settlements, especially around the margins of the earlier PPNB settlement. Within these sediments are various constructions such as hearths and ovens, which, on the basis of associated finds, can be attributed to the poorly documented (at least in the Negev and Sinai deserts) Late Neolithic through Chalcolithic periods, datable to the 8–6th millennia BP (uncalibrated). Several of the earlier PPNB structures continued to be used, and were usually modified (*e.g.,* added walls and hearths), and excavation of earlier deposits. A few poorly preserved new structures were also documented. All these activities seemingly resulted in admixture with material remains of the earlier PPNB occupation. Bone preservation for this phase was poor, and charcoal is sparse throughout the layer, except when directly associated with stone-lined hearths and ovens.

   In general, the deposits of this level are less obviously anthropogenic. Taken in conjunction with the marked decrease in the density of associated small finds, the overall impression is of sporadic and much less intense occupation of the site throughout this prolonged phase. That hunting continued to be practiced is indicated by distinctive arrowheads of the period amongst the chipped-stone tools, almost invariably mixed with types characteristic of the preceding phase. Grinding stones are also quite common. Rodent activities and the extremely fluid nature of the sandy, ashy sediments made assignment of specific loci or phases difficult. Charcoal from this and the previous phase included *Tamarix* sp., *Haloxylon persicum, Retama roetam, Anabasis articulata* and *Acacia tortilis,* all species currently present in Biqat Uvda or the adjacent Rift Valley (Lipschitz 1986).

4. The topmost layer excavated shows evidence for continued occupation of the immediate area during the Early Bronze Age (5th millennium BP (uncalibrated)), as indicated by the presence of a large site a few tens of meters from the Neolithic site. The fact that the former is mostly deflated on the surface of the alluvial fan, and that parts of the upper phase of Nahal Issaron are exposed signifies that, since the 5th millennium BP (uncalibrated), geomorphological conditions remained relatively stable, with virtually no aggradation of the alluvial fan, but rather minor deflation.

   Because of the complex stratigraphic sequence at Nahal Issaron, we could not always assign features or sublayers within structures to specific phases. For example, we have been unable to isolate any definitely undisturbed subassemblages belonging to Phase C. In almost all instances, flint tools common to the late phase of the PPNB are also present. These could either be intrusive or, alternatively, represent a conservative continuation of PPNB knapping traditions into the Late Neolithic of the desert regions (see Gopher, Goring-Morris and Gordon, in press). Farther north, in the Mediterranean regions of the Levant, evidence is also increasing for such continuity throughout the 8th millennium BP, and perhaps even later.

Settlement Patterns

The site of Nahal Issaron is of considerable importance in that it provides the longest and most complete evidence for semicontinuous occupation, from the 9th through 6th/5th millennia BP (uncalibrated), of any locality investigated to date in the Negev and Sinai (and perhaps the Transjordanian desert areas). Following a possible brief and ephemeral founders' phase, indirect evidence indicates that the main, late PPNB settlement may have been occupied on a seasonal (winter/spring?) basis by a small band of hunter-gatherers when climatic conditions were more favorable than the present regime. Arrowheads, notches and denticulates dominated the chipped stone assemblage, with few scrapers or burins, and with sickle blades entirely absent. Small quantities of distinctive, elongated borers are also present. Such a band may have been mobile for much of the year or, alternatively, based farther away in more favorable environmental settings (southern Transjordan? southern Sinai?), in light of similar stylistic attributes of the chipped stone tools to sites in those regions. The settlement at Nahal Issaron is located midway between the two regions, both of which have furnished evidence for relatively dense occupation at this time, for example, at Basta. Though permanently occupied farming and herding communities are documented in the Mediterranean zone of the Levant at this time, the peripheral desert regions continued to be occupied by small, mobile bands of hunter-gatherers.

The settlements at Nahal Issaron became increasingly sporadic and less intensive with time. Given the poor bone preservation at the site, it is not possible to determine whether these occupants were primarily hunter-gatherers or herders, hunters and gatherers (arrowheads are the most diagnostic chipped stone tools). Though presence of grinding stones indicates some form of (vegetal?) processing, the absence of sickleblades suggests that agriculture was not practiced prior to the Early Bronze Age in this area. Pastoralist economies in the peripheral regions of the Levant developed during the Late Neolithic and Chalcolithic, though evidence of their growth and diffusion is extremly scanty in the region (Goring-Morris 1994).

Conclusion

The series of ^{14}C dates obtained from the complex stratigraphic sequence at Nahal Issaron illustrates the importance of close collaboration between field archaeologists and scientists working with dating methods. The present case study also demonstrates the importance of obtaining series of dates

from individual sites and layers to offset likely problems of intrusions and other taphonomic processes. Combined with the architectural remains and other artifacts of the material culture recovered during the excavations, the evidence leaves little doubt that Nahal Issaron represents a key site for comprehending cultural processes in the southern Negev during the Early Holocene, a period during which hunter-gatherers shifted to pastoralist economies.

ACKNOWLEDGMENTS

The excavations at Nahal Issaron were funded by and conducted under the auspices of the Emergency Archaeological Survey of the Negev and the Israel Department of Antiquities (presently the Israel Antiquities Authority). In particular, the authors wish to thank A. Eitan and R. Cohen for support and encouragement. Subsequent analyses of the material culture remains were funded by a grant from the Israel Academy of Sciences, and most of the ^{14}C dates were funded by the Israel Antiquities Authority. We gratefully acknowledge the contribution of dates from Pretoria by J. C. Vogel.

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[RADIOCARBON, VOL. 36, NO. 3, 1994, P. 399–405]

COMPARISON OF MANUAL AND AUTOMATED PRETREATMENT METHODS FOR AMS RADIOCARBON DATING OF PLANT FOSSILS

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ABSTRACT. A new automated pretreatment system for the preparation of materials submitted for accelerator mass spectrometry (AMS) analysis is less time-consuming and results in a higher sample yield. The new procedure was tested using two groups of plant fossils: one group was pretreated using the traditional method, and the second, using the automated pretreatment apparatus. We compared the time it took to complete the procedure and the amount of sample material remaining. The automated pretreatment apparatus proved to be more than three times faster and, in most cases, produced a higher yield. We also observed a darker discoloration of the KOH solutions, indicating that the automated system is more thorough in removing humates from the specimen compared to the manual method.

INTRODUCTION

Chemical pretreatment of routine samples for AMS ^{14}C analysis is labor intensive, requiring as much as one-third of the time required for a complete sample analysis. Standard manual pretreatment methods (Gagnon and Jones 1993) are slow because a technician can process only 1 or 2 samples at a time. These methods also commonly result in a large percentage of sample loss. To speed pretreatment time and reduce sample loss, we designed and constructed an automated system controlled by a personal computer (Fig. 1). The system runs multiple samples simultaneously and yields a higher percentage of sample material. Here we compare pretreatment results of 11 samples using standard manual methods and our automated system. On average, the automated system reduced pretreatment time by 70% and sample loss by 4%.

METHODS

Eleven plant fossils of different ages were selected to demonstrate the effects of manual and automated pretreatment methods on the types of materials commonly submitted for AMS analysis (Table 1). All specimens were cleaned of foreign matter, and split into two samples weighing 0.01–0.10 g. One sample was pretreated using the manual method (denoted by a suffix M on the sample number), and the other sample was pretreated using the automated system (suffix A). The samples were weighed before and after the pretreatment procedures to determine the amount of sample loss. Pretreatment times do not include drying time. All samples were processed through the same sequence of reagents (Table 2). Deionized water and distilled HCl were used for reagent mixing and to decrease contamination; all glassware was heated to 550°C for 1 h.

Automated Pretreatment Method

Each sample was placed in a vertical borosilicate glass column (10 mm ID × 100 mm long) with a Teflon filter end-cap fixed to each end (Fig. 2). The filter end-caps were fitted with 25-μ polyethylene disposable frits that were replaced with each sample change. Teflon tubing leading from pressurized reagent containers were attached to the top filter end-cap to allow reagents to flow through

TABLE 1. Sample Materials Selected for Comparison of Pretreatment Methods and Their AMS Ages

Lab no.	Sample no.	Pretreatment method	Amt. C dated (mg)	Sample type	Location	Fraction modern (FM)	FM SD	^{14}C Age (yr BP)
--	HB415-416A	Automated	--	Moss	Harberton, Argentina	--	--	Not dated
--	HB415-416M	Manual	--	Moss	Harberton, Argentina	--	--	Not dated
--	HB561-562A	Automated	--	Moss	Harberton, Argentina	--	--	Not dated
--	HB561-562M	Manual	--	Moss	Harberton, Argentina	--	--	Not dated
CAMS-6343	HB310-311A	Automated	1.24	Moss	Harberton, Argentina	0.6372	0.004	3620 ± 60
CAMS-6342	HB310-311M	Manual	1.17	Moss	Harberton, Argentina	0.6422	0.005	3560 ± 60
CAMS-6340	CHEM-409A	Automated	1.28	Wood	Hiscock site, New York	0.3159	0.0024	9260 ± 70
CAMS-6341	CHEM-409M	Manual	0.74	Wood	Hiscock site, New York	0.32	0.003	9150 ± 80
CAMS-6345	NSRL-747A	Automated	1.23	Twig*	Rockfall Cave, New Mexico	0.716	0.009	2680 ± 100
CAMS-7556	NSRL-747A	Automated	1.20	Twig*	Rockfall Cave, New Mexico	0.7246	0.005	2590 ± 60
CAMS-7199	NSRL-747M	Manual	1.50	Twig*	Rockfall Cave, New Mexico	0.7279	0.0077	2550 ± 90
CAMS-16812	NSRL-531A	Automated	1.22	Stems	Rampart Cave, Arizona	0.2576	0.0018	10,900 ± 60
CAMS-16813	NSRL-531M	Manual	0.88	Stems	Rampart Cave, Arizona	0.2566	0.0016	10,930 ± 60
CAMS-6369	NSRL-748A	Automated	1.11	Charcoal	Hermit's Cave, New Mexico	0.6631	0.007	3300 ± 90
CAMS-6383	NSRL-748A	Automated	1.11	Charcoal	Hermit's Cave, New Mexico	0.6572	0.005	3370 ± 70
CAMS-6365	NSRL-748M	Manual	1.41	Charcoal	Hermit's Cave, New Mexico	0.6636	0.007	3290 ± 90
CAMS-6364	NSRL-749A	Automated	1.66	Charcoal	Hermit's Cave, New Mexico	0.6454	0.005	3520 ± 70
CAMS-6366	NSRL-749M	Manual	1.54	Charcoal	Hermit's Cave, New Mexico	0.6482	0.0052	3480 ± 70
CAMS-6368	NSRL-750A	Automated	0.98	Charcoal	Hermit's Cave, New Mexico	0.4988	0.004	5590 ± 70
CAMS-6381	NSRL-750M	Manual	1.23	Charcoal	Hermit's Cave, New Mexico	0.4972	0.004	5610 ± 70
CAMS-5897	NSRL-805A	Automated	1.30	Wood	Fairbanks Glacier, Alaska	Not reported	Not reported	5610 ± 140
CAMS-5898	NSRL-805A	Automated	1.30	Wood	Fairbanks Glacier, Alaska	Not reported	Not reported	5400 ± 130
CAMS-5899	NSRL-805A	Automated	1.72	Wood	Fairbanks Glacier, Alaska	Not reported	Not reported	5320 ± 130
CAMS-6344	NSRL-805M	Manual	1.06	Wood	Fairbanks Glacier, Alaska	0.5115	0.007	5380 ± 120
--	NSRL-746A	Automated	--	Wood	Rockfall Cave, New Mexico	--	--	Not dated
CAMS-7555	NSRL-746M	Manual	1.2	Wood	Rockfall Cave, New Mexico	0.2131	0.0021	12,420 ± 80

*Archaeological sample; probably a yucca spine tied into a knot

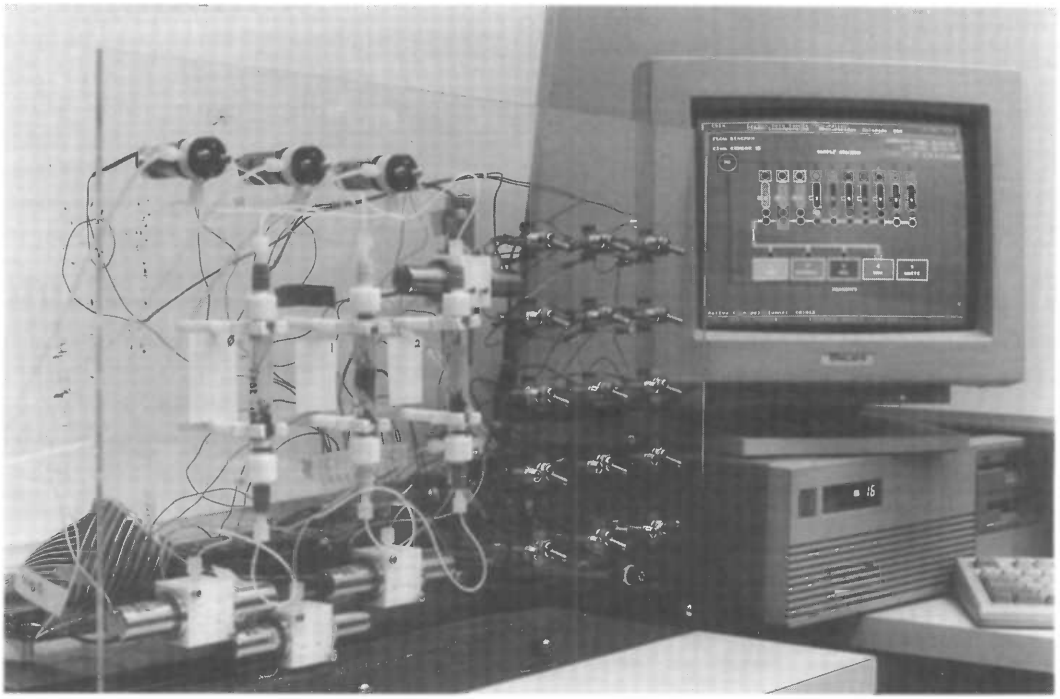

Fig. 1. Computer-automated system for chemically pretreating wood, charcoal and plant fossils for AMS ^{14}C dating. An IBM-compatible personal computer controls the movement of four solvents over samples contained in the glass columns.

the glass column. Each column drained through Teflon tubing attached to the bottom filter end-cap to a waste receptacle. Our system handles up to four different reagents (Table 2) and processes up to 3 sample columns simultaneously, but it could be modified to run as many as 5–10 samples. Each sample was weighed in the glass column including the filter end-caps and remained in its column throughout the pretreatment process.

We used an IBM-compatible personal computer to control the flow of reagents through the automated pretreatment apparatus. Specially designed computer software activates solenoid switches that control the flow of the reagents for time intervals specified by the program (Table 2). We used the same sequence for all samples except NSRL-750A (Table 1) because the discoloration of the KOH solution after its third treatment led us to infer that this sample needed additional pretreatment. Because discoloration of the KOH solution usually signifies contamination with humates, we ran sample NSRL-750A through the entire program sequence again (Table 2).

After drying, the final sample weight was calculated by total yield, and total recoverable yield. The total yield was calculated by subtracting the weight of the sample in the column from the initial weight of the column before pretreatment. The total recoverable yield was the weight of the dried sample after removal from the column. We noted only minor differences in these two values (see below and Fig. 3).

Manual Pretreatment Method

We pretreated the manual samples in the original sample vials, using the same sequence of reagents used in the automated pretreatment method (Table 2). Reagents were added and removed using

TABLE 2. Program sequence for one complete sample run with the automated pretreatment system. Our solvent reagents are made from deionized H_2O and a stock solution of distilled, constant-boiling HCl

Step	Sample Column		Reagent	Time (sec)
1	Fill	#1	H_2O pH6.5	50
2	Fill	#2	H_2O pH3	90
3	Purge			30
4	Fill	#3	0.5N HCl	60
5	Hold	#3	0.5N HCl	300
6	Purge			30
7	Fill	#1	H_2O pH 6.5	90
8	Purge			30
9	Fill	#4	0.5% KOH	60
10	Hold	#4	0.5% KOH	600
11	Purge			30
12	Fill	#1	H_2O pH 6.5	120
13	Purge			30
14	Fill	#2	H_2O pH 3	90
15	Purge			30
16	Fill	#1	H_2O pH 6.5	90
17	Purge			30
18	Fill	#4	0.5% KOH	60
19	Hold	#4	0.5% KOH	600
20	Purge			30
21	Fill	#1	H_2O pH 6.5	120
22	Purge			30
23	Fill	#2	H_2O pH 3	90
24	Purge			30
25	Fill	#1	H_2O pH 6.5	90
26	Purge			30
27	Fill	#4	0.5% KOH	60
28	Hold	#4	0.5% KOH	600
29	Purge			30
30	Fill	#1	H_2O pH 6.5	150
31	Purge			30
32	Fill	#2	H_2O pH 3	200
33	Purge			120
34	End			

pipettes with the tips modified to *ca.* 100 μ in diameter to minimize the amount of sample loss. A single pipette was used for each reagent to reduce contamination of the reagents. The time for each step was kept as close as possible to the times of the automated sequence including the time needed to add and remove reagents. After drying, the total yield was calculated by subtracting the initial weight of the sample vial from the final weight.

RESULTS

Time

All 11 samples processed using the automated system were completed in a total of 4.7 h; processing with the manual method required 15.7 h, or 3.4 times longer than the automated method (Fig. 4). The main reasons for the time savings are: 1) multiple samples can be run simultaneously in the automated method; and 2) adding and draining the reagents takes just a few seconds with the automated system, whereas adding and removing reagents manually using pipettes is very time-consuming.

Sample Yield

In 9 of 11 specimens treated, the percent of total yield was higher for the automated system than the manual method. However, after the samples were removed from the glass columns, the total recoverable yield using the automated system was greater only in 6 of 11 specimens (Fig. 3). Apparently, fibrous or minute amounts of sample material were trapped in the frits at the end of the columns and could not be removed. The differences in yield in the automated system ranged from a minimum of 0.5% for HB561-562A to a maximum of 7% for NSRL-531A (Fig. 3). For one sample (NSRL-746), the wood completely dissolved during automated pretreatment, whereas the yield during manual pretreatment was 45.54%. The reason for higher manual yield was that the solvents were added very slowly to lessen physical and chemical deterioration of the very friable wood. Although slow, gentle pretreatment yielded wood for dating, it is very possible that contaminants (*e.g.*, humates) could remain. Because no test exists presently to determine when contamination removal is complete and sample dissolution begins, we favor pretreating all samples to completion. If the material disintegrates totally, the sample is labeled "not datable due to dissolution during pretreatment".

Quality of Pretreatment

In the first steps of the manual pretreatment process, some samples (especially mosses) float, thus reducing surface contact with the reagents. With the manual method, these buoyant samples were submerged only after special attention from the technician. The automated samples do not suffer

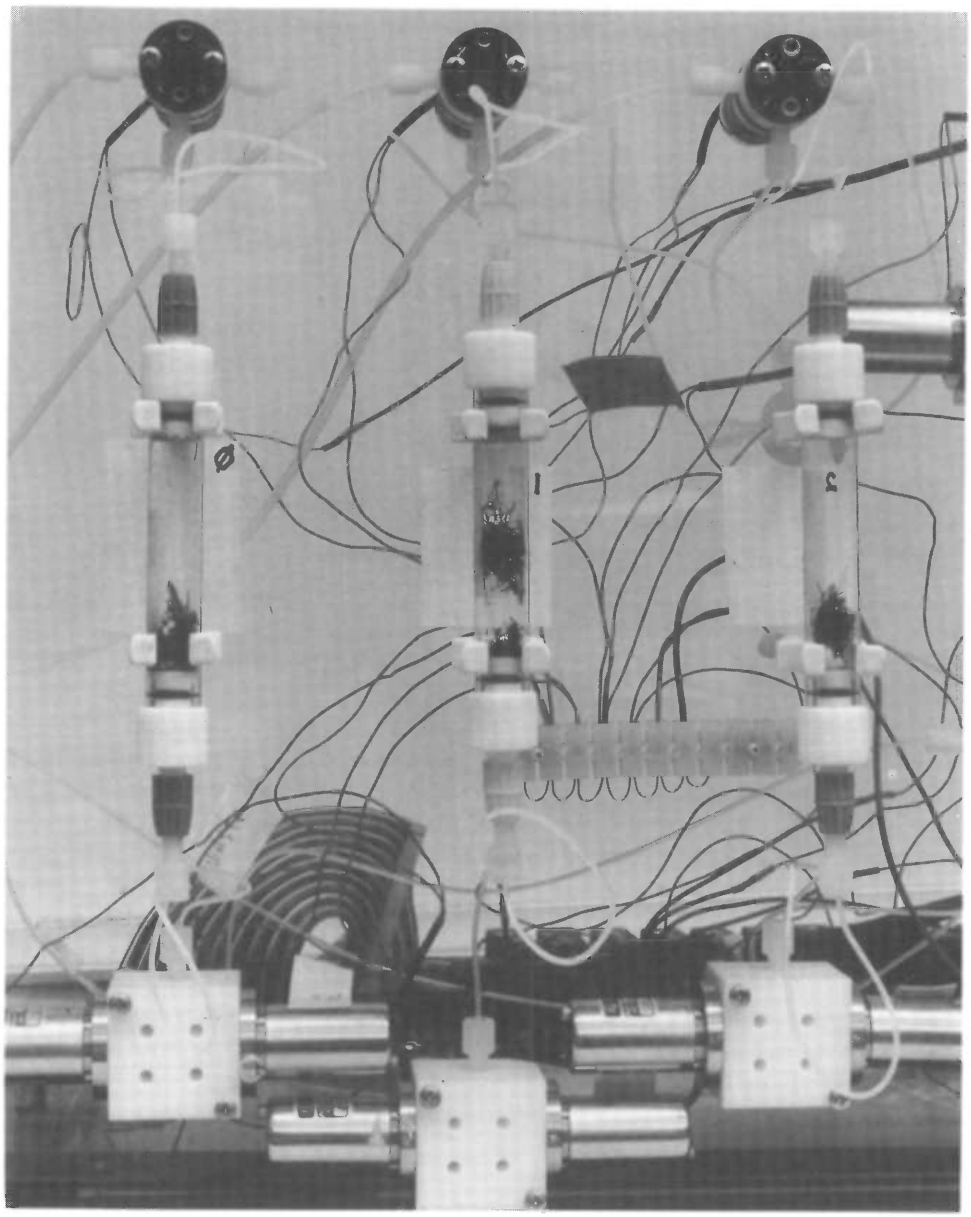

Fig. 2. Close-up of glass columns containing plant macrofossils ready for chemical pretreatment. Solenoid valves control the flow of the reagents upwards into the columns during pretreatment, and purge downward by using nitrogen gas pressure.

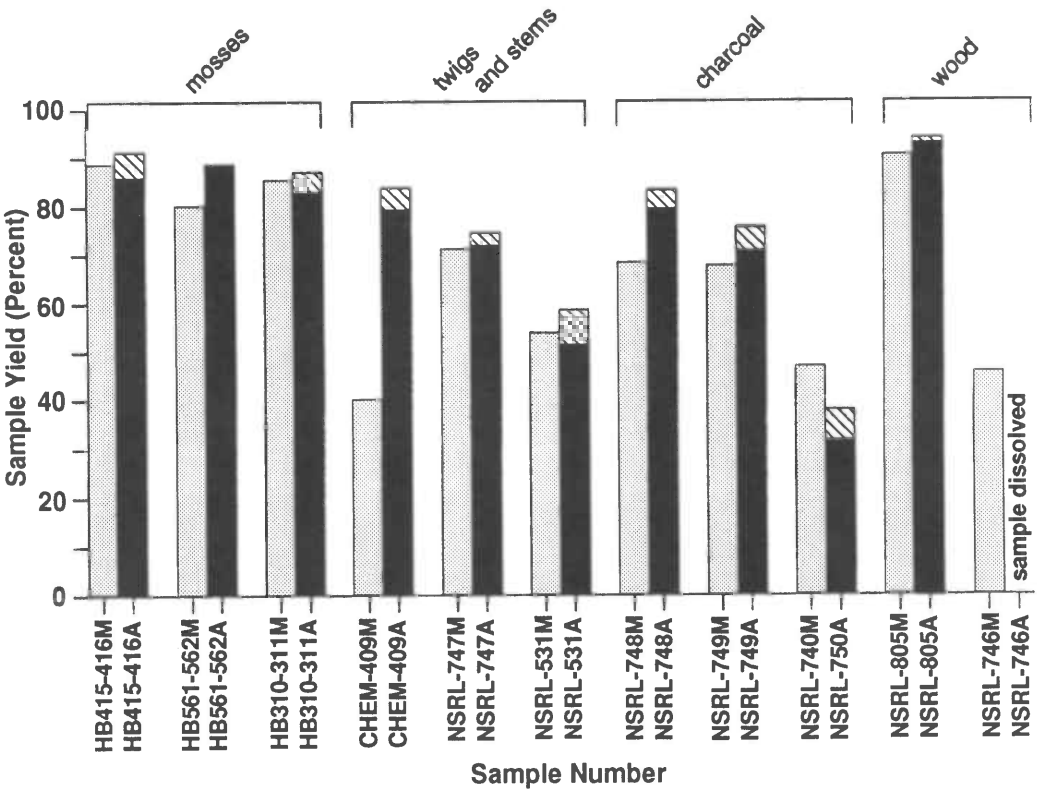

Fig. 3. Sample yields for manual and automated pretreatment methods. ▯ = total yield from manual method; ■ = total recoverable yield from automated method; ▨ = percent of sample not lost during pretreatment but not recoverable from the glass column; ▨ + ■ = total yield from automated method. Note higher percentage of total yield in automated samples. There was no significant difference between total yield and recoverable yield for most materials.

from this problem because they are sealed in glass columns and thus are completely submerged during the entire pretreatment process. The reagents used with the automated system showed more discoloration than the manually treated samples; in particular, the degree of brown discoloration from humates leached from the sample during the KOH steps is an indication of the degree of surface contact between the sample and the reagents. Thus, the automated process appears to be more effective in removing humic acid contaminants from the sample. There was also a much greater chance for human error with the manual method. A distracted technician can easily lose track of the sequence and add the wrong reagent. Contamination of the reagents is more likely because the containers are unsealed and pipettes can be inadvertently switched between reagents. With the automated system, the sample is only minimally disturbed because the sample is in contact only with the reagents flowing in and draining from the column.

Conclusions and Recommendations

Because labor costs are a large part of the cost of pretreatment, time savings reduce the cost of pretreatment. The automated method was more than three times faster than the manual method, making the automated method more cost-effective.

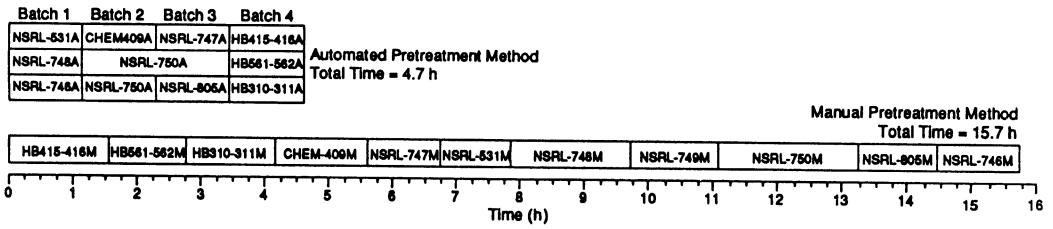

Fig. 4. Cumulative time required to complete pretreatments on 11 specimens using the automated system and the manual method. Using the automated system, three samples were processed simultaneously, permitting all samples to be run in 4 batches. NSRL-750A was run twice because discolored KOH reagents indicated incomplete pretreatment. The total time to process all 11 samples using the automated system was 4.7 h, compared to 15.7 h using the manual method.

The total recoverable yield is dependent on the method used and the type of sample material. In most cases, the automated method produced a higher yield, probably because less material is lost draining the reagents through filters than by siphoning off reagents manually. Extremely fragile materials that require special care, such as very soft wood or fine-grained charcoal, showed a higher yield by manual pretreatment. For most materials (plants, mosses, twigs and stems, most charcoal and fibrous wood) the yield is higher using the automated method. A necessary modification would be to use finer porosity frits in the filter end-caps. Smaller pore sizes would be smoother and occlude less of the fibrous sample. The second modification would be to decrease the gas pressure that moves the solutions in and out of the system. By decreasing the flow rate, the automated system would more closely mimic the manual pretreatment of delicate samples.

The darker discoloration of the KOH solutions we observed during the automated pretreatments indicates that this method is more thorough in removing humates from the specimens. Although there was no statistically significant difference in the paired ^{14}C ages, 6 out of 7 pairs of samples gave older ages for the automated samples, thus supporting our observation that the automated pretreatment process was slightly better (Table 1).

The next generation instrument is under development and will provide more control over pretreatment conditions. The improvements will include: 1) ability to vary linearly the KOH concentrations from 0.01% to 0.5%; 2) change flow rates to accommodate friable samples, 3) provisions for treating samples from room temperature to 80°C; 4) improvement of software to enable rerunning of specific, severely contaminated samples; and 5) rewriting the software for Macintosh systems.

ACKNOWLEDGMENTS

Our research is supported by the National Earthquake Hazards Reduction Program and the Global Change and Climate History Program of the U.S. Geological Survey, the U.S. Nuclear Regulatory Commission and National Science Foundation Grants EAR 90-18678, EAR 90-18958 and EAR 9118683. We thank Glenn Fryer, CIMAX, Inc., Breckenridge, Colorado, for his assistance in programming the DOS software to control the instrumentation.

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[RADIOCARBON, VOL. 36, NO. 3, 1994, P. 407–412]

POLLEN CONCENTRATE PREPARATION FROM HIGHLY ORGANIC HOLOCENE PEAT AND LAKE DEPOSITS FOR AMS DATING[1]

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ABSTRACT. Many of the problems inherent with conventional ^{14}C dating of lake and peat deposits are eliminated by AMS dating of pollen concentrates. Published work describes production of pollen concentrates through expulsion of most of the deposit matrix by repeated deflocculation, selective sieving and final retention of the largest subfossil pollen taxa. Less suited to pollen concentrate production are the highly organic peats and lake muds from the British Isles and Europe. In this study we tested the combined effectiveness of physical, chemical and microbiological degradation and elimination techniques for pollen concentrate production on highly organic peats and a lake mud. We also reviewed methods of enhancing concentrations of smaller sub-fossil pollen grains. Here we present a novel method of assessing AMS dating precision of pollen concentrates by comparing their calibrated dates with a volcanic event of known historical age.

INTRODUCTION

Radiocarbon dating by accelerator mass spectrometry (AMS) minute quantities of subfossil pollen grains eliminates many of the problems inherent with whole deposits and provides an alternative to conventional ^{14}C dating of, for example, Late Pleistocene and Holocene deposits. Some of the components of these deposits may not be contemporary with the pollen (O'Sullivan, Oldfield and Battarbee 1973; Hirons 1988; Peglar, Fritz and Birks 1989; Hall 1990). Brown *et al.* (1989) and Regnell (1992) have shown how valuable pollen concentrates are for AMS dating.

Using a suite of ^{14}C dated samples from a lowland raised bog peat profile, Pilcher, Hall and McCormac (ms.) have demonstrated the value of high-precision, multisample conventional dating constrained by volcanic ash or micro-tephra from the eruption of the Icelandic volcano Hekla in AD 1104. We suggest that pollen concentrates from a rapidly developing, finely particulate sediment that contains a layer of volcanic ash of known historical age offer a novel method of assessing the precision of AMS dating. Calibrated dates distributed along the ^{14}C calibration curve are assessed against the historical date of the volcanic event. This technique is independent of any comparison with conventionally derived ^{14}C dates (Burleigh, Leese and Tite 1986; Lowe *et al.* 1988; Regnell 1992). Confirmation of the precision of AMS dates obtained by this method offers an advance on conventional ^{14}C techniques and would be of great value in establishing particularly the dates of Early Holocene volcanic events recorded as tephra layers in sediments of complex origin, for example, the woody fibrous peats commonly found near the bottom of lowland raised bog deposits.

For AMS dating, preparing relatively pure pollen samples requires the removal of the organic fraction of the deposit matrix without using carbon-based chemicals. However, it is mostly organic deposits, often richest in pollen, that present the greatest challenge to preparing pollen concentrates.

[1]This paper was presented at the AMS Sample Preparation Workshop, 15th International Radiocarbon Conference, 14 August 1994, Glasgow, Scotland

For standard pretreatment of pollen concentrates for optical microscopy (Faegri and Iversen 1989; Cwynar, Burden and McAndrews 1979; Bowler and Hall 1989), palynologists resort to combinations of destructive chemical and physical procedures, which deflocculate the deposit material and destroy celullose and lignins while leaving the pollen grains intact. None of these processes entirely rids the final sample of non-pollen carbonaceous materials. Microscopic examination reveals that, even after processes that destroy cellulose plant parts, matrix detritus always remains.

Processing organic deposits for AMS dating precludes the use of carbon-based chemicals. Less efficient methods relying on deflocculation of the matrix by solutions of strong alkalis and bleaches (Brown *et al.* 1989) must be employed. Bowler and Hall (1989) show that these procedures work quite well for relatively finely particulate lake sediments, the more so if they contain sufficient amounts of large pollen grains to comprise a suitably sized sample for AMS dating (Brown *et al.* 1989). The best combination of procedures for producing pollen concentrates from highly organic deposits has yet to be evaluated.

Preparing pollen concentrates from peats and organic-rich lake sediments from northwest Europe poses two main difficulties:

1. Pollen concentrates based on large pollen grains alone are not generally applicable to many northern European deposits (Bennett 1984; Bradshaw and Brown 1987) as the Late Pleistocene and Holocene pollen flora of this large area is composed principally of species with pollen grains in the size range of 20–50 μ.
2. Highly organic peats from lowland raised bogs and upland blanket bogs range in degrees of humification from very poor, in young, lowland raised bog peats, to almost complete at the base of many blanket peat profiles. No single procedure is suitable for all peat deposits.

We intend to develop a rapid and inexpensive method of preparing pollen concentrates from highly organic deposits using readily available materials. This is not because whole deposits are unsuitable for conventional dating, but because we wish to tackle the problem of working with deposit types generally resistant to chemical degradation. To this end, we review the efficiency of published procedures when applied to some of the highly organic types of deposit common throughout the British Isles and northwestern Europe. We report the preliminary results of a microbiological treatment intended to digest fibrous plant parts. In addition, we suggest a procedure for evaluating AMS dates using pollen concentrates from a deposit containing volcanic ash of known historical date.

METHODS AND DISCUSSION

Site and Sample Selection

We chose five sample types to represent highly organic deposits. In general, the lowland raised bog peats of the north of Ireland are less decomposed then the upland blanket peats from the same region. They contain almost no inorganic fraction except minute quantities of plant silica, quartz and Icelandic volcanic glass (Pilcher and Hall 1992). All of the test samples were obtained from sites in Northern Ireland. Three lowland raised bog peat samples, variously humified, came from an exposed face at a large lowland raised bog in south County Antrim (Sluggan Bog, Irish Grid Ref. J099921). This is a large area of lowland raised bog peat which has been cut extensively for the provision of horticultural peat products. There is a small remnant of uncut peat from which three sample types were obtained.

Of these, the most poorly decomposed was a recent peat composed of recognizable plant remains, such as leaves and stem fragments of *Sphagnum* and epidermal and vascular tissue of *Eriophorum*.

Two older, more decomposed, peats were somewhat woody, the younger of the two being additionally fibrous.

A highly decomposed upland blanket peat with no recognizable plant structure came from the Mourne Mountains, County Down (Lough Shannagh, Irish Grid Ref. J292258). Extensive areas of blanket peats are present in this area. A coarse detritus lake mud where few plant parts were visible to the naked eye came from Long Lough (Irish Grid Ref. J380556), a small interdrumlin lake, also in County Down. We chose this sediment type so that we could assess the difficulties of working with a largely organic deposit which contained greater amounts of inorganic material than is present in peats.

Pollen Concentrate Preparation

We report here on the most effective combination of deflocculation, bleaching and sieving techniques from the literature that we used on our samples. We assessed procedures qualitatively, relying on optical comparison of a treated sample with its deflocculated control sample. Comparisons of five replicates per treatments were made by optical microscopic examination.

We made standard pollen pretreatments on all samples to assess the size range of the pollen taxa and the nature of the degraded matrix (Faegri and Iversen 1989). Other samples of each type of deposit were burned (Pilcher and Hall 1992), so that we could assess their inorganic content.

In all cases, examination by optical microscopy showed that the pollen spectrum spanned the size range 20–50 μ. Only in the upland blanket peats was there an abundance of Ericaceous pollen grains >50 μ. Knowing the pollen size range is essential when selecting polyester mesh grids for selective sieving. The lowland raised bog peats were almost free of inorganic inclusions such as quartz particles or diatoms. The upland blanket peat contained a small amount of quartz-like material. The lake mud contained fine clay particles and diatoms.

Samples of all deposits were deflocculated in 10% KOH solution (Faegri and Iversen 1989). The efficiency of matrix elimination by selective sieving on precision-woven polyester meshes was investigated (Cwynar, Burden and McAndrews 1979; Bowler and Hall 1989) in conjunction with ultrasonic agitation. Another means of deflocculating carbonaceous contaminants, bleaching, was assessed (Brown *et al.* 1989; Regnell 1992).

We recommend the following combination of procedures:

1. Deflocculate all deposit types in cold 10% KOH solution for 12 h.
2. Remove some of the diatoms from the lake mud by treatment with 10% KOH solution at 85°C for 1 h.
3. Wash samples through precision-woven polyester meshes of the size range 250, 120 and 70 μ to remove the larger fraction of the inorganic and organic matrix of all the deposits. A series of washings on meshes of decreasing grid size is more successful for removing the fibrous fraction of the least humified peat than repeated washings through 70 μ polyester mesh alone.
4. A final wash and retention of the sample on 24-μ polyester mesh is a reasonable compromise for all of the deposits in this part of the pollen concentration process. Finer mesh sizes retain more pollen but also more finely particulate matrix fragments. We chose 24-μ mesh even though further elimination of the finer fraction of the matrix caused some pollen loss.
5. Combining washing on 24-μ mesh with agitation in an ultrasonic tank for a maximum of 15 min greatly improves the concentration of pollen in all samples. This treatment removes virtually all of the finely particulate upland peat matrix, as well as much of the remaining matrix from

the lake mud. It also benefits the less humified peats by expelling many of the long slender fiber fragments.

6. Milton™ Sterilising Fluid (Proctor and Gamble Ltd, 2% w/v sodium hypochlorite and 16.5% w/v sodium chloride solution) is an inexpensive and readily available bleach used to sterilize babies' feeding equipment. Treatment in a half-strength solution of the bleach for 15 min further deflocculates the matrix, which can be removed by washing through 24-μ polyester mesh, with ultrasonic agitation, thus enhancing pollen concentration.

The purest pollen concentrate was prepared from the upland peat. Its matrix was finely particulate and responded well to expulsion by repeated deflocculation and selective sieving. Final samples of this peat were composed of 77% pollen (Fig.1). The coarser matrices of the lowland peats were much more difficult to remove. No combination of processes was successful in completely removing all plant fibers. A general compromise on bleaching times and sieving has yet to be achieved for poorly humified peat types. Pollen percentages in the final samples of the more poorly humified lowland peats ranged from 16%, in the youngest and most poorly humified peat, to 34% in the woody and fibrous peat. Final concentration of the pollen content of the lake mud was difficult to estimate. It was clear that most of the organic material had been removed from the final sample but considerable numbers of diatoms remained. Only *ca.* 25% of the final sample was composed of pollen. We suggest further improvements to this total below.

In the course of the investigation, we made the following observations:

1. The pollen content of samples was reduced when prepared by ultrasonic treatments lasting longer than 15 min. We suspect that pollen may be destroyed during longer treatments.

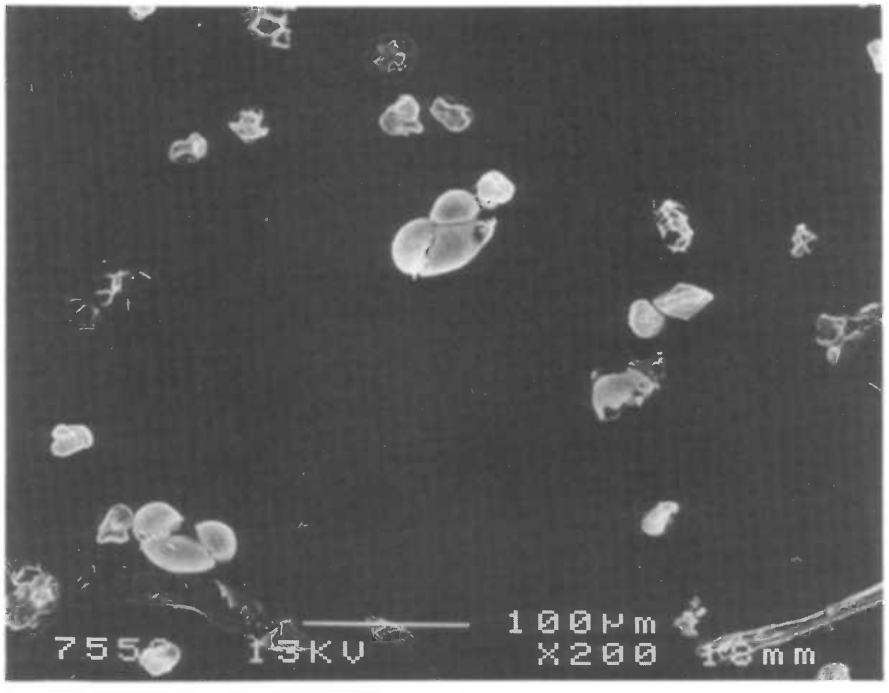

Fig. 1. Pollen concentrate prepared by deflocculation and selective sieving of an upland blanket peat

2. Matrix deflocculation by bleaching was no more effective after 1 h than after 15 min. The over-bleached material lost of most of its color, making it difficult to assess if more matrix had been expelled after further sieving.

3. Further refinement is needed to prepare almost pure pollen concentrates from fibrous matrices such as poorly humified peats. At this stage, we recommend a compromise between overall sample loss with enrichment of the pollen content *versus* selective matrix loss using a wider mesh size. We now suggest mesh between 30 and 40 μ and less vigorous sieving. A treatment with hot HF followed by HCl, a stage in standard pollen pretreatment (Faegri and Iversen 1989), would remove more of the inorganic fraction of the lake mud, in particular, the diatom flora. We stress that these processes must be fine-tuned to the individual requirements of each deposit; compromises depend, in part, on the initial size of the sample and its pollen concentration.

The previous investigations show that chemical treatments alone do little to reduce the size of the coarse fibrous peat fragments. The purity of the pollen concentrate from the upland blanket peat, whose original matrix was fine particulate, shows that the key to good pollen concentrate preparation must include a means of breaking up larger fragments without damaging the pollen. For this reason, we tested a microbiological degradation treatment, which might act similarly to the natural processes of humification.

As most of the matrix material from our subfossil deposits was either cellulose or lignin-based, we chose to test a proprietory microbiological activator, Fertosan™, used in domestic septic tanks. This product claims to accelerate the breakdown of paper-based products in septic tanks. Fertosan™ is fungal-based and contains members of the following families and subfamilies: Ascomycetes, Basidiomycetes, Fungi Imperfecti Hypomycetes, Zygomycetes and the bacteria-like Actinomycetes.

We suspended 15 g (dry weight) samples of whole deposits in culture medium. One set of replicates of each deposit type was also sieved to retain only the <75 μ fraction of the matrix. After centrifugation, these were also suspended in culture medium. All samples were suspended in 50 ml of aqueous standard chloride-free minimal salts medium to which 1 ml of 0.1% ammonium nitrate solution was added to provide a nitrogen source. Control replicates contained distilled water only. The pH of all samples was adjusted to 6.5. Each was innoculated with 20-ml aliquots of Fertosan™, prepared according to instructions (80 g 1000 ml^{-1} water), and incubated at 30°C with occasional stirring.

After six weeks, each sample was washed and sieved through 24-μ polyester mesh. Microscopic examination of the treated peat samples revealed many fibrous fragments, demonstrating that little microbiological digestion had taken place. The treated and untreated digestates looked much the same except for the lake mud samples. Here the deposit was very heavily contaminated with fungal spores the same size as the pollen grains, demonstrating that including fungal digestion in this treatment was counter-productive! Nevertheless, the spores showed considerable microbiological activity and would imply that some species of fungi metabolize the organic component of lake mud as a substrate, which is encouraging.

Conclusion

More work is required to identify a product that will degrade cellulose and related materials in peat without creating more problems than it solves. Other products similar in function to Fertosan™, but based on bacteria might offer an alternative. An accelerated digestion process, which includes the bacteria and fungi that naturally turn dead plants into peats, should be more promising. Cellulose-decomposing bacteria, such as species of *Cellvibrio*, *Cellulomonas* and *Pseudomonas*, common in the microbiological flora of peat litter, may provide an innoculum. We encourage continued investigation.

Publications on the preparation of pollen concentrates from whole lake muds have opened the way for more innovative sample preparation techniques for AMS dating. Here we have described our method of preparing samples from some of the most difficult deposits. We expect to continue making improvements.

Acknowledgments

We thank Prof. J. R. Pilcher for his comments on the text.

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RADIOCARBON UPDATES

New Tucson Telephone Area Code

Please note that the telephone area code for the Tucson area has changed from 602 to **520,** effective 19 March 1995. This affects *RADIOCARBON* and all University of Arizona telephone numbers.

New Laboratory

The radiocarbon laboratory formerly at the University of Wales, Cardiff, has moved with Dr. Quentin Dresser to Swansea, at the following address:

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Wales

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E-mail: ggdress@geog1.swan.ac.uk

Relocations

Dr. Alexander Cherkinsky, formerly of the Institute of Geography, Moscow, has joined Geochron Laboratories, Krueger Enterprises, Inc. His new address is:

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Radiocarbon Laboratory
Geochron Laboratories
711 Concord Avenue
Cambridge, Massachusetts 02138 USA

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Fax: 617-661-0148

Richard G. Cresswell moved from the Isotrace Laboratory in Toronto, Canada to join Keith Fifield at the ANU AMS Program. His new address is:

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Canberra, ACT 0200 Australia

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E-mail: richard.cresswell@anu.edu.au

Roberto Gonfiantini, formerly director of the Isotope Hydrology Section, IAEA, Vienna, has moved to Belgium, where his work will involve the assessment and establishment of new isotopic standards for geochemical investigations. His new address is:

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Institute for Reference Materials and Measurements
Commission of the European Communities
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Meetings

The **8th International Conference on Luminescence and Electron Spin Resonance Dating** will be held at Australian National University, Canberra, 22–26 April 1996. Sponsored by the Quaternary Dating Research Centre of the Division of Archaeology and Natural History, LED 1996 will bring together experts from around the world to discuss such topics as fundamental studies of the basic physical phenomena, dosimetry, advances in equipment technology and the application of the dating techniques in Quaternary research and archaeology. The program will include invited lectures and poster presentations; the luminescence laboratories at Adelaide, Wollongong and Canberra will organize pre-conference field trips. For further information, please contact:

Mrs. Judy Papps, Conference Secretary
Quaternary Dating Research Centre
ANH, RSPAS
Australian National University
Canberra ACT 0200, Australia

Tel.: 61 6 249 4764
Fax: 61 6 249 0315
E-mail: Judy.Papps@anu.edu.au

The **International Symposium on Archaeometry** will be held at the University of Illinois at Urbana-Champaign, 20–24 May 1995. For information, please contact:

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The Institute of Nuclear Sciences and Technology of Havana, Cuba, is sponsoring the **First Workshop of the Department of Environment,** to be held in Havana, 15–16 June 1995. Topics will include environmental simulation, ecological protection, environmental radiological protection, and clean technology. Authors submitting papers should send an abstract in English or Spanish not exceeding 500 words to the Organizing Committee before 1 May 1995. For more information, please contact:

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Fax: (537) 33-1188; 33-1325
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Travel Grant

The American Geophysical Union, jointly with the U.S. National Committee for the International Union of Quaternary Research (USNC/INQUA), is expecting to obtain funding for its travel grant program to the XIVth INQUA Congress in Berlin, Germany, August 3–10, 1995. Pre- and post-congress field excursions are planned. The U.S. National Committee, under the sponsorship of AGU, and with the cooperation of the American Quaternary Association (AMQUA), seeks to ensure appropriate U.S. representation by providing travel grants to enable Quaternary scientists residing in the United States (regardless of citizenship) to participate in the activities of the congress. Travel grants, which will cover only a portion of a participant's expenses (mainly airfare), are to be awarded competitively, in part on the evaluation of papers submitted for presentation at the congress. The Awards Subcommittee also plans special consideration for those judged to benefit most by participation at this important international event.

The completed application, including the abstract of your paper and a one page curriculum vitae, must be received or postmarked by January 31, 1995. Travel grant applications and detailed instructions are available from:

Anne Linn
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2101 Constitution Avenue NW
Washington, DC 20418 USA

Tel.: (202) 334-2744

Internet Resources

The Radiocarbon Dating Laboratory at the University of Waikato, New Zealand, now has a site on the World Wide Web at the following URL:

`http://www2.waikato.ac.nz/c14/`

Information regarding the laboratory, including requirements for sample size, options for dating precision and pretreatments are included. For the first time, it is possible to submit ^{14}C sample data by simple electronic means. A reproduction of the Waikato sample submission form is included on the Web and may be filled out and electronically submitted with an acknowledgment of receipt seconds later. This speeds up the process of entering information on the lab database and is a convenient, simple and accessible method of transmitting data for submitters. For further information, contact Thomas Higham: Higham@waikato.ac.nz.

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LABORATORIES – CODE DESIGNATIONS[4]

A	Arizona	USA
AA	NSF	USA
AAR	University of Aarhus	Denmark
AC	Ingeis	Argentina
AECV	Alberta Environmental Center of Vegreville	Canada
ALG	Algiers	Algeria
ANTW	Antwerp	Belgium
ANU	Australian National University	Australia
ANUA	ANU Accelerator	Australia
B	Bern	Switzerland
Ba	Bratislava	Slovakia
Beta	Beta Atantic	USA
Birm	Birmingham	USA
Bln	Berlin	Germany
BM	British Museum	England
BS	Birbal Sahni Institute	India
BSG	Brock University	Canada
CAMS	Center for Accelerator Mass Spectrometry	USA
CENA	Centro Energia Nuclear na Agricultura	Brazil
CG	Institute of Geology	China
CH	Chemistry Laboratory	India
CRCA	Cairo	Egypt
CU	Charles University	Czech Republic
DE	USGS, Denver	USA
Deb	Debrecen	Hungary
DEM	Demokritos	Greece
DRI	Desert Research Institute	USA
ENEA	ENEA, Bologna	Italy
ETH	ETH/AMS Facility	Switzerland
F	Florence	Italy
Fr	Freiberg	Germany
Fra	Frankfurt	Germany
FZ	Fortaleza	Brazil
GAK	Gakushuin University	Japan
Gd	Gliwice	Poland
Gif	Gif sur Yvette	France
Gif A	Gif sur Yvette and Orsay	France
GIN	Geological Institute	Russia
GrN	Groningen	The Netherlands
GrA	Groningen Accelerator	The Netherlands
GSC	Geological Survey	Canada
GU	Scottish Universities Research & Reactor Centre	Scotland
GX	Geochron Laboratories	USA
HAM	Hamburg	Germany
HAR	Harwell	England
Hd	Heidelberg	Germany
Hel	Helsinki	Finland
HL	Second Institute of Oceanography	China
Hv	Hannover	Germany
I	Teledyne Isotopes	USA
IAEA	International Atomic Energy Agency	Austria
IAEA-MEL	Marine Environmental Laboratory	Monaco
IEMAE	Institute of Evolutionary Morphology and Animal Ecology	Russia
IGAN	Institute of Geography	Russia
IOAN	Institute of Oceano-graphy	Russia
IRPA	Royal Institute of Cultural Heritage	Belgium
ISGS	Illinois State Geological Survey	USA
IVAN	Institute of Volcanology	Ukraine
IWP	Institute of Water Problems	Russia
JGS	Geological Survey of Japan	Japan
JUBR	Biren Roy Research Laboratory	India
K	National Museum	Denmark
KAERI	Korean Atomic Energy Research Institute	Korea
KCP	National Cultural Property Research Institute	Korea
KI	Kiel	Germany
KIEV	Institute of Radio-Geochemistry of the Environment	Ukraine
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MGU	Moscow	Russia
ML	Miami	USA
N	Nishina Memorial	Japan
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NTU	National Taiwan University	Republic of China
NU	Nihon University	Japan
NZ	New Zealand	New Zealand
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Q	Cambridge	England
QL	Quaternary Isotope Laboratory	USA
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RCD	Radiocarbon Dating	England
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TK	University of Tokyo	Japan
TKU	Turku	Finland
Tln	Tallinn	Estonia
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WAT	University of Waterloo	Canada
WHAMS	National Ocean Sciences AMS Facility	USA
WIS	Wisconsin	USA
Wk	University of Waikato	New Zealand
XLLQ	Xian Laboratory of Loess and Quaternary Geology	China
Z	Zagreb	Croatia

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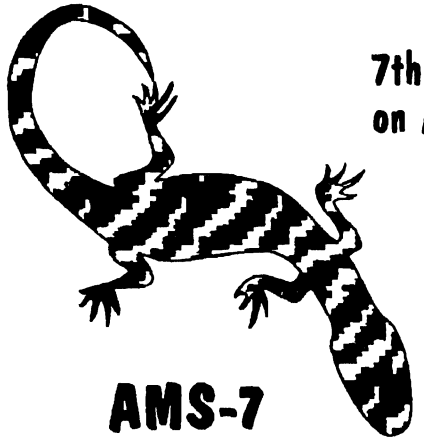

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The purpose of *RADIOCARBON* is to publish technical and interpretive articles on all aspects of ^{14}C and other cosmogenic isotopes. In addition, we present regional compilations of published *and unpublished* dates along with interpretive text. Besides the triennial Proceedings of Radiocarbon Conferences, we publish Proceedings of conferences in related fields and Special Issues that focus on particular themes. 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 BOOK REVIEWS. 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. 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 3½″ or 5¼″ 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:

For	*Date*
Vol. 38, No. 1, 1996	September 1, 1995
Vol. 38, No. 2, 1996	January 1, 1996
Vol. 38, No. 3, 1996	May 1, 1996

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 $\delta^{14}C$ 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 $\delta^{14}C$ as the observed deviation from the standard. At the New Zealand Radiocarbon Dating Conference it was recommended to use $\delta^{14}C$ 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 $\delta^{13}C = -19‰$.

In several fields, however, age corrections are not possible. $\delta^{14}C$ 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.

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