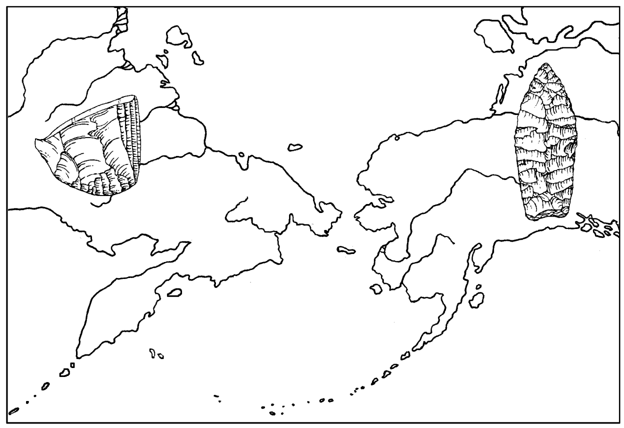
Radiocarbon

An International Journal of Cosmogenic Isotope Research

VOLUME 44 / NUMBER 2 / 2002



Special Section

Old and New World Connections   pp 403–530

Guest edited by Yaroslav V Kuzmin

Department of Geosciences
The University of Arizona
4717 East Fort Lowell Road
Tucson, Arizona 85712-1201 USA

ISSN: 0033-8222

RADIOCARBON
An International Journal of Cosmogenic Isotope Research

Published by
Department of Geosciences
The University of Arizona

Published three times a year at The University of Arizona, Tucson, AZ 85712-1201 USA.

Cover image of Old and New World projectiles designed by Yaroslav V Kuzmin (see page 403). Adapted in part from an image of a Mesa-site projectile point in an article by Michael L Kunz and Richard E Reanier, "The Mesa Site, Iteriak Creek" in *American Beginnings: The Prehistory and Palaeoecology of Beringia*, edited by Frederick Hadleigh West, p 497–504. © 1996 University of Chicago Press. All rights reserved.

Subscription rate (2003): $175.00 (institutions), $80.00 (individuals). Foreign postage is extra. A complete price list, including proceedings of international conferences, special publications and back issues, appears on the inside back cover of this issue. *Advertising rates* available upon request, or see www.radiocarbon.org/adrates.html.

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

Authors: See our "Information for Authors" document at www.radiocarbon.org/Authors/ for guidelines on manuscript submission and format. All correspondence and manuscripts should be addressed to the Managing Editor, *RADIOCARBON*, Department of Geosciences, The University of Arizona, 4717 East Fort Lowell Road, Tucson, AZ 85712-1201 USA. Tel.: +1 520 881-0857; Fax: +1 520 881-0554; Email: editor@radiocarbon.org.

List of laboratories. Our comprehensive list of laboratories is published annually, and is also available at www.radiocarbon.org/Info/lablist.html. We ask all laboratory directors to provide their laboratory code designation, as well as current telephone and fax numbers, and email addresses. Changes in names or addresses, additions or deletions should be reported to the managing editor. Conventional and AMS laboratories are arranged in alphabetical order by country, and we include laboratories listed by code designation.

RADIOCARBON on the World Wide Web: http://www.radiocarbon.org/

RADIOCARBON is indexed and/or abstracted by the following sources: *Anthropological Index; Anthropological Literature; Art and Archaeology Technical Abstracts; Bibliography and Index of Geology* (GeoRef); *British Archaeological Bibliography; Chemical Abstracts; Chemistry Citation Index; Current Advances in Ecological and Environmental Sciences; Current Contents* (ISI); FRANCIS (Institut de l'Information Scientifique et Technique – CNRS); *Geographical Abstracts; Geological Abstracts; Oceanographic Literature Review; Science Citation Index; Social Sciences Citation Index*.

Vol 44, Nr 2 **Radiocarbon** 2002

CONTENTS

EDITORIAL BOARD

RADIOCARBON, Vol 44, Nr 2, 2002, Pages 403–631

RADIOCARBON, Vol 44, Nr 2, 2002, p 403–405

INTRODUCTION

Yaroslav V Kuzmin
Special section guest editor

Pacific Institute of Geography, Far Eastern Branch of the Russian Academy of Sciences, Radio St. 7, Vladivostok 690041, Russia. Email: ykuzmin@tig.dvo.ru

Oh, East is East, and West is West, and never the twain shall meet,
Till Earth and Sky stand presently at God's great Judgment Seat;
But there is neither East nor West, Border, nor Breed, nor Birth,
When two strong men stand face to face,
tho' they come from the ends of the earth!

—Rudyard Kipling "The Ballad of East and West"

The idea to assemble this special section came to my mind in May 2000, when I was at the NSF-Arizona AMS Facility at the University of Arizona in Tucson, Arizona, USA, and organizing the complete set of *Radiocarbon* collected by Prof Douglas J Donahue in the laboratory. At the time, I was a "freshman" on the journal's editorial board. Before that, I was involved in several projects, dealing with the peopling of North America, under IREX and Fulbright fellowships. Having seen several special issues, "Calibration" 1986, 1993, and 1998 issues; "Paleoastrophysics and Paleogeophysics"; "^{14}C Cycling and the Oceans"; "Varves/Comparison", etc., I thought: "Why has an important subject, like the ^{14}C evidence of the peopling of the New World, never had the opportunity to be the focus of a *Radiocarbon* special issue?" Fortunately, this raw idea was immediately supported by the journal's editor, A J T Jull, and was finally approved by the editorial board at a business meeting, held at the Ma'ale Hachamicha Hotel in the Judean Hills near Jerusalem on 20 June 2000.

After a search for possible contributors (some of were invited, some contacted *Radiocarbon* after seeing the announcement on the journal's webpage), work started on this subject. Two and a half years later, we have a collection of papers that constitute the special section, *"Old and New World Connections"*. Since the Old World is essentially in the East, and the New World in the West, they did not get along well in post-WWII times, an echo of the Cold War. Nowadays, there is no more "stand face to face" as is mentioned in the epigraph; we instead cooperate in the study of the complex and intriguing process of the peopling of the New World, and this is a good example of such joint efforts. It is also reflected in the special section's logo (see the front cover of this issue), where two well-known artifact types, the wedge-shaped microcore of the Dyuktai culture of Yakutia and the lanceolate projectile point from the Mesa site of Alaska, represent two sides of the same story—human migration from West to East, from the Old World to the New one.

In this special section, the Old World means Asia (Japan, Korea, and the Asiatic part of Russia), and the New World consists of the Americas and Australia. All papers generally follow the "Out of Asia" scenario, assuming that Asia was the source of the initial peopling for both the Americas and Australia. The main focus here is the ^{14}C chronology of the prehistoric occupation, with emphasis on the earliest evidences of human presence in Asia, North and South America, and Australia, within the limit of ^{14}C dating, about the last 45,000–50,000 ^{14}C years.

S J Fiedel presents a comprehensive critical review of the peopling of the Americas, with extensive use of the ^{14}C data corpus from Paleoindian complexes and from other early sites. He assumes that the ^{14}C age of the best-known possible pre-Clovis sites, such as Bluefish Cave 1, Meadowcroft Rockshelter, Cactus Hill, and Monte Verde, still remains uncertain. Thus, Clovis is the earliest firmly documented prehistoric complex in the Americas south of the former continental ice sheets, and may be dated to approximately 11,600–10,700 ^{14}C years ago (BP). The ^{14}C age of the earliest Alaskan sites, such as Swan Point, Mead, and Broken Mammoth, is approximately 11,800–11,700 BP. Calibration of ^{14}C dates allows us to estimate the real, astronomical age of the Clovis complex, corresponding to approximately 13,200 calendar years ago (cal BP); and for the earliest Alaskan complexes it is approximately 13,800–13,400 cal BP. Considering that the route for the earliest inhabitants of North America was from Alaska southward, Fiedel assumes that the "ice-free" corridor between the shrinking Laurentide and Cordilleran glaciers was open from approximately 12,500 BP, and this allowed people to move southward. As for the Paleoindian ancestral cultural complexes in Asia, Fiedel provisionally proposes southern Siberia (and possibly northern China) based on both genetic evidences and ^{14}C-dated archaeological assemblages.

T G Arnold performs a thorough analysis of the ^{14}C data from the very important part of northern North America, in terms of the initial peopling, the so-called Ice Free Corridor. He presents 255 carefully selected ^{14}C dates from 164 localities, and they are used to examine when this Corridor became accessible for human migration from Alaska southward at the end of the Pleistocene. A List of chosen ^{14}C dates is also provided, and makes this paper a good source of original data. As for timing when the Ice Free Corridor became open for human migration, Arnold proposes approximately 11,000 BP, unlike Fiedel at approximately 12,500 BP (this issue). This means that it was "too late" for Clovis ancestors to take this migration route southward, because Clovis is dated no later than approximately 11,600 BP.

R Gillespie provides a critical overview of the existing chronometric evidences for the peopling of Greater Australia, which is another important issue in world prehistory. After careful evaluation of chronometric dates from key sites, produced by ^{14}C, TL, OSL, ESR, AAR, and U/Th methods, the tentative conclusion is that the earliest human sites in Australia may be dated to approximately 50,000 cal BP, i.e. approximately 48,000 BP. The extinction of several Australian megafaunal species corresponds to this time.

K Bae reports on the available ^{14}C dates for Paleolithic sites in Korea. This is the first systematic presentation of chronological evidences about the initial settling of this part of East Asia, which is crucial for understanding the peopling of the Japanese Islands. The earliest ^{14}C dates, approximately 54,720–50,300 BP, are right on the edge of the radiocarbon method limit, and should be treated with great caution only as minimal age estimates. The Middle to Upper Paleolithic transition in Korea could be provisionally placed at around 36,000–30,000 BP. A very important event in northeast Asian prehistory, the introduction of microblade technology in the form of wedge-shaped microcores and microblades, can now be established in Korea as early as approximately 24,000 BP. These data create the background for future studies of the Paleolithic geoarchaeology and chronology of the Korean Peninsula.

A Ono, H Sato, T Tsutsumi, and Y Kudo assemble the most complete list of Paleolithic ^{14}C dates from the Japanese Islands ever published, which consists of 416 values (plus 13 Incipient Jomon dates). The previous selection of Japanese Paleolithic ^{14}C dates published in English includes 207 values (Ono et al. 1998:51–7). The list published in this volume thereby doubles the number of dates! Furthermore, Ono and co-authors provide a careful interpretation of the existing ^{14}C chronology of the Japanese Paleolithic. The Middle to Upper Paleolithic transition in Japan can now be dated to approximately 34,000 BP. Microblade technology, corresponding to the Final Paleolithic, appeared first in Hokkaido, northernmost Japan, at approximately 20,500 BP, and in central and southern Japan at approximately 15,500 BP. The Final Paleolithic-Jomon transition, characterized by the emergence of pottery vessel manufacture, occurred within the latest phase of the Pleistocene, at approximately 13,000 BP.

H Takamiya and H Obata discuss the issue of the peopling of the southernmost part of the Japanese Islands, particularly the Ryukyu Archipelago, along with the Kyushu and Shikoku Islands. This is one of the most important places in East Asia in terms of the chronology and anthropology of modern humans. Several well-preserved *Homo sapiens sapiens* skeletal remains were found on Okinawa Island, and associated material was dated to approximately 32,000–16,600 BP. If these age determinations are correct, this might also mean that by at least 32,000 BP ancient people were able to use watercraft to cross the sea straits between Okinawa and either mainland East Asia or Kyushu. Even though the lowermost ocean water level was about 120–130 m below the present one at the Last Glacial Maximum (ca. 20,000–18,000 BP), Okinawa was not connected to other large islands and the mainland because of straits up to 1000 m deep (Gorshkov 1976:281).

S A Vasil'ev, Y V Kuzmin, L A Orlova, and V N Dementiev produce a brief review of the Siberian Paleolithic ^{14}C chronology. They also compile a list of Paleolithic ^{14}C dates for the territory of the Asiatic part of Russia, Siberia, and the Russian Far East, consisting of 446 values. This is the most complete database of the Siberian Paleolithic ^{14}C chronology published so far. The issue of the Pleistocene bone collagen dating is discussed, based on experience obtained in Russian ^{14}C laboratories during the last 30 years. The phenomenon of wide variations in the Paleolithic ^{14}C date series is also discussed, in particular with respect to the dating of mammoth bones and ivory. Early Upper Paleolithic sites are known from Southern Siberia as early as approximately 40,000 BP. In central eastern Siberia, or Yakutia, closely related to the issue of the peopling of the New World, the earliest Dyuktai cultural sites may date to approximately 25,000 BP, and definitely to approximately 18,000 BP. Modern humans at approximately 13,000 BP occupied extreme Northeastern Siberia—the Arctic Ocean coast, the Kolyma River headwaters, and the Kamchatka Peninsula (using data published as of mid-2002).

The articles in this special section summarize the existing knowledge of the chronology of human occupation of significant parts of both the Old and New Worlds, and show directions for future research. Several ^{14}C date lists comprise a comprehensive supplement to other lists published recently (Bonnichsen and Turnmire 1999; Dillehay 2000; Holliday 2000). Hopefully, in the following or next decade, most of the issues raised in the papers presented here, will be solved.

Finally, I would like to express my deep gratitude to colleagues and friends who helped in the realization of the idea to produce this *Radiocarbon* special section. I am especially grateful to A J Timothy Jull for constant support; to Kimberley T Elliott for assembling papers and conceiving the title, "Old and New World Connections"; to P Jeffrey Brantingham for editorial work in the early stage of production; and to all reviewers for useful comments and suggestions. In the long run, we "come from the ends of earth!"

REFERENCES

Bonnichsen R, Turnmire KL, editors. 1999. *Ice Age people of North America: environments, origins, and adaptations of the first Americans*. Corvallis, Oregon: Oregon State University Press. 672 p.

Dillehay TD. 2000. *The settlement of the Americas: a new prehistory*. New York: Basic Books. 384 p.

Gorshkov SG, editor. 1976. *World ocean atlas. Volume 1. Pacific Ocean*. Oxford: Pergamon Press. 302 p.

Holliday VT. 2000. The evolution of Paleoindian geochronology and typology on the Great Plains. *Geoarchaeology* 15(3):227–90.

Ono A, Sato H, Sasaki T, Matsumoto S. 1998. Japanese Islands. In: Kuzmin YV, editor. *Radiocarbon chronology of the Stone Age of Northeast Asia*. Vladivostok: Pacific Institute of Geography. p 49–57.

RADIOCARBON, Vol 44, Nr 2, 2002, p 407–436

INITIAL HUMAN COLONIZATION OF THE AMERICAS: AN OVERVIEW OF THE ISSUES AND THE EVIDENCE

Stuart J Fiedel

The Louis Berger Group, 1819 H Street, NW, Suite 900, Washington, DC 20006 USA. Email: sfiedel@earthlink.net.

INTRODUCTION

Out of Asia, But When?

Ever since José de Acosta's prescient speculation, in 1590, that Native Americans were descended from "savage hunters" who had followed game animals across a land bridge from northeastern Asia into northwestern America (Acosta 1604), most serious scholars have assumed that this was the migration route. The main point of dispute has been the date when the ancestral Asians made the crossing. After many nineteenth-century claims of the discovery of stone tools or bones of "early man" failed to withstand scientific scrutiny, a conservative reaction set in, embodied by the hyper-skeptical Aleš Hrdlička of the Smithsonian Institution. Hrdlička dismissed all claims of a human presence in the Americas prior to about 5000 years ago.

However, in 1926, obviously man-made spearpoints were found embedded within the skeletons of extinct giant bison, near Folsom, New Mexico. Prominent scholars viewed the finds in-situ in 1927 and 1928, and verified the coexistence of humans ("Paleoindians") and giant mammals (megafauna) that died out at the end of the Ice Age, then estimated as about 10,000 years ago.

Within the next decade, similar, but not identical points were found alongside the bones of mammoths at Dent, Colorado, and at Blackwater Draw, near Clovis, New Mexico (Cotter 1937). Later investigations at Blackwater Draw in 1949–1950 demonstrated that these points and the associated mammoth skeletons occurred in sediments stratified below the level containing Folsom points (Sellards 1952). Soon, Clovis-like fluted points were being found across the whole of North America, and even in Central America. Junius Bird (1938) excavated points with fishtail-like stems at the southern tip of South America, in apparent association with bones of extinct horses. Very similar stemmed points were later found in Ecuador and Central America. These points appeared to be derivative variants of the Clovis type.

Application of the new radiocarbon dating method in the early 1950s initially yielded problematic late dates for Folsom, but a date of 10,780 ± 135 BP[1] for the Lindenmeier site, published in 1960, appeared valid. In 1959, the Lehner Clovis site was dated at 11,290 ± 500 and 11,180 ± 140 BP (Haury et al. 1959; Haynes 1992). Dates for other sites supported this chronology. It should be noted, however, that Ernst Antevs, based on his climatic-stratigraphic correlations of American sequences with European late glacial chronology, questioned the accuracy of the ^{14}C dates. He preferred a date of ~13,000 BP for Clovis (Antevs 1935, 1953, 1959).

By the mid-1960s, a coherent picture of initial human colonization seemed to be emerging, as outlined by C Vance Haynes (1964, 1966). Clovis artifacts were made by the first inhabitants of the continent. Their ancestors, hunting people of the northern Eurasian grasslands, had crossed the 1500-km-wide land-bridge, called Beringia, exposed by lowered sea level during the late Pleistocene. However, eastern Beringia (modern Alaska) was sealed off from North America by two massive coalescent ice sheets (the Cordilleran to the west, the Laurentide to the east). The glaciers

[1]Here, "BP" refers to uncalibrated conventional radiocarbon age; "cal BP" connotes corrected dates (Fiedel 1999a).

receded as climate warmed toward the end of the Pleistocene, and a passage opened between them—the "ice-free corridor." Ancestral Paleoindians ventured south through the corridor around 11,500 BP, stumbling upon a hunters' paradise of naive megaherbivores that had evolved no defensive strategies against human predation. Paul S Martin (1973) seized upon this aspect of the Clovis-first theory, creating an elegant model that explained both the ubiquitous appearance of fluted spearpoints and the apparently simultaneous demise of numerous species of giant Pleistocene fauna. Martin theorized that Paleoindians had engaged in a killing spree, a blitzkrieg-like rapid advance that resulted in overkill and extinction of the megafauna by 10,000 BP.

PRE-CLOVIS SITES?

A persistent faction of "Early Man" enthusiasts has chafed under the temporal constraints of this Clovis-first model. Claims for ages in excess of 11,500 BP have been advanced for numerous sites, but they have always foundered when the contexts or the often ambiguous artifacts themselves were scrutinized closely (e.g. by Haynes 1974; Waters 1985; Lynch 1990). The continuing absence of verified pre-Clovis sites has been attributed to drastic post-glacial transformation of the landscape, to a generalized and very simple lithic technology that is difficult to recognize, or to a thin and transient early population. Pre-Clovis advocates do not explain why similar factors have not prevented discovery of indisputable Lower and Middle Paleolithic sites in Eurasia. Why are stone flakes made by small-brained early hominins in Ethiopia 2.5 million years ago immediately recognizable as artifacts (Semaw 2000), while supposed >15,000-year-old "tools" from the Americas (e.g. the 50,000-year-old quartzite "choppers" from Pedra Furada in eastern Brazil) are indistinguishable from naturally fractured stones (Meltzer et al. 1994)?

At several sites, indubitable lithic artifacts have been found, but their contextual and behavioral associations with early strata or ^{14}C-dated organics of pre-Clovis age are ambiguous. Deeply stratified points and blades, associated with bones of extinct fauna, were reported from four locations at Valsequillo in Puebla, Mexico (Irwin-Williams 1967, 1978, 1981). However, the finds became embroiled in controversy when the project geologists, despite the misgivings of the excavator (Irwin-Williams 1981), maintained that the sites were about 250,000 years old (Steen-McIntyre et al. 1981; Szabo et al. 1969). This date proved unacceptable even to the most ardent advocates of pre-Clovis colonization (e.g. Bryan 1978:315). Pichardo (2000) has recently argued for a date of about 15,000 BP, based on faunal and stratigraphic correlation.

At Taima-Taima in Venezuela, Bryan et al. (1978) found the midsection of an El Jobo point lying (but not actually embedded) within the pubic cavity of a juvenile mastodon. Unworked pebbles were also present in the cavity, suggesting post-depositional disturbance that could also have brought the midsection into fortuitous association with the fossil. ^{14}C dates of ca. 12,600 to 14,400 BP were obtained for samples of soil organics, bone, and twigs interpreted as the stomach contents of a mastodon. The presence of coal in the vicinity, and permeation of the deposits by groundwater, raised the possibility that the early dates reflected contamination with old carbon (Haynes 1974; Dincauze 1984; Waters 1985; Lynch 1990).

In Bluefish Cave 1, in the northern Yukon, a few stone artifacts—wedge-shaped cores, microblades, and burins—were found in apparent association with remains of mammoth, horse, bison, and other Pleistocene mammals (Morlan and Cinq-Mars 1982; Cinq-Mars and Morlan 1999). ^{14}C dates on the bones ranged between 12,210 ± 210 and 25,000 BP. If the dates and association are valid, this would be the oldest cultural material from eastern Beringia. However, it remains uncertain whether the lithic artifacts, typical of the somewhat later Paleoarctic tradition (11,700 BP and later) are displaced. Supposed bone artifacts in the cave can be reasonably attributed to non-human agency, such as carnivore gnawing (Dixon 1999:61).

At two sites in southeastern Wisconsin, artifacts have been found in association with mammoth bones. At the Schaefer site, a few lithic flakes were found in association with bones directly dated to about 12,300 BP. At the nearby Hebior site, a rather crude biface was found lying within a pile of mammoth bones dated to about 12,500 BP (Overstreet and Stafford 1997). At first glance, the reported finds appear to convincingly demonstrate pre-Clovis human activity, but the behavioral relationship of the artifacts and bones has yet to be clarified and explained.

A lithic assemblage consisting of small blades, flake knives, and a reworked lanceolate point ascribed to the "Miller" type, was recovered from Stratum IIA of Meadowcroft Rockshelter in southwestern Pennsylvania (Adovasio et al. 1990, 1999). Taking the ^{14}C dates at face value, the artifacts from the lower third of Stratum IIA date between 16,205 ± 975 (SI-2354) and 12,800 ± 870 (SI-2489) BP. The Miller point, ascribed to middle IIA, is bracketed by the 12,800 ± 870 date and a date of 11,300 ± 700 (SI-2491) on charcoal from a nearby firepit. Despite frequent assertions that the six dates from lower IIA occur in appropriate stratigraphic order, their actual relative and absolute depths have nowhere been reported. Although the site apparently was painstakingly excavated, detailed plan views and profiles of features and artifact distributions have yet to be published more than 20 years later. The problems here are: 1) the plant remains and the few identifiable animal bones found in Stratum IIA all belong to species found in Holocene deciduous forests (Guilday and Parmalee 1982), not the boreal spruce/pine forest with patches of tundra that prevailed in this region just after the glacial maximum, when the ice sheet lay 80 km to the north (Mead 1980); 2) there is some doubt whether the dated material from IIA was human-created charcoal; samples may have been contaminated by microscopic coal fragments (Tankersley and Munson 1992), by soluble organics in groundwater (Haynes 1980, 1991a), or by non-cultural charcoal churned up by rodents or by Archaic human pit-diggers from the lowest layers of the shelter, where naturally created charcoal lenses yielded dates in excess of 21,000 BP (Kelly 1987); 3) there are no Clovis or early Early Archaic components with diagnostic artifacts, and the ^{14}C dates jump abruptly from 11,300 in middle IIA to 9115 ± 115 BP (SI-2061) in the upper third of the stratum—a hiatus of some 3000 calendar years; and 4) the Miller point type, as reconstructed from the Meadowcroft specimen and others collected at the nearby, undated Krajacic site, looks like an Agate Basin variant (Boldurian 1985; Adovasio 1993:212). This suggests an age of about 10,000 BP, not 12,800–11,300 BP as indicated by ^{14}C assays.

At Cactus Hill in southeastern Virginia, Archaic assemblages occur in expected stratigraphic order within a ridge of stabilized wind-blown sand. Below them lies a Clovis horizon, with a date of 10,920 ± 250 BP. Lying 3–6 inches below the Clovis level is a small assemblage of quartzite blades and bladelets, and three pentagonal, unfluted points made of a metavolcanic stone (McAvoy and McAvoy 1997; McAvoy et al. n.d.; Johnson 1997). Dates of 15,070 ± 70 (Beta-81590), 16,670 ± 730 (Beta-97708), and 16,940 ± 50 (Beta-128330/A) (but also an anomalously late date of 9250 ± 60 BP [Beta-93899]) have been obtained on charcoal particles from this level. The problematic issues at this site are: 1) If the ~15,000 BP (ca. 17,800 cal BP) date is correct, some 5000 years intervened between the pre-Clovis and Clovis occupations, while only 3 inches of sand accumulated; 2) downward drifting of cultural material and animal burrowing are acknowledged problems at the site, and these processes are blamed for the 9250 BP date and several others that seem too recent. The possibility that the dated charcoal represents pre-human, naturally produced material, e.g. from forest fires, cannot yet be excluded.

Monte Verde, in the lake district of southern Chile, was dramatically promoted from troublesome enigma to putative "paradigm-buster" in 1997 when a small archaeological delegation certified the validity of pre-Clovis evidence there (Meltzer et al. 1997). The small assemblage of indisputable artifacts includes a carefully pressure-flaked, narrow lanceolate point, two similar midsection fragments, a slate rod produced by grinding, and a quartzite biface. If their discovery had not been reported, it is doubtful whether the mélange of organic debris at Monte Verde would have won acceptance as a human habitation site (Fiedel 1999b). Yet, none of the several incompatible site maps in the massive final report (Dillehay 1989, 1997) indicates the find-spots of these artifacts. Three stone scrapers, still mounted in wooden hafts with bitumen, also have been mentioned in various preliminary publications, but only one is briefly described and depicted, and none are mapped, in the final report (Dillehay 1997). Apart from the few well-made, curated lithics, hundreds of supposed tools are merely unmodified but ostensibly utilized broken or rounded river cobbles. Recognizable debitage from lithic flaking—a practically universal marker of Stone Age human encampments—seems, inexplicably, to be absent.

Aside from the lithics, the ostensible evidence of a human presence at Monte Verde consists of a diverse aggregate of organic materials preserved beneath an anoxic peat layer. Dillehay discerned, in a jumble of logs and branches, the quadrilateral foundations of 12 connected rectangular rooms. Tiny fragments of mastodon skin may be remnants of the hut's roof. A separated ovoid "structure" of compacted sand and gravel, about 1 m in diameter, Dillehay has interpreted variously as a shaman's residence or a mastodon-butchering station. The preserved plant assemblage is dominated by club moss (*Lycopodium*) spores, totora reed (*Scirpus*) and bulrushes (*Carex*), but also includes a few pieces of wild potato skin, various plants that are used medicinally today, and seaweed derived from the Pacific coast, some 30 km to the west. Some 400 bones, exhibiting minimal modification, represent remains of six mastodon-like proboscideans (gomphotheres). A scapula from an extinct species of guanaco was also found.

These remains on the north bank of Chinchihuapi Creek, known as Monte Verde (MV) II, have been dated to around 12,570 BP, on the basis of associated ^{14}C dates on wood, bone, and ivory "artifact" samples that range from around 11,700 to 12,800 BP (ca. 13,400–15,300 cal BP). The overlying peat that sealed and preserved the organic remains immediately after abandonment of the settlement (Dillehay 1989:236; Tuross and Dillehay 1995) dates between 10,300 and 12,000 BP, with four dates in the 11,600–11,800 BP range (Dillehay 1997:43). The most likely age of the supposed human occupation thus appears to be only slightly earlier than the peat, or about 11,800–12,000 BP (ca. 14,000–13,500 cal BP).

Dillehay has reported possible evidence of a much earlier human presence at Monte Verde. On the south side of the creek, in a deeper (by 80 cm) and older layer, two dozen cracked pebbles of basalt and andesite were found near two ostensible hearths. Carbonized wood from these features dates to about 33,000 BP (possibly ca. 38,000–40,000 cal BP; see Beck et al. 2001). Judging from published illustrations (Collins in Dillehay 1997:462–3), at least one of the stones reportedly found at this MV-I locus was certainly chipped by humans. This tool yielded protein residue that may be derived from a mastodon (Tuross and Dillehay 1995) (although no bone or skin was preserved in this locus). If its original position has been accurately reported and post-depositional disturbance can be ruled out, this artifact would offer strong support to an inference of human occupation of MV-I at 33,000 BP. However, Dillehay (1997:774–5) has hesitated to affirm the cultural status and ostensible antiquity of the MV-I material.

Even setting aside the ambiguous MV-I component, if MV-II is a human encampment, its expedient lithic assemblage (so amorphous that it cannot be termed accurately either a "pebble tool" or "unifacial" industry) is unique, as is its early date. The problems with samples, contexts, and associations, that preclude acceptance of pre-11,500 BP ^{14}C dates from other South American sites (e.g. El Abra, Quirihuac, Muaco, Taima Taima) have been amply discussed by Lynch (1990) (see also Waters 1985).

A REVISED, PRECISE CHRONOLOGY FOR CLOVIS: WHEN, EXACTLY, DID THEY ARRIVE?

Based on initial ^{14}C results and Pleistocene stratigraphic research, Clovis was usually ascribed an age of around 12,000–11,000 BP. In the early 1980s, averaging of replicate ^{14}C dates on charcoal samples from Paleoindian sites such as Lehner and Murray Springs, resulted in a tighter estimate for the florescence of Clovis culture: 11,200–10,900 BP (Haynes et al. 1984; Haynes 1992). Dates for Folsom sites sometimes overlapped with Clovis dates, in the range of 10,600–11,000 BP; but since the Clovis mammoth kills were stratified below Folsom material at Blackwater Draw, it seemed certain that these cultures were successive, not contemporaneous.

Since the 1970s, archaeologists had realized that fluctuating ratios of ^{14}C and ^{12}C in the past had affected ^{14}C dates significantly, so that ^{14}C ages were about 1000 years too young around 8000 BP. Preliminary indications suggested that this difference narrowed in the early Holocene, so Paleoindian specialists were not too concerned about the possible effects of calibration on their chronology. However, recent research has shown that late Pleistocene ^{14}C dates are about 2000 years younger than calendrical ages (for a detailed discussion, see Fiedel 1999a). Clovis-associated dates ranging from 11,300 to 10,700 BP correspond to a short period from about 13,200 to 12,800 cal BP (Taylor et al. 1996) (so it turns out that Antevs's [1953] estimate was correct, after all). The earliest credible Clovis dates of around 11,550–11,600 BP, obtained from the Aubrey site in northern Texas (Ferring 1995, 2001) and the Anzick burial in Montana (Sellars 1999), probably correspond to around 13,400 cal BP (or possibly as early as ca. 13,650 [Friedrich et al. 2001:Figure 7]). However, these few early dates may be misleading outliers. Tom Stafford (personal communication 2002), who ran the Anzick dates, now regards the 11,550 ± 60 BP date as erratic, and prefers a date of around 10,700 BP.

For the moment, the limit of precise calibration based on German tree rings (ca. 11,900 cal BP) (Friedrich et al. 1999) falls just short of the era of Paleoindian migrations. Older, "floating" tree-ring sequences of Bølling-Allerød age from Switzerland and Germany may soon be tied securely to the later continuous sequence (Friedrich et al. 2001). Until then, there are several ways to translate ^{14}C dates of 12,000–10,000 BP into "real" calendrical or sidereal years (Table 1). Paired high-precision TIMS U-Th and AMS ^{14}C dates on corals (e.g. Burr et al. 1998) have some utility, but uncertainty about late glacial fluctuations of localized marine reservoir effects limits their reliability. ^{14}C dating of terrestrial macrofossils (e.g. twigs) incorporated within varved lakebed deposits avoids this problem, but uncertainties in this method arise from the possibilities of missing or duplicated varves, vertical displacement of dated samples, and also the evidently peculiar carbon contents of some plant materials (Turney et al. 2000). Furthermore, the varve sequences need to be anchored to some fixed event(s). The ^{14}C-dated varves from Lake Suigetsu in Japan (Kitigawa and van der Plicht 1998, 2000) and the varved marine sediments in the Cariaco Basin off Venezuela (Hughen et al. 1998, 2000) both overlap the German dendrochronological record at the recent end, and can be tied to the latter by wiggle-matching the ^{14}C dates. There is, nevertheless, an approximately 100-calendar-year offset between Cariaco and Suigetsu dates. The Cariaco ^{14}C dates are derived from marine foraminifera embedded in the sediments, and therefore a correction for reservoir effect must be applied. Although the assumption of an invariant local reservoir effect of 420 years throughout the late-glacial is defensible (Hughen et al. 1998, 2000), the possibility of intermittent spikes cannot be precluded.

Table 1 Comparison of radiocarbon and calendar year dates for deglacial events

Climate event	GRIP	GISP2	Cariaco (varves)	Cariaco (^{14}C)	Central Europe varves	Central Europe dendro-
YD end	11,550	11,645	11,565	10,050	11,535	11,570
GS-1						
YD onset	12,700	12,940	12,950	11,100	12,693–12,538	
GI-1a warming	12,800–12,700	13,100–12,940	13,100–12,950	11,250–11,100		
[LST eruption]	—	—	[=13,130]	[=11,300]	12,836 or 12,880	13,130 (=11,070 ^{14}C)
IACP or GI-1b	13,150–12,850	13,250–13,100	13,300–13,100	11,500–11,250	13,214–12,801	
GI-1c						
OD or GI-1d	14,050–13,900	14,100–14,000	14,100–14,000	12,300–12,100		
GI-1e						
Bølling onset	14,700	14,700	14,700	12,550		

Temporal variations in thickness of the Cariaco varves (the "grey scale") allow correlation with the apparently synchronous fluctuations of oxygen isotope ratios in Greenland ice sheet cores. The rapid onset (cooling) and termination (warming) of the Younger Dryas (YD) climatic episode are crucial marker events for correlation of these records. Both events are clearly recorded as dramatic changes in snow accumulation, temperature, chemical composition, and dust content, in both the GRIP and GISP2 cores from the Greenland ice sheet. Based on counts of annual accumulation layers, the dates for YD termination (the start of the Holocene) are ~11,550 ± 90 cal BP (GRIP) and 11,645 ± 200 (GISP2). Unfortunately, there is an unresolved 200-year discrepancy, centered on the 12,500–12,800 cal BP span at the start of the Younger Dryas, between the two cores (Southon 2002). The GISP2 date for YD onset is 12,940 ± 260 cal BP but the GRIP date is ~12,700 ± 100 cal BP. The Cariaco date of around 12,950 cal BP supports the GISP2 date.

Lakebed cores in northern Europe and northeastern North America also can be synchronized with the ice core climate records by wiggle-matching fluctuations in oxygen isotope ratios (Schwander et al. 2000; Yu and Eicher n.d.). These lakebed records show that both vegetation (as manifest in the pollen record) and insects responded very rapidly to the Younger Dryas climate changes. In varved lakebed sediments, once the marker of YD onset is recognized, decadal or annual chronological resolution of pollen sequences can be achieved, which renders less precise carbon dating superfluous. It is important to realize, however, that almost all European analysts use the GRIP date of around 12,700 cal BP for YD onset. This can cause problems when lakebed data are combined with INTCAL98 dates, which are based mainly upon the Cariaco varves (Stuiver et al. 1998).

The Lake Suigetsu record, and dated cores from several European lakes, indicate a date reversal or short plateau about 150–200 years before the onset of the Younger Dryas (Goslar et al. 1999:33; Andresen et al. 2000). This event is probably causally related to the brief (ca. 200-year) cold snap within the Allerød called the Gerzensee oscillation or Intra-Allerød Cold Period (IACP). The initial Cariaco Basin report (Hughen et al. 1998) seemed to show the same ^{14}C event at 13,150 cal BP, but the latest decadal sequence reveals no significant break in the ^{14}C dates of around 11,300 BP for this time (Hughen et al. 2000). Nevertheless, the date reversal at ~13,200 cal BP (GISP2) also appears in ^{14}C dates from preserved tree stumps of the Bølling-Allerød period at Dättnau, Switzerland. K F Kaiser (1989) has constructed a floating tree-ring chronology for these stumps. Kaiser suggests that an 8-year period of thin rings represents the trees' stunted growth in response to the eruption of the Laacher See volcano in Germany. Tephra from this eruption (LST) serves as a stratigraphic marker (carbon-dated to 11,230 ± 40 BP [Hajdas et al. 1995]) within varved lake bed sediments in Central Europe. The thin rings at Dättnau provide a later date for the LST of 11,070 ± 60 BP, and German poplars buried by the tephra have been dated to 10,986 ± 46 (Baales and Street 1996) and 11,063 ± 12 BP (Friedrich et al. 1999). ^{14}C dates on Dättnau tree-rings from about 50 years before the LST are in the range of 10,750–10,950 BP (Kaiser n.d.). Varve counts, as well as the Dättnau tree-rings, show that the LST dates from roughly 190 years before the YD onset (i.e. 13,130 cal BP, using the GISP2 date for YD of 12,940; or 12,836 cal BP [Schwander et al. 2000, using a GRIP and varve-based date of 12,693 for YD onset]). For the moment, we are faced with an unexplained discrepancy of about 250 ^{14}C years between the Cariaco varves (where 13,130 cal BP=~11,280 to 11,300 ± 50 BP) and the German trees. One possibility is that the oceanic reservoir effect in the Cariaco basin changed significantly between 12,000 and 11,000 BP, so that the standard 420-year correction is not applicable. For comparison, reservoir age in Pacific waters off the coast of British Columbia increased by more than 50% (from 800 to 1250 years) during the same period (Kovanen and Easterbrook 2002).

How does all this affect Clovis chronology? The most precisely dated Clovis sites are Lehner and Murray Springs, both in Arizona. The ^{14}C date for Lehner, averaged from 12 charcoal assays, is 10,930 ± 40 BP. The date for Murray Springs, averaged from eight assays, is 10,900 ± 50 BP (Haynes 1993:221). The most precise of the Lehner dates are 10,950 ± 90 (SMU-290), 10,940 ± 100 (A-378), 10,950 ± 110 (SMU-194), and 10,710 ± 90 BP (SMU-340). The most precise date from Murray Springs is 10,840 ± 70 BP (SMU-41). Based on the latest Cariaco data (Hughen et al. 2000), both sites would fit within a tight calibrated interval ~12,900–12,850 cal BP. This would put them about 100 years after the Younger Dryas onset. However, the most precise Folsom-associated date is 10,665 ± 85 BP (SI-3732) from Agate Basin, and the average of six charcoal-derived dates from the Folsom type-site is 10,890 ± 50 BP. The former date calibrates to about 12,820–12,650 cal BP, while the latter is indistinguishable from the Murray Springs date. Thus, if the latest Cariaco calibration (Hughen et al. 2000) is correct for this period, western Clovis would be contemporaneous with Folsom. This conclusion seems dubious on stylistic and stratigraphic grounds, so, pending further elucidation of this interval, I prefer a pre-LST age for Clovis, ~13,200 cal BP.

The cause of the Younger Dryas stadial remains to be determined. A popular theory attributes the sudden temperature decline to a breakdown of the ocean's thermohaline circulation system, perhaps caused by Laurentian ice sheet meltwater pouring into the North Atlantic (Broecker et al. 1988). If the ocean surface suddenly became colder, thus absorbing less atmospheric carbon, the same process might account for the peculiar ^{14}C increase that accompanies the YD onset. This increase of ca. 70 per mil is manifest as a jump in dates from about 11,100 to 10,700 BP in a century or less around 12,900 cal BP. After this steep decline, ^{14}C dates within the Younger Dryas form a long plateau with several descending steps: samples dating from ~12,750–12,650 cal BP yield dates of ~10,600 BP; samples dating between ~12,650 and 12,150 cal BP produce ^{14}C dates of ~10,400–10,500 BP; and ^{14}C dates from the 12,150–11,800 cal BP span are ~10,200–10,300 BP. The last section of the plateau extends beyond the YD termination (ca. 11,550 cal BP); ^{14}C dates for samples in the interval from 11,800 to 11,250 cal BP are ~10,150–10,000 BP (Hughen et al. 2000).

The climatic effects of the Younger Dryas are most evident along the rim of the North Atlantic. As one moves away from this area, the effects become more subtle and may be obscured by lack of resolution and dating problems in pollen cores (Yu 2000; Yu and Wright 2001). It is also likely that regional effects may have been out of phase because of changes in air circulation patterns. The black mats recognized by Haynes (1991b etc.) in the Southwest and southern Plains probably mark the onset of the regional equivalent of the YD (Fiedel 1999a). However, we cannot be sure that they are exactly synchronous with YD onset in the North Atlantic; calibration using the new Cariaco data (Hughen et al. 2000) would imply that the black mats date to about 100–200 years after the isotope signature of YD onset in the Greenland ice cores. Clovis artifacts and mammoth skeletons occur just beneath the black mats, but never above them; Folsom points are always within or above the mats. As these features are attributable to increased spring discharge (Quade et al. 2000), they imply a higher water table, increased precipitation, and reduced evaporation, i.e., relatively wet and cold conditions. Globally, however, the YD is characterized as a generally dry period.

Only in the Northeast is there the potential to establish an unambiguous stratigraphic correlation of the YD, *sensu strictu* as a North Atlantic rim phenomenon, and Paleoindian occupation. The ^{14}C dates of ~10,600 BP (~12,750 cal BP) from the Debert site (MacDonald 1968) suggest that it was occupied just after the YD onset. Recognition of permafrost effects at the site supports this interpretation. However, Bonnichsen and Will (1999) have raised doubts about dates from Debert and other Paleoindian sites in the Northeast, suggesting that presumed cultural features may actually be tree-burns that are unrelated to human activities. They contend that the climatic stress and regional aridity of the YD may have rendered trees more susceptible to fire. This argument seems dubious in the case of Debert, where the clustering of artifacts and charcoal features in "hot spots" (MacDonald 1968) is not easily explained away as fortuitous.

A spectacular cache of giant Clovis points at the East Wenatchee site in Washington State lay directly upon sediments that contained particles of Glacier Peak tephra (Mehringer and Foit 1990). Haynes (no date) fancifully speculates that the cache might have been a ritual offering to appease the spirits responsible for the eruption that the Paleoindians had just witnessed. This tephra is widespread in the Northwest and northern Plains. In several lake beds, dates for Glacier Peak tephra layers (actually representing three sequential eruptions—G, M, and B—that are chemically indistinguishable) cluster around 11,200 BP (Mehringer et al. 1984; Foit et al. 1993). At Indian Creek, Montana, the tephra date is reported as 11,125 ± 130 BP, and a Clovis occupation stratified above it was dated to 10,980 ± 150 BP (Davis 2001). It is possible that minute particles of volcanic glass from the Glacier Peak eruptions were aerially transported to Greenland and deposited in the ice. Particles traceable to the eruption of Mount Mazama, another volcano in the Cascade Range, have recently been detected in the annually layered GISP2 core, and allowed precise dating of that event (7627 ± 150 cal BP) (Zdanowicz et al. 1999). Diagnostic particles from the Laacher See volcano, virtually contemporaneous with Glacier Peak, might also be identified. Barring that, chemical signatures of these events (sulfate peaks) may be identifiable in the ice. Curiously, so far there are no reported signatures of eruptions in the GISP2 core dating between 13,553 and 13,084 cal BP (Zielinski et al. 1996). Finding ice core records of the Laacher See and Glacier Peak eruptions within this interval would accomplish a neat correlation of Old World and New World chronologies.

CLOVIS ORIGINS: ASIA, BUT WHERE EXACTLY?

Wide (probably premature) acceptance of Monte Verde as a valid pre-Clovis site has thrown Paleoindian studies into disarray, with many calling for new models and even a new "paradigm" in the wake of the perceived collapse of the Clovis-first scenario. If Monte Verde was occupied by hunter-foragers before 12,000 BP (ca. 14,100 to 13,500 cal BP), ancestors of this population previously must have traversed either the coast or interior of North America (perhaps decades, perhaps millennia earlier) (Meltzer 1997). However, no proven sites of comparable or greater antiquity have been found in North America, and no similar lithic industry has been identified in any potential Asian ancestral region. Apart from the well-made bifaces, the extreme simplicity of the Monte Verde "tools" is only vaguely reminiscent of the simple flake and core industries of Southeast Asia and Australia. In view of the dissimilarity of Monte Verde and Clovis points, and the absence from the

MV-II assemblage of formal endscrapers, sidescrapers, gravers, or blades, it is difficult to envision a common ancestral tradition that might have spawned such profoundly different cultures.

For now, I will leave Monte Verde hanging in limbo, due to its unacknowledged or unresolved problems of documentation (the most serious of which still have not been addressed in the new volume of errata [Dillehay 2002]). Nevertheless, if one were to take the ^{14}C dates from Cactus Hill and Meadowcroft at face value, they would indicate that a population with Upper Paleolithic-style biface and blade technology, but lacking fluted points, was present in eastern North America around 15,000 BP (ca. 18,000 cal BP). Such an industry could be termed "proto-Clovis," on the assumption that, with the addition of fluting and a few other distinctive stylistic elements, Clovis could have developed from it (Carlson 1991; Haynes 1987, Fiedel 1999a, 2000). Even if those early dates are rejected as aberrant and implausible, the stratigraphy at Cactus Hill suggests that an assemblage of proto-Clovis aspect may have preceded Clovis by at least a few hundred years. Again, taking dates and association at face value, the artifacts associated with the Wisconsin mammoths imply a human presence around 12,400 BP.

If all of these cases are set aside as ambiguous and still unproven, the logical problem remains of deriving Clovis from some earlier culture. The hypothetical ancestral culture(s?) must be sought in Northeast Asia, Alaska (i.e. eastern Beringia), or somewhere in North America, south of the former glacial front (but, as an American proto-Clovis culture could hardly be autochthonous, one would still be compelled to seek its precursor in the Old World). Recently, Stanford (1998) and Bradley have revived the old idea (e.g. Greenman 1963) that Clovis was derived from the Solutrean culture of Iberia. Apart from other implausible aspects of this theory, temporal discontinuity alone precludes a direct Solutrean-Clovis connection. In western Europe, the Solutrean complex is succeeded by the Magdalenian ~16,500 BP (19,000 cal BP), some 6000 years before Clovis appears in North America. The stylistic similarities (e.g. outre-passé flaking) between Paleoindian points and Solutrean bifaces are more credibly attributed to convergence (Straus 2000).

Recent genetic analyses (e.g. Underhill et al. 2000; Ingman et al. 2000) indicate that ancestors of anatomically modern Eurasian *Homo sapiens* emigrated from Africa about 55,000 years ago and replaced archaic *Homo* populations. The appearance of Upper Paleolithic toolkits, dominated by blades, generally (but not always) marks the arrival of *Homo sapiens*. Such blade-dominated assemblages, along with bone tools and ornaments, abruptly replace Levallois-Mousterian industries in southwestern Siberia about 43,000–35,000 BP (Goebel 1993; Goebel and Aksenov 1995), although the Mousterian may have persisted in the Altai mountains to as late as 29,000 BP (Kuzmin and Orlova 1998). If 43,000 BP (ca. 46,000 cal BP?) is the date of entry of *Homo sapiens* into Northeast Asia, it represents the earliest possible baseline for Paleoindian ancestry.

Both mtDNA and Y-chromosome haplotype distributions in extant human populations point to the region surrounding Lake Baikal as the ancestral homeland of Native Americans (or at least, the last surviving pocket of a once more widespread ancestral Northeast Asian population, subsequently displaced elsewhere in the region). A minor genetic input from the Lower Amur region can also be traced (Karafet et al. 1999; Lell et al. 2002). Almost all Native Americans belong to one of four mtDNA haplogroups (A, B, C, and D), each representing a female descent lineage. A small percentage of Native North Americans belong to a fifth haplogroup, X, which is also present in European and Near Eastern populations and has recently been found in southern Siberian natives (Brown et al. 1998; Derenko et al. 2001). The ubiquitous occurrence of the five haplogroups is probably the result of a single migration by a group initially containing all these Asian-derived haplotypes (Merriwether et al. 1994; Kolman et al. 1996; Malhi et al. 2002). Although the four major Amerind haplogroups are widespread in East Asia, only in south-central Siberia (Tuva) and Mongolia do they co-occur and characterize a large percentage of the present population (Derenko et al. 2000; Schurr 2000). Several recent analyses of Y-chromosome structure (Underhill et al. 1996; Bianchi et al. 1997, 1998; Santos et al. 1999) have indicated that all the male descent lineages in the Americas similarly converge toward a single ancestral population. Southern/central Siberia seems to be the area where two ancestral gene pools overlap: one that encompasses the female lineages of America, northern China and Mongolia, and the other, a male lineage that is ultimately related to the ancestors of modern Europeans, and not to East Asian Mongoloids. Perhaps, Paleoindian ancestors emerged as the product of genetic and cultural exchanges around Lake Baikal between proto-Mongoloid natives (mainly females?) and proto-Caucasoids (mainly males?) who carried the Russian Upper Paleolithic complex into the region along with Y haplotype 10 or M45 (Semino et al. 2000) and mtDNA haplotype X.

The ongoing controversy over the racial identity and final disposition of "Kennewick Man," a skeleton from Washington dated to 7900 BP (8900 cal BP) (Chatters 2000), has revived interest in the small number of North and South American skeletons that date from the early Holocene. Some physical anthropologists, abetted by a credulous press (e.g. Rensberger 1997), have indulged in speculation about the supposed relationships of Kennewick Man to Polynesians, and of "Luzia," a ca. 10,500 BP Brazilian, to Australians, Melanesians, or Africans (Neves et al. 1998). In fact, despite all the pre-Clovis hysteria, not much is new. Paleoindians as well as Archaic Indians tended to have longer and more rugged heads than their descendants (Steele and Powell 1992, 1994), a poorly explained tendency that is also well-known in Old World populations (Howells 1967:283). Amerind skulls sometimes display superficial resemblances to other human populations, apart from the classic or specialized Mongoloids of eastern Asia (Howells 1967:296,307). The skeletal record of the latter population is actually very sparse. The earliest known modern *sapiens* specimens in northern China are still the three individuals from Zhoukoudian. They are probably not much older than 10,000 BP, yet they do not display the typical features of modern Mongoloid peoples (Cunningham and Wescott 2002).

> They are an odd group. The male skull strongly suggests the Upper Paleolithic men of Europe. One of the women looks faintly Negroid ('Melanesian' Dr. Weidenreich called her). The other woman looks Eskimo-like…. Now it is characteristic of Indian populations, with their nondescript cranial form, to give such pale imitations of other racial types…. Actually, this apparently strange assortment in the Upper Cave really looks like a group of American Indians (Howells 1967:307).

It is only around 7000 BP that Chinese Neolithic skeletons appear indisputably Mongoloid (Brown, in press 1999; Kamminga and Wright 1988). Since the ancestors of Paleoindians undoubtedly had left Asia prior to 11,000 BP (13,000 cal BP), we should not expect the earliest people in the Americas to closely resemble the more recent North Asian Mongoloids (Lahr 1995). Like the group responsible for the Zhoukoudian burials, the founding Paleoindian band must already have contained a fair amount of both genetic and phenotypic diversity. Geographic and genetic isolation of far-ranging groups after several generations may have accentuated their pre-existing differences, resulting in the eight distinctive North American cranial types that were recognized by Neumann (1952). Isolation and drift after the rapid expansion, at 13,000 cal BP, of speakers of a presumed ancestral Amerind language (Greenberg 1987; but see Goddard and Campbell 1994) also could have produced the 7 distinct macrophyla that linguists recognize in North America: Uto-Aztecan, Hokan, Penutian, Macro-Siouan, Algonquian, Na-Dene (Athapaskan), and Eskimo-Aleut.

The available genetic data compel us to seek archaeological traces of Paleoindian ancestors in the Trans-Baikal region. Reliable early dates from Upper Paleolithic sites near Lake Baikal and the upper Lena River suggest initial occupation around 37,000 BP, and there are numerous dates of

~23,000–26,000 BP (Kuzmin and Orlova 1998; Kuzmin and Tankersley 1996). The site of Mal'ta, best known for its carved ivory figures of swans and of humans in parka-like clothing, has yielded dates of ~20,000 BP on bone samples. About 900 km to the east, in the Aldan River area of Yakutia, Ust Mil 2 and Ikhine 2 may have been occupied as early as 30,000–35,000 BP, but this dating is suspect (Yi and Clark 1985). A more secure date for initial settlement of this region may be the 18,300 ± 180 date on wood from Verkhne-Troitskaya; after this isolated date, the next good dates are 15,200 ± 300, on charcoal from Avdeikha, and 14,000 ± 100, also on charcoal, from Dyuktai Cave, level 7b. Goebel (1998) suggests that at the glacial maximum, around 18,000 BP (22,000 cal BP), Siberia became so cold that it was virtually uninhabitable, and former residents retreated southward.

Just east of the Aldan sites, the Verkhoyansk Mountains seem to mark an ecological boundary (Hoffecker et al. 1993), which apparently was not breached by western Siberian people until the sudden global warming at 12,500 BP (14,700 cal BP). Only two sites tentatively dated to about 13,000–11,000 BP are known from this far northeastern section of Siberia (or western Beringia): Berelekh (Mochanov and Fedoseeva 1996a) and Bolshoi Elgakhchan (Kiryak 1996).

The early Siberian Upper Paleolithic toolkits were dominated by macroblades, but it appears that, perhaps as early as 24,000 BP (Kuzmin and Orlova 1998) and certainly by ~18,000 BP (Goebel et al. 1991, 2000), microblade-dominated assemblages of the Dyuktai culture (Mochanov and Fedoseeva 1996b) were prevalent all over Northeast Asia. Dyuktai assemblages also typically include well-made bifaces. The latter are credible prototypes for Paleoindian bifaces, although the Asian points were not fluted. A crudely, probably accidentally fluted point has recently been reported from the site of Uptar in Siberia, but it is a unique specimen in a context that may not be much older than 8300 BP (King and Slobodin 1996). Another striking difference between Dyuktai and Paleoindian assemblages is the absence from the latter of microblades and the small boat- or wedge-shaped cores from which they were struck. Most archaeologists view this distinction as so significant that it would appear to preclude Dyuktai as a candidate for Paleoindian ancestry.

In contrast, the Dyuktai roots of the Paleoarctic tradition or Denali complex of Alaska (eastern Beringia) are universally acknowledged. Paleoarctic lithic assemblages contain the same kinds of microblades and cores as Dyuktai. F H West (1981, 1996) has been the foremost proponent of the view that the Paleoarctic tradition gave rise to Clovis (see also Carlson 1991 and Morlan 1991). He is compelled to admit that the complete abandonment of microblade technology by Clovis is a problem, but suggests that a sort of cultural mutation must have occurred, perhaps during the passage through the ice-free corridor.

Critics of West's model have objected that the Paleoarctic tradition is too late to be ancestral to Clovis, because it dates after 10,700 BP in Alaska (Hoffecker et al. 1993:51). They identify the slightly earlier Nenana complex of central Alaska as a more credible Paleoindian ancestor because 1) it seems to be marginally earlier than Clovis, and 2) it contains various tools on blades and flakes, not microblades. However, there is still the small problem of fluted points. Nenana assemblages do include small triangular and teardrop-shaped (Chindadn) points, but these are a far cry from classic Clovis fluted points. It is even possible that Nenana is only a contemporaneous functional variant of Denali, and not a separate culture at all. This possibility is raised by recently reported dates of ~11,680 BP for a Nenana-like component with microblades at Swan Point in the Tanana Valley (Holmes 1998). Elsewhere, however, stratigraphic and chronological separation of Nenana assemblages, lacking microblades, from later Denali assemblages is clear. At Dry Creek, for example, a Nenana assemblage (dated 11,120 ± 85 BP) is stratified below a Denali component (10,690 ± 250 BP) (Goebel et al. 1991). The earliest occupation level at Broken Mammoth, about 15 km west of

Swan Point, dates to around 11,770 BP (Holmes 1996), and there are two dates of around 11,600 BP from the Mead site, about 1 km north of Broken Mammoth (Hamilton and Goebel 1999). These ^{14}C dates, associated with rather meager and typologically indeterminate lithic assemblages, push the initial colonization of central Alaska back to around 13,400–13,800 cal BP. Another early Alaskan culture is represented by unfluted, Agate Basin-like points at the Mesa site. Most dates from this site are around 10,000 BP, but one hearth (perhaps a remnant of an earlier Paleoarctic occupation) produced dates of 11,660 ± 80 and 11,190 ± 70 BP on a single split charcoal sample (Kunz and Reanier 1994).

In sharp contrast to Clovis, there is no evidence of mammoth-hunting at any of the early Alaskan sites. Mammoth ivory artifacts are present, both at Broken Mammoth and Swan Point, but in each case, ^{14}C dates have shown the ivory to be centuries earlier than the other material at the site. The inhabitants seem to have been scavenging the tusks of long-dead mammoths as raw material for tools. They were actually hunting elk, bison, sheep, and smaller game, particularly waterfowl, which account for about 40% of the meat (Yesner 1998a). If mammoths actually had vanished from eastern Beringia before Nenana people arrived (but see Lea 1996), it is reasonable to suppose that the invention of the Clovis point and its related delivery system (bone foreshafts, etc.) resulted from their initial encounter with living mammoths, south of the ice sheets (Pearson 1997).

If we reject the proposition that Clovis mutated, perhaps by a cultural founder effect, from the Dyuktai-Paleoarctic microblade tradition, can Clovis be credibly derived from some other ancestral lithic tradition in Asia? Several authors have looked westward to the Russian Upper Paleolithic. Sites of the Streletskayan complex, dated around 35,000–24,000 BP (Bradley et al. 1995), contain bifacially thinned triangular points and retouched blades that resemble both Nenana and Clovis tools (Haynes 1982; Pearson 1997; Bradley 1997). However, these sites, north of the Black Sea, are thousands of kilometers west of Beringia, and some 14,000 or more years earlier than Clovis. The Mal'ta-Afontova sites of the Lake Baikal and Yenisei regions are eastern outliers of this Russian Upper Paleolithic tradition; at Mal'ta, it may have lasted beyond 15,000 BP. The Ust'-Kova site in the northern Angara region of central Siberia, dated to 23,920 ± 310 BP, contains a blade-dominated industry, with bifaces, that has been compared to Nenana assemblages (Goebel et al. 1991) and also to Clovis (Tankersley et al. 1996).

In view of the oft-remarked similarities of the Zhoukoudian Upper Cave skulls to Amerinds, perhaps we should not exclude northern China from consideration as the Paleoindian homeland. Recent research there has shown that assemblages containing mainly macroblades and leaf-shaped bifaces, along with some microblades, were present at 12,700 BP, but that the microlithic element became predominant after 11,600 BP (Elston et al. 1997). Upper Paleolithic emigrants moving north from China (perhaps spurred by competition from the people who made microliths and the earliest ceramics, dated around 13,000 BP in the Amur basin [Kuzmin and Orlova 2000]) might have traveled northeast through the Amur River Basin in the Russian Far East and along the western side of the Sea of Okhotsk before arriving in Kamchatka (this route was the one favored by Chard 1960).

Some Upper Paleolithic assemblages from the Russian Far East (e.g. Ustinovka 1, ca. 16,000–10,000 BP [Vasilievsky 1996]) are vaguely similar to Paleoindian toolkits. However, microblades seem to have become part of the regional lithic tradition as early as 24,000–20,000 BP (Derevianko 1989).

The enigmatic Ushki Lake sites of central Kamchatka may have some bearing on this migration scenario. Layer 7, the lowest occupation level at Ushki I, contained stemmed bifacial points, one leaf-shaped point, burins, end and side scrapers, and stone beads. Notably absent are microblades and wedge-shaped cores, which occur in the overlying Layer 6 (Dikov 1996; Dikov and Titov 1984). Dates of 14,300–13,600 BP (ca. 17,000–16,000 cal BP) were obtained for Layer 7, as well as an anomalous date of 9750 BP (Hoffecker et al. 1993). Layer 6, only some 30 cm above Layer 7, has produced dates of 10,860 to 10,360 BP (12,900–12,000 cal BP). The ostensibly lengthy hiatus between occupations has raised some doubt about the accuracy of the Layer 7 dates. Indeed, new dates put Layer 7 at ~11,300 BP (Goebel et al. 2002). Although the Ushki assemblage does not look much like Clovis, at least it seems to show that non-microlithic cultures were present in Northeast Asia at the time of Clovis ancestors' emigration.

Based on the meager extant data from Northeast Asia and Beringia, three different origins can be hypothesized for Clovis: 1) Clovis developed around 13,400 cal BP (11,600 BP) from Nenana (Goebel et al. 1991; Yesner 1998b), which in turn had developed from some as yet-unidentified, Ushki-like macroblade tradition of eastern Beringia; 2) Clovis arose by dramatic transformation of an offshoot of the Dyuktai/Paleoarctic tradition, with sudden loss of microblade technology (West 1996); and 3) Earliest Clovis was a distinct culture of northern Alaska, ultimately derived from a Siberian or northern Chinese macroblade/biface tradition, and while perhaps distantly related to both Nenana and Paleoarctic cultures, did not develop from either. Under hypotheses 1) and 2), the differentiation of Clovis from the ancestral cultures would most likely have occurred after emigration southward from Beringia, either during the trek through the ice-free corridor or somewhere in North America, south of the ice sheets. This scenario has the obvious corollary that pre-Clovis or proto-Clovis microblade or Nenana-like assemblages will be found in North America—something like Cactus Hill, perhaps. Under the third hypothesis, earliest Clovis sites would be found in Alaska, and Clovis would appear full-blown, without local antecedents, south of the glaciers.

Unfortunately, the small fluted points found in northern Alaska, on the surface or in shallow mixed contexts, cannot be dated (Clark and Clark 1983; Reanier 1995; Hamilton and Goebel 1999). They are usually considered to represent a northward reflux of relatively late (ca. 10,500 BP?) Paleoindians from the northern Plains (Clark 1991; Dixon 1999:181–9). However, the multiple fluting and inverted-v-shaped basal concavities that characterize the Alaskan points are diagnostic of neither the Folsom nor Goshen point-making traditions that prevailed in the northern Plains from around 10,900 to 10,000 BP. These attributes occur instead in California and Mid-Atlantic fluted points (Anderson and Faught 1998) that may be relatively early; multiple flutes also occur on Clovis-like points from Guatemala and Chile (Lynch 1983:97,104). It is unclear why any late Paleoindian hunters would have been drawn back to the far north during the Younger Dryas; bison, their preferred prey, did not migrate north. A southern Paleoindian migration into Alaska would have been difficult at 10,500 BP, because these immigrants would have confronted expanding Paleoarctic Denali populations. As an alternative to the dominant view, the geographic segregation of fluted point finds in northern Alaska from the Nenana sites in central Alaska, might be interpreted as indicating two contemporaneous but distinct cultures ~11,600 BP (13,400 cal BP). If dubious identifications of mammoth residues on Alaskan points could be confirmed (Loy and Dixon 1998), the case for a northern Alaskan (or eastern Beringian) emergence of basic Clovis lifeways would be strengthened.

On the assumption that ancestral Paleoindians from Alaska passed through a widening ice-free corridor ~11,600 BP (ca. 13,400 cal BP), we might expect to find proto-Clovis or earliest Clovis sites at the southern end of the corridor, in the northern Plains. Although there are many stray fluted point finds from Alberta (Ives et al. 1993), including a "stubby" type that is a plausible transitional form from Nenana triangular points, only one point has been found in a datable context in western Canada. This small fluted (or basally thinned) point from Charlie Lake Cave, British Columbia, was in a level that yielded three dates on bison bone collagen: 10,770 ± 120, 10,450 ± 150, and 10,380 ±

160 BP (Fladmark et al. 1988). While these dates suggest a probable Younger Dryas age for the occupation, as they are collagen-derived they might actually be too young. A Clovis-era age is thus not excluded (recall that some Clovis sites, including the Anzick child burial, have yielded ca. 10,700 BP dates!).

A proto-Clovis assemblage might look like the material from Cactus Hill, with its unfluted points, small blades, and conical cores (McAvoy and McAvoy 1997). Bladelets also occur in a probably early Clovis assemblage at the Big Pine Tree site in South Carolina (Goodyear 1997), and in Stratum IIA at Meadowcroft Rockshelter. Or, Clovis precursors might have produced the artifacts found at Santa Isabel Iztapan, near Mexico City, in the early 1950s (Aveleyra 1956). Both an unfluted lanceolate point and a bipointed laurel leaf or Lerma-like point were found there among the bones of a single mammoth. This faunal association strongly suggests a pre-Younger Dryas age, although the ^{14}C date reported in the 1950s was only ~9250 BP (MacNeish 1983). The lanceolate is a plausible prototype for Clovis (Haynes 1987), while the laurel leaf form, made by the same band of hunters, could be ancestral to the El Jobo points of South America (Pichardo 2000).

A few dates from other areas hint at a human presence around 12,000 BP (ca. 13,500–14,000 cal BP). In Florida, a wooden stake inserted, perhaps by human action, into a tortoise shell in the Little Salt Spring sinkhole, yielded a date of 12,030 ± 200 BP (but the shell itself is much older, 13,450 ± 190 BP) (Clausen et al. 1979:611). Several dates for Zone D of the Page-Ladson site, which contained an ostensibly incised mastodon tusk, ranged from 13,130 ± 200 to 11,770 ± 90 BP (Faught 1996:162). In the absence of a definitely associated lithic industry, the affiliations of this dimly perceived occupation remain obscure.

Similarly, the early dates of 11,840 ± 130, 11,700 ± 95, and 11,450 ± 110 BP, reported for the "pre-Folsom" level at Agate Basin in Wyoming (Haynes et al. 1984) cannot yet be tied to early Clovis or to any other culture. It should be noted that dates associated with unfluted lanceolate Goshen points in the northern Plains range from about 10,200 BP (Donohue 1998) as far back as 11,570 ± 170 BP (Frison 1991, 1993, 1996) or ~13,400 cal BP. If the earlier dates are not erroneous (lignite contamination is suspected at the Mill Iron site) Goshen might be ancestral to Clovis, or else some still earlier common ancestral culture, without fluted points, remains to be found.

Several groups of diverse Beringian ancestry may have undertaken exploratory forays throughout North and South America after 14,700 cal BP. However, in the period of climatic oscillation after ~13,400 cal BP (11,500 BP), the people who made Clovis points and associated tools perhaps enjoyed a unique technological/adaptive advantage (as efficient mammoth-killers?) over any potential competitors, and rapidly expanded their range throughout North America. In Central America, stylistic drift resulted in emergence of the fishtail point variant (probably derived from southeastern Clovis) (Morrow and Morrow 1999; Pearson 1998). People who made fishtail points reached Tierra del Fuego by about 13,000 cal BP. If they encountered a precursor population of the El Jobo complex in South America (which still seems improbable), they either absorbed or replaced them. Continuing stylistic drift and isolation, coupled with rapid adaptation to diverse and changing terminal Pleistocene environments, probably resulted in emergence of distinctive regional styles (e.g. Monte Alegre in Brazil, Paijanense in coastal Peru, Dalton in the southern Midwest, etc.) by ~12,500 cal BP.

MIGRATION ROUTES: COAST OR INTERIOR?

The first successful human colonization of Beringia probably occurred soon after the onset of the Bølling-Allerød period (14,700 cal BP, ca. 12,500–12,900 BP), when temperatures rose abruptly in the northern hemisphere. By 12,500 BP, summers in Beringia were as warm as they are today (Elias

2000). Rising temperatures and increased insolation caused rapid retreat and melting of the great ice sheets. Although the late Pleistocene geology of western Canada is still somewhat debatable, there is a consensus that the Laurentide and Cordilleran glaciers had coalesced during the Last Glacial Maximum (22,000–19,000 cal BP). The Cordilleran glacier already was shrinking along its western margin at 13,300 BP (ca. 16,000 cal BP) (Cowan and Bornhold 1998). The Laurentide ice sheet suffered catastrophic ablation around 12,500 BP, causing a global meltwater pulse (MWP IA) in the ocean (Fairbanks et al. 1992; Sowers and Bender 1995). In the southern Pacific, MWP IA is manifest as a rapid 16-meter rise in sea level between 14,600 and 14,300 cal BP (Hanebuth et al. 2000). As the ice sheets receded, an "ice-free" corridor opened between them, filled with meltwater lakes. ^{14}C dates from these lakes are often unreliable, due to hardwater effects and bulk samples. In any case, it seems a safe assumption that a corridor was open soon after the documented Laurentide ablation, around 12,500 BP, and revegetation of the barren landscape was probably rapid. A vegetative cover of herbs, grasses, sedges, mosses, and algae is reconstructed for the southern end of the corridor at 12,000–11,700 BP (Ives et al. 1993). Mammoth, horse, camel, elk, and musk-ox bones occur in late Pleistocene terraces of the Peace River valley in Alberta, leading Fladmark et al. (1988:382) to conclude that "the later stages of the ice-free corridor clearly were not inhospitable."

The ice-free corridor has long been regarded as the most likely route of Paleoindian entry into North America. Despite recent advocacy of an alternative coastal migration route (Fladmark 1979, 1983; Gruhn 1988, 1994; Fedje et al. 1996; Josenhans et al. 1997; Mandryk 1998; Dixon 1999, Fedje and Josenhans 2000) the corridor remains a viable option (Jackson and Duk-Rodkin 1996; Ives et al. 1993; Wilson and Burns 1999).

Advocates of a coastal migration (e.g. Dixon 1999:249) often cite Monte Verde (Dillehay 1997). However, if it really is a human habitation site (see Fiedel 1999b for a skeptical assessment), Monte Verde offers no evidence of a marine orientation. It sits beside a creek, some 20 miles from the Pacific shore. The faunal assemblage includes no fish or marine shellfish (Dillehay 1997:674). Only the presence of seaweed suggests that the inhabitants ever visited the shore. Not the subsistence pattern, but only the early date of Monte Verde (ca. 12,500–12,000 BP) might imply a coastal route, because it leaves so little time for a long overland journey from a just-opened and inhospitable corridor almost to the tip of South America. Furthermore, the absence of any similar sites of comparable antiquity in North America can be conveniently explained by supposing a journey by boat that left no traces on the land.

Without a pressing need to account for the chronological and cultural anomaly of Monte Verde, the search for a coastal migration route loses its urgency. Granted, recent research suggests that the coast of western Canada may have offered migrants a more attractive landscape than the ice-free corridor. Coastal ice had receded from most areas of British Columbia and Alaska by 14,000 BP (ca. 16,500 cal BP), and these areas were vegetated by 13,000 BP (Josenhans et al. 1997). Drowned Late Pleistocene coastal landscapes have been recognized at a depth of more than 150 m in the waters off the Queen Charlotte Islands, and a single basalt flake, estimated to date to ca. 10,200 BP, was recently dredged up from this context (Fedje and Josenhans 2000). Bears were living on Prince of Wales Island by 12,300 BP (Heaton et al. 1996). If these omnivores could thrive on the coast, so too, perhaps, could people. But, mere potential for habitation is one thing, archaeological demonstration is something else entirely. Despite years of contracted and academic survey work, neither the Northwest nor California coast has yet produced a single credible pre-Clovis site. Coastal route advocates lament that Holocene sea-level rise has drowned the evidence that would prove their case. However, there are elevated headlands along the Alaska coast that would have been habitable in the late Pleistocene (Yesner 1998a), and on the coast of mainland British Columbia, some near-coastal Pleistocene areas now sit more than 200 m above the present sea level, because of isostatic postglacial uplift (Josenhans et al. 1997:74). No early sites have yet been identified in these areas. In any case, as Meighan (1983) and Dillehay and Meltzer (1991:291) observe, even if the littoral-focused sites of coastal foragers are now underwater, their subsistence-settlement system probably also had an interior aspect, which should be archaeologically recoverable.

The earliest known lithic industries on the North Pacific coast are no older than 9800 BP (about 11,200 cal BP, or 2,000 years later than Clovis). Lithic assemblages in the Alexander Archipelago in southeast Alaska date to 9500–9000 BP (Ackerman 1992). In Gwaii Haanas, off the British Columbia coast, the earliest microblades and bifaces date to about 9400 BP (Fedje et al. 1996). On Prince of Wales Island, the same cave (49-PET-408) that yielded 12,300 BP bear bones contained human bones, but the latter date only to around 9800 BP (or ca. 9200 BP, corrected for marine reservoir effect [Dixon 1999:118]). At Namu, on the central British Columbia coast, an assemblage of unifacial pebble tools, leaf-shaped, unstemmed bifaces, scrapers, and gravers, dates from 9720 ± 140 BP (Carlson 1998). In western Oregon, the earliest site near the coast (50 km inland) dates to barely 9000 BP.

In California, numerous claims of great antiquity for both alleged stone tools (e.g. Calico Hills) and for human skeletal remains (e.g. Sunnyvale, Del Mar, Yuha), have been effectively refuted (e.g. Meighan 1983; Stanford 1983; Taylor et al. 1985; Taylor 1991:90). In fact, there is now no unambiguous evidence of pre-Clovis people in coastal (nor interior) California. Although numerous Clovis points have been found on the surface at California interior sites (e.g. Borax Lake), only a few isolated fluted points have turned up near the coast (Erlandson 1994). Excavations at Daisy Cave on San Miguel Island (Erlandson and Moss 1996, Erlandson et al. 1996, Erlandson 1998) show that the Channel Islands off southern California were occupied by 10,400 BP. New ^{14}C dates of ~11,000 BP have been obtained for Arlington Springs Woman, a partial skeleton excavated in the 1960s on nearby Santa Rosa Island (Wisner 1999; Stafford et al. 2002). This makes her a possible Clovis contemporary, but not a predecessor. Claims of association on Santa Rosa Island of ostensible artifacts and hearths with bones of pygmy mammoths, dated around 40,000–12,000 BP (Orr 1968), have not withstood close scrutiny (Stanford 1983:71; Waters 1985:132; Cushing et al. 1986). The first nearly intact skeleton of a pygmy mammoth was found on the island in 1994. It is a very aged individual, who seems to have died naturally and was not dismembered or butchered by humans. A ^{14}C date of about 12,840 BP has been reported (Agenbroad et al. 1995). A renewed effort to date other pygmy mammoths might yield interesting results, as a test of the coastal hypothesis. Island fauna are generally hunted to extinction soon after humans arrive (e.g. moas in New Zealand [Holdaway and Jacomb 2000]). The age of the last pygmy mammoth should tell us when humans first occupied the coast of southern California (Johnson 1983:513; Meighan 1983:450). A pygmy mammoth vertebra recently has been dated to ~11,030 BP (Agenbroad 2002).

Two sites found recently in southern Peru, which offer clear evidence of surprisingly early intensive use of marine resources, have been cited in support of a coastal migration model. At Quebrada Tacahuay, a hearth dated to around 10,530–10,770 BP (ca. 12,300–12,850 cal BP) was associated with bones of cormorants, other birds, anchovies, and sea mammals (Keefer et al. 1998; deFrance et al. 2001). Quebrada Jaguay 280, located 220 km to the north, is of similar antiquity; the lowest level yielded dates of 11,088 ± 120 and 11,105 ± 260 BP, and the overlying layer dates to ~10,700 BP (Sandweiss et al. 1998, 2000). The dated levels contained remains of drumfish and clams. At Quebrada Jaguay 280, obsidian was found, that can be traced to a source in the Andes, 130 km inland. It was probably acquired there during the interior phase of a seasonal round that included terrestrial hunting as well as periodic visits to the shore. Comparably early dates of ~11,000 BP have been obtained from Fell I or fishtail point occupations in Patagonia and the Pampas of Argentina (Nami 1996, Flegenheimer and Zarate 1997), where hunting of horses and other Pleistocene fauna is attested. The Peruvian sites probably represent, not waterborne coastal migrants, but an early stage of coastal adaptation by groups previously committed, like their contemporaries in Patagonia and Chile (e.g. at Tagua Tagua [Nunez and Santoro 1990]), to terrestrial hunting and gathering.

THE OVERKILL HYPOTHESIS: DID PALEOINDIAN HUNTING FINISH OFF THE MEGAFAUNA?

More than 30 genera of large-bodied mammals (megafauna) in the Americas became extinct around 11,000 BP (13,000 cal BP). These animals had thrived in the sustained warm climate of the last interglacial, and had survived many sudden temperature changes (18 warm Dansgaard-Oeschger interstadials and six cold Heinrich events) during the Wisconsin glaciation, after around 70,000 cal BP. The warm-cold oscillations that marked the final stages of the Pleistocene between around 17,000 and 11,500 cal BP were not markedly more severe than the earlier temperature spikes. The only obvious difference about this deglacial period was the arrival of humans at 13,500 cal BP. Martin (1973) theorized that Paleoindian hunters, radiating rapidly through the continent in a sort of "blitzkrieg" movement, slaughtered the unwitting megafauna in a few centuries. Martin's critics have wondered why, of all the species that disappeared, only a few (mammoth, mastodon, possibly horse, sloth, and camel) are actually represented by skeletal remains at Paleoindian kill or campsites. On the other hand, Paleoindians clearly did hunt bison and caribou, both of which survived the extinction episode. Critics of the overkill hypothesis also note that a number of bird species died out, which would be difficult to attribute directly to human predation (Grayson 1991). Some have suggested that the ostensible suddenness of the extinction was illusory, that the die-off may have occurred gradually over millennia (Meltzer and Mead 1985). However, recent AMS dates on bone reaffirm that extinction of all megafauna occurred abruptly between 11,400 and 10,800 BP (13,000 cal BP) (Graham 1998; Graham et al. 2002). These dates equate to the onset of the Younger Dryas cold episode. In numerous exposed stratigraphic profiles in the Southwest, a thin aquoll or "black mat" (spring-laid soil) directly overlies the bones of the last mammoths. The black mats appear to represent a regional pluvial period, with increased spring discharge, at the onset of the Younger Dryas (Haynes 1998 and undated; Quade et al. 1998).

Alternative, environmental explanations of the great extinction rely on the sharp contrasts between late Pleistocene and Holocene conditions, such as reduced patchiness of vegetation zones and more extreme seasonal variation (e.g. Graham 1998). The obvious problem with such models is that, in North America, the megafaunal extinction occurred at the onset of the Younger Dryas (13,000 cal BP), 1500 years before the rapid warming that marked the start of the Holocene (11,570 cal BP). In southern South America, deglacial warming began about 17,000 cal BP (14,000 BP), and the environment seems to have approached essentially modern conditions by 12,500 BP (14,500 cal BP). Yet, Paleoindian hunters were killing horses in Patagonia around 12,900–12,200 cal BP (Alberdi et al. 2001; Nami 1996), while ground sloths were still living there (Long and Martin 1974; Long et al. 1998). Thus, it seems that the South American megafauna might have survived regional warming and environmental change, had they not suffered predation pressure from humans.

The overkill theory for American extinction has been strengthened by re-analyses of analogous cases. In Australia, the arrival of humans around 50,000 cal BP was soon followed by the extinction of giant birds and marsupial megafauna, around 46,000 cal BP (Flannery 1999; Miller et al. 1999; Turney et al. 2001; Roberts et al. 2001). In New Zealand, in the late 13th century, several species of moa, with an estimated population of 158,000 birds, appear to have been wiped out by the first Maori settlers in about 50–160 years (Holdaway and Jacomb 2000).

However, the overkill theory is confounded by an odd paradox in Beringia. On the one hand, it seems that mammoth had disappeared from eastern Beringia at least several hundred years before initial occupation by Nenana foragers. On the other hand, on Wrangel Island, which would have been in north-central Beringia before the ocean waters rose, dwarf mammoths seem to have persisted until 3700 BP (Vartanyan et al. 1995). While their survival suggests that climate change alone was not enough to cause extinction, it also raises the question, how could efficient proto-Paleoindian hunters have missed this pocket of vulnerable megafauna en route to America?

RAPID INITIAL COLONIZATION: WHY AND HOW DID THEY GO SO FAR, SO FAST?

Clovis expansion across the whole of North America was almost incredibly rapid. The earliest relatively precise charcoal-based ^{14}C dates yet obtained for North American Clovis are two dates of around 11,550 BP (about 13,300–13,400 cal BP) for the Aubrey site in Texas (Ferring 1995, 2001). The oldest of the amino-acid-based dates for the child buried with a Clovis tool cache at Anzick, Montana, is 11,550 ± 60 (CAMS-35912) (Sellars 1999). However, dates for most western Clovis sites cluster around 10,900 BP. New AMS dates from the Clovis stratum at Shawnee-Minisink in eastern Pennsylvania (10,940 ± 90 [Beta-101935] and 10,900 ± 40 BP [Beta-127162]) (Dent 1999) show that Eastern Clovis is as old as the classic southwestern sites.

The fishtail (or Fell 1) points found in Central America (Snarskis 1979; Ranere and Cooke 1991; Ranere 1997; Pearson 1998), Ecuador (Mayer-Oakes 1984), Chile (Núñez and Santoro 1990), Patagonia (Bird 1938, Nami 1996), and the Pampas (Flegenheimer 1986/1987) are clearly derived, with slight stylistic modification, from North American Clovis (Lynch 1983; Morrow and Morrow 1999). Fell 1 fishtail points in the Southern Cone have been securely dated at ~10,300–11,100 BP or approximately 12,300–13,000 cal BP (e.g. at Cueva del Medio in Patagonia [Nami 1996] and at Cerro La China and Cerro El Sombrero in the Pampas [Flegenheimer 1986/1987; Flegenheimer and Zarate 1997]). Several ostensibly older dates of around 13,000–12,000 BP have also been reported for Los Toldos 3, Level 11 (12,600 ± 600); Cueva del Lago Sofia (11,570 ± 60 and 12,990 ± 241); and Piedra Museo (ca. 12,700) (Politis 1997), but all these dates seem to be erratic, as associated assemblages are either clearly Fell I or are probable functional variants that lack the diagnostic points (Nami 1994). Recently reported AMS dates for these sites imply that all dates older than 11,300 BP are in fact erratic outliers (Steele et al. 2001).

Thus, the interval separating the initial inhabitants of the Southern Cone from the earliest Clovis hunters in Texas is probably only 400 years (13,400–13,000 cal BP). At a reasonable pace of 24 km per day, it would have taken Clovis ancestors 80 days to walk 1900 km through the ice-free corridor. To get from the southern end of the corridor to Texas by the most direct route, they would have covered about 2100 km, perhaps in a matter of months or a few years (Haynes, undated). If the initial Clovis-descended colonists, setting out from Panama, moved at a comparable rate on an essentially linear route of around 6400 km along the Andean chain, they would have reached Tierra del Fuego in much less than 400 years, as required by the chronological evidence.

Such rapid travel across vast distances is clearly feasible, even if the motivation behind it is debatable. More difficult to envision and accept is the rate of demographic increase that must be postulated to fill up the American continents in four centuries. At a density characteristic of recent Subarctic hunting peoples, 1 person per 200 km^2, the Paleoindian population would have had to reach about 125,000 to accomplish this. Starting from a pioneering band of 50, this number would have been attained in about 300 years, assuming exponential growth and 25 years per generation. But, is such rapid growth (each couple rearing, on average, four children to adulthood) possible while maintaining high mobility? Modeling by Surovell (2000) indicates that it is indeed feasible. Beaton (1991), Anderson (1995), and MacDonald (1998) suggest plausible social mechanisms by which Paleoindian mating networks could have assured their reproductive success.

The most obvious, and traditionally assumed, motivation for far-ranging Paleoindian movements is a commitment to hunting of migrating herds of big game. However, it has become fashionable to question the supposedly "macho" image that was evoked initially by repeated associations of Clovis points with mammoth skeletons. A more generalized foraging strategy is now often assumed, punctuated by rare episodes of megafauna-hunting. However, total rejection of the traditional model seems unwise. Paleoindians, descended from the Upper Paleolithic hunters of northern Eurasia and Beringia, had a long tradition of primary dependence on meat. Plant foods were simply insufficient to support human life in Arctic and Sub-Arctic latitudes. Furthermore, a colonizing population could rely on pre-existing knowledge of the behavior of large, far-ranging mammals, while it would have taken years to acquire intimate knowledge of the distribution and uses of territorially restricted and variable plant species. Because of rapidly changing environments, late Pleistocene fauna probably often shifted their ranges and density. These changes would have prevented Paleoindians from settling in at a particular location and predicting the scheduled movements of their prey. Thus, hunting of megafauna and frequent movement would have been elements of a successful adaptation for early Paleoindians (Kelly and Todd 1988).

As the Paleoindians moved southward into temperate deciduous forests, then into equatorial montane forests and even rainforests, many more potential plant foods would have become accessible, while the density of megafauna diminished. Consumption of fish and berries is attested at the Shawnee-Minisink site (McNett 1985). Bison and deer are reported from Aubrey, but so is turtle; it is as yet unclear whether bones of small mammals, fish, and birds in pond sediments represent a cultural or natural deposit (Ferring 1995, 2001). Whatever the precise balance of large and small game in Clovis subsistence, the collapse of megafaunal populations at 13,000 cal BP (11,000 BP) compelled Paleoindians everywhere to adopt more broad-spectrum diets. Evidence has been accumulating in South America of a rapid change in subsistence after 11,000 BP. Roosevelt et al. (1996) present evidence of intensive consumption of tree fruits, along with fish, birds, mollusks, reptiles, amphibians, small- and medium-sized mammals, in the Monte Alegre culture in the Brazilian Amazon, by around 10,600 BP. Basal layers of several central Brazilian rockshelters also indicate broad-spectrum use of fruits, roots, and small game starting between ~11,000 and 10,500 BP (Kipnis 1998; Prous and Fogaça 1999). Some sites in this region have produced even older dates, e.g. Lapa do Boquete (three dates ca. 12,000 BP, and two ca. 11,440 BP), Santana do Riacho (11,960 ± 250 BP), and Sitio do Meio (two dates ca. 12,300 BP). It seems likely that these ostensibly pre-Clovis dates are misleading outliers, like the Southern Cone dates older than 11,300 BP (Steele et al. 2001). The contemporaneous appearance of a marine adaptation in coastal Peru between 11,000 and 10,700 BP has already been noted. Hunting peoples can quickly and radically alter their subsistence modes. In an analogous case, Thule whale-hunters abandoned whaling and became reliant on fishing, sealing, and caribou-hunting within 200 years after their initial rapid colonization of the Canadian Arctic (McGhee 1984; Fiedel 1998; Whitridge 2001). Evidence of broad-spectrum economies, even as early as 11,000 BP, is not incompatible with initial migration a few hundred years earlier.

The known distribution of fluted points (Anderson and Faught 1998, 2000) shows no obvious relationship to environmental parameters, as the concentrations encompass several distinct vegetation zones. Thus, it does not appear that Paleoindians were searching for any particular preferred habitat. Perhaps, Haynes's "Clovis drought" (probably corresponding to the warm spike at the end of the Allerød, ca. 13,100 cal BP) caused fragmentation of mammoth herds into oasis-like refugia around remnant lakes. A leap-frogging strategy (Anderson and Faught 1998; Anthony 1990; Fiedel and Anthony 1979), rapidly covering long distances from one refugium to the next, might have been most efficient way for Clovis hunters to encounter their preferred prey (G Haynes 1999). There may be a processual similarity in the island-hopping of the early Polynesian Lapita people, the movement of Linearbandkeramik people between patches of arable soil in Central Europe, and Clovis migration between dispersed mammoth refugia, which would explain the seemingly explosive character of each of these population movements.

WHAT CAN RADIOCARBON DATING CONTRIBUTE TO PALEOINDIAN STUDIES?

Archaeologists, of course, can always use more Paleoindian sites, particularly undisturbed sites with intact stratigraphy, discrete features and activity areas and datable charcoal. Important recently discovered sites include Aubrey and Gault in Texas, Big Eddy in Missouri (Ray et al. 1998), and Carson-Conn-Short (Broster and Norton 1996) in Tennessee. We may hope that more such sites will be found in Siberia, Alaska, the ice-free corridor, and the west coast. Whatever turns up in the future, for now, more judicious and rigorous application of ^{14}C and ancillary chronometric techniques to the existing data base can clarify the chronology and processes of Amerindian migration.

The development of AMS dating in the 1980s has introduced much greater precision when dealing with small samples. Its effect is clearly seen in the case of the Shawnee-Minisink site in Pennsylvania. Conventional dates run in the 1970s, with sigmas ranging from 300 to 1000 years, had suggested an age of about 10,600 BP. Fortunately, some carbonized hawthorn plum seeds from a hearth had been saved, and recently run AMS dates put the Clovis occupation at about 10,900–10,950 BP, coeval with classic southwestern Clovis sites such as Lehner and Murray Springs. Unfortunately, technical innovations do not offer a panacea for problems of degraded, dislocated, or contaminated samples. All too often, dates from Northeastern Paleoindian sites come out too young to be credible. Is the seemingly more recent charcoal derived from trees that grew and burned on these sites millennia after human occupation? In other cases (Meadowcroft, Cactus Hill), the dates seem too old to be accepted without hesitation.

Tom Stafford's recent development of protocols for dating purified amino acids from bone allows direct dating of late Pleistocene faunal and human remains (Stafford 1994), with a precision of ±60 years. Preliminary reports of the faunal dating project undertaken by Stafford, Graham, and Semken (e.g. Graham 1998; Graham et al. 2002) indicate that terminal Pleistocene extinction was rapid indeed. Final dates for 17 megafauna species cluster between 11,400 and 10,800 BP. Although Graham has suggested, based on dates of around 10,800 BP, that the proboscideans were the last to go, we should recall that dates of 10,800 have also been obtained for Clovis sites that appear to be of late Allerød age. Furthermore, because of the rapid increase in ^{14}C at the Younger Dryas onset, dates drop from about 11,200 to 10,800 BP in about a century of real time (Hughen et al. 2000). The apparent precision of the new bone dates is not always definitive. Consider, for example, the range of reported dates for the Anzick child burial, which was associated with a spectacular Clovis artifact cache. Should we put greatest reliance on a date of 10,240 ± 120, 10,710 ± 100, 10,940 ± 90, or 11,550 ± 60 BP? Haynes (personal communication) generally takes the oldest of any series of bone dates as the most credible.

Poor survival of charcoal, bone, and other organic materials of terminal Pleistocene age is an insuperable problem for ^{14}C dating. Can other methods yield reliable dates using lithics and sediments as samples? Obsidian hydration dating has produced dates that are sometimes credible, often clearly erratic (e.g. Bell 1977; Clark 1984; Basgall 1995). A better understanding has been achieved of the variables that can affect hydration (Ridings 1996; Jones et al. 1997). It now appears that surface finds are not suitable samples, which unfortunately excludes most Paleoindian-age finds, such as Alaskan fluted points. ^{14}C and cation dating of rock varnish on tools and petroglyphs, once touted as proof of pre-Clovis occupation of western North America (Whitley and Dorn 1993) has been shown to be completely unreliable (Dorn 1996). In the near future, refinement of methods for thermoluminescence (TL) dating of burnt chert and optically stimulated luminescence (OSL) dating of aeolian sand grains (Feathers 1997) may yield reliable and moderately precise dates for these materials (see now, e.g. Rich and Stokes 2001; Hilgers et al. 2001). However, in cases where results can be compared to ^{14}C dates, accuracy has been highly variable, and precision is unimpressive. For example, Roosevelt et al. (1996) obtained 49 AMS and 7 conventional dates for Pedra Pintada, all clustering around 10,500–10,000 BP (ca. 12,500-11,300 cal BP). TL dates ranged from 9530 ± 780 to 16,190 ± 930; OSL dates were 12,491 ± 1409, 12,536 ± 4125, and 13,106 ± 1628 bp. TL dating of Jinmium Rockshelter in Australia produced grossly erroneous dates in excess of 100,000 years for material that OSL puts at less than 10,000 years old (Roberts et al. 1998). At Cactus Hill, OSL dates for an Early Archaic level (with Fort Nottoway points) are 9189 ± 1101 and 12,391 ± 1864 bp; the expected calibrated age was about 10,000 cal BP (McAvoy et al., undated). It seems that when enough OSL dates are run, the average may correspond pretty closely to the age established by ^{14}C.

In the not so distant future, I am confident that we will know, perhaps with decadal precision, exactly when Paleoindians arrived in America, how long it took them to people the continent, and how they affected the native fauna. Establishment of a precise chronology is critical for modeling and understanding the colonization process. Once this has been achieved, there will be profound theoretical repercussions in ethnology, genetics, historical linguistics, demography, and ecology.

REFERENCES

Ackerman RE. 1992. Earliest stone industries on the North Pacific coast of North America. *Arctic Anthropology* 29(2):18–27.

Acosta J de. 1604. *The natural and moral history of the Indies.* English translation by Grimston E, 1604. Markham CR, editor, 1880.

Adovasio JM. 1993. The ones that will not go away: a broad view of pre-Clovis populations in the New World. In: Soffer O, Praslov ND, editors. *From Kostenki to Clovis.* New York: Plenum Press. p 199–218.

Adovasio JM, Donahue J, Stuckenrath R. 1990. The Meadowcroft Rockshelter radiocarbon chronology 1975-1990. *American Antiquity* 55(2):348–54.

Adovasio JM, Pedler D, Donahue J, Stuckenrath R. 1999. No vestige of a beginning nor prospect for an end: two decades of debate on Meadowcroft rockshelter. In: Bonnichsen R, Turnmire KL, editors. *Ice Age peoples of North America: environments, origins, and adaptations of the first Americans.* Oregon State University Press. p 416–31.

Agenbroad L. 2002. Pygmy mammoths (*Mammuthus exilis*) and a human presence on Santa Rosa Island: coincidence or extinction? Paper presented at 67th annual meeting of Society for American Archaeology. Denver. 20–24 March.

Agenbroad L, Morris D, Rockwell T, Roth L. 1995. A preliminary report of the recovery of the first nearly complete skeleton of the pygmy (dwarf) mammoth, *Mammuthus exilis*, from North America. Paper presented at INQUA Congress XIV, Berlin.

Alberdi MT, Miotti T, Prado JL. 2001. *Hippidion saldiasi* Roth, 1899 (Equidae, Perissodactyla), at the Piedra Museo site (Santa Cruz, Argentina): its implication for the regional economy and environmental reconstruction. *Journal of Archaeological Science* 28:411–9.

Anderson DG. 1995. Paleoindian interaction networks in the eastern woodlands. In: Nassaney MS, Sassaman KE, editors. *Native American interaction: multiscalar analyses and interpretations in the Eastern woodlands.* Knoxville: University of Tennessee Press. p 10–26.

Anderson DG, Faught MK. 1998. The distribution of fluted Paleoindian projectile points: update 1998. *Archaeology of Eastern North America* 26:163–88.

Anderson DG, Faught MK. 2000. Paleoindian artefact distributions: evidence and implications. *Antiquity* 74: 507–13.

Andresen CS, Bjorck S, Bennike O, Heinemeier J, Kromer B. 2000. What do δ^{14}C changes across the Gersenzee oscillation/GI-1b event imply for deglacial oscillations? *Journal of Quaternary Science* 15:203-214.

Antevs E. 1935. Age of the Clovis lake clays. *Academy of Natural Sciences of Philadelphia Proceedings* 87: 304–12.

Antevs E. 1953. Age of the Clovis fluted points with the

Naco mammoth. *American Antiquity* 19(1):15–7.
Antevs E. 1959. Geological age of the Lehner mammoth site. *American Antiquity* 25(1):31–4.
Anthony DW. 1990. Migration in archeology: the baby and the bathwater. *American Anthropologist* 92(4): 895–914.
Aveleyra A, de Anda L. 1956. The second mammoth and associated artifacts at Santa Isabel Iztapan, Mexico. *American Antiquity* 22:12–28.
Baales M, Street M. 1996. Hunter-gatherer behavior in a changing late glacial landscape: Allerød archaeology in the central Rhineland, Germany. *Journal of Anthropological Research* 52:281–316.
Basgall ME. 1995. Obsidian hydration dating of early Holocene assemblages in the Mojave Desert. *Current Research in the Pleistocene* 12:57–60.
Beaton JM. 1991. Colonizing continents: some problems from Australia and the Americas. In: Dillehay TD, Meltzer DJ, editors. *The first Americans: search and research.* Boca Raton: CRC Press. p 209–30.
Beck JW, Richards DA, Edwards RL, Silverman BW, Smart PL, Donahue DJ, Herrera-Osterheld S, Burr GS, Calsoyas L, Jull AJT, Biddulph D. 2001. Extremely large variations of atmospheric ^{14}C concentration during the last glacial period. *Science* 292:2453–8.
Bell RE. 1977. Obsidian hydration studies in highland Ecuador (El Inga). *American Antiquity* 42(1):68–77.
Bianchi NO, Bailliet G, Bravi CM, Carnese RF, Rothhammer F, Martinez-Marignac VL, Pena SD. 1997. Origin of Amerindian Y-chromosomes as inferred by the analysis of six polymorphic markers. *American Journal of Physical Anthropology* 102(1):79–89.
Bianchi NO, Catanesi CI, Bailliet G, Martinez-Marignac VL, Bravi CM, Vidal-Rioja LB, Herrera RJ, Lopez-Camelo JS. 1998. Characterization of ancestral and derived Y-chromosome haplotypes of New World native populations. *American Journal of Human Genetics* 63(6):1862–71.
Bird J. 1938. Before Magellan. *Natural History* 41(1): 16–28.
Boldurian A. 1985. Variability in flintworking technology at the Krajacic Site: possible relationships to the Pre-Clovis Paleoindian occupation of the Cross Creek drainage in southwestern Pennsylvania. Unpublished PhD dissertation. University of Pittsburgh.
Bonnichsen R, Will RT. 1999. Radiocarbon chronology of Northeastern Paleo-American sites: discriminating natural and human burn features. In: Bonnichsen R, Turnmire KL, editors. *Ice Age people of North America, environments, origins, and adaptations.* Corvallis: Oregon State University Press. p 395–415.
Bradley BA. 1997. Bifacial thinning in the early Upper Paleolithic of Eastern Europe. *Chips* 9(2):8–9.
Bradley BA, Anikovich M, Giria E. 1995. Early Upper Palaeolithic in the Russian Plain: Streletskayan flaked stone artefacts and technology. *Antiquity* 69:989–98.
Broecker WS, Andree M, Wolfli W, Oeschger H, Bonani G, Kennett J, Peteet D. 1988. The chronology of the last deglaciation: implications to the cause of the Younger Dryas event. *Paleoceanography* 3:1–19.
Broster JB, Norton MR. 1996. Recent Paleoindian research in Tennessee. In: Anderson DG, Sassaman KE, editors. *The Paleoindian and Early Archaic Southeast.* Tuscaloosa: University of Alabama Press. p 288–97.
Brown MD, Hosseini SH, Torroni A, Bandelt HJ, Allen JC, Schurr TG, Scozzari R, Cruciani F, Wallace DC. 1998. mtDNA haplogroup X: an ancient link between Europe/Western Asia and North America? *American Journal of Human Genetics* 63(6):1852–61.
Brown P. [in press 1999] The earliest East Asians: a view from the Late Pleistocene and Neolithic of China and Japan. In: Omoto K, editor. *Interdisciplinary perspectives on the origins of the Japanese.* Kyoto: International Research Center for Japanese Studies.
Bryan AL. 1978. An overview of Paleo-American prehistory from a circum-Pacific perspective. In: Bryan AL, editor. *Early Man in America from a Circum-Pacific Perspective.* Occasional Papers No. 1. Edmonton: University of Alberta, Department of Anthropology. p 306–27.
Bryan AL, Casamiquela RM, Cruxent JM, Gruhn R, Ochsenius C. 1978. An El Jobo mastodon kill at Taima-Taima, Venezuela. *Science* 200:1275–7.
Burr GS, Beck JW, Taylor FW, Récy J, Edwards RL, Cabioch G, Corrège T, Donahue DJ, O'Malley JM. 1998. A high-resolution radiocarbon calibration between 11.7 and 12.4 ka BP derived from ^{230}Th ages of corals from Espiritu Santo Island, Vanuatu. *Radiocarbon* 40(3):1093–105.
Carlson RL. 1991. Clovis from the perspective of the ice-free corridor. In: Bonnichsen R, Turnmire KL, editors. *Clovis: origins and adaptations.* Corvallis, Oregon: Center for the Study of the First Americans. p 81–90.
Carlson RL. 1998. Coastal British Columbia in the light of North Pacific maritime adaptations. *Arctic Anthropology* 35(1):23–35.
Chard C. 1960. Routes to Bering Strait. *American Antiquity* 28(2):151–8.
Chatters JC. 2000. The recovery and first analysis of an Early Holocene human skeleton from Kennewick, Washington. *American Antiquity* 65(2):291–316.
Cinq-Mars J, Morlan RE. 1999. Bluefish Caves and Old Crow Basin: a new rapport. In: Bonnichsen R, Turnmire KL, editors. *Ice Age people of North America, environments, origins, and adaptations.* Corvallis: Oregon State University Press. p 200–12.
Clark DW. 1984. Some practical applications of obsidian hydration dating in the Subarctic. *Arctic* 37:91–109.
Clark DW. 1991. The northern (Alaska-Yukon) fluted points. In: Bonnichsen R, Turnmire KL, editors. *Clovis: origins and adaptations.* Corvallis, Oregon: Center for the Study of the First Americans. p 35–48.
Clark DW, Clark AM. 1983. Paleo-Indians and fluted points: Subarctic alternatives. *Plains Anthropologist*

28(102):283–92.

Clausen CJ, Cohen AD, Emiliani C, Holman JA, Stipp JJ. 1979. Little Salt Spring, Florida: a unique underwater site. *Science* 203:609–14.

Cotter JL. 1937. The occurrence of flints and extinct animals in pluvial deposits near Clovis, New Mexico, pt. IV, Report on the excavations at the gravel pit in 1936. *Proceedings of the Philadelphia Academy of Natural Sciences* 89:1–16.

Cowan EA, Bornhold BD. 1998. Late Pleistocene geomarine record in Saanich Inlet, British Columbia: results from ODP sites 1033 and 1034. Paper presented at the annual meeting of the Geological Society of America, Toronto.

Cunningham DL, Wescott DJ. 2002. Within-group human variation in the Asian Pleistocene: the three Upper Cave crania. *Journal of Human Evolution* 42:627–38.

Cushing J, Wenner AM, Noble E, Daily M. 1986. A groundwater hypothesis for the origin of "fire areas" on the northern Channel Islands, California. *Quaternary Research* 26:207–17.

Davis LB. 2001. Folsom complex antecedents in Montana: the MacHaffie and Indian Creek Paleoindian occupational sequences. Paper presented at meeting of Canadian Archaeological Association, Banff, May 10.

DeFrance SD, Keefer DK, Richardson JB, Umire Alvarez A. 2001. Late Paleo-Indian coastal foragers: specialized extractive behavior at Quebrada Tacahuay, Peru. *Latin American Antiquity* 12(4):413–26.

Dent RJ. 1999. Shawnee Minisink: new dates on the Paleoindian component. Poster presented at the 64th annual meeting of the Society for American Archaeology, Chicago.

Derenko MV, Malarchuk BA, Dambeva IK, Shaikhaev GO, Dorzhu CM, Nimaev DD, Zakharov IA. 2000. Mitochondrial DNA variation in two Siberian aboriginal populations: implications for the genetic history of North Asia. *Human Biology* 72(6):945–74.

Derenko MV, Grzybowski T, Malarchuk BA, Czarny J, Miscicka-Sliwka D, Zakharov IA. 2001. The presence of mitochondrial haplogroup X in Altaians from South Siberia. *American Journal of Human Genetics* 69: 237–41.

Derevianko AP. 1989. The Late Pleistocene sites in the Slendia River basin and their significance for correlation with Upper Paleolithic assemblages of the Pacific. *Circum-Pacific Prehistory Conference Program and Abstracts.* Seattle. p 36.

Dikov NN. 1996. The Ushki sites, Kamchatka Peninsula. In: West FH, editor. *American beginnings: the prehistory and palaeoecology of Beringia.* University of Chicago Press. p 244–50.

Dikov NN, Titov EE. 1984. Problems of the stratification and periodization of the Ushki sites. *Arctic Anthropology* 21(2):1–68.

Dillehay TD. 1989. *Monte Verde, a Late Pleistocene settlement in Chile. Volume 1. Palaeoenvironment and site context.* Washington DC: Smithsonian Institution Press.

Dillehay TD. 1997. *Monte Verde, a Late Pleistocene settlement in Chile.* Volume 2. *The archaeological context and interpretation.* Washington, DC: Smithsonian Institution Press.

Dillehay TD. 2002. Errata. *Monte Verde, a Late Pleistocene settlement in Chile.* Volume 2. *The archaeological context and interpretation.* Washington, DC: Smithsonian Institution Press.

Dillehay TD, Meltzer DJ. 1991. Finale: processes and prospects. In: Dillehay TD, Meltzer DJ, editors. *The first Americans: search and research.* Boca Raton: CRC Press. p 287–94.

Dincauze D. 1984. An archaeo-logical evaluation of the case for pre-Clovis occupations. In: Wendorf F, Close A, editors. *Advances in world archaeology.* Volume 3. New York: Academic Press. p 275–323.

Dixon EJ. 1999. *Bones, boats, and bison: archeology and the first colonization of western North America*. Albuquerque: University of New Mexico Press.

Donohue JA. 1998. The chronology of the Jim Pitts site and implications for the temporal placement of the Goshen-Plainview complex in the northwestern Plains. Paper presented at 63rd annual meeting of Society for American Archaeology, Seattle.

Dorn RI. 1996. Uncertainties in the radiocarbon dating of organics associated with rock varnish: a plea for caution. *Physical Geography* 17(6):585–91.

Elias SA. 2000. Late Pleistocene climates of Beringia based on analysis of fossil beetles. *Quaternary Research* 53(2):229–35.

Elston RG, Cheng X, Madsen DB, Kan Z, Bettinger RL, Jingzen L, Brantingham PJ, Huiming W, Jun Y. 1997. New dates for the North China Mesolithic. *Antiquity* 71(274):985–93.

Erlandson JM. 1994. *Early hunter-gatherers of the California coast.* New York: Plenum Press.

Erlandson JM. 1998. Paleocoastal occupations of Daisy Cave, San Miguel Island, California. Paper presented at 63rd Annual Meeting of the Society for American Archaeology, Seattle.

Erlandson JM, Kennett DL, Ingram BL, Guthrie DA, Morris DP, Tveskov MA, West GJ, Walker PL. 1996. An archaeological and paleontological chronology for Daisy Cave (CA-SMI-261), San Miguel Island, California. *Radiocarbon* 38(2):355–73.

Erlandson J, Moss ML. 1996. The Pleistocene-Holocene transition along the Pacific coast of North America. In: Straus LG, Eriksen BV, Erlandson JM, Yesner DR, editors. *Humans at the end of the Ice Age: the archaeology of the Pleistocene-Holocene transition.* New York: Plenum Press. p 278–302.

Fairbanks RG, Charles CD, Wright JD. 1992. Origin of global meltwater pulses. In: Taylor RE, Long A, Kra RS, editors. *Radiocarbon after four decades.* New York: Springer-Verlag. p 473–500.

Faught MK. 1996. Clovis origins and underwater prehistoric archaeology in northwestern Florida. PhD dissertation. University of Arizona, Department of Anthropology.

Feathers JK. 1997. The application of luminescence dating in American archaeology. *Journal of Archaeological Method and Theory* 4(1):1–66.

Fedje DW, Josenhans H. 2000. Drowned Forests and Archaeology on the Continental Shelf of British Columbia, Canada. *Geology* 28(2):99–102.

Fedje DW, McSporran JB, Mason AR. 1996. Early Holocene archaeology and paleoecology at the Arrow Creek sites in Gwaii Haanas. *Arctic Anthropology* 33(1):116–42.

Ferring CR. 1995. The Late Quaternary geology and archaeology of the Aubrey Clovis site, Texas: a preliminary report. In: Johnson E, editor. *Ancient peoples and landscapes*. Lubbock: Museum of Texas Tech University. p 273–81.

Ferring CR. 2001. *The archaeology and paleoecology of the Aubrey Clovis site (41DN479), Denton County, Texas*. Report from Center for Environmental Archaeology, University of North Texas, to U.S. Army Corps of Engineers, Fort Worth District.

Fiedel SJ. 1998. Rapid migrations by Arctic hunting peoples: Clovis and Thule. Paper presented at 63rd annual meeting of Society for American Archaeology, Seattle, March 26.

Fiedel SJ. 1999a. Older than we thought: implications of corrected dates for Paleoindians. *American Antiquity* 64(1):95–116.

Fiedel SJ. 1999b. Artifact provenience at Monte Verde: confusion and contradictions. *Scientific American Discovering Archaeology* 1(6):Special Report 1–12.

Fiedel SJ. 2000. The peopling of the New World: present evidence, new theories, and future directions. *Journal of Archaeological Research* 8(1):39–103.

Fiedel SJ, Anthony D. 1979. The diffusion of the early European Neolithic: a reconsideration. Paper delivered at the Second Eastern European Archaeology (Hleb i Vino) Conference. University of Pennsylvania, Philadelphia.

Fladmark KR. 1979. Routes: alternate migration corridors for early man in North America. *American Antiquity* 44:55–69.

Fladmark KR. 1983. Times and places: environmental correlates of mid-to-late Wisconsinan human population expansion in North America. In: Shutler R Jr, editor. *Early man in the New World.* Beverly Hills: Sage Publications. p 13–42.

Fladmark KR, Driver JC, Alexander D. 1988. The Paleoindian component at Charlie Lake Cave (HbRf 39), British Columbia. *American Antiquity* 53(2):371–84.

Flannery TF. 1999. Debating extinction. *Science* 283: 182–3.

Flegenheimer N. 1986–1987. Excavaciones en el sitio 3 de la localidad Cerro La China (Prov. de Bs. As.) *Relaciones de la Sociedad Argentina de Antropología* T. XVII-I:7–28.

Flegenheimer N, Zarate M. 1997. Considerations on radiocarbon and calibrated dates from Cerro La China and Cerro El Sombrero, Argentina. *Current Research in the Pleistocene* 14:27–8.

Foit FF Jr, Mehringer PJ Jr, Sheppard JC. 1993. Age, distribution, and stratigraphy of Glacier Peak tephra in eastern Washington and western Montana, United States. *Canadian Journal of Earth Sciences* 30:535–52.

Friedrich M, Kromer B, Spurk M, Hofmann J, Kaiser KF. 1999. Paleo-environment and radiocarbon calibration as derived from Lateglacial/Early Holocene tree-ring chronologies. *Quaternary International* 61:27-39.

Friedrich M, Kromer B, Kaiser KF, Spurk M, Hughen KA, Johnsen SJ. 2001. High-resolution climate signals in the Bølling-Allerød Interstadial (Greenland Interstadial 1) as reflected in European tree-ring chronologies compared to marine varves and ice-core records. *Quaternary Science Reviews* 20:1223–32.

Frison GC. 1991. The Goshen Paleoindian complex: New data for Paleoindian research. In: Bonnichsen R, Turnmire KL, editors. *Clovis: origins and adaptations.* Corvallis, Oregon: Center for the Study of the First Americans. p 133–52.

Frison GC. 1993. The North American Paleoindian: a wealth of new data but still much to learn. *Plains Anthropologist* 38(145), Memoir 27. p 5–16.

Frison GC. 1996. *The Mill Iron site.* Albuquerque: University of New Mexico Press.

Goddard I, Campbell L. 1994. The history and classification of American Indian languages: what are the implications for the peopling of the Americas? In: Bonnichsen R, Steele DG, editors. *Method and theory for investigating the peopling of the Americas.* Corvallis, Oregon: Center for the Study of the First Americans. p 189–208.

Goebel T. 1993. Characterizing the Siberian Middle-Upper Paleolithic transition. Paper presented at 58th Annual Meeting of the Society for American Archaeology, St Louis, Missouri, USA.

Goebel T. 1998. The Siberian Upper Paleolithic: hard environments, limiting factors, and human range expansion into northern Asia. Paper presented at 63rd Annual Meeting of the Society for American Archaeology, Seattle, 25–29 March.

Goebel T, Aksenov M. 1995. Accelerator radiocarbon dating of the initial Upper Palaeolithic in southeastern Siberia. *Antiquity* 69:349–57.

Goebel T, Powers R, Bigelow N. 1991. The Nenana complex of Alaska and Clovis origins. In: Bonnichsen R, Turnmire KL, editors. *Clovis: origins and adaptations.* Corvallis, Oregon: Center for the Study of the First Americans. p 49–80.

Goebel T, Waters MR, Buvit I, Konstantinov MV, Konstantinov AV. 2000. Studenoe-2 and the origins of microblade technologies in the Transbaikal, Siberia. *Antiquity* 74:567–75.

Goebel T, Waters MR, Dikova M. 2002. The Ushki sites, Kamchatka, and the Pleistocene peopling of the

Americas. Paper presented at 67th annual meeting of Society for American Archaeology, Denver. 20–24 March.

Goodyear AC. 1997. Clovis utilization at southeastern U.S. quarries: the Big Pine Tree site, Allendale, South Carolina. Paper presented at 62nd Annual Meeting of the Society for American Archaeology, Nashville.

Goslar T, Wohlfarth B, Bjorck S, Possnert G, Bjorck J. 1999. Variations of atmospheric ^{14}C concentrations over the Allerød-Younger Dryas transition. *Climate Dynamics* 15:29–42.

Graham R. 1998. Mammals' eye view of environmental change in the United States at the end of the Pleistocene. Paper presented at 63rd Annual Meeting of the Society for American Archaeology, Seattle.

Graham R, Stafford T, Lundelius E, Semken H, Southon J. 2002. C-14 Chronostratigraphy and Litho-stratigraphy of Late Pleistocene Megafauna Extinctions in the New World. Paper presented at 67th annual meeting of Society for American Archaeology, Denver, 20–24 March.

Grayson DK. 1991. Late Pleistocene mammalian extinction in North America: taxonomy, chronology, and explanations. *Journal of World Prehistory* 5(3):193–231.

Greenberg JH. 1987. *Language in the Americas.* Palo Alto, California: Stanford University Press.

Greenman E. 1963. The Upper Palaeolithic and the New World. *Current Anthropology* 4:41–91.

Gruhn R. 1988. Linguistic evidence in support of the coastal route of earliest entry into the New World. *Man* 23:77–100.

Gruhn R. 1994. The Pacific Coast route of initial entry: an overview. In: Bonnichsen R, Steele DG, editors. *Method and theory for investigating the peopling of the Americas.* Corvallis, Oregon: Center for the Study of the First Americans. p 249–56.

Guilday JE, Parmalee PW. 1982. Vertebrate faunal remains from Meadowcroft Rockshelter, Washington County, Pennsylvania. In: Carlisle RC, Adovasio JM, editors. *Meadowcroft: collected papers on the archaeology of Meadowcroft Rockshelter and the Cross Creek drainage.* p 163–74.

Hajdas I, Ivy-Ochs SD, Bonani G, Lotter AF, Zollitschka B, Schluchter C. 1995. Radiocarbon age of the Laacher See tephra: 11,230 ± 40 BP. *Radiocarbon* 37(2):149–54.

Hamilton TD, Goebel T. 1999. Late Pleistocene peopling of Alaska. In: Bonnichsen R, Turnmire KL, editors. *Ice Age people of North America, environments, origins, and adaptations.* Covallis: Oregon State University Press. p 156–99.

Hanebuth T, Stattegger K, Grootes PM. 2000. Rapid flooding of the Sunda Shelf: a Late-Glacial sea-level record. *Science* 288:1033–5.

Haury EW, Sayles EB, Wasley WW. 1959. The Lehner Mammoth site, southeastern Arizona. *American Antiquity* 25(1):2–30.

Haynes CV Jr. 1964. Fluted projectile points: their age and dispersion. *Science* 145:1408–13.

Haynes CV Jr. 1966. Elephant-hunting in North America. *Scientific American* 214(6):104–12.

Haynes CV Jr. 1974. Paleoenvironments and cultural diversity in late Pleistocene South America: a reply to A. L. Bryan. *Quaternary Research* 4:378–82.

Haynes CV Jr. 1980b. Paleoindian charcoal from Meadowcroft Rock Shelter: is contamination a problem? *American Antiquity* 45:583–7.

Haynes CV Jr. 1982. Were Clovis progenitors in Beringia? In: Hopkins DM, Matthews JV, Schweger CE, Young SB, editors. *Paleoecology of Beringia.* New York: Academic Press. p 383–98.

Haynes CV Jr. 1987. Clovis origin update. *The Kiva* 52(2):83–93.

Haynes CV Jr. 1991a. More on Meadowcroft radiocarbon chronology. *The Review of Archaeology* 12(1):8–14.

Haynes CV Jr. 1991b. Geoarchaeological and paleohydrological evidence for a Clovis-age drought in North America and its bearing on extinction. *Quaternary Research* 35:438–50.

Haynes CV Jr. 1992. Contributions of radiocarbon dating to the geochronology of the peopling of the New World. In: Taylor RE, Long A, Kra RS, editors. *Radiocarbon after four decades.* New York: Springer-Verlag. p 355–74.

Haynes CV Jr. 1993. Clovis-Folsom geochronology and climatic change. In: Soffer O, Praslov ND, editors. *From Kostenki to Clovis: Upper Paleolithic-Paleoindian adaptations.* New York: Plenum Press. p 219–36.

Haynes CV Jr. 1998. Geochronology of the stratigraphic manifestation of paleoclimatic events at Paleoindian sites. Paper presented at 63rd Annual Meeting of the Society for American Archaeology, Seattle.

Haynes CV Jr [no date]. Clovis, pre-Clovis, climate change, and extinction. Unpublished manuscript.

Haynes CV Jr, Donahue DJ, Jull AJT, Zabel TH. 1984. Application of accelerator dating to fluted point Paleoindian sites. *Archaeology of Eastern North America* 12:184–91.

Haynes, G. 1999. The role of mammoths in rapid Clovis dispersal. In: Haynes G, Klimowicz J, Reumer WF, editors. Mammoths and the Mammoth fauna: studies of an extinct ecosystem. *DEINSEA* 6:9–38.

Heaton TH, Talbot SL, Shields GF. 1996. An Ice Age refugium for large mammals in the Alexander Archipelago, Southeast Alaska. *Quaternary Research* 46:186–92.

Hilgers A, Murray AS, Schlaak N, Radtke U. 2001. Comparison of quartz OSL protocols using Lateglacial and Holocene dune sands from Brandenburg, Germany. *Quaternary Science Reviews* 20(5–9):731–6.

Hoffecker JF, Powers WR, Goebel T. 1993. The colonization of Beringia and the peopling of the New World. *Science* 259:46–53.

Holdaway R, Jacomb C. 2000. Rapid extinction of the Moas (Aves:Dinornithiformes): model, test, and implications. *Science* 287:2250–4.

Holmes CE. 1998. New data pertaining to Swan Point, the oldest microblade site known in Alaska. *Current Research in the Pleistocene* 15:21–2.

Howells W. 1967. *Mankind in the making.* Garden City: Doubleday.

Hughen KA, Overpeck JT, Lehman SJ, Kashgarian M, Southon JR, Peterson LC, Alley R, Sigman DM. 1998. Deglacial changes in ocean circulation from an extended radiocarbon calibration. *Nature* 391:65–8.

Hughen KA, Southon JR, Lehman SJ, Overpeck JT. 2000. Synchronous radiocarbon and climate shifts during the last deglaciation. *Science* 290:1951–4.

Ingman M, Kaessmann H, Paabo S, Gyllensten U. 2000. Mitochondrial genome variation and the origin of modern humans. *Nature* 408:708–13.

Irwin-Williams C. 1967. Association of early man with horse, camel and mastodon at Hueyatlaco, Valsequillo (Puebla, Mexico). In: Martin PS, editor. *Pleistocene extinctions.* New Haven: Yale University Press. p 337–47.

Irwin-Williams C. 1978. Summary of archaeological evidence from the Valsequillo region, Puebla, Mexico. In: Browman DL, editor. *Cultural continuity in Mesoamerica*. London: Mouton. p 7–22.

Irwin-Williams C. 1981. Letter: commentary on geologic evidence for age of deposits at Hueyatlaco archaeological site, Valsequillo, Mexico. *Quaternary Research* 16:258.

Ives JW, Beaudoin AW, Magne MPR. 1993. Evaluating the role of a Western Corridor in the peopling of the Americas. Paper presented at Circum-Pacific Prehistory Conference, 2–6 August 1989. Revised for Proceedings volume, in press.

Jackson LE Jr, Duk-Rodkin A. 1996. Quaternary geology of the ice-free corridor: Glacial controls on the peopling of the New World. In: Akazawa T, Szathmary EJE, editor. *Prehistoric Mongoloid dispersals.* Oxford: Oxford University Press. p 214–27.

Johnson DL. 1983. The California continental borderland: landbridges, watergaps and biotic dispersals. In: Masters PM, Fleming NC, editors. *Quaternary coastlines and marine archaeology: towards the prehistory of land bridges and continental shelves.* London: Academic Press. p 481–528.

Johnson MF. 1997. Confirmation of McAvoy's early Cactus Hill sequence. Paper presented at Middle Atlantic Archaeological Conference, Ocean City, Maryland.

Jones MD, Sheppard PJ, Sutton DG. 1997. Soil temperature and obsidian hydration dating: a clarification of variables affecting accuracy. *Journal of Archaeological Science* 24:505–17.

Josenhans H, Fedje D, Pienitz R, Southon J. 1997. Early Humans and Rapidly Changing Holocene Sea Levels in the Queen Charlotte Islands-Hecate Strait, British Columbia, Canada. *Science* 277:71–4.

Kaiser KF. 1989. Late glacial reforestation in the Swiss Mittelland, as illustrated by the Dättnau Valley. In: Rose J, Schluchter C, editors. *Quaternary type sections: imagination or reality.* Rotterdam: Balkema. p 161–78.

Kaiser KF. [no date]. ^{14}C and dendro years, Dättnau: Boelling/Alleroed chronologies. Graph formerly posted at www.wsl.ch/forest/dendro/images/dendroy.jpg.

Kamminga J, Wright RVS. 1988. The Upper Cave at Zhoukoudian and the origins of the Mongoloids. *Journal of Human Evolution* 17:739–67.

Karafet TM, Zegura SL, Posukh O, Osipova L, Bergen A, Long J, Goldman D, Klitz W, Harihara S, de Knijff P, Griffiths RC, Templeton AR, Hammer MF. 1999. Ancestral Asian source(s) of New World Y-chromosome founder haplotypes. *American Journal of Human Genetics* 64(3):817–31.

Keefer DK, deFrance SD, Moseley ME, Richardson JB III, Satterlee DR, Day-Lewis A. 1998. Early maritime economy and El Niño events at Quebrada Tacahuay, Peru. *Science* 281(5384):1833–5.

Kelly RL. 1987. A comment on the Pre-Clovis deposits at Meadowcroft Rockshelter. *Quaternary Research* 27:332–4.

Kelly RL, Todd LC. 1988. Coming into the country: Early Paleoindian hunting and mobility. *American Antiquity* 53(2):231–44.

King MB, Slobodin SB. 1996. A fluted point from the Uptar site, northeastern Siberia. *Science* 273: 634–6.

Kipnis R. 1998. Early hunter-gatherers in the Americas: Perspectives from central Brazil. *Antiquity* 72:581–92.

Kiryak MA. 1996. Bolshoi Elgakhchan 1 and 2, Omolon River basin, Magadan district. In: West FH, editor. *American beginnings: the prehistory and palaeoecology of Beringia.* Chicago: University of Chicago Press. p 228–36.

Kitigawa H, van der Plicht J. 1998. Atmospheric radiocarbon calibration to 45,000 yr B.P.: Late Glacial fluctuations and cosmogenic isotope production. *Science* 279:1187–90.

Kitigawa H, van der Plicht J. 2000. Atmospheric radiocarbon calibration beyond 11,900 cal BP from Lake Suigetsu laminated sediments. *Radiocarbon* 42(3): 369–80.

Kolman CJ, Sambuughin N, Bermingham E. 1996. Mitochondrial DNA analysis of Mongolian populations and implications for the origin of New World founders. *Genetics* 142(4):1321–34.

Kovanen DJ, Easterbrook DJ. 2002. Paleodeviations of radiocarbon marine reservoir values for the northeast Pacific. *Geology* 30(3):243–6.

Kunz ML, Reanier RE. 1994. Paleoindians in Beringia: evidence from Arctic Alaska. *Science 263*: 660–2.

Kuzmin YV, Orlova LA. 2000. The Neolithization of Siberia and the Russian Far East: radiocarbon evidence. *Antiquity* 74:356–64.

Kuzmin YV, Orlova LA. 1998. Radiocarbon chronology of the Siberian Paleolithic. *Journal of World Prehistory* 12(1):1–53.

Kuzmin YV, Tankersley KB. 1996. The colonization of eastern Siberia: an evaluation of the Paleolithic age radiocarbon dates. *Journal of Archaeological Science* 23:577–85.

Lahr MM. 1995. Patterns of modern human diversification: implications for Amerindian origins. *Yearbook of Physical Anthropology* 38:163–98.

Lea PD. 1996. Vertebrate tracks in Pleistocene eolian sand-sheet deposits of Alaska. *Quaternary Research* 45(2):226–40.

Lell JT, Sukernik RI, Starikovskaya YB, Su B, Jin L, Schurr TG, Underhill PA, Wallace DC. 2002. The dual origin and Siberian affinities of Native American Y chromosomes. *American Journal of Human Genetics* 70:192–206.

Long A, Martin PS. 1974. Death of American ground sloths. *Science* 186:638–40.

Long A, Martin PS, Lagiglia HA. 1998. Ground sloth extinction and human occupation at Gruta del Indio, Argentina. *Radiocarbon* 40(2):693–700.

Loy TH, Dixon EJ. 1998. Blood residues on fluted points from eastern Beringia. *American Antiquity* 63(1):21–46.

Lynch TF. 1983. The Paleo-Indians. In: Jennings JD, editor. *Ancient South Americans.* San Francisco: Freeman. p 86–137.

Lynch TF. 1990. Glacial-age man in South America? A critical review. *American Antiquity* 55(1): 12–36.

MacDonald DH. 1998. Subsistence, sex and cultural transmission in Folsom culture. *Journal of Anthropological Archaeology* 17:217–39.

MacDonald GF. 1968. *Debert, a Paleo-Indian site in central Nova Scotia*. Anthropology Papers No. 16, National Museums of Canada, Ottawa.

MacNeish RS. 1983. Mesoamerica. In: Shutler R Jr, editor. *Early Man in the New World.* Beverly Hills: Sage Publications. p 125–36.

Malhi RS, Eshleman JA, Greenberg JA, Weiss DA, Schultz Shook BA, Kaestle FA, Lorenz JG, Kemp BM, Johnson JR, Smith DG. 2002. The structure of diversity within New World mitochondrial DNA haplogroups: implications for prehistory of North America. *American Journal of Human Genetics* 70:905–19.

Mandryk CAS. 1998. Evaluating paleoenvironmental constraints on interior and coastal entry routes into North America. Paper presented at 63rd annual meeting of Society for American Archaeology, Seattle.

Martin PS. 1973. The discovery of America. *Science* 179: 969–74.

Mayer-Oakes WJ. 1984. Fluted projectile points—A North American *shibboleth* viewed in South American perspective. *Archaeology of Eastern North America* 12:231–47.

McAvoy JM, McAvoy LD. 1997. *Archaeological investigations of site 44SX202, Cactus Hill, Sussex County, Virginia*. Virginia Department of Historic Resources, Research Report Series No. 8, Richmond.

McAvoy JM, Baker JC, Feathers JK, Hodges RL, McWeeney LJ, Whyte TR. [no date]. Summary of Research at the Cactus Hill Archaeological site, 44SX202, Sussex County, Virginia: Report to the National Geographic Society in compliance with stipulations of grant #6345-98.

McGhee R. 1984. Thule prehistory of Canada. In: Damas D, editor. *Arctic*, *handbook of North American Indians.* Volume 5. Washington DC: Smithsonian Institution Press. p 369–76.

McNett CW, editor. 1985. *Shawnee Minisink: a stratified Paleoindian-Archaic site in the upper Delaware Valley of Pennsylvania.* New York: Academic Press.

Mead JI. 1980. Is it really that old? A comment about the Meadowcroft Rockshelter "overview." *American Antiquity* 45(3):579–81.

Mehringer PJ Jr. Foit FF Jr. 1990. Volcanic ash dating of the Clovis cache at East Wenatchee, Washington. *National Geographic Research* 6(4):495–503.

Mehringer PJ Jr, Sheppard JC, Foit FF Jr. 1984. The age of Glacier Peak tephra in west-central Montana. *Quaternary Research* 21:36–41.

Meighan CW. 1983. Early man in the New World. In: Masters PM, Fleming NC, editors. *Quaternary coastlines and marine archaeology: towards the prehistory of land bridges and continental shelves.* London: Academic Press. p 441–62.

Meltzer DJ. 1997. Monte Verde and the Pleistocene peopling of the Americas. *Science* 276:754–5.

Meltzer DJ, Adovasio JM, Dillehay TD. 1994. On a Pleistocene human occupation at Pedra Furada, Brazil. *Antiquity* 68:261.

Meltzer DJ, Grayson DK, Ardila G, Barker AW, Dincauze DF, Haynes CV, Mena F, Nunez L, Stanford DJ. 1997. On the Pleistocene Antiquity of Monte Verde, Southern Chile. *American Antiquity* 62(4):659–63.

Meltzer DJ, Mead JI. 1985. Dating Late Pleistocene extinctions: Theoretical issues, analytical bias, and substantive results. In: Mead JI, Meltzer DJ, editors. *Environments and extinctions: man in Late Glacial North America.* Orono: Center for the Study of Early Man. p 145–74.

Merriwether DA, Rothhammer F, Ferrell RE. 1994. Genetic variation in the New World: ancient teeth, bone, and tissue as sources of DNA. *Experientia* 50:592–601.

Miller GH, Magee JW, Johnson BJ, Fogel ML, Spooner NA, McCulloch MT, Ayliffe LK. 1999. Pleistocene extinction of *Genyornis newtoni*: human impact on Australian megafauna. *Science* 283:205–8.

Mochanov YA, Fedoseeva SA. 1996a. Berelekh, Allakhovsk region. In: West FH, editor. *American begin-*

nings: the prehistory and palaeoecology of Beringia. Chicago: University of Press. p 218–21.

Mochanov YA, Fedoseeva SA. 1996b. Dyuktai Cave. In: West FH, editor. *American beginnings: the prehistory and palaeoecology of Beringia.* Chicago: University of Press. p 164–71.

Morlan RE. 1991. Peopling of the New World: a discussion. In: Bonnichsen R, Turnmire KL, editors. *Clovis: origins and adaptations.* Corvallis, Oregon: Center for the Study of the First Americans. p 303–8.

Morlan RE, Cinq-Mars J. 1982. Ancient Beringians: human occupation in the Late Pleistocene of Alaska and the Yukon Territory. In: Hopkins DM, Matthews JV Jr, Schweger CE, Young SB, editors. *Paleoecology of Beringia.* New York: Academic Press. p 353–81.

Morrow J, Morrow T. 1999. Geographic variation in fluted projectile points: a hemispheric perspective. *American Antiquity* 64(2):215–30.

Nami HG. 1994. Reseña sobre los avances de la arqueología finipleistocénica del extremo sur de Sudamérica. *Revista Chungara* 26(2):145–63.

Nami HG. 1996. New assessments of early human occupations in the Southern Cone. In: Akazawa T, Szathmáry EJE, editors. *Prehistoric Mongoloid dispersals.* Oxford: Oxford University Press. p 256–69.

Neumann GK. 1952. Archeology and race in the American Indian. In: Griffin JB, editor. *Archeology of Eastern United States.* Chicago: University of Chicago Press. p 13–34.

Neves WA, Powell JF, Prous A, Ozolin EG. 1998. Lapa Vermelha IV, Hominid 1: morphological affinities of the earliest known American. *American Journal of Physical Anthropology* Supplement 26:169.

Núñez L, Santoro C. 1990. Primeros poblamientos en el cono sur de America (XII-IX milenio A.P.) *Revista de Arqueologia Americana* 1:91–139.

Orr PC. 1968. *Prehistory of Santa Rosa Island.* Santa Barbara, California: Santa Barbara Museum of Natural History.

Overstreet DF, Stafford TW Jr. 1997. Additions to a revised chronology for cultural and non-cultural mammoth and mastodon fossils in the southwestern Lake Michigan basin. *Current Research in the Pleistocene* 14:70–1.

Pearson GA. 1997b. Non-Mongoloid Pleistocene expansions: old and new ideas on the origins of the first Americans. Paper presented at 24th annual meeting of Alaska Anthropological Association, White Horse, Yukon.

Pearson GA. 1998. Pan-American Paleoindian dispersals as seen through the lithic reduction strategies and tool manufacturing techniques at the Guardiria site, Turrialba valley, Costa Rica. Paper presented at 63rd annual meeting of Society for American Archaeology, Seattle.

Pichardo M. 2000. Redating Iztapan and Valsequillo, Mexico. *Radiocarbon* 42(2):305–10.

Politis G. 1997. The peopling of the Americas viewed from the Southern Cone. Paper presented at 62nd Annual Meeting of the Society for American Archaeology, Nashville.

Prous A, Fogaça E. 1999. Archaeology of the Pleistocene-Holocene boundary in Brazil. *Quaternary International* 53/54:21–41.

Quade J, Forester RM, Pratt WL, Carter C. 1998. Black mats, spring-fed streams, and Late Glacial age recharge in the southern Great Basin. *Quaternary Research* 49:129–48.

Ranere AJ. 1997. Paleoindian expansion into tropical America: the view from Central America. Paper presented at 62nd Annual Meeting of the Society for American Archaeology, Nashville.

Ranere AJ, Cooke RG. 1991. Paleoindian occupation in the Central American tropics. In: Bonnichsen R, Turnmire KL, editors. *Clovis: origins and adaptations.* Corvallis, Oregon: Center for the Study of the First Americans. p 237–54.

Ray JH, Lopinot NH, Hajic ER, Mandel RD. 1998. The Big Eddy site: a multicomponent Paleoindian site on the Ozark border, southwest Missouri. *Plains Anthropologist* 43(163):73–81.

Reanier RE. 1995. The antiquity of Paleoindian materials in northern Alaska. *Arctic Anthropology 32*(1):31–50.

Rensberger B. 1997. Putting a new face on prehistory: skeletons suggest Caucasoid early Americans. *Washington Post*. April 15.

Rich J, Stokes S. 2001. Optical dating of geoarchaeologically significant sites from the southern High Plains and south Texas, USA. *Quaternary Science Reviews* 20(5–9):949–59.

Ridings R. 1996. Where in the world does obsidian hydration dating work? *American Antiquity* 61(1):136–48

Roberts R, Bird M, Olley J, Galbraith R, Lawson E, Laslett G, Yoshida H, Jones R, Fullagar R, Jacobsen G, Hua Q. 1998. Optical and radiocarbon dating at Jinmium rockshelter in northern Australia. *Nature* 393: 358–60.

Roberts RG, Flannery TF, Ayliffe LK, Yoshida H, Olley JM, Prideaux GJ, Laslett GM, Baynes A, Smith MA, Jones R, Smith BL. 2001. New ages for the last Australian megafauna: continent-wide extinction about 46,000 years ago. *Science* 292(5523):1888.

Roosevelt AC, Lima da Costa M, Lopes Machado C, Michab M, Mercier N, Vallada H, Feathers J, Barnet W, Imazio da Silveira M, Henderson A, Sliva J, Chernoff B, Reese DS, Holman JA, Toth N, Schick K. 1996. Paleoindian cave dwellers in the Amazon: the peopling of the Americas. *Science* 272:373–84.

Sandweiss DH, McInnis H, Burger RL, Cano A, Ojeda B, Paredes R, del Carmen Sandweiss M, Glascock MR. 1998. Quebrada Jaguay: early South American maritime adaptations. *Science 281* (5384):1830–2.

Sandweiss DH, Tanner B, Sanger D, Andrus F, Piperno

D. 2000. Paleoindian-age domestic structure at a Peruvian fishing site. Paper presented at 65th annual meeting of Society for American Archaeology, Philadelphia.

Santos FR, Pandya A, Tyler-Smith C, Pena SDJ, Schanfield M, Leonard WR, Osipova Crawford MH, Mitchell RJ. 1999. The Central Siberian origin for Native American Y chromosomes. *American Journal of Human Genetics* 64:619–28.

Schurr TG. 2000. Mitochondrial DNA and the peopling of the New World. *American Scientist* 88:246–53.

Schwander J, Eicher U, Ammann B. 2000. Oxygen isotopes of lake marl at Gerzensee and Leysin (Switzerland) covering the Younger Dryas and two minor oscillations and their correlation to the GRIP ice core. *Palaeogeography, Palaeoclimatology, Palaeoecology* 159:203–14.

Sellars VS. 1999. The accuracy of AMS ^{14}C dates on human bone and associated vertebrate remains—determining chronologies for late Pleistocene human occupation of the New World. Poster presented at "Clovis and Beyond" conference, Santa Fe, New Mexico.

Sellards EH. 1952. *Early man in America.* Austin: University of Texas Press.

Semaw S. 2000. The world's oldest stone artifacts from Gona, Ethiopia: their implications for understanding stone technology and patterns of human evolution between 2.6-1.5 million years ago. *Journal of Archaeological Science* 27(12):1197–214.

Semino O, Passarino G, Oefner PJ, Lin AA, Arbuzova S, Beckman LE, De Benedictis G, Francalacci P, Kouvatsi A, Limborska S, Marcikae M, Mika A, Mika B, Primorac D, Santachiara-Benerecetti AS, Cavalli-Sforza LL, Underhill PA. 2000. The genetic legacy of Paleolithic *Homo sapiens* in extant Europeans: A Y chromosome perspective. *Science* 290:1155–9.

Snarskis M J. 1979. Turrialba: a Paleoindian quarry and workshop site in eastern Costa Rica. *American Antiquity* 44(1):110–24.

Southon J. 2002 A first step to reconciling the GRIP and GISP2 ice-core chronologies, 0–14,500 yr B.P. *Quaternary Research* 57:32–7.

Sowers T, Bender M. 1995. Climate records covering the last deglaciation. *Science* 269: 210–4.

Stafford TW Jr. 1994. Accelerator C-14 dating of human fossil skeletons: assessing accuracy and results on New World specimens. In: Bonnichsen R, Steele DG, editors. *Method and theory for investigating the peopling of the Americas.* Corvallis, Oregon: Center for the Study of the First Americans. p 45–56.

Stafford TW Jr. Sellars VS, Johnson JR. 2002. Chronostratigraphy at Arlington Springs, a Paleoindian site in insular California. Paper presented at 67th annual meeting of Society for American Archaeology, Denver, 20–24 March.

Stanford D. 1983. Pre-Clovis occupation south of the ice sheets. In: Shutler R Jr. *Early man in the New World.* Beverly Hills: Sage Publications. p 65–72.

Stanford D. 1998. The first Americans: a new perspective. Paper presented at 33rd Annual Symposium of Archeological Society of Maryland, Crownsville, 18 April.

Steele DG, Powell JF. 1992. Peopling of the Americas: paleobiological evidence. *Human Biology* 64:303–36.

Steele DG, Powell JF. 1994. Paleobiological evidence of the peopling of the Americas: a morphometric view. In: Bonnichsen R, Steele DG, editors. *Method and theory for investigating the peopling of the Americas.* Corvallis, Oregon: Center for the Study of the First Americans. p 141–64.

Steele J, Politis G, Pettitt P. 2001. AMS radiocarbon dating of the earliest Paleoindian occupation of the southern cone of South America. Paper presented at 66th Annual Meeting of the Society for American Archaeology, New Orleans, 18–22 April.

Steen-McIntyre V, Fryxell R, Malde HE. 1981. Geologic evidence for age of deposits at Hueyatlaco archeological site, Valsequillo, Mexico. *Quaternary Research* 16:1–17.

Straus LG. 2000. Solutrean settlement of North America? A review of reality. *American Antiquity* 65(2): 219–26.

Stuiver M, Reimer PJ, Bard E, Beck JW, Burr GS, Hughen KA, Kromer B, McCormac FG, van der Plicht J, Spurk M. 1998. INTCAL98 radiocarbon age calibration 24,000–0 cal BP. *Radiocarbon* 40(3):1041–83.

Surovell TA. 2000. Early Paleoindian women, children, mobility, and fertility. *American Antiquity* 65:493–508.

Szabo BJ, Malde HE, Irwin-Williams C. 1969. Dilemma posed by uranium-series dates on archaeologically significant bones from Valsequillo, Puebla, Mexico. *Earth and Planetary Science Letters* 6: 237–44.

Tankersley KB, Munson CA. 1992. Comments on the Meadowcroft Rockshelter Radiocarbon Chronology and the Recognition of Coal Contaminants. *American Antiquity* 57:321–6.

Tankersley KB, Tompkins C, Kuzmin YV. 1996. Clovis precursors: the Siberian roots of fluted points. Paper presented at 61st Annual Meeting of the Society for American Archaeology, New Orleans, 10–14 April.

Taylor RE. 1991. Frameworks for dating the Late Pleistocene peopling of the Americas. In: Dillehay TD, Meltzer DJ, editor. *The first Americans: search and research.* Boca Raton: CRC Press. p 77–112.

Taylor RE, Payen LA, Prior CA, Slota PJ Jr, Gillespie R, Gowlett JAJ, Hedges REM, Jull AJT, Zabel TH, Donahue DJ, Berger R. 1985. Major revisions in the Pleistocene age assignments for North American human skeletons by C-14 accelerator mass spectrometry: none older than 11,000 C-14 years B.P. *American Antiquity* 50(1):136–40.

Taylor RE, Haynes CV Jr, Stuiver M. 1996. Clovis and

Folsom age estimates: stratigraphic context and radiocarbon calibration. *Antiquity* 70(269):515–25.

Turney CSM, Coope GR, Harkness DD, Lowe JJ, Walker MJC. 2000. Implications for the dating of Wisconsinan (Weichselian) late-glacial events of systematic radiocarbon age differences between terrestrial plant macrofossils from a site in SW Ireland. *Quaternary Research* 53(1):114–21.

Turney CSM, Bird MI, Fifield LK, Roberts RG, Smith M, Dortch CE, Grun R, Lawson E, Ayliffe LK, Miller GH, Dortch J, Cresswell RG. 2001. Early human occupation at Devil's Lair, southwestern Australia 50,000 years ago. *Quaternary Research* 55(1):3–13.

Tuross N, Dillehay TD. 1995. The mechanism of organic preservation at Monte Verde, Chile, and one use of biomolecules in archaeological interpretation. *Journal of Field Archaeology* 22(1):97–110.

Underhill DA, Li J, Zemans R, Oefner PJ, Cavalli-Sforza LL. 1996. A Pre-Columbian Y chromosome-specific transition and its implications for human evolutionary history. *Proceedings of the National Academy of Sciences* 93:196–200.

Underhill DA, Shen P, Lin AA, Jin L, Passarino G, Yang WH, Kauffman E, Bonne-Tamir B, Bertranpetit J, Francalacci P, Ibrahim M, Jenkins T, Kidd JR, Mehdi SQ, Seielstad MT, Wells RS, Piazza A, Davis RW, Feldman MW, Cavalli-Sforza LL, Oefner PJ. 2000. Y chromosome sequence variation and the history of human populations. *Nature Genetics* 26(3):358–61.

Vartanyan SL, Arslanov KA, Tertychnaya TV, Chernov SB. 1995. Radiocarbon dating evidence for mammoths on Wrangel Island, Arctic Ocean, until 2000 BC. *Radiocarbon* 37(1):1–6.

Vasilievsky RS. 1996. Ustinovka 1. In: West FH, editor. *American beginnings: the prehistory and palaeoecology of Beringia.* Chicago: University of Chicago Press. p 255–67.

Waters MR. 1985. Early man in the New World: an evaluation of the radiocarbon-dated pre-Clovis sites in the Americas. In: Mead JI, Meltzer DJ, editors. *Environments and extinctions: man in Late Glacial North America.* Orono: Center for the Study of Early Man. p 125–44.

West FH. 1981. *The archaeology of Beringia.* New York: Columbia University Press.

West FH, editor. 1996. *American beginnings: the prehistory and palaeoecology of Beringia*. Chicago: University of Chicago Press.

Whitley DS, Dorn RI. 1993. New perspectives on the Clovis vs. pre-Clovis controversy. *American Antiquity* 58(4):626–47.

Whitridge P. 2001. Zen fish: a consideration of the discordance between artifactual and zooarchaeological indicators of Thule Inuit fish use. *Journal of Anthropological Archaeology* 20:3–72.

Wilson MC, Burns JA. 1999. Searching for the earliest Canadians: wide corridors, narrow doorways, small windows. In: Bonnichsen R, Turnmire KL, editors. *Ice Age people of North America, environments, origins, and adaptations.* Corvallis: Oregon State University Press. p 213–48.

Wisner G. 1999. Channel Island woman may be oldest yet. *Mammoth Trumpet* 14(3):1.

Yesner DR. 1998a. Origins and development of maritime adaptations in the northwest Pacific region of North America: a zooarchaeological perspective. *Arctic Anthropology* 35(1):204–22.

Yesner DR. 1998b. Colonization models, archaeological signatures, and early sites in interior Alaska. Paper presented at 63rd Annual Meeting of the Society for American Archaeology, Seattle, 26 March.

Yi S, Clark G. 1985. The "Dyuktai Culture" and New World origins. *Current Anthropology* 26(1): 1–20.

Yu Z. 2000. Ecosystem response to Lateglacial and early Holocene climate oscillations in the Great Lakes region of North America. *Quaternary Science Reviews* 19:1723–47.

Yu Z, Eicher U. Three amphi-Atlantic century-scale cold events during the Bølling-Allerød warm period. *Géographie Physique et Quaternaire*. Forthcoming.

Yu Z, Wright HE Jr. 2001. Response of interior North America to abrupt climate oscillations in the North Atlantic region during the last deglaciation. *Earth-Science Reviews* 52:333–69.

Zdanowicz CM, Zielinski GA, Germani MS. 1999. Mount Mazama eruption: calendrical age verified and atmospheric impact assessed. *Geology* 27(7):621–4.

Zielinski GA, Mayewski PA, Meeker LD, Whitlow S, Twickler MS. A 110,000-yr record of explosive volcanism from the GISP2 (Greenland) ice core. *Quaternary Research* 45(2):109–18.

RADIOCARBON, Vol 44, Nr 2, 2002, p 437–454

RADIOCARBON DATES FROM THE ICE-FREE CORRIDOR

Thomas G Arnold

Department of Archaeology, Simon Fraser University, Burnaby, BC, Canada V5A-1S6. Email: tarnold@sympatico.ca.

ABSTRACT. The Ice-Free Corridor has been hypothesized as the main migration route into the Americas since the 1930s. Radiocarbon dates have been used by archaeology, geology, and palynology to date the corridor. A total of 564 ^{14}C dates ranging between 20,000 and 8000 BP from the corridor area were gleaned from the published literature**.** After assessing these dates for suitability, 255 were plotted over four time periods. The results indicate that the corridor was not feasible as an early human migration route until after 11,000 BP, or after the appearance of Clovis south of the continental glaciers.

INTRODUCTION

The hypothesized Ice-Free Corridor has provided archaeology with a convenient explanation to account for the initial colonization of the Americas south of the Late Wisconsin ice sheets. Defined as an unglaciated area along the eastern slopes of the Rocky Mountains between the westward advancing Laurentide ice sheet and the eastward flowing Cordilleran and mountain glaciers (Figure 1), it was first proposed by Johnson (1933:22) to account for the then recently discovered Folsom points.

Debate over whether it was a deglaciation or a glacial maximum corridor has continued over the decades with an entire issue of *Quaternary International* (Volume 32; Mandryk and Rutter 1996) dedicated to this discussion (the following list of publications provides an introduction to the literature on the Ice-Free Corridor and should not be considered exhaustive: Antevs 1934; Bryan 1969; Reeves 1973; Fladmark 1979; Rutter 1980; Holloway et al. 1981; Hickman et al. 1983; Jackson 1983; White and Mathewes 1986; Schweger and Hickman 1989; Bobrowsky and Rutter 1992; Mandyrk 1992; Meltzer 1993; Beaudoin et al. 1996; Burns 1996; Catto et al. 1996; Levson and Rutter 1996; Mandryk 1996; Wilson 1996; Driver 1998; Schwegar 1989b). Mandryk (1992:20–53) provides a chronology of the debate. To summarize briefly, prior to the advent of radiocarbon dating, the last glacial maximum was estimated to have occurred about 25,000 years ago (Johnson 1933:24; Antevs 1935:304,306,307) with the formation of the corridor occurring sometime between 20,000 and 15,000 years ago. Despite the lack of archaeological evidence at this time for Clovis or Folsom age sites in Alaska or northeast Asia, the corridor was seen as the route of entry for Palaeoindian cultures south of the glacial ice. ^{14}C dating revised these interpretations by showing that Clovis, Folsom, and the Late Wisconsin glaciation were more recent than previously assumed. According to Mandryk (1992:31–2), because archaeology was unwilling to accept a Mid-Wisconsin human entry into the New World, archaeologists redefined Johnson's deglaciation corridor as a glacial maximum corridor. Mandryk (1992:38) characterizes post-1960s corridor research as continuing to focus on the physical existence and timing of the corridor, with less debate on its environment.

This paper re-evaluates the ^{14}C dates from the corridor, what they suggest about the timing of its appearance and the potential role of the corridor in the settlement of the Americas.

METHOD

The study area is shown in Figure 2 with its western limits defined by the Rocky Mountain Trench extending north from the Canada/United States border along the Columbia, Fraser, and Kenchika river valleys in British Columbia. This western limit is extended in the Yukon Territory along the Liard, Frances, and Pelley river valleys and follows the Yukon River to the Alaska/Yukon border where it proceeds north along the border to the Beaufort Sea. The northern limit is the northern coast

Canada (and immediate offshore islands) east from the Alaska/Yukon border to its intersection with the eastern limit in Queen Maude Gulf. The eastern limit begins with the political boundary between the Canadian provinces of Manitoba and Saskatchewan and extends north from the 60th parallel to Queen Maude Gulf. The southern limit of the study area runs along the Canada/United States border. This study area covers the eastern slopes of the Rocky Mountains, the potential northern staging area in the present-day Yukon and the southern outlet area in southern Alberta, Canada. ^{14}C dates from within this study area and bracketed between 20,000 and 8000 BP were collected from a variety of published sources including journals, books, dissertations, theses, and databases. A total of 574 ^{14}C dates from 343 separate sites were gleamed from the published literature.

Assessing these ^{14}C dates follows Nelson (1998). These dates were assessed based on the ^{14}C event of the sample dated, the samples relationship to its stratigraphic provenance, and whether it conformed to a standard ^{14}C date as defined by Stuiver and Polach (1977:356). This process reduced the original 574 dates to 255 dates from 164 locations. Figures 3A and 3B display the distributions of

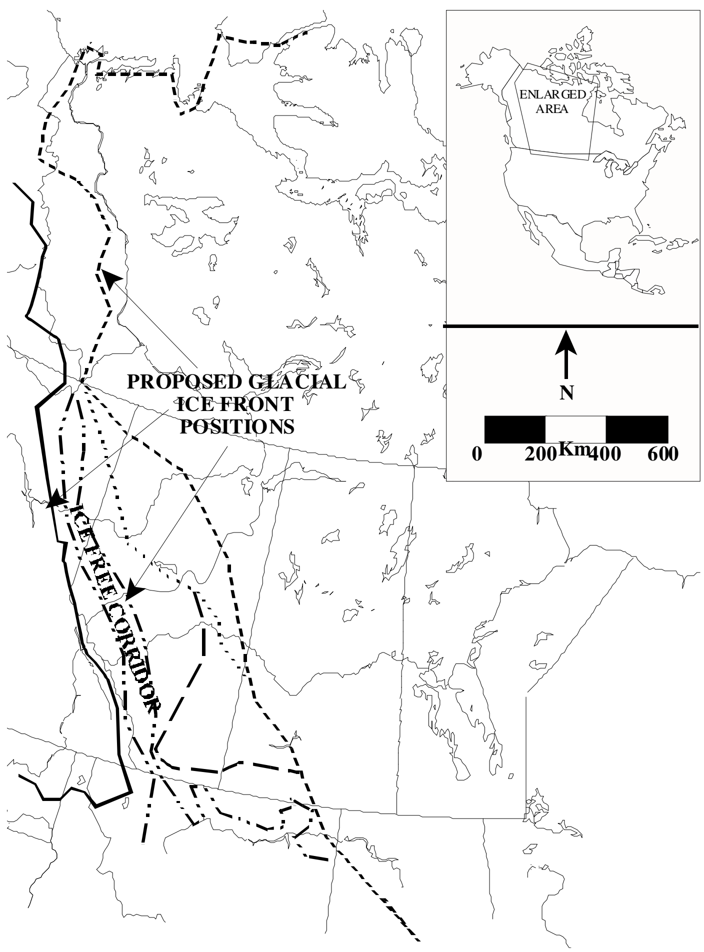


Figure 1 Traditional view of the Ice-Free Corridor (after Reeves 1973)

dated locations before and after assessment. The reasons for rejected dated samples being eliminated from the study were:

1. The ^{14}C event could not be identified or was known to provide unreliable dates (e.g., freshwater shell, plants or lake sediment samples are known to be affected by hard water in the study area).
2. The dated sample is not closely related to its stratigraphic provenance. The sample was from the surface, was redeposited, or the sample came from wide stratigraphic context.
3. Dated sample were not pretreated properly or did not correspond to other dates from the same stratigraphic context.

Figure 4 notes physiographic features mentioned in the text and Figures 5–9 illustrate the distribution of these dated locations through time. Table 1 (see Appendix) lists the name, date, 1 standard deviation, and reference for each site location.

Figure 2 Location of study area

Prelude to Late Wisconsin Maximum

Prior to the last glacial maximum the study area was devoid of ice as evident by dated plant and animal remains (Vincent 1989:112–3; Hughes et al. 1981:338; Burns1996:108; Burns and Young 1994: 394; Young et al. 1992:1576, 1994:685). As the Mid-Wisconsin drew to a close the Laurentide continental glacier advanced. In the north the glacier advanced west of the Mackenzie River and was

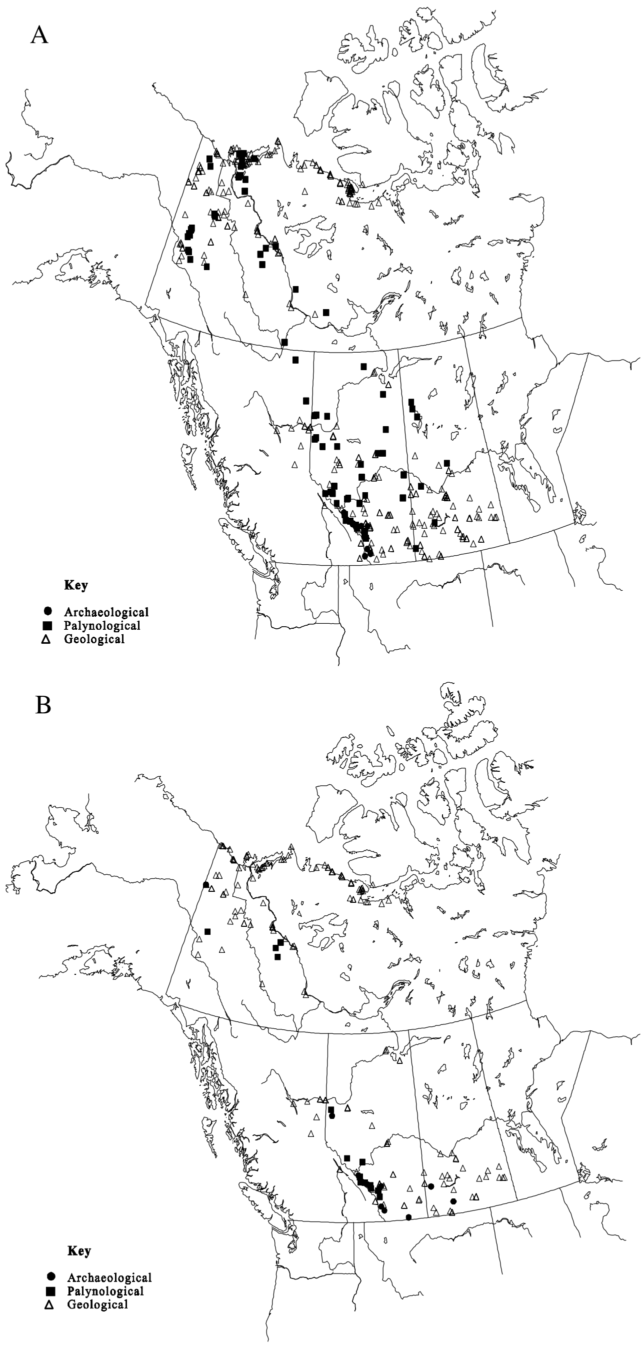


Figure 3 Radiocarbon dated site locations before (A) and after (B) assessment

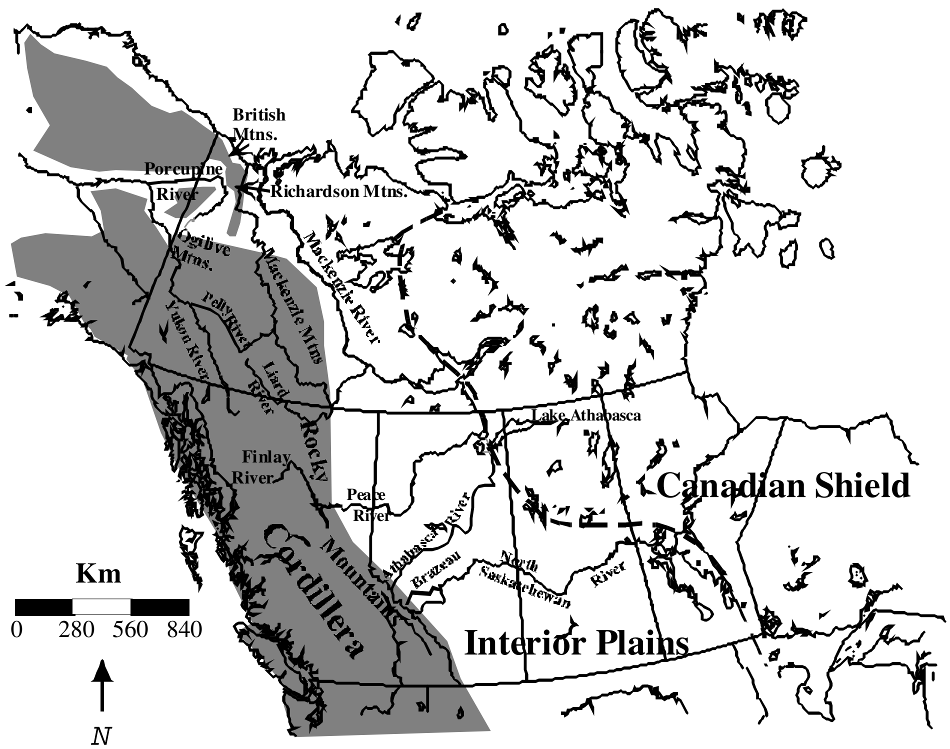


Figure 4 Geographical features of the study areas (after Driver 1998)

blocked by the Richardson and Mackenzie Mountains (see Figure 4 for place names) (Vincent 1989: 129–30; Hughes et al. 1981:329–65). In some instances ice lobes reached 40 km up some river valleys in the Mackenzie Mountains but it was only during the retreat of the Laurentide ice that some mountain glaciers appear to have coalesced with continental ice (Vincent 1989:130). In the Laird River valley, in southeast Yukon, a date of 23,900 ± 1140 BP (GSC-2811) from the upper zone of a silt unit was overlain by till indicating that Cordilleran and mountain glaciers advanced through the Laird Plain after this time (Klassen 1987:8; Klassen 1978:1884). No evidence for coalescence between the Laurentide and Montane or Cordilleran glaciers exists on the eastern slopes of the mountains.

Further south in the northern Rocky Mountains of northeastern British Columbia, the sedimentary successions indicate that Late Wisconsin Laurentide ice reached no higher then 950 m asl in the mountains or foothills in the Peace River district and that it occurred after 22,000 BP (Catto et al. 1996:24–6; Liverman et al. 1989:266–74). Montane glaciers did not reach the eastern slopes of the Rocky Mountains until after the Laurentide began to recede. This was evident by the presence of ^{14}C dates west of the Finlay River of 18,750 ± 120 (TO-709) and 15,180 ± 100 (TO-708) (Catto et al. 1996:23–29; Bobrowsky and Rutter 1992:16–19).

Recent geological research south of the Athabasca River indicated that coalesced glaciers, at the height of the Late Wisconsin, blocked southwestern and central Alberta. Subtill and paleontological studies by Young et al. (1994:683–6, 1999:1567–81) indicated that only Late Wisconsin ice advanced from the north and east and flowed south and west across Alberta up to 1400 m asl. Levson and Rutter (1996:33–51), citing lithologic, stratigraphic, and morphologic evidence, concluded that

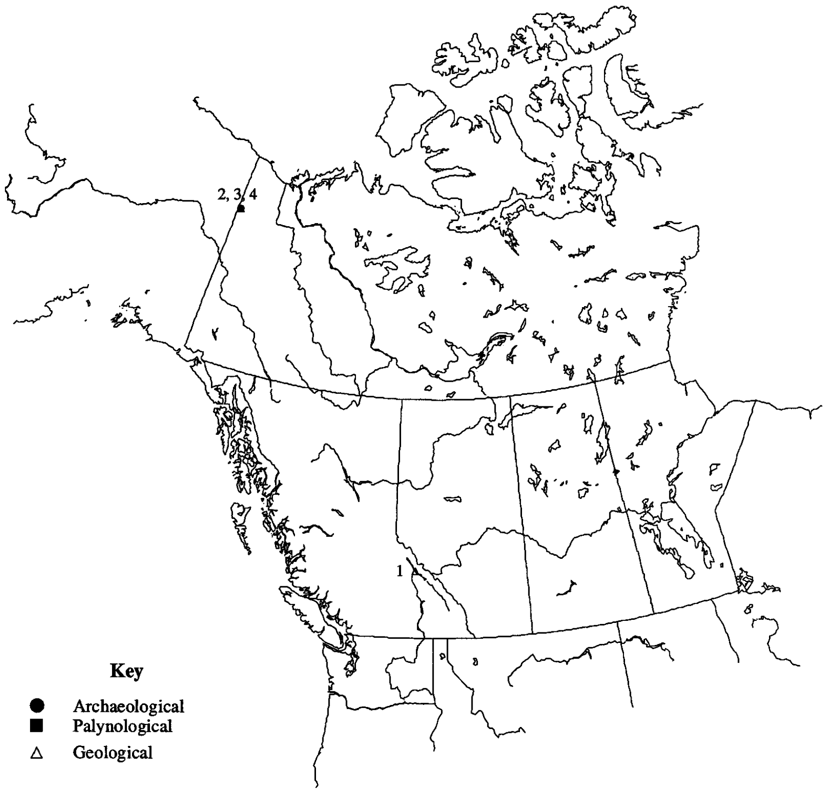


Figure 5 Period 1 site locations, 20,000–17,001 BP

the advancing Laurentide ice coalesced with combined valley and Cordilleran glaciers flowing east out of the Athabasca, Brazeau, and North Saskatchewan river valleys and flowed to the southeast. Since the natural flow out of these valleys was to the northeast, downhill, only the advancing Laurentide ice sheet could have provided the diversion necessary to deflect the east flowing glaciers upslope (Levson and Rutter 1996:44–46, 48) to the south.

Period I: 20,000–17,001 BP

This time period is represented by only four dates from three sites ranging from 19,650 BP to 17,880 BP (Figure 5). The sites are at opposite ends of the study area and confirm that the height of the glaciation occurred during this time period. The environment was either too severe or the landscape was covered by glaciers to permit plants or animals to survive. The three dates from the two Bluefish Cave sites confirm that eastern Beringia remained unglaciated at the height of glaciation. The lone date from the Rocky Mountain Trench in the south suggests that Cordilleran glaciers reached their maximum extent sometime after 18,500 BP since the sample came from a sand and silt unit that underlay two separate tills (Berry and Dimmie 1982:70).

Period II: 17,000–14,001 BP

There is an increase in the number of sites during this post-glacial maximum period (Figure 6). Their distribution suggests that deglaciation was occurring simultaneously at either end of the corridor. In the south one dated sample, on badly weathered bone (AECV-681C), appears to be from

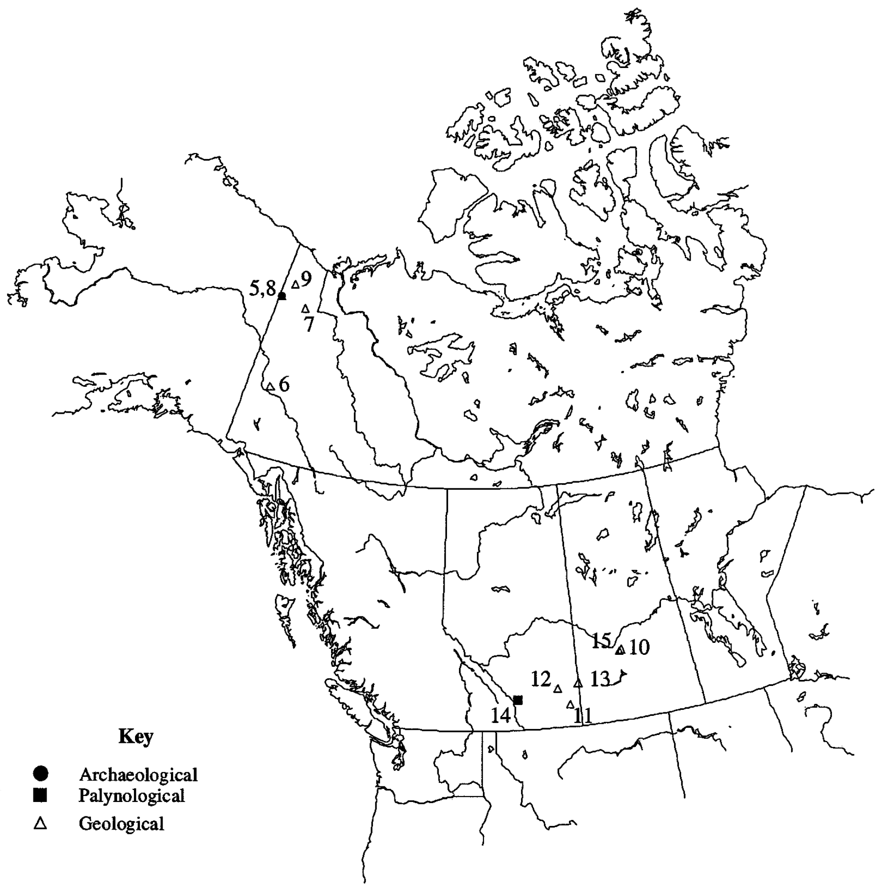


Figure 6 Period 2 site locations, 17,000–14,001 BP

lacustrine sediments overlying bedrock and may represent the earliest glacial lake sediments in the region (Evens 2000:940). Other bone sample dates that have been identified as mammoth (GCS-1199) and the genus *Equus* (S-1305) came from possible lacustrine or riverine sands or gravels (Lowdon et al 1975:16; Rutherford et al. 1979:54). The wood sample from the base of the Cartwright Lake core indicates that trees or shrubs were again present in the foothills of the Rocky Mountains. In the north, dated samples indicated the environment supported mammoth (GSC-1893 and GSC-3053) and muskox (RIDDL-557). The latter sample was from a lower loess layer from Bluefish Cave 3 (Cinq-Mars in Morlan 2001) and indicated a dry wind blown environment. Dated wood samples from Old Crow River (GSC-730-2) and the Upper Porcupine River (GSC-2431) indicate trees or shrubs were also present at this time.

Period III: 14,000–11,001 BP

Fifty-three dated site locations occurred in this time period (Figure 7). As with Period II, the dated site locations occurred in two groups at opposite ends of the study area but the extent of the site distribution has increased. In the north three sub-groups or clusters were indicated along the coast, the Mackenzie River and eastern Beringia (Yukon). The dated samples from the Coastal and Northeastern cluster were all conducted on plant material (wood, grass, moss) except for two marine shell dates from along the eastern coast. With the exception of the marine shells, which came from fine-grained marine sediments, the remaining Coastal Cluster dates derive from a variety of geological context including outwash plain, glaciofluvial gravels, and peat deposits. The Northeastern Cluster sample material came mainly from deltaic deposits along the Mackenzie River associated with Glacial Lake Mackenzie (Smith 1992; 1994; Lemmen et al. 1995). The lone exception, Andy Lake (TO-2295) (Szeicz et al. 1995), came from a small lake in the Mackenzie Mountains to the west indicating this had become ice-free by this time. The Northwest Cluster sample material included a wider range of material including faunal remains. The latter included horse, mammoth, caribou, moose, mountain sheep, saiga antelope, owl, and bison, which suggested a rich diverse environment in this area. Identified floral samples included willow and possible birch.

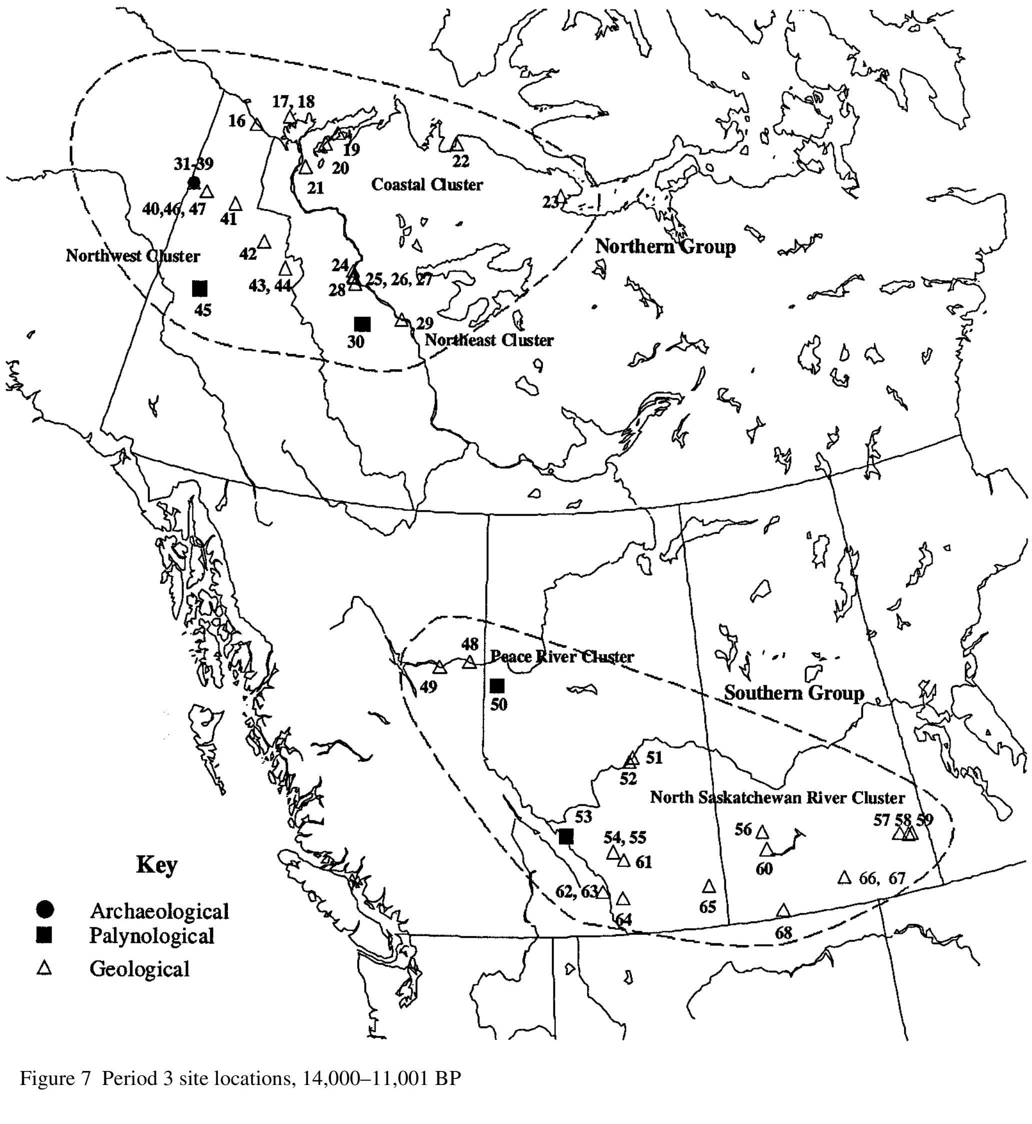


Figure 7 Period 3 site locations, 14,000–11,001 BP

In the south, the large cluster south of the North Saskatchewan River has grown and sites were present throughout Alberta and Saskatchewan. Dated faunal remains included mammoth, bison, and horse while willow was the only identified floral remain dated. To the northwest of this cluster was the small (3 dated site locations) Peace River Cluster. These two southern clusters appear separated by an area containing no dated site locations. This suggests a second area able to support plants and animals was developing independently of the older and more southern North Saskatchewan Cluster.

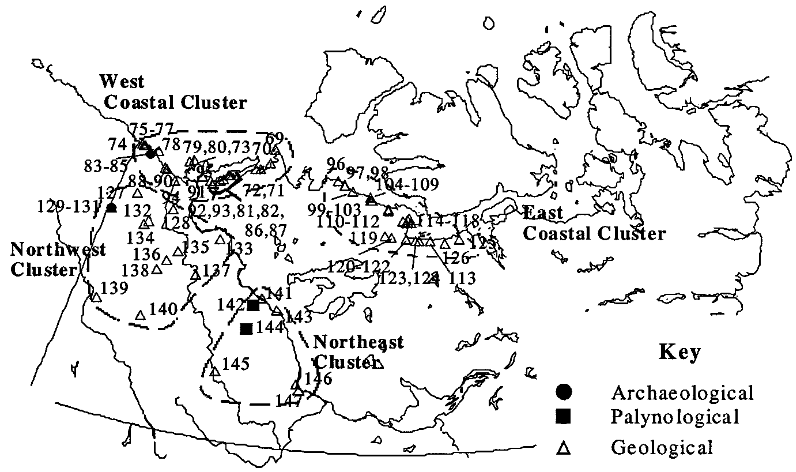


Figure 8 Period 4 northern group site locations, 11,000–8000 BP

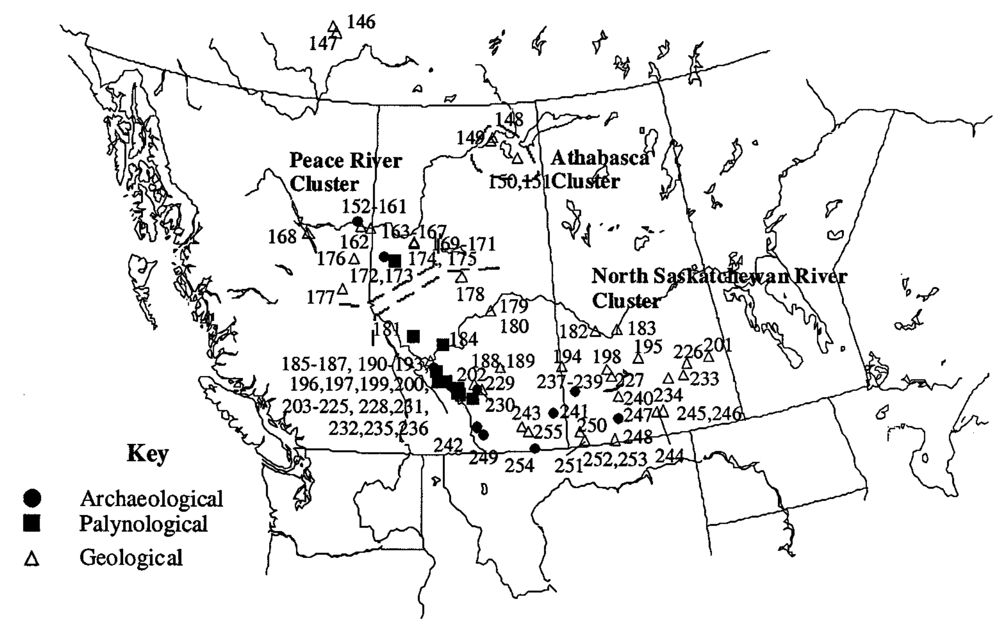


Figure 9 Period 4 southern group site locations, 11,000–8000 BP

Period 4: 11,000–8000 BP

One hundred and eighty-seven dated samples from 165 separate site locations were included in this period (Figures 8 and 9). These included 51 archaeological dates (from 16 sites), 115 geological dates (from 102 sites), and 18 palynological dates (from 11 sites). It was during this period that the distribution of dated sites came closest to encompassing the entire length of the ice-free corridor, from the northern coast and Beringian Refugia to the Canada/United States border. Several gaps appeared in this distribution that may reflect a sporadic or patchy colonization process of recently deglaciated landscape. These gaps exist between the Peace Cluster and the Athabasca Cluster and between the Athabasca Cluster and the Northeastern Cluster. The area in between these clusters may not necessarily have been devoid of all plants and animals but were substantially more barren to the point that the preservation of datable material was more unlikely.

DISCUSSION

I have interpreted these distributions as representing evidence of areas able to support plant and animal life while those areas devoid of dated samples could not. Such an interpretation has been proposed by other researchers (e.g. Burns 1996:107–12; Wilson 1996:97–105). An alternative interpretation could involve a lack of research in areas devoid of dated samples, a lack of exposure of appropriate sediment layers, or a lack of preservation.

Figure 3A should dispel the notion that a lack of research has greatly influenced the distributions. It shows that dated samples have been recovered from throughout the study area. In addition, date lists (e.g. Clague 1980; Jackson and Pawson 1984; Bobrowsky and Rutter 1992:16–17; Lemmen et al. 1995; Liverman et al. 1989; Burns and Young 1994; Burns 1996; Young et al. 1999; Young et al. 1994) that include dates both younger and older than the dates included in this study provide additional evidence that a lack of research is not an acceptable explanation. Similarly, the presence of dated samples from geological contexts older than 20,000 BP indicates that a lack of exposure of appropriate geological sections cannot explain the distribution. Finally, I would argue that the lack of preservation supports the interpretation presented above because the areas lacking dated samples were barren only in the sense that they could not support sufficient plant or animal populations to leave evidence in the geological record, not that they were necessarily devoid of all life (Wilson 1996: 97–105).

Palynology provides support for such an interpretation. In palynology, pollen grains are counted within a specified volume of sediment. For these counts to be statistically meaningful, a minimum number of grains must be counted per volume analyzed (Berglund and Ralska-Jasiewiczowa 1986: 462). This means that layers of sediment that do not reach these minimum counts can be considered barren. I would argue, by rough analogy, that the same is true for geological layers in areas that have not as yet provided dated samples.

I would further argue that if the environment were not productive enough to leave evidence in the geological record than it could not support human populations. Although future research may add new dated sample locations, the most parsimonious explanation of the present evidence indicates that the corridor could not have been used as an early human migration route until after 11,000 BP. This is too late to account for Clovis, which first appears about 11,500 BP (Taylor et al. 1996). Thus, alternative migration routes or time periods must be considered to explain the appearance of Clovis and Folsom at the end of the Pleistocene.

ACKNOWLEDGMENTS

This research was conducted as partial fulfillment of my doctoral studies in the Department of Archaeology, Simon Fraser University. Financial support was provided by both the Department of Archaeology and Simon Fraser University. The following professors provided much needed guidance for which I am grateful: Dr K Fladmark, Dr J Driver, and Dr E Nelson.

REFERENCES

Antevs E. 1934. Climate and early man in North America. *American Journal Science* 28:304–11.

Apland B, Harington CR. 1994. Pleistocene bison skeleton (Bison bison cf. Occidentalis) from Clayhurst crossing, British Columbia. *Geographie physique et Quaternarie* 48(2):213–23.

Beaudoin AB. 1991. Alberta radiocarbon dates 1988–1989, Archaeology in Alberta 1988 and 1989, Archaeological Survey, Provincial Museum of Alberta, *Occasional Paper*, No. 33

Beaudoin AB, Wright M, Ronaghan B. 1996. Late Quaternary landscape history and archaeology in the 'Ice-Free Corridor': some recent results from Alberta. *Quaternary International* 32:113–26.

Beierle B, Smith DG. 1998. Severe drought in the early Holocene (10,000–6800 BP) interpreted from lake sediment cores, southwestern Alberta, Canada. *Palaeogeography, Palaeoclimatologty, Palaeoecology* 140:75–83.

Berglund B, Ralska-Jasiewiczowa M. 1986. Pollen analysis and pollen diagrams. In: Berglund BE, editor. *Handbook of Holocene palaeoecology and palaeohydrology.* London: Wiley & Sons Ltd. p 455–84.

Berry JC, Drimmie RJ. 1982. University of Waterloo radiocarbon dates I. *Radiocarbon* 24(1):68–82.

Blake Jr W. 1983. Geological Survey of Canada radiocarbon dates XXIII. Geological Survey of Canada. Paper 83–7.

Blake Jr W. 1984. Geological Survey of Canada radiocarbon dates XXIV. Geological Survey of Canada. Paper 84–7.

Blake Jr W. 1986. Geological Survey of Canada radiocarbon dates XXV. Geological Survey of Canada. Paper 85–7

Blake W Jr. 1987. Geological Survey of Canada Radiocarbon Dates XXVI. Geological Survey of Canada, Paper 86–7.

Blake W Jr. 1988. Geological Survey of Canada Radiocarbon Dates XXVII. Geological Survey of Canada, Paper 87–7.

Bryan AL. 1969. Early man in America and the Late Pleistocene chronology of western Canada and Alaska. *Current Anthropology* 10(4):339–65.

Bobrowsky P, Rutter NW. 1992. The Quaternary geologic history of the Canadian Rocky Mountains. *Geographie physique et Quaternaire* 46(1):5–50.

Burns JA. 1986. A 9000-year-old Wapiti (Cervus elaphus) skeleton from northern Alberta, and its implications for the Early Holocene Environment. *Géographie physique et Quaternaire* Vol. XL(1):105–8.

Burns JA. 1996. Vertebrate paleontology and the alleged Ice-Free Corridor: the meat of the matter. *Quaternary International* 32:107–12.

Burns JA, Young RR. 1994. Pleistocene mammals of the Edmonton area, Alberta. Part I. The carnivores. *Canadian Journal of Earth Sciences* 31:393–400.

Catto N, Liverman DGE, Bobrowsky P, Rutter N. 1996. Laurentide, cordilleran, and montane glaciation in the western Peace River – Grande Prairie Region, Alberta and British Columbia, Canada. *Quaternary International* 32:21–32.

Christiansen EA. 1979. The Wisconsinan deglaciation of southern Saskatchewan and adjacent areas. *Canadian Journal of Earth Sciences* 16:913–38.

Christiansen EA. 1983. The Denholm landslide, Saskatchewan, Part I: Geology. *Canadian Geotechnical Journal* 20:197–207.

Christiansen ES, Sauer EK. 1988. Age of the Frenchman Valley and associated drift south of the Cypress Hills, Saskatchewan, Canada. *Canadian Journal of Earth Sciences* 25:1703–8.

Cinq-Mars J. 1979. Bluefish Cave I: a Late Pleistocene eastern Beringian cave deposit in the northern Yukon. *Canadian Journal of Archaeology* 3:1–32.

Cinq-Mars J, Harington CR, Nelson DE, MacNeish RS. 1991. Engigstciak revisted: a note on early Holocene AMS dates from the Buffalo Pit. In: NOGAP Archaeological Project: an integrated archaeological research and management approach. Canadian Archaeological Association, *Occasional Paper* No. 1.

Clague JJ. 1980. Late Quaternary geology and geochronology of British Columbia: Part 1: radiocarbon dates. Geological Survey of Canada, Paper 80–13

Driver JC. 1998. Human adaptation at the Pleistocene/Holocene boundary in western Canada, 11,000 to 9000 BP. *Quaternary International* 49/50:141–50.

Driver JC, Handly M, Fladmark KR, Nelson DE, Sullivan GM, Preston R. 1996. Stratigraphy, radiocarbon dating and culture history of Charlie Lake Cave, British Columbia. *Arctic* 49(3):265–77.

Dyck W, Fyles JG. 1962. Geological Survey of Canada radiocarbon dates I. *Radiocarbon* 4:13–26.

Dyck W, Fyles JG. 1963. Geological Survey of Canada radiocarbon dates II. *Radiocarbon* 5:39–55.

Dyck W, Fyles JG. 1964. Geological Survey of Canada radiocarbon dates III. *Radiocarbon* 6:167–81.

Dyck W, Lowdon JA, Fyles JG, Blake W Jr. 1966. Geological Survey of Canada radiocarbon dates V. *Radiocarbon* 8:96–127.

Evans DJA. 2000. Quaternary geology and geomorphology of the Dinosaur Provincial Park area and surrounding plains, Alberta, Canada: the identificaiton of former glacial lobes, drainage diversions and meltwater flood tracks. *Quaternary Science Reviews* 19:931–58.

Evans DJA, Campbell IA. 1992. Glacial and Postglacial stratigraphy of Dinosaur Provincial Park and surrounding plains, southern Alberta, Canada. *Quaternary Science Reviews* 11:535–55.

Fladmark KR. 1979. Routes: alternative migration corridors for early man in North America. *American Antiquity* 44(1):55–69.

Fladmark KR, Driver JC, Alexander D. 1988. The Paleoindian component at Charlie Lake Cave (HbRf-39). *British Columbia American Antiquity* 53(2):371–84.

Harington CR, Cinq Mars J. 1995. Radiocarbon dates on Saiga Antelope (Saiga tatarica) fossils from Yukon and the Northwest Territories. *Arctic* 48(1):1–7.

Harrison JE. 1976. Dated organic material below Mazama (?) tephra: Elk Valley, British Columbia. Geological Survey of Canada, *Paper* 76-1C

Head T. 1999. Report of radiocarbon dating analysis from BETA Analytic. Copy provided by T Head, Bison Historical Services, Calgary, Alberta.

Hickman M, Schweger CE. 1996. The Late Quaternary palaeoenvironmental history of a presently deep freshwater lake in east-central Alberta, Canada and palaeoclimate implications. *Palaeogeography, Palaeoclimatology, Palaeoecology* 123:161–78.

Hickman M, Schweger CE, Habgood T. 1984. Lake Wabamun, Alta.: a paleoenvironmental study. *Canadian Journal of Botany* 62:1438–65.

Holloway RG Bryant VM Jr, Valastro S. 1981. A 16,000 year pollen record from Lake Wabamun, Alberta, Canada. *Palynology* 5:195–208.

Hughes OL, Harington CR, Janssens, JA, Matthews, JV, Morlan, RE, Rutter NW, Schweger CE. 1981. Upper Pleistoncene stratigraphy, paleoecology, and archaeology of the northern Yukon interior, eastern Beringia 1. Bonnet Plume Basin. *Arctic* 34(4):329–65.

Jackson LE, Pawson M. 1984. Alberta radiocarbon dates: listings of radiocarbon dates with regional significance to the Late Quaternary geochronology and geomorphology of Alberta. Geological Survey of Canada, Paper 83-25.

Jackson LE Jr. 1983. Comments on chronology of Late Wisconsinan glaciation in middle North America. *Quaternary Science Review* 1:vii–xiv.

Johnson WA. 1933. Quaternary geology of North America in relation to the migration of man. In Jenness D, editor. *The American Aborigines.* Toronto: University of Toronto Press. p 11–45.

Klassen RW. 1978. A unique stratigraphic record of the late Tertiary-Quaternary events in southeastern Yukon. *Canadian Journal of Earth Sciences* 15:1884–6.

Klassen RW. 1987. The Tertiary Pleistocene stratigraphy of the Laird Plain, Southeastern Yukon Territory. Geological Survey of Canada, *Paper* 86-17.

Lemmen DS, Duk-Rodkin A, Bednarski JM. 1995. Late glacial drainage systems along the northwestern margin of the Laurentide Ice Sheet. *Quaternary Science Reviews* 13:805–28.

Levson VM, Rutter NW. 1996. Evidence of cordilleran Late Wisconsinan glaciers in the 'Ice-Free Corridor'. *Quaternary International* 32:33–51.

Liverman DGE, Catto NR, Rutter NW. 1989. Laurentide Glaciation in west-central Alberta: a single (Late Wisconsinan) event. *Canadian Journal of Earth Sciences* 26:266–74.

Lowdon JA, Blake W Jr. 1968. Geological Survey of Canada radiocarbon dates VII. *Radiocarbon* 10:207–45.

Lowdon JA, Blake W Jr. 1970. Geological Survey of Canada radiocarbon dates IX. *Radiocarbon* 12:46–86.

Lowdon JA, Blake W Jr. 1973. Geological Survey of Canada radiocarbon dates XIII. Geological Survey of Canada, Paper 73–7.

Lowdon JA, Blake W Jr. 1975. Geological Survey of Canada radiocarbon dates XV. Geological Survey of Canada, Paper 75–7.

Lowdon JA, Blake W Jr. 1976. Geological Survey of Canada radiocarbon dates XVI. Geological Survey of Canada, Paper 76–7.

Lowdon JA, Blake W Jr. 1977. Geological Survey of Canada radiocarbon dates XVII. Geological Survey of Canada, Paper 77–7.

Lowdon JA, Blake W Jr. 1978. Geological Survey of Canada radiocarbon dates XVIII. Geological Survey of Canada, Paper 78–7.

Lowdon JA, Blake W Jr. 1979. Geological Survey of Canada radiocarbon dates XIX. Geological Survey of Canada, Paper 79–7.

Lowdon JA, Blake W Jr. 1980. Geological Survey of Canada radiocarbon dates XX. Geological Survey of Canada, Paper 80–7.

Lowdon JA, Fyles JG, Blake W Jr. 1967. Geological Survey of Canada radiocarbon dates VI. *Radiocarbon* 9:167–8.

Lowdon JA, Robertson IM, Blake W Jr. 1971. Geological Survey of Canada radiocarbon dates XI. *Radiocarbon* 13:255–324.

MacDonald GM, Beukens RP, Kieser WE. 1991. Radiocarbon dating of limnic sediments: a comparative analysis and discussion. *Ecology* 72(3):1150–5.

Mandryk CS. 1992. Paleoecology as contextual archaeology: human viability of the Late Quaternary ice-free corridor, Alberta, Canada. Unpublished PhD dissertation. University of Alberta, Edmonton.

Mandryk CS. 1996. Late Wisconsinan deglaciation of

Alberta: processes and paleogeography. *Quaternary International* 32:79–85.

Mandryk CS, Rutter N. 1996. The Ice-Free Corridor revisted. In: Mandryk CS, Rutter N, guest editors. *Quaternary International* 32.

Mathews WH. 1980. Retreat of the last ice-sheets in northeastern British Columbia and adjacent Alberta. Geological Survey of Canada. *Bulletin* 331

McCallum KJ, Dyck W. 1960. University of Saskatchewan radiocarbon dates II. *American Journal of Science, Radiocarbon Supplement* 2:73–81.

McCallum KJ, Wittenberg J. 1962. University of Saskatchewan radiocarbon dates III. *Radiocarbon* 4: 71–80.

McCallum KJ, Wittenberg J. 1965. University of Saskatchewan radiocarbon dates IV. *Radiocarbon* 7: 229–35.

McCallum KJ, Wittenberg J. 1968. University of Saskatchewan radiocarbon dates V. *Radiocarbon* 10: 374–5.

McNeely R. 1989. Geological Survey of Canada radiocarbon dates XXVIII. Geological Survey of Canada, Paper 88–7.

McNeely, R. and McCuaig, S. 1991. Geological Survey of Canada radiocarbon dates XXIX. Geological Survey of Canada, Paper 89–7.

McNeely, R. and Jorgensen, PK. 1992. Geological Survey of Canada radiocarbon dates XXX. Geological Survey of Canada, Paper 90–7.

Meltzer DJ. 1993. Pleistocene peopling of the Americas. *Evolutionary Anthropology* 1(5):157–69.

Meyer D, Liboiron H. 1990. A Paleoindian drill from the Niska site in southern Saskatchewan. *Plains Anthropologists* 35(129):299–302.

Morlan RE. 1980. Taphonomy and archaeology in the Upper Pleistocene of the northern Yukon Territory: a glimpse of the peopling of the New World. National Museum of Man, Archaeological Survey of Canada. *Mercury Series Paper* No. 94.

Morlan RE. 2001. Canadian Archaeological Radiocarbon Database. Complied by Richard E Morlan. Database programming and design by Pictographics Ltd.

Nelson DE. 1998. *Radiocarbon dating definitions and their consequences*. Isotope Lab Internal Report.

Rains B, Welch J. 1988. Out-of-phase Holocene terraces in part of the North Saskatchewan river basin, Alberta. *Canadian Journal of Earth Sciences* 25:454–64.

Reasoner MA, Hickman M. 1989. Late Quaternary Environmental change in the Lake O'Hara Region, Yoho National Park, British Columbia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 72:291–316.

Reasoner MA, Osborn G, Rutter NW. 1994. Age of the Crowfoot advance in the Canadian Rocky Mountains: a glacial event coeval with the Younger Dryas oscillation. *Geology* 22:439–42.

Reeves BOK. 1973. The nature and age of the contact between the laurentide and cordilleran ice-sheets in the western interior of North America. *Arctic and Alpine Research* 5(1):1–16.

Reeves BOK, Dormaar JF. 1972. A partial holocene pedological and archaeological record from the southern Alberta Rocky Mountains. *Arctic and Alpine Research* 4(4):325–36.

Ronaghan B. 1993. The James Pass project: early Holocene occupation in the front ranges of the Rocky Mountains. *Canadian Journal of Archaeology* 17:85–91.

Rutherford AA, Wittenberg J, Wilmeth R. 1979. University of Saskatchewn radiocarbon dates VIII. *Radiocarbon* 21(1):48–94.

Rutter NW. 1980. Late Pleistocene history of the western Canadain Ice-Free Corridor. *Canadian Journal of Anthropology* 1:1–7.

Schweger CE, Hickman M. 1989. Holocene paleohydrology of central Alberta: testing the general-circulation-model climate simulations. *Canadian Journal of Earth Sciences* 26:1826–33.

Schweger CE. 1989. Paleoecology of the western Canadian Ice-Free Corridor. In: Fulton RJ,e ditor. *Quaternary geology of Canada and Greenland.* Ottawa: Geological Survey of Canada.

Shackleton DM, Hills LV. 1977. Post-glacial ungulates (Cervus and Bison) from Three Hills, Alberta. *Canadian Journal of Earth Sciences* 14:963–86.

Smith DG. 1992. Glacial Lake Mackenzie, Mackenzie Valley, Northwest Territories, Canada. *Canadian Journal of Earth Sciences* 29:1756–66.

Smith DG. 1994. Glacial Lake McConnell: paleogeography, age, duration, and associated river deltas, McKenzie River Basin, Western Canada. *Quaternary Science Review* 13:829–43.

Stuiver M, Polach H. 1977. Reporting on ^{14}C data. *Radiocarbon* 19(3):355–63.

Szeicz JM, MacDonald GM, Duk-Rodkin A. 1995. Late Quaternary vegetation history of the central Mackenzie Mountains, Northwest Territories, Canada. *Palaeogeography, Palaeoclimatology, Palaeoecology* 113:351–71.

Taylor RE, Haynes CV Jr, Stuiver M. 1996. Clovis and Folsom age estimates: stratigraphic context and radiocarbon calibrations. *Antiquity* 70(269):515–25.

Van Dyke S. 1994. Oldman River Dam Prehistoric Archaeology Mitigation Program technical series no. 1: campsites study. Archaeological Survey of Alberta, Manuscript Series, Alberta Culture, Provincial Museum of Alberta.

Vincent JS. 1989. Quaternary geology of the northern Canadian Interior Plains. In: Fulton RJ, editor. *Quaternary geology of Canada and Greenland.* Geological Survey of Canada, No. 1. p 100–37.

Walton A, Trautman MA, Friend JP. 1961. Isotopes, Inc. radiocarbon measurements I. *Radiocarbon* 3:47–59.

White JM, Osborn G. 1992. Evidence for a Mazama-like tephra deposited ca. 10,000 BP at Copper Lake, Banff

National Park, Alberta. *Canadian Journal of Earth Sciences* 29:52–62.

White JM, Mathewes RW. 1986. Postglacial vegetation and climatic change in the upper Peace River District, Alberta. *Canadian Journal of Botany* 64:2305–18.

Wilson MC. 1996. Late Quaternary vertebrates and the opening of the Ice-Free Corridor, with special reference to the genus bison. *Quaternary International* 32: 97–105.

Wilson M, Churcher CS. 1978. Late Pleistocene cameloops from the Gallelli Pit, Calgary, Alberta: Morphology and geologic setting. *Canadian Journal of Earth Sciences* 15(5):729–40.

Woolf K. 1993. Radiocarbon chronology for glacial Lake Peace. Unpublished MS thesis. Department of Geography, Simon Fraser University.

Young RR, Burns JA, Rains RB, Chowalter DB. 1999. Late Pleistoncene glacial geomorphology and environment of the Hand Hills region and southern Alberta, related to Middle Wisconsin fossil prairie dog sites. *Canadian Journal of Earth Sciences* 36:1567–81.

Young RR, Burns JA, Smith DG, Arnold LD, Rains RB. 1994. A single Late Wisconsin Laurentide glaciation, Edmonton area and southwestern Alberta. *Geology* 22:683–6.

APPENDIX

Table 1: Site Identification (Site Name, Date±error (1 SD), Lab No., Reference)

1. Rocky Mnt. House, 18430±340, WAT-130, Berry and Dimmie 1982
2. Blufish Cave 2, 19640±170, RIDDL-330, Morlan ±2001
3. Bluefish Cave 3, 18970±14 90, TO-1266, Morlan 2001
4. Bluefish Cave 2, 17880±330, CRNL-1221, Morlan 2001
5. Bluefish Cave 3, 14370±130, RIDDL-557, Morlan 2001
6. Scroggie Creek, 16200±70, GSC-1893, Blake 1988
7. Upper Porcupine River, 15920±110,GSC-2431, Lowdon and Blake 1980
8. Bluefish Cave 2, 15540±70, GSC-3053, McNeely 1989
9. Old Crow River, 14390±80, GSC-730-2, Blake 1988
10. Sutherland, 14040±470, S-685, Rutherford et al. 1979; Christiansen 1979
11. Medicine Hat, 15200±130, GSC-1399, Lowdon and Blake 1975
12. Provincial Park, 16790±270, AECV-681C, Evans and Campbell 1992
13. Empress CPR Pit, 14200±560, GSC-119, Lowdon and Blake 1975
14. Cartwright Lake, 15670±960, TO-5190, Beierle and Smith 1998
15. Riddell series, 15340±500, S-1305, Rutherford et al. 1979
16. King Point, 11300±50, GSC-3982, Blake 1987
17. Garry Island, 11300±190, S-278, Lowdon et al. 1971
18. Garry Island, 11700±250, S-277, Lowdon et al. 1971
19. Eskimo Lakes, 13000±70, GSC-1995, Blake 1987
20. Eskimo Lakes, 12900±80, GSC-1784-2, Blake 1987
21. Twin Lakes, 11470±70, GSC-1514, Lowdon and Blake 1973
22. Pearce Point, 11790±170, AECV-643Cc, McNeely and Johnson 1992
23. Coppermine, 11170±80, TO-1231, McNeely and Johnson 1992
24. Mountain River, 11440±90, TO-1191, Smith 1992; Lemmen et al. 1995
25. Mountain River, 11530±170, I-3734, Smith 1992; Lemmen et al. 1995
26. San Sault Rapid, 11200±110, GSC-1573, Lowdon and Blake 1979
27. Mountain River, 11140±160, TO-1190; Smith 1994; Smith 1992
28. Mountain River, 11760±90, I-3913, Smith 1994; Smith 1992
29. Little Bear River, 11550±180, I-15020, Smith 1994; Lemmen et al. 1995
30. Andy Lake, 12060±80, TO-2295, Szeicz et al. 1995
31. Bluefish Cave 1, 12900±50, GSC-2881, Cinq-Mars 1991
32. Bluefish Cave 1, 12845±250, CRNL-1220, Morlan 2001
33. Bluefish Cave 1, 12830±60, CAMS-23468, Morlan 2001
34. Bluefish Cave 1, 11570±60, CAMS-23472, Morlan 2001
35. Bluefish Cave 1, 12210±210, RIDDL-277, Morlan 2001
36. Bluefish Cave 1, 13580±80, CAMS-23473, Morlan 2001
37. Bluefish Cave 3, 13390±180, RIDDL-279, Harington and Cinq-Mars 1979
38. Bluefish Cave 3, 12370±440, CRNL-1236, Morlan 2001
39. Bluefish Cave 3, 13350±100, BETA-129151, Morlan 2001
40. Old Crow, MkVl-9, 11990±90, I-7765, Morlan 1980
41. Upper Porcupine, 13500±160, GSC-2553, Lowdon and Blake 1980
42. Caribou River, 12400±60, GSC-3691, McNeely and McCuaig 1991
43. Snake River, 11800±70, GSC-2745, McNeely 1989
44. Snake River, 11700±50, GSC-2693, McNeely 1989
45. North Fork Pass, 11250±80, GSC-470, Lowdon and Blake 1968
46. Old Crow, MkVl-9, 12220±750, QU-783, Morlan 1980
47. Old Crow, MkVl-9, 12460±220, I-3574, Morlan 1980
48. Rocky Mtn Portage, 11600±1000, I-2244A, Mathews 1980
49. Fort St. John, 13970±170, TO-2742, Catto et al. 1996
50. Boone Lake, 11700±260, SFU-223, White and Mathewes 1986
51. Clover Bar S & G, 11620±170, AECV-1203C, Burns and Young 1994
52. North Sask River, 11430±420, S-2385, Rains and Welch 1988
53. Crowfoot Lake, 11330±220, CAMS-3065, Reasoner et al. 1994
54. Clark Gravel Pit, 11370±90, GSC-613, Lowdon et al 1967
55. Clark Gravel Pit, 11100±80, GSC-989, Lowdon and Blake 1970
56. Gunworth, 12160±250, S-198, McCallum and Wittenberg 1965
57. Marieval, 12030±210, S-553, Christiansen 1979
58. Camp Mackay, 11120±150, S-793, Rutherford et al. 1979
59. Esterhazy, 11260±150, S-794, Rutherford et al. 1979
60. Kyle, 12080±200, S-246, MaCallum and Wittenberg 1968

Table 1: Site Identification (Site Name, Date±error (1 SD), Lab No., Reference)

61. Gallelli Gravel Pit, 11300±290, RL-757, Wilson and Churcher 1978
62. Elk Valley, 11920±120, GSC-2142, Harrison 1976
63. Elk Valley, 12200±80, GSC-2275, Harrison 1976
64. Oldman Drainage, 11220±60, BETA-79915, Morlan 2001
65. Lindo Bluff, 11200±100, GSC-805, Lowdon and Blake 1968
66. Scrimbit, 11720±310, S-83, Rutherford et al. 1979
67. Scrimbit, 11520±310, S-80, Rutherford et al. 1979
68. Frenchman Valley, 11480±260, S-2932, Christiansen and Sauer 1983
69. Baillie Island, 9580±70, GSC-2030, Lowdon and Blake 1978
70. Cape Monte Casino, 9020±40, GSC-1989, Lowdon and Blake 1978
71. Nicholson Point, 9020±80, GSC-4362, McNeely and McCuaig 1991
72. Liverpool Bay, 9180±80, GSC-1327, Lowdon and Blake 1973
73. Pelly Island, 9180±60, GSC-2197, Lowdon and Blake 1979
74. Backhouse River, 10900±40, GSC-1853, Lowdon and Blake 1976
75. Komakuk Beach, 10200±60, GSC-1838, Lowdon and Blake 1976
76. Komakuk, 9900±100, GSC-4342, McNeely and Jorgensen 1992
77. Komakuk, 10580±370, TO-651, McNeely and Jorgensen 1992
78. Pauline Cove, 9380±90, GSC-1483, Lowdon and Blake 1976
79. Garry Island, 9500±150, S-276, McCallum and Wittenberg 1968
80. Garry Island, 9730±70, GSC-575, Lowden et al. 1971
81. Eskimo Lakes, 9180±50, GSC-2023, Blake 1987
82. Eskimo Lakes, 10300±60, GSC-1936, Blake 1987
83. Engigstciak, 9870±80, RIDDL-362, Cinq-Mars 1991
84. Engigstciak, 9770±180, RIDDL-281, Cinq-Mars 1991
85. Engigstciak, 9870±180, RIDDL-319, Cinq-Mars 1991
86. Eskimo Lakes, 9130±140, GSC-1653, Blake 1987
87. Eskimo Lakes, 10700±130, GSC-1710, Blake 1987
88. Sabine Point, 8980±50, GSC-3914, Blake 1987
89. Sabine Point, 11000±50, GSC-3986, Blake 1987
90. Sabine Point East, 9940±50, GSC-2022, Lowdon and Blake 1976
91. Tuktoyaktuk Pen., 9560±80, GSC-1169, Lowdon and Blake 1973
92. Zed Lake, 9640±180, GSC-1469-3, Lowdon and Blake 1976
93. Zed Lake, 9790±90, GSC-1469-2, Lowdon and Blake 1976
94. Coal Mine Lake, 10300±60, GSC-3729, McNeely and Jorgensen 1992
95. Holmes Creek, 9340±130, GSC-1495, Lowdon and Blake 1978
96. Keats Point, 10840±180, AECV-644Cc, McNeely and Jorgensen 1992
97. Clinton Point, 10340±140, AECV-642CC, McNeely and Jorgensen 1992
98. Clinton Point, 10410±140, AECV-645CC, McNeely and Jorgensen 1992
99. Buchanan River, 9810±60, GSC-4347, McNeely and McCuaig 1991
100. Buchanan River, 10700±50, GSC-4318, McNeely and McCuaig 1991
101. Tinney Point, 10000±170, AECV-462CC, McNeely and Jorgensen 1992
102. Tinney Point, 10620±160, AECV-444CC, McNeely and Jorgensen 1992
103. Buchanan River, 10600±60, GSC-4339, McNeely and Jorgensen 1992
104. Clifton Point, 10700±50, GSC-4390, McNeely and McCuaig 1991
105. Clifton Point, 8890±60, GSC-4425, McNeely and McCuaig 1991
106. Clifton Point, 10300±50, GSC-4402, McNeely and McCuaig 1991
107. Clifton Point, 10400±50, GSC-4424, McNeely and McCuaig 1991
108. Clifton Point, 9300±540, AECV-712CC, McNeely and Jorgensen 1992
109. Clifton Point, 9600±140, AECV-473CC, McNeely and Jorgensen 1992
110. Harding River, 10530±260, I(GSC)-25, Walton et al. 1961
111. Dolphin Strait, 10420±540, AECV-713Cc, McNeely and Jorgensen 1992
112. Dolphin Strait, 10040±240, AECV-474Cc, McNeely and Jorgensen 1992
113. Kugaryuk River, 9100±180, I(GSC)-16, Walton et al. 1961
114. Coppermine, 9540±40, GSC-4696, McNeely and Jorgensen 1992
115. Basil Bay, 9480±60, GSC-4930, McNeely and Jorgensen 1992
116. Coppermine, 10700±50, GSC-4916, McNeely and Jorgensen 1992
117. Coppermine, 9190±80, GSC-4709, McNeely and Jorgensen 1992
118. Basil Bay, 9120±60, GSC-4845, McNeely and Jorgensen 1992
119. Richardson River, 10300±120, GSC-3663, Blake 1983
120. Coppermine, 9800±140, AECV-403Cc, McNeely and Jorgensen 1992
121. Cox Lake, 9430±60, GSC-3941, Blake 1987
122. Coppermine River, 9820±50, GSC-3327, Blake 1983
123. Coronation Gulf, 9801±50, AECV-404Cc, McNeely and Jorgensen 1992
124. Coronation Gulf, 9560±130, AECV-472Cc,McNeely and Jorgensen1992
125. Coronation Gulf, 9620±70, GSC-3584, Blake 1983
126. Tree River, 10215±220, I(GSC)-17, Walton et al. 1961

Table 1: Site Identification (Site Name, Date±error (1 SD), Lab No., Reference)

127. Old Crow Basin, 10400±90, GSC-2773, Blake 1984
128. Rat River, 9970±90, GSC-147, Dyck and Fyles 1964
129. Blue Fish Cave 1, 10230±140, RIDDL-559, Morlan 2001
130. Blue Fish Cave 2, 10230±140, RIDDL-561, Morlan 2001
131. Blue Fish Cave 3, 10820±60, CAMS-23467, Morlan 2001
132. Whitefish Lake, 9530±90, GSC-1829, Lowdon et al. 1977
133. Grandview Hills, 9560±60, GSC-2298, Lowdon and Blake 1979
134. Upper Porcupine, 9190±50, GSC-3573, Lowdon and Blake 1980
135. Caribou River, 9780±60, GSC-3573, McNeely 1989
136. Peel River, 10600±90, GSC-2393, Lowdon and Blake 1979
137. Many Beaver Lake,8910±70, GSC-1865, McNeely 1989
138. Hungry Creek, 8980±50, GSC-2341, Hughes et al. 1981; McNeely 1989
139. Hunker Creek, 9520±70, GSC-73, Dyck and Fyles 1963
140. Corkery Creek, 9000±50, GSC-4020, McNeely and McCuaig 1991
141. Norman Wells, 9320±50, GSC-2206, Lowdon and Blake 1979
142. Bell's Lake, 10230±150, TO-2375, Szeicz et al. 1995
143. Great Bear River, 10600±130, GSC-2328, Lowdon and Blake 1979
144. Keele Lake, 9560±70, TO-3989, Szeicz et al. 1995
145. Howard=s Pass, 9610±50, GSC-3532, Blake 1983
146. Root River, 10290±180, AECV-917C, Smith 1992; Smith 1994
147. Fort Simpson, 9110±240, AECV-916C, Smith 1994
148. Peace Delta, 9830±80, WAT-2662, Smith 1994
149. Peace Delta, 9850±80, WAT-2661, Smith 1994
150. Athabasca Delta, 9710±130, AECV-1183C, Smith 1994
151. Athabasca Delta, 9910±50, GSC-4302, Smith 1994
152. Charlie Lake Cave, 10770±120, SFU-454, Fladmark et al. 1988
153. Charlie Lake Cave, 10380±160, SFU-378, Fladmark et al. 1988
154. Charlie Lake Cave, 10290±100, CAMS-2137, Fladmark et al. 1988
155. Charlie Lake Cave, 10100±210, RIDDL-392, Fladmark et al. 1988
156. Charlie Lake Cave, 10450±150, SFU-300, Fladmark et al. 1988
157. Charlie Lake Cave, 10560±80, CAMS-2134, Fladmark et al. 1988
158. Charlie Lake Cave, 9670±150, CAMS-2136, Fladmark et al. 1988
159. Charlie Lake Cave, 9760±160, SFU-355, Fladmark et al. 1988
160. Charlie Lake Cave, 9490±140, CAMS-2318, Driver et al. 1996
161. Charlie Lake Cave, 10500±80, CAMS-2129, Fladmark et al. 1988
162. Ostero Gravel Pit, 10240±160, AECV-1206C, Lowdon and Blake 1979
163. Clayhurst Pit, 10580±210, CAMS-398, Apland and Harington 1994
164. Clayhurst Pit, 10600±160, AA-1219, Apland and Harington 1994
165. Clayhurst Pit, 10340±150, CAMS-150, Apland and Harington 1994
166. Clayhurst Pit, 10230±140, AECV-1558C
167. Clayhurst Pit, 10750±180, RIDDL-220
168. Finlay-Parsnip, 9280±100, GSC-1497
169. Watino, 10200±50, GSC-2895, Lowdon and Blake 1979
170. Watino, 10200±50, GSC-2902, Lowdon and Blake 1979
171. Wakaluk Quarry, 9080±310, S-2614, Burns 1986
172. Saskatoon Mtn., 9380±360, AECV-1474C, Beaudoin et al. 1996
173. Saskatoon Mtn, 9360±60, CAMS-12365, Beaudoin et al. 1996
174. Wood Bog, 9630±650, AECV-470C, Beaudoin et al 1996
175. Wood Bog, 9730±110, AECV-1620C, Beaudoin et al 1996
176. Tumbler Ridge, 10380±100, BETA-44201, Woolf 1993
177. Summit Creek, 10000±50, GSC-2964, Lowdon and Blake 1980
178. Freeman River, 10900±80, GSC-859, Lowdon et al. 1971
179. Whitemud Creek, 8195±1090, S-1798, Rains and Welsh 1988
180. North Sask. River, 10740±470, S-1923, Lowdon and Blake 1979
181. Lorraine Lake, 9180±320, AECV-591C, Beaudoin 1991
182. Denholm Testhole, 10880±660, S-1374, Christiansen 1983
183. Eagle Testhole, 10760±780, S-2097, Christiansen 1983
184. Nordegg Pond, 8930±150, BETA-252261, Mandryk 1992
185. North Sask. Crossing, 9330±90, GSC-332, Dyck et al. 1966
186. James Pass, 9750±80, TO-2999, Ronaghan 1993
187. James Pass, 10140±80, TO-3000, Ronaghen 1993
188. Three Hills, 9670±60, I-8579, Shackleton and Hills 1977
189. Three Hills, 9720±150, GSC-1894, Shackleton and Hills 1977
190. Crowfoot Lake, 9060±370, CAMS-3064., Reasoner et al. 1994
191. Crowfoot Lake, 10070±420, CAMS-3177, Reasoner et al. 1994
192. Crowfoot Lake, 10020±70, CAMS-3063, Reasoner et al. 1994

Table 1: Site Identification (Site Name, Date±error (1 SD), Lab No., Reference)

193. Crowfoot Lake, 9470±70, CAMS-6843, Reasoner et al 1994
194. Green, 10800±160, S-227, McCallum and Wittenberg 1965
195. Kenaston, 10150±200, S-97, McCallum and Wittenberg 1962
196. Lake O=hara, 10100±200, RIDDL-433, Reasoner and Hickman 1989
197. Lake O=hara, 10060±160, RIDDL-511, Reasoner and Hickman 1989
198. Wiseton, 10600±140, S-232, Rutherford et al. 1973
199. Copper Lake, 10490±160, RIDDL-664, White and Osborn 1992
200. Copper Lake, 9650±150, RIDDL-88, White and Osborn 1992
201. Yorkton, 10300±80, GSC-1356, Lowdon and Blake 1976
202. Griffen Gravel Pit, 10760±80, GSC-612, Lowden et al. 1967
203. Vermilion Lakes, 10180±130, RIDDL-73, Fedje et al. 1995
204. Vermilion Lakes, 9700±130, RIDDL-83, Fedje et al. 1995
205. Vermilion Lakes, 10040±160, RIDDL-72, Fedje et al. 1995
206. Vermilion Lakes, 10040±200, RIDDL-71, Fedje et al. 1995
207. Vermilion Lakes, 10100±210, RIDDL-81, Fedje et al. 1995
208. Vermilion Lakes, 10570±150, RIDDL-85, Fedje et al. 1995
209. Vermilion Lakes, 9570±150, RIDDL-75, Fedje et al. 1995
210. Vermilion Lakes,9870±230, RIDDL-317, Fedje et al. 1995
211. Vermilion Lakes, 10310±190, RIDDL-528, Fedje et al. 1995
212. Vermilion Lakes, 10060±220, RIDDL-84, Fedje et al. 1995
213. Vermilion Lakes, 10010±180, RIDDL-82, Fedje et al. 1995
214. Vermilion Lakes, 10210±130, RIDDL-282, Fedje et al. 1995
215. Vermilion Lakes, 10390±140, RIDDL-70, Fedje et al. 1995
216. Vermilion Lakes, 9840±60, GSC-3804, McNeely and McCuaig 1991
217. Vermilion Lakes, 10660±650, RIDDL-216, Fedje et al. 1995
218. Vermilion Lakes, 9880±140, AECV-121C, Fedje et al. 1995
219. Vermilion Lakes, 9840±200, RIDDL-77, Fedje et al. 1995
220. Vermilion Lakes, 10310±230, RIDDL-318, Fedje et al. 1995
221. Vermilion Lakes, 10270±100, RIDDL-79, Fedje et al. 1995
222. Vermilion Lakes, 10090±130, AECV-124C, Fedje et al. 1995
223. Vermilion Lakes, 10780±180, RIDDL-215, Fedje et al. 1995
224. Vermilion Lakes, 11000±1600, RIDDL-217, Fedje et al. 1995
225. Second Lake, 9455±450, S-2759, Fedje 1986
226. Kelliher, 9600±120, S-182, McCallum and Wittenberg 1965
227. Dinsmore, 10300±140, S-110, McCallum and Wittenberg 1962
228. Johnson Lake, 9440±230, TO-5186, Beierle and Smith 1998
229. Aquitaine Pit, 10200±140, GSC-3065, Blake 1986
230. EgPn-480, 9540±70, BETA-127235, Head 1999
231. Lower Burstall Lake, 9180±60, CAMS-20358, Beierle and Smith 1998
232. Kananakis Valley, 10400±60, GSC-2965, Lowdon and Blake 1980
233. Sioux Crossing, 10110±190, S-1304, Rutherford et al. 1979
234. Earl Grey, 10280±230, S-165, McCallum and Wittenberg 1965
235. Toboggan Lake, 10400±70, TO-149, MacDonald et al. 1991
236. Toboggan Lake, 9100±360, TO-211, MacDonald et al. 1991
237. Heron Eden, 9290±110, S-3308, Morlan 2001
238. Heron Eden, 9010±120, S-3114, Morlan 2001
239. Heron Eden, 10290±100, S-3118, Morlan 2001
240. Herbert, 10000±300, S-41, McCallum and Dyck 1960
241. EaPo-100, Lindo Site, 9790±190, GAK-5097, Rutherford et al. 1984
242. The Gap, 9520±240, GX-0956, Reeves and Dormaar 1972
243. Taber Provincial Park, 10500±100, GSC-3, Dyck and Fyles 1962
244. Crane Valley, 10800±300, S-128, McCallum and Wittenberg 1962
245. Scrimbit, 10400±250, S-85, Rutherford et al. 1979
246. Scrimbit, 10000±250, S-81, Rutherford et al. 1979
247. Niska, 8475±650, S-2510, Meyer and Liboiron 1990
248. Niska, 10880±70, TO-956, Meyer and Liboiron 1990
249. DjPm-16, Oldman River, 9600±210, AECV-746C, Van Dyke 1994
250. Frenchman Valley, 9225±330, S-2931, Klassen 1993
251. Robsart, 9500±40, GSC-4098, McNeely and McCuaig 1991
252. Val Marie, 9880±110, TO-2212, Klassen 1993
253. Val Marie, 9910±80, TO-1711, Klassen 1993
254. Fletcher Site, 9380±110, TO-1097, Wilson et al. 1991
255. Oldman River, 11000±250, S-68, McCallum and Dyck 1960

RADIOCARBON, Vol 44, Nr 2, 2002, p 455–472

DATING THE FIRST AUSTRALIANS

Richard Gillespie

Dizzy Heights, Ripps Road, Stokers Siding NSW 2484, Australia. Email: dizzy@better.net.au.

ABSTRACT. The dating of selected archaeological and megafaunal sites from the Australian region is reviewed, with emphasis on recent work at some of the oldest sites. Improved chemical procedures with decreased analytical background for ^{14}C analysis, combined with new luminescence dating methods, has confirmed many of the results processed decades ago and significantly increased the maximum age for some others. The oldest occupation horizons in four different regions reliably dated by defendable multi-method results are in the range 42–48,000 calendar years ago, overlapping with the age range for similarly well-dated undisturbed sites containing the youngest extinct megafauna. There is less secure evidence suggesting some archaeology may be earlier and some megafauna may have survived later than this period.

INTRODUCTION

Estimates of the time since humans first occupied the extended Late Pleistocene continent Sahul (sometimes called Greater Australia or Meganesia) have steadily increased since systematic archaeological excavation and radiocarbon dating became established in the 1960s. Jones (1968) considered 30,000 BP a reasonable estimate for the earliest arrivals, based on the available evidence showing 3 or 4 sites with ^{14}C dates of more than 20,000 BP. In the second edition of *The Prehistory of Australia* (Mulvaney 1975) an appended date list documented four sites in Australia and one in New Guinea with ^{14}C results older than 25,000 BP. The current edition (Mulvaney and Kamminga 1999) provides an overview of the hundreds of dates now accumulated for Late Pleistocene archaeological sites in Sahul. Some of the robust debate about claims for earliest occupation of the region is presented in Murray (1998).

Traditional ^{14}C dating using radiometric counting has become less important in Sahul, as elsewhere, since accelerator mass spectrometry (AMS) laboratories began to take on large workloads from the mid 1980s. In many situations this new measurement technology also allowed better pretreatment chemistry to be applied in the isolation and decontamination of specific sample components. At about the same time newer thermoluminescence (TL), optically stimulated luminescence (OSL), electron spin resonance (ESR), amino acid racemization (AAR), and uranium-thorium series (U/Th) dating methods began to make significant contributions to archaeology and the earth sciences. These and other techniques operate under different rules and on different materials to ^{14}C. An “archaeological event” such as a fire may sensibly be ^{14}C dated using charcoal, whereas luminescence methods on quartz sand are likely to be dating an “environmental event” such as exposure to sunlight, not necessarily directly associated with the target archaeological event. However, since everyone should eventually get the same answer to questions like “when did humans first colonize Australia” or “when did the megafauna become extinct” there are some instructive examples of cross-dating with different numerical methods.

Projects such as dating the first Australians or Americans have always been clouded by the bias brought to the debate by specialists from different academic fields. The physicists and chemists in dating laboratories argue about their measurements and what is being measured; archaeologists and geologists argue about associations between artifacts of human occupation and the sediments in which they are found. Dating specialists have a qualitatively different attitude to (and confidence in) their measurements compared with fieldworkers and theoreticians in other specialties. In a context of peopling the New Worlds, these related debates are all directed toward the establishment of an agreed time scale for human movements around the planet. The records we accumulate from excavations and numerical dating are necessarily discontinuous and incomplete, but there is now such a large dataset built in to the literature that deviations from established wisdom require stringent scrutiny.

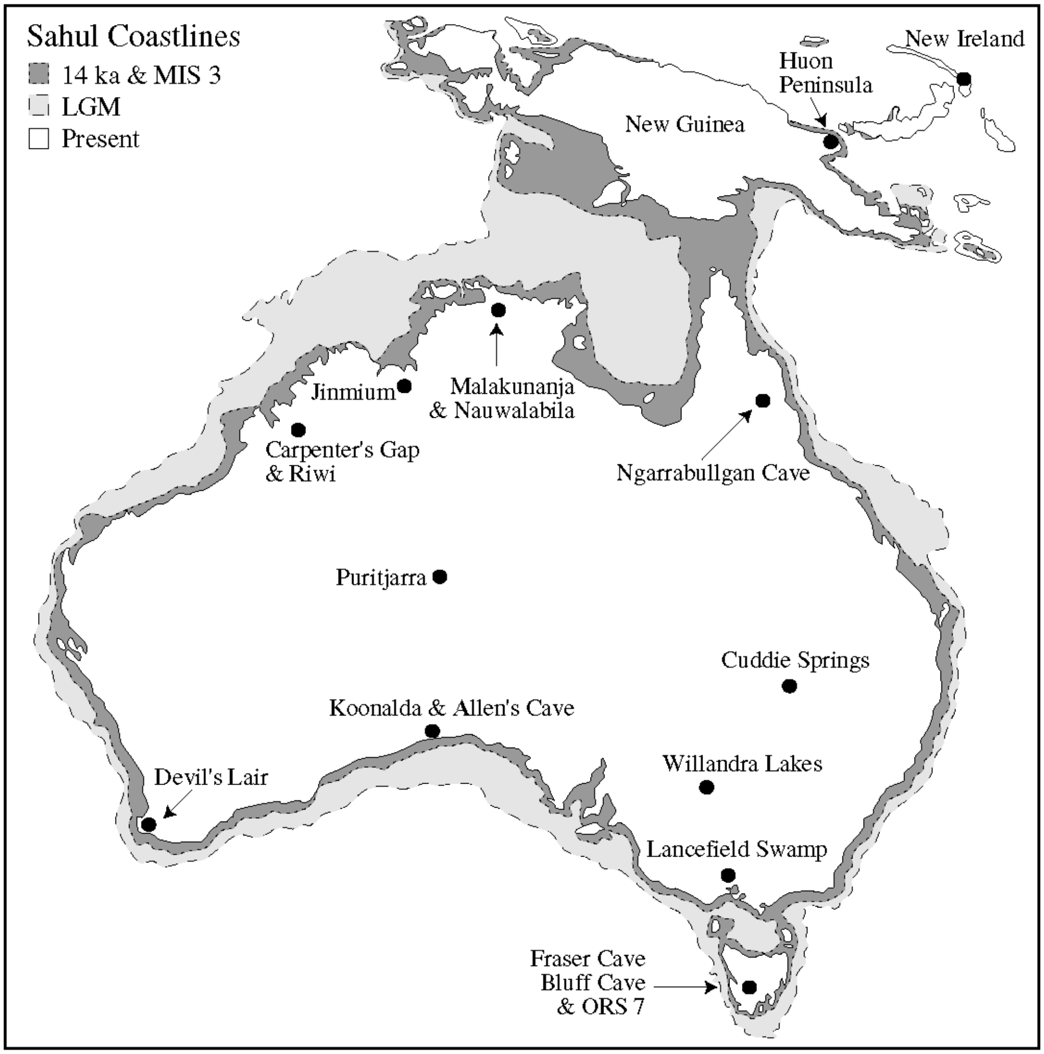


Figure 1 Map of the Australian region showing the location of sites discussed, with extended Sahul landmass at LGM (20–24 ka) and 14 ka (as proxy for Marine Isotope Stage 3), modified after Smith (1998).

A useful guide to the Australian debate is the concept of an "event horizon" (Chappell 1991), which places a maximum possible age limit on ^{14}C dates based on available technology and promotes calibration of the reported conventional ^{14}C ages. This idea is further developed to reconcile dating results over the 30 years since the "event horizon" for Australian archaeology was reported as >37,800 BP, revealing strong similarities with archaeology and megafauna debates in Europe and the Americas.

Geographical Background

Getting to Australia has always involved sea crossings, because on timescales relevant to human evolution Sahul has always been an island continent. Assuming an African origin for modern *Homo sapiens*, the only human species known in the archaeological record of Sahul (Groves 1996), likely routes would have been eastward through what are now the islands of Indonesia in South East Asia.

Throughout much of the Pleistocene, including the Last Glacial Maximum (LGM), the currently large islands of Australia, Tasmania, and New Guinea were linked by lowland plains. Reconstructions based on Huon Peninsula raised coral terraces and on marine cores from several regions show that during LGM sea level was about 120 meters below present (Chappell et al. 1996b; Shackleton 2000). Much attention has been given to the LGM period (20–25 ka) in relation to the peopling of Australia, because crossing from Southeast Asia (Sundaland) then would not have required as many (or as lengthy) sea voyages. Unlike the Americas, where first occupation appears to be a post-LGM event, it has been known for decades that the peopling of Australia began well before LGM.

It now seems probable that an extended Sahul continent existed not only at LGM but also throughout most of Marine Isotope Stage 3 (MIS3, 30–70 ka). Sea level fluctuated during MIS3 with decreasing amplitude in a range of about 60 ± 20 meters below present (Chappell et al. 1996b). Following LGM, sea level rose rapidly to reach a range similar to that in MIS3 by about 14 ka, shortly before Tasmania and New Guinea became isolated from Australia. The degree of difficulty for intrepid seafarers traveling from Asia to colonize Sahul would not have been significantly greater during MIS3 than at LGM, and there were no continental ice sheet barriers in Sahul to thwart enterprising explorers. These first arrivals in the eastern New World, making landfall possibly in northwestern New Guinea, would have been able to walk from the equator almost halfway to the south pole. Approximate coastlines for Sahul at LGM and at 14 ka (as proxy for MIS3) are shown in Figure 1 (modified after Smith 1998), with the present geography and location of sites discussed here.

^{14}C Results from Selected Archaeological Sites

Only a few of the oldest well-documented archaeological sites in Sahul are considered, where recent work has begun to systematically refine the chronology of human occupation and the related topic of Late Pleistocene megafaunal extinction. The Holocene is mostly ignored to concentrate on Late Pleistocene sites with the traditional boundary at 10,000 BP. This more or less rules out calibration of ^{14}C results with the published tree ring records, so all ^{14}C dates have been recalculated from the original Conventional Radiocarbon Age data using a second order polynomial. The equation is Calibrated Age = $1.40(\mathrm{CRA}) - 6.83 \times 10^{-6}(\mathrm{CRA})^2 - 1969$, described in Gillespie (1998) as a compromise between coral and magnetic data. This calibration adds a maximum adjustment of 4000 years at 30,000 BP, decreasing to 3000 years at 40,000 BP and 1000 years at 50,000 BP. Calibration becomes increasingly uncertain with age but this curve is compatible with the comprehensive data in Yokoyama et al (2000). Calibrated ^{14}C dates provide the best available numbers for direct comparison with "absolute" dates from other methods expressed in calendar years (where 1000 years = 1 ka).

Figure 2 shows histograms of ^{14}C dates from selected archaeological sites or regions to give an idea of the continental spread of Pleistocene ^{14}C dates. This diagram simply records the number of finite calibrated ^{14}C dates in each 1000 year interval, giving all results equal value and ignoring the error terms. The dashed line at 40 ka approximates the ^{14}C "event horizon" for Australian laboratories around 1970, and the shaded region represents LGM.

1. *Tasmania*. A compilation of dates from three sites, Fraser Cave (Kiernan et al. 1983), Bluff Cave, and ORS7 (Cosgrove 1989) are shown; all samples were charcoal given standard acid/alkali/acid pretreatment. The ^{14}C record shows occupation back to 34 ka, the youngest starting date for any of the regions considered here.
2. *New Ireland*. Again three sites are combined: Matenkupkum, Balof 2, and Panakiwuk (Allen et al. 1988; Allen 1989). The group of 5 oldest dates are on marine shell from one midden layer in the Matenkupkum cave site, where a steeply sloping shelf and tectonic processes have left the site 15 meters above present sea level. Other dates are on shell, bone or charcoal and all shell

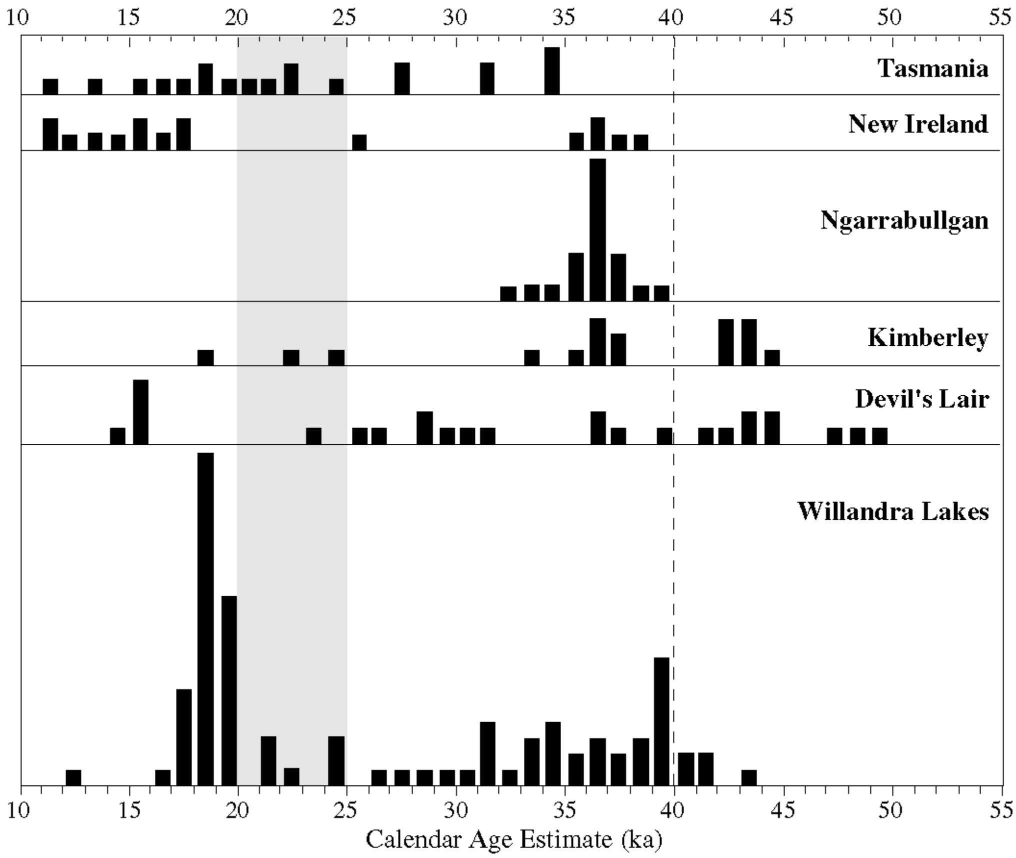


Figure 2 Calibrated ^{14}C dates from selected Sahul archaeological sites, displayed as the number of results in each 1000-year interval (references in text).

dates have been corrected for a marine reservoir effect of 400 years. New Ireland was separated from Sahul by deep water throughout the Late Pleistocene, apparently no barrier to occupation by 36 ± 2 ka. This is only slightly younger than about 40 ka for archaeology on the Huon Peninsula, New Guinea, suggested by U/Th dating of coral terraces and TL dating of a tephra sequence, (Groube et al. 1986).

3. *Ngarrabullgan*. A cave site about 100 km west of Cairns in north Queensland, situated on a table-top mountain 200-400 meters above surrounding plains and hills. This dry site has few mammals to disturb the deposits, with good preservation of charcoal and organic residues on stone tools. Results from AMS dating of 18 separate fragments of charcoal from a single occupation layer show a Gaussian distribution about 36 ± 2 ka, confirmed by OSL dates of 35 ka from the base of the same layer (David et al. 1997; Bird et al. 1999). An undated unit with sparse artifacts immediately underlying this charcoal-rich layer may represent leakage from above, not necessarily older occupation.
4. *Kimberley*. This region of northwestern Australia has been considered one of the likely entry points for early settlers in Sahul, via the present island of Timor. Excavations in a limestone shelter at Carpenter's Gap (O'Connor 1995; McConnell and O'Connor 1997) revealed about 1 meter of occupation sediments containing well-preserved macro plant remains: seeds, glumes

and stem fragments of grasses, and seeds of edible fruit. Similarly, test excavations in a limestone cave site at Riwi (Balme 2000) yielded cultural deposits with well-preserved organic remains. The fairly consistent sequence of ^{14}C dates from both sites using radiometric and AMS methods has a maximum age of 44 ka. Shell dates approximately 35 ka have recently been obtained (O'Connor et al. 2002) from the Lene Hara archaeological site on Timor.

5. *Devil's Lair*. This cave site in southwestern Australia was first excavated in the 1970s, yielding a stratified sequence more than 4 meters deep with ^{14}C dates on charcoal extending to 38 ka (Dortch and Merrilees 1973; Dortch 1979; Dortch and Dortch 1996). Subsequent resampling for ^{14}C, OSL and ESR dating has extended occupation of the cave to around 48 ka (Layer 30, Turney et al. 2001). Sparse artifacts in Layers 32–38 are slightly older, with good agreement between ^{14}C and OSL in Layer 39 below the archaeology at 50 ka. ESR measurements (early uptake model) on teeth from an extant marsupial are in agreement with this sequence to 44 ka, but yield older dates than other methods on samples from Layer 39.
6. *Willandra Lakes*. Mungo is one of the icons of Australian archaeology; Lake Mungo is one of a series of large lakes formerly part of the Murray-Darling river system that drains a large fraction of eastern Australia. These Willandra lakes are now permanently dry, but during the Late Pleistocene they contained large quantities of fresh water which attracted some of the earliest residents. A National Park and World Heritage Area is centred on Lake Mungo, reflecting the wealth of archaeology and environmental history.

   Large-scale archaeological excavations were carried out in the early 1970s near the south end of the Mungo lunette, penetrating more than 2 meters to sterile sands (Mulvaney 1974; Shawcross and Kaye 1980; Shawcross 1998). ^{14}C and TL dating results from the Willandra lakes have been recently reviewed (Bowler 1998; Bowler and Price 1998; Gillespie 1998). TL dating of heated sediments from under, and heat retainers within, hearths in the Mungo lunette overlap with calibrated ^{14}C dates on charcoal from the same fireplaces in the range 34 ± 3 ka (Barbetti and Polach 1973; Huxtable and Aitken 1977; Bell 1991). This period of human occupation coincides with deposition of Arumpo Unit sediments although the hearths are dug into older units. The oldest ^{14}C dates on charcoal, emu eggshell, lacustrine shell, and fish otolith at 40 ± 3 ka are from locations close to a transition zone in the lunettes, where clay-rich sediments derived from the lake floor during times of lower, fluctuating water levels (Upper Mungo Unit) overly quartz dominant sediments from a high lake level phase (Lower Mungo Unit). TL dates on unheated sediments are widely scattered and not consistent with the ^{14}C record (Oyston 1996; Bowler and Price 1998). Ongoing new work suggests that the Upper Mungo occupation horizons are close to 44 ka (Spooner et al. forthcoming).

Dating the Human Bones

Although human skeletal remains have been found in many other Sahul locations, only material recovered from the Willandra Lakes region is considered. The first of more than 100 separate burials was found by Jim Bowler during geomorphic fieldwork at Lake Mungo in 1968. It is somewhat ironic that Mungo is one of the least suitable lakes for detailed reconstruction of this rich prehistory. A large fraction of the archaeological sites, mostly hearths or other fireplaces and shell middens, are found in the lunettes developed by aeolian processes on the eastern margins of the lakes. The Mungo lunette is most strongly eroded, possibly because this lake was only filled by fluctuating overflow from Lake Leaghur to the immediate north. Whatever the mechanism, large areas of the Mungo lunette have lost several meters of sediment, exposing the human bones but also rendering much of the stratigraphy horizontal. The "Walls of China" mobile white dune downwind of the Mungo lunette was present before European settlement and sheep grazing has accelerated erosion over the past 150 years.

Burial Mungo 1 (or WLH-1), yielded dates of 28 ka on an acid insoluble residue and 22 ka on "apatite" (Bowler et al. 1972). Later work showed that >90% of the carbon in this burnt bone was alkali-soluble humic acids dated at 29 ka, with an A/B/A insoluble residue at 20 ka. Burnt bone burials near Lake Garnpung (WLH-23, 24 and 122) also yielded abundant humic acids several millennia older than the A/B/A insoluble residues dated at 13–14 ka (Gillespie 1997). The established Willandra chronology was questioned by a recent study on unburnt bone from the Mungo 3 skeleton (a.k.a. WLH-3 or LM3), with U/Th and ESR dates in the range 50–78 ka and a combined estimate of 62 ± 6 ka (Simpson and Grün 1998; Thorne et al. 1999). OSL dates at 61 ± 2 ka were obtained from sediments underlying the burial horizon, supporting the younger end of the U/Th/ESR range (these sands must be older than the burial). These results have been criticized on stratigraphic and technical grounds (Bowler and Magee 2000; Gillespie and Roberts 2000). No ^{14}C dates have been reported for the Mungo 3 skeleton, nor on any archaeological material associated with the burial, and the response of Grün et al. (2000) has not resolved all the issues.

As an added complication, previously unpublished results on several more human bones are presented in Tables 1 and 2 (Keith Fifield and Tie-Mei Chen, personal communication). AMS ^{14}C measurements and alpha spectrometry U/Th measurements were made on samples of post-cranial bone fragments in 1988-90, using procedures described in Fifield et al. (1992) or Chen and Yuan (1988). Samples from burials WLH-15 and WLH-55 were chosen because only those 2 from 56 unburnt skeletons analyzed contained >0.2% nitrogen (Webb 1989). These proved to have well-preserved collagen, from which a total amino acids fraction was prepared by standard methods (Gillespie et al. 1986), yielding post-bomb Modern and Late Holocene dates. Burnt bone from burial WLH-28 was given standard room temperature A/B/A pretreatment chemistry to produce both humic acids (12 ka) and insoluble residue (14 ka) dates. Direct comparison between ^{14}C and U/Th methods on WLH-55

Table 1 ^{14}C measurements on Willandra Lakes human bone samples[a]

Burial	Lab nr	Fraction dated	^{14}C age BP
WLH-55	ANUA-36	Collagen amino acids	4000 ± 1000
WLH-15	ANUA-35	Collagen amino acids	117 ± 5.0 %M
WLH-28	ANUA-33	A/B/A residue	12,000 ± 1000
	ANUA-34	Humic acids	9000 ± 1000

[a]AMS ^{14}C age estimates (Keith Fifield personal communication 1990) determined on post-cranial fragments of human bone burials from the Willandra Lakes, described in Webb (1989).

Table 2 U/Th series measurements on Willandra Lakes human bones[a]

Burial	Lab nr	U (ppm)	$^{234}U/^{238}U$	$^{230}Th/^{234}U$	^{230}Th age (ka)
WLH-55	BKY 88034	2.62 ± 0.14	1.30 ± 0.09	0.055 ± 0.013	6.2 ± 0.2
		1.39 ± 0.17		0.225 ± 0.062	28.4 ± 9.2
WLH-18	BKY 88032	4.5 ± 0.2	1.12 ± 0.06	0.171 ± 0.014	20.3 ± 1.8
WLH-52	BKY 88033	3.65 ± 0.22	1.36 ± 0.10	0.714 ± 0.048	125 ± 15
		3.65 ± 0.22	1.35 ± 0.10	0.690 ± 0.048	118 ± 14

[a]Alpha spectrometry U/Th age estimates (Tie-Mei Chen personal communication 1989) determined on post-cranial fragments of human bone burials from the Willandra Lakes, described in Webb (1989).

produced equivocal results, with very different U/Th age estimates from two separate fragments. A Holocene age was expected because of the unusually well-preserved collagen, which is supported by the younger U/Th date; the older age of 28 ka may be explained by recent leaching of uranium from the bone. A 20 ka date for WLH-18 is unexceptional, but the U/Th estimate of 125 ka for burial WLH-52 is at least twice the age of any archaeological site in Sahul.

Additional Sites Where New OSL Methods Have Been Important

Development of new techniques in optically stimulated luminescence dating has given additional information on some sites where ^{14}C or TL dating is equivocal: sediments with no suitable carbonaceous material and/or the true age is beyond the practical ^{14}C range, and unheated sediments where TL fails to yield stratigraphically consistent results.

1. *Jinmium*. The sandstone rock shelter site of Jinmium in northwestern Australia came to notoriety with TL dates suggesting pecked cupules on buried rocks were older than 58 ka, ochre at 75–116 ka, with stone artifacts and first occupation at 116–176 ka (Fullagar et al. 1996). These results were widely disbelieved, with criticism on dating and sedimentological grounds (e.g. Roberts 1997; Spooner 1998). Subsequent resampling for OSL and AMS ^{14}C dating has radically reduced the maximum age for the deposits. Small samples of charcoal from the cultural layers treated with either A/B/A or strong oxidation chemistry yielded ^{14}C dates in the range 80–3870 BP; OSL dates agree with the ^{14}C where direct comparisons were made and suggest that the all the cultural deposits are Holocene (Roberts et al. 1998a; 1999). AMS ^{14}C dating of oxalate carbon from rock varnish also suggests that the pecked cupule artwork is most probably of Holocene age (Watchman et al. 2000). In this example the TL dating of unheated sediments has been shown to yield incorrect age estimates, whereas OSL methods are likely to be correct because they measure a signal that is known to be rapidly reset by exposure to sunlight.
2. *Nullabor Plains*. Koonalda Cave is part of a large underground karst system developed in Eocene limestone, with water-deposited sediments on the cave floor containing hearths ^{14}C dated in the range 16–27 ka (Wright 1971). Subsequent resampling has confirmed dates for the deepest charcoal, but OSL results are considered unacceptable because a surface sample yielded an age estimate of 9.2 ± 1.1 ka (Roberts et al. 1996). The presence of significant disequilibrium in the radionuclide decay chains suggests that leaching (which may not have been constant) has taken place; geomorphic, ^{137}Cs, and ^{210}Pb excess data support an age of less than 100 years for the surface deposits. These analyses demonstrate that luminescence methods are unsuitable for deep cave sites where episodic storage and transport in darkness result in overestimation of the time since last exposure to sunlight.
   Allen's Cave is a small rock shelter in a shallow collapsed sinkhole developed in Miocene limestone, with hearth charcoal dated to a maximum of 20 ka (Martin 1973). Subsequent resampling yielded a near modern OSL age at the surface, good agreement between ^{14}C, TL, and OSL dates at 10–11 ka and extended the occupation sequence to about 40 ka (Roberts et al. 1996). The first application of single-aliquot and single-grain OSL measurements to archaeological sediments in Australia (Murray and Roberts 1997), demonstrated that single-aliquot estimates were consistent with traditional multiple-aliquot TL and OSL results, and that single-grain OSL measurements allow further refinement in sediments where the TL/OSL signal was incompletely reset during deposition.
3. *Puritjarra*. The sandstone rock shelter at Puritjarra, in the Cleland Hills west of Alic Springs, provided the first evidence that people lived in the arid central Australian region during the Late Pleistocene (Smith 1987). First occupation was estimated at about 35 ka from TL dating, but there was an offset between the ^{14}C and TL chronologies (Smith et al. 1997). This anomaly has

now been resolved using ABOX pretreatment chemistry on charcoal samples (Smith et al. 2001).

4. *Malakunanja II and Nauwalabila I*. These two sites in the wet tropical "Top End" of northern Australia were first excavated as part of an archaeological survey (Kamminga and Allen 1973) instrumental in the 1979 establishment of Kakadu National Park. ^{14}C dates on charcoal from these rock shelter sites extended to approximately 23 ka; subsequent resampling has confirmed dates for these cultural deposits with TL/OSL results similar to ^{14}C dates in the 15–30 ka range. Below these occupation layers charcoal is very scarce to absent, but consistent TL and OSL dates suggest that artifacts in levels dated to 50–60 ka represent earlier occupation (Roberts et al. 1990a, 1994, 1998b). There has been strong archaeological criticism of this luminescence chronology (Allen 1989; Bowdler 1990; Hiscock 1990; Allen 1994; Allen and Holdaway 1995; O'Connell and Allen 1998); some of the unresolved issues are addressed in the discussion below.

People and Megafauna

Several Australian sites have been promoted as demonstrating a significant overlap of human occupation with extinct megafauna, usually on the basis of ^{14}C dates on bones or charcoal from sediments in which they are found. These results are by no means universally accepted and many dates have been rejected (Baynes 1995) on criteria proposed by Meltzer and Mead (1985), the two sites discussed illustrate some of the difficulties in dating and interpretation.

1. *Lancefield Swamp*. In Figure 3, the upper panel shows ^{14}C and other dates from Lancefield Swamp, a spring site in southeastern Australia with abundant megafauna and sparse archaeology. The megafaunal remains occur in a discrete bone bed 1.5–1.7 m below present surface, underlain by a channel fill from which charcoal was dated to about 30 ka (Gillespie et al. 1978). Bones and teeth are very poorly preserved, with extensive mineral replacement (sometimes retaining the fibrous texture of dentine or collagen) but containing little or no residual protein; ^{14}C dates on bone fractions are widely scattered and unreliable. This poor bone preservation is in sharp contrast with other organic materials within the site: there is some charcoal, well-preserved unburnt macro plant debris and pollen throughout the sequence, plant roots below the bone bed were post-bomb modern. Recent studies using AAR and ESR methods on extinct marsupial teeth from Lancefield Swamp yielded age estimates in the range 38–60 ka (van Huet et al. 1998), significantly older than the original charcoal dates would suggest for the archaeology.
2. *Cuddie Springs*. The lower panel of Figure 3 shows ^{14}C charcoal dates from Cuddie Springs, an ephemeral lake/swamp site with megafauna and archaeology (Dodson et al. 1993; Furby et al. 1993; Fullagar and Field 1997; Field and Boles 1998). Megafaunal remains are found throughout a >13 m sequence, including near-surface locations also containing modern cow bones. Of most interest are Stratigraphic Units 6a and 6b at 1.0–1.7 m below present surface, containing extant and extinct fauna, charcoal and stone artifacts in fine-grained sediments. ^{14}C results on charcoal show a random age/depth distribution with a range of about 32–37 ka, supported by an OSL date of around 35 ka in the same deposits (Field and Dodson 1999). There are also well-preserved organic residues on stone tools, pollen, unburnt macro plant debris, and fragments of freshwater shell, but no dates on these materials have been reported. Bones and teeth are extensively degraded with no residual protein, and in common with Lancefield Swamp the extinct megafauna skeletal remains are not articulated.

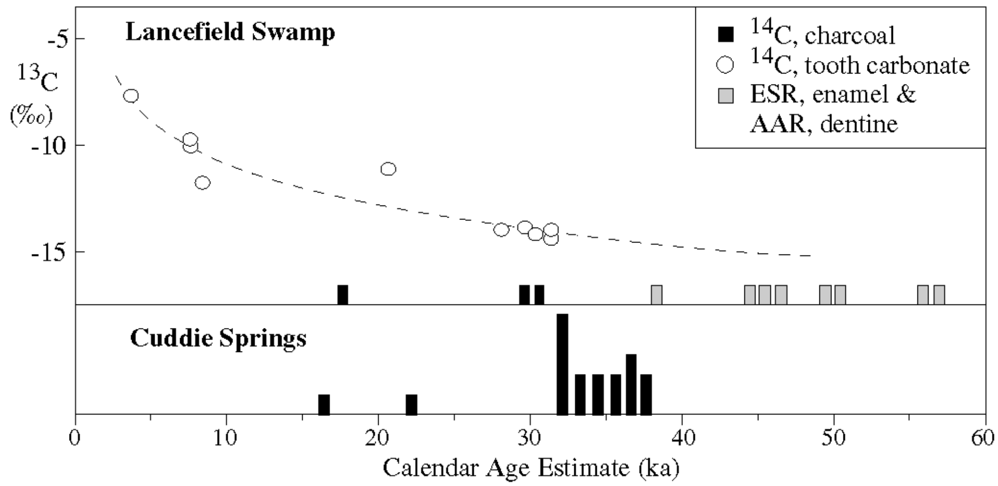


Figure 3 ^{14}C and other dates from selected megafauna sites. Lancefield Swamp data from Gillespie et al. (1978) and van Huet et al. (1998); Cuddie Springs data from Field and Dodson (1999), Fifield et al. (2001), and Roberts et al. (2001).

DISCUSSION

Archaeological criticism of ^{14}C and luminescence chronologies for the first occupation of Australia (e.g. Allen and Holdaway 1995; O'Connell and Allen 1998) appears to be based on concern that: the ^{14}C chronology extends only to about 40,000 BP, some TL/OSL dates are older than any ^{14}C results, U/Th/ESR dates for the Mungo 3 skeleton at >60 ka are older still, and Sahul dates >50 ka are earlier than ^{14}C dates from Europe and therefore a major revision of world prehistory is required to accommodate them.

Figure 4A shows histograms of calibrated ^{14}C dates >35 ka from Australia (n=82, this work) and from Europe (n=131 *modern* and n=76 *Neanderthal*, Bocquet-Appel and Demars 2000). Under the Allen and coworkers interpretation, this would imply that *modern* humans arrived in Australia at the same time as both *modern* humans and extinct *Neanderthal* arrived in Europe, possibly about 50 ka. Similarly, the distributions in Figure 4B would imply that *modern* Australians, who were certainly eating the extant fish, shellfish, and emu, could also have been eating the extinct *Genyornis* (n=22, Miller et al. 1999) over this time range.

These are clearly not realistic interpretations because we know, for example, that the representative extinct megafauna were present in Europe and Australia much earlier than 50 ka. Chappell et al. (1996a) pointed out that such distributions are simply reflecting the limitations of ^{14}C dating, including contributions from chemical decontamination, analytical background and calibration. The fact that older ^{14}C dates exist for geological samples is irrelevant because sufficient carbon in uncontaminated form is rare in the oldest archaeological sites. Over the three decades of ^{14}C dating results from Europe and Australia shown in Figure 4A, chemistry has improved and analytical background reduced from about 1% to 0.1%, resulting in a change of the applicable "event horizon" from about 40 ka to 50 ka. Similar technological advances have also been made in other dating methods, but incorrect dates have not been removed from the distributions.

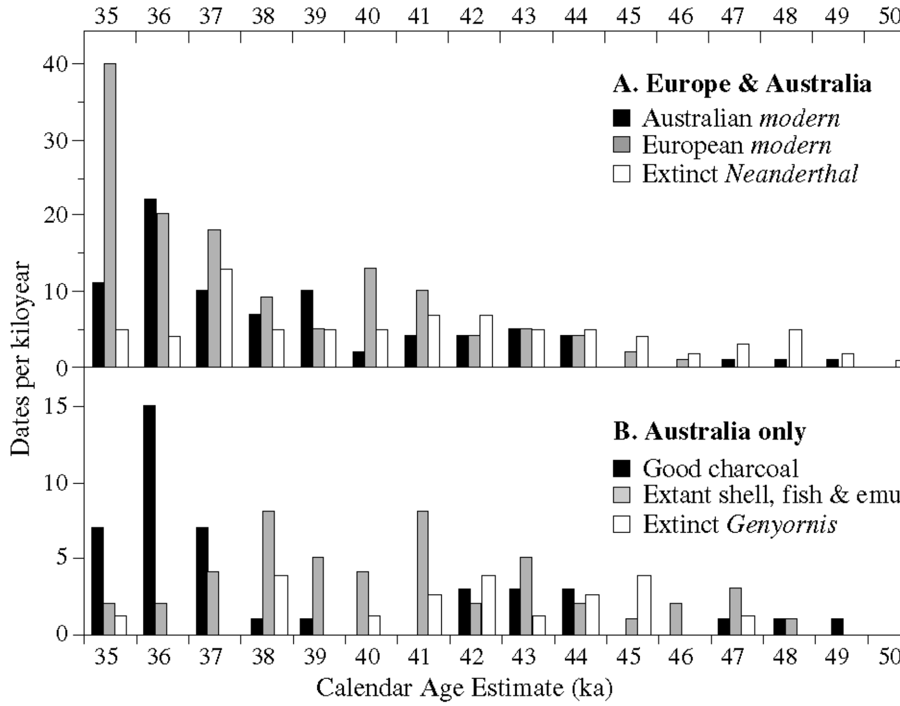


Figure 4 **A:** Distribution of calibrated ^{14}C dates from Australian and European archaeology. Australian data from Figure 2 (references in text); European data from Bocquet-Appel and Demars (2000). B: Distribution of calibrated ^{14}C dates on different sample materials. Data from Figure 2 and Miller et al. (1999).

(A) Filtering the ^{14}C Dataset

Many black samples labeled "charcoal" from Australian archaeological sites turn out to contain almost no real charcoal; all fractions have similar carbon content and might more descriptively be labeled unburnt detritus or "compost" (Gillespie 1998). Shell middens in the Willandra Lakes are usually found in black, compost-rich sediments with alkali-soluble fractions frequently older than A/B/A residues, but it is not clear from what source this carbon is derived. Wet oxidation pretreatment methods can remove compost without destroying real charcoal (Gillespie 1990, 1997; Bird and Grocke 1997; Bird et al. 1999; Turney et al. 2001; Fifield et al. 2001). With these observations in mind, ^{14}C measurements on Australian black samples may be loosely divided into 3 phases:

Phase 1—minimal chemistry with a ^{14}C "event horizon" near 38–40,000 BP (e.g. Polach et al. 1970; Gillespie and Temple 1973).

Phase 2—improved A/B/A chemistry with a ^{14}C "event horizon" of 42–44,000 BP (most post-1980 work).

Phase 3—ABOX-SC chemistry with a ^{14}C "event horizon" of 48–50,000 BP (Bird et al. 1999; Fifield et al. 2001; Turney et al. 2001).

In the most recent Phase 3 work, ABOX-SC refers to acid/base/dichromate oxidation followed by a 3-temperature stepped combustion, which adds reassurance that the chemistry has been successful because unburnt organics will combust at a lower temperature than charcoal. Some idea of the magnitude of contamination and/or analytical background limitations for charcoal samples from the Devil's Lair site is shown in Table 3. For samples near the lowest occupation horizon (Layers 27–28) the Phase 1 dates are about 15,000 years younger than overlapping Phase 3, OSL and ESR dates around 44 ka, with Phase 2 dates close to the Phase 3 results. Below all the archaeology (Layer 39), Phase 1 and 2 dates are 8–10,000 years younger than Phase 3 and OSL dates of approximately 50 ka from the same layer, but the ESR dates are 13–24,000 years older.

Table 3 Magnitude of contamination and background limitations at Devil's Lair[a]

Method	Layers 27–28	Layer 39
Phase 1	24,600 ± 800 BP (SUA-31) 27,700 ± 700 BP (SUA-539)	37,750 ± 2500 BP (SUA-698)
Phase 2	38,800 ± 1750 BP (OZD-327) 40,500 ± 1750 BP (OZD-330) 41,500 ± 2000 BP (OZD-329)	40,400 ± 1900 BP (OZD-331)
Phase 3	41,460 ± 1300 BP (ANUA-11709) (44.3 ± 2.6 ka)	48,130 ± 2300 BP (ANUA-11511) (49.6 ± 4.6 ka)
OSL	43.4 ± 2.2 ka (DL8) 44.4 ± 2.1 ka (DL7)	51.1 ± 2.6 ka (DL17)
ESR (EU)	42 ± 3 ka (#1437B) 44 ± 3 ka (#1437A)	64 ± 7 ka (#1448B) 75 ± 7 ka (#1448A)

[a]OSL, ESR, and ^{14}C data from Gillespie and Temple (1973), Dortch (1979), and Turney et al. (2001). Layers 27–28 are close to the lowest occupation levels, Layer 39 is below the deepest artifacts.

Similar comparisons using ABOX-SC procedures in the Kimberley sites (Carpenter's Gap and Riwi) and in the Willandra Lakes suggest the oldest occupation horizons are 43-44 ka (Fifield et al. 2001; Spooner et al. forthcoming). The numerous Willandra Lakes ^{14}C carbonate dates on shells, emu eggshells and fish otoliths with Phase 1 or 2 results near 36,000 BP (40 ka) would now also appear to be 3000–4000 years too young on the same criteria. Support for this interpretation comes from paired ^{14}C and TIMS U/Th results with extended leaching experiments on Huon Peninsula coral carbonate (Yokoyama et al. 2000), suggesting that carbonate contamination may account for 3000–4000 years of the age differences found.

Thus both charcoal and carbonate samples are subject to contamination and often give incorrect results in the >30,000 BP period, even when the dates are clearly resolved from the "event horizon". Removing the dubious organics, shell, otolith and eggshell dates from the Australian dataset in Figures 2 and 4A leaves the charcoal results shown in Figure 4B as the most reliable ^{14}C evidence for human occupation. These 44 "good" charcoals are all finite age estimates younger than 50 ka and well supported by some combination of TL, OSL, U/Th, and ESR dating.

(B) The Bone Dates

The direct ^{14}C dating of bone has had a troubled history, in most cases because the samples fail to meet one of the original assumptions for the method: "the possibility of obtaining unaltered samples" (Arnold and Libby 1949). Poor organic preservation in most Willandra human bones is similar to bones from other semi-arid open sites in Australia or elsewhere. Well-documented methods for reliable ^{14}C measurements on single amino acids from bone collagen (e.g. Stafford et al. 1991) have not been applicable because almost no protein has been found. Phase 1 or 2 chemistry has so far produced no results older than about 28 ka for the Mungo 1 cremation, with a younger group of burials at 13–14 ka near Lake Garnpung (WLH-23, 24 and 122; Gillespie 1997).

There are additional problems for U/Th/ESR methods because the mineral components as well as the organics have been altered by diagenesis. The movement of isotopes into and out of bones and sediments is complicated by changing hydrology and the commonly applied Early or Linear Uptake models do not necessarily cover all possibilities (e.g. Hedges and Millard, 1995; Millard and Pike 1999). For the WLH-50 burial around 14 ka, TIMS and gamma spectrometry U/Th dates overlap convincingly (Simpson and Grün 1998), but there is just as much variability in the individual U/Th/ESR results on the Mungo 3 skeleton (Thorne et al. 1999) as in the Upper Mungo occupation ^{14}C results. It is worth repeating that these human burials were originally dug into sediments older than the occupation surface of the day, which may also have been deflated prior to burial. Samples for OSL dating of sediments underlying the Mungo 3 skeleton were taken several hundred meters from the burial site and may not be relevant to the skeleton's precise position (Bowler and Magee 2000; Grün et al. 2000). While there is no doubt that some Lower Mungo sediments deeper than the burial are 60 ka, this is a maximum possible age and places no limit on how much later the burial pit was actually dug into the lunette. Similar remarks apply to the U/Th results on WLH-52 in Table 3, where there is no environmental information available and the apparent age corresponds to deposits underlying the Lower Mungo: the Golgol Unit (96–126 ka) in which no cultural material has been found (Bowler 1998; Bowler and Price 1998). The considerable uncertainty about the true age of all the Willandra skeletons suggest that none of the dates should be accepted at face value.

Some of the conclusions drawn from a DNA study (Adcock et al. 2001) of Mungo 3 and several other Willandra Lakes and Kow Swamp human burials depend on their true age. Table 1 includes ^{14}C dates for WLH-15 (modern) and WLH-55 (late Holocene) for which DNA extraction has been reported. A reanalysis of the genetic data suggests that Mungo 3 and the other skeletons all fit within modern human variability (Cooper et al. 2001), so judgement should probably be withheld until both the dating and the DNA analysis have been replicated. Whether the Mungo 3 remains turn out to be 40, 50, or 60 ka does not seem to matter for the human origins debate, with *modern* people living in Africa >100 ka there is plenty of time to reach Europe or Australia by any of those dates.

(C) The Luminescence Results

In the Arnhem Land sites Malakunanja II and Nauwalabila I, there is compost but very little charcoal throughout the sequences studied so ^{14}C has limited value. The main point of divergence between commentators concerns the luminescence results suggesting that there was human occupation 50–60 ka. Applying the same kind of analysis to the Malakunanja II data, there is reasonable agreement between Phase 2 ^{14}C and multiple-aliquot TL dates near modern at the surface of a Holocene shell midden, and between Phase 2 or 3 ^{14}C and TL dates of 15–25 ka in occupation deposits approximately 1.5–2.2 m below surface. Very consistent multiple-aliquot TL, single-aliquot OSL and single-grain OSL dates around 44 ka overly a pit containing artifacts, with sediments at the lowest artifact level about 2.5 m deep dated by TL/OSL at approximately 60 ka, but single-grain OSL dates group near 55 ka (Roberts et al. 1998b). Similarly, at Nauwalabila I there is an OSL date near modern at the surface and reasonable agreement between Phase 2 ^{14}C, TL, and OSL dates in cultural levels 1.1–1.8 m below surface at 13–30 ka. Deeper sediments have little or no charcoal, with artifacts in sediments at 2.3–3.0 m bracketed by 53–60 ka OSL dates (Roberts et al.1994). The TL/OSL methods applied to these sites are the same as those showing such good cross-dating results at, for example, Devil's Lair (Turney et al. 2001).

(D) The Megafauna

An alternative presentation of the AMS data from Lancefield Swamp is given at the top of Figure 3, showing the change in carbonate δ^{13}C and ^{14}C age with increasing acetic acid extraction time on megafaunal teeth, reaching a plateau for "apatite carbonate" with $\delta^{13}C = -14‰$ after about 90 hours. The cluster of results near 30 ka is the same age as charcoal from channel fill underlying the bone bed. A fitted logarithmic curve suggests recent "exogenous carbonate" diffusing into the teeth, trending toward an equilibrium isotopic composition between modern and fossil carbonate. This interpretation supports the idea that high-energy fluvial transport deposited gravels containing the bones and charcoal at that time (van Huet et al. 1998), and also reset the carbon isotopes in megafaunal teeth. Extrapolating the diffusion curve implies a true age for the megafauna older than that represented by the charcoal, perhaps similar to (or greater than) the ESR and AAR estimates.

Direct AAR dating was also attempted on marsupial teeth from Cuddie Springs, but few amino acids were found and D/L ratios widely scattered (Clarke 1999). The ^{14}C and OSL ages imply that both charcoal and sand were deposited at the same time, but neither is necessarily dating the megafauna or the stone tools. No hearth structures have been reported, suggesting that the charcoal came from somewhere else, and the nearest source of stone is 4 km from the site. David (2001) points out that seed grinding tools from Cuddie Springs are assigned the same 35 ka age as the charcoal and sand, whereas examples from most other Sahul sites are of Holocene age, and suggests that European well-digging and other operations may be partly responsible for some disturbance of the deposits. Single-grain OSL measurements (Roberts et al. 2001) also suggest that there has been disturbance at the site because sediments throughout the sequence contain quartz grains with different optical ages, with the maximum age in Stratigraphic Unit 6 identical to the multi-aliquot OSL result.

Roberts et al. (2001) studied 28 megafaunal sites using OSL dating of quartz in sediments containing the bones (or attached to bones in museum specimens), and TIMS U/Th dating of flowstones in cave deposits bracketing the most recent occurrence of megafauna. Only sites with articulated skeletal remains in undisturbed deposits were used to estimate an extinction time of 46 ka (95% confidence interval 39.8–51.2 ka) for the flightless bird *Genyornis* and several genera of large marsupials and reptiles. This accords well with the estimate of 50 ± 5 ka for extinction of *Genyornis* determined using TIMS U/Th on eggshell and OSL on sediments containing eggshell reported by Miller et al. (1999). These results all predate human occupation at Cuddie Springs and do not support the contention that extinct megafauna survived until Last Glacial Maximum (Field and Boles 1998). In terms of organic preservation, bone taphonomy and stone tool distribution, both Lancefield Swamp and Cuddie Springs might be described as "disharmonious assemblages" containing components with different true ages.

(E) Do the Outliers Fit?

Removing some of the dross from all distributions yields the dataset shown in Figure 5, where ^{14}C dates are arranged in decreasing order and dates from other methods in increasing order. This diagram illustrates the right tail of a distribution of good archaeological charcoal dates >40 ka from Devil's Lair, Carpenter's Gap, Riwi, and Mungo, but the left tails of distributions for archaeological TL/OSL and U/Th/ESR dates (Devil's Lair, Malakunanja, Nauwalabila, and Mungo), and non-archaeological TL/OSL and U/Th dates on megafauna from diverse sites throughout the continent. Convergence of these overlapping distributions can be seen at 44–46 ka, with a divergence near 60 ka represented only by TL/OSL dates from Malakunanja and Nauwalabila plus the combined U/Th/ESR date on Mungo 3.

The isotopic and other measurements made on skeletal remains and sediments are not the issue here, debate is about whether or not the outliers are compatible with other work in the region. For the bone dates there is not enough supporting geochemical evidence, and even with high resolution measurements the problems are not necessarily resolvable for degraded material from disturbed locations.

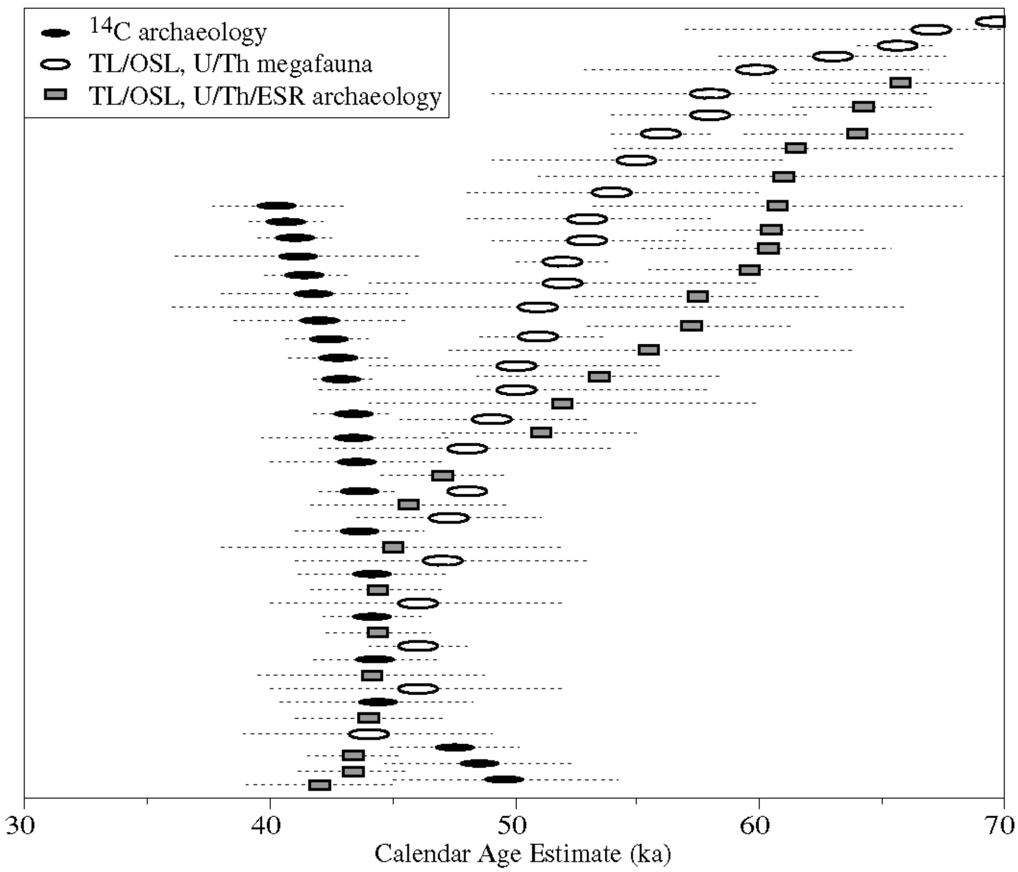


Figure 5 Distribution of Australian archaeology and extinct megafauna results. Black ovals are calibrated ^{14}C dates from archaeological sites at Devil's Lair, Carpenter's Gap, Riwi, and Mungo; gray squares are archaeological TL/OSL and U/Th/ESR dates from Devil's Lair, Malakunanja II, Nauwalabila I, and Mungo; white ovals are TL/OSL dates from diverse megafauna sites and U/Th dates on *Genyornis* eggshell. Data from Miller et al. (1999), Thorne et al. (1999), Fifield et al. (2000), Roberts et al. (1994, 1998b, 2001), Turney et al. (2001), and Spooner et al. (forthcoming).

The stratigraphic situation at several of these sites is similar in the sense that artifacts are found below (but not too far below) definite cultural horizons, so it is not possible to rule out leakage from younger deposits. Artifacts in sediments deeper than 44 ka occupation at Devil's Lair are still <50 ka, artifacts at Malakunanja are within reach of 44 ka occupation, artifacts in Mungo sediments deeper than probable 44 ka occupation are undated, and the Mungo 3 burial could have been inserted from 44 ka cultural levels. Nauwalabila is then the only survivor with artifacts possibly >50 ka. Good scientific evidence confirming occupation of Sahul older than this may still eventuate from one of these sites (and more sites will surely be found) but age estimates and stratigraphic associations in this period require more than standard analysis.

These issues have a certain resonance with the establishment of pre-Clovis occupation and with Late Pleistocene megafaunal extinction in the Americas (e.g. Haynes 1969; Martin 1986; Meltzer et al. 1997). In the American debates a shift of only about 1000 years near 14 ka is involved, which should be well within reliable dating range for most numerical methods, but environmental circumstances often thwart both the best of intentions and available technology. The Australian debates are even less tractable, because the total number of reliable dates in the 40–70 ka range is small and standard errors too large to resolve some of the questions. There is very little reliable evidence for any of the extinct Australian megafauna surviving later than 46 ± 4 ka, overlapping the earliest multi-dated human cultural deposits at 45 ± 3 ka, which could be interpreted as supporting the global "blitzkrieg hypothesis" for megafaunal extinction proposed by Martin (1984).

CONCLUSIONS

Dating the first Australians has become an issue for which ^{14}C may no longer be the final word, because we are near a reliable age limit for the method. The "event horizon" with best available technology is about 50 ka, with realistically large error ranges reflecting uncertainty in both measurement and calibration of ^{14}C dates. Other dating methods such as OSL, ESR, AAR, and U/Th extend the available age range, sometimes by an order of magnitude, and there is increasingly good agreement between methods within the ^{14}C limits. Direct bone dating remains a difficult problem throughout the Late Pleistocene, and significant technical developments have been required in all dating techniques to push back the time of first human occupation from the very uncertain >37,800 BP of thirty years ago.

There are currently four widely separated regions of Australia with human occupation layers dated at 45 ± 3 ka by some combination of overlapping ^{14}C, TL, OSL, and ESR results: Devil's Lair in the southwest, Carpenter's Gap and Riwi in the northwest, Malakunanja in the north, and Mungo in the southeast. According to the most recent TL, OSL, and U/Th results, many species of megafauna from all climatic zones became extinct at about the same time as people spread across the continent. Age resolution is not yet good enough in this period to precisely define when the first boat people arrived or the last big animal died, and the possible existence of older archaeology or younger megafauna will require further archaeological and stratigraphic confirmation.

ACKNOWLEDGMENTS

Although I have been involved with the ^{14}C dating of samples from several of the sites mentioned here, most of the work discussed is not mine and the interpretation presented is a personal one reflecting bias from my background as a ^{14}C chemist. This view does not always agree with those published by excavators or dating scientists. Particular thanks to Michael Bird, Tie-Mei Chen, Keith Fifield, Bert Roberts, Nigel Spooner, and Matthew Spriggs for generously making available unpublished results; and to Jim Bowler, John Chappell, Charlie Dortch, Judith Field, John Magee, Paul Martin, Peter White, and many others for stimulating discussions.

REFERENCES

Adcock GJ, Dennis ES, Easteal S, Huttley GA, Jermilin LS, Peacock WJ and Thorne A. 2001. Mitochondrial DNA sequences in ancient Australians: implications for modern human origins. *Proceedings of the National Academy of Science* 98:537–42.

Allen J. 1989. When did humans first colonize Australia? *Search* 20:149–54.

Allen J. 1994. Radiocarbon determinations, luminescence dating and Australian archaeology. *Antiquity* 68:339–43.

Allen J, Holdaway S. 1995. The contamination of Pleistocene radiocarbon determinations in Australia. *Antiquity* 69:101–12.

Allen J, Gosden C, Jones R, White JP. 1988. Pleistocene dates for the human occupation of New Ireland, northern Melanesia. *Nature* 331:707–9.

Arnold JR, Libby WF. 1949. Age determinations by radiocarbon content: checks with samples of known age. *Science* 110:678–80.

Barbetti M, Polach HA. 1973. ANU radiocarbon datelist V. *Radiocarbon* 15(2):241–51.

Balme J. 2000. Excavations revealing 40,000 years of occupation at Mimbi Caves in south central Kimberley of Western Australia. *Australian Archaeology* 51:1–5.

Baynes A. 1999. The question "Why did the Australian Pleistocene megafauna become extinct" currently is unanswerable because there are no reliable dates for any of the species. In: Baynes A, Long JA, editors. *Papers in vertebrate palaeontology.* Perth: Records of the Western Australian Museum. Supplement 57. p 391.

Bell WT. 1991. Thermoluminescence dates for the Lake Mungo Aboriginal fireplaces and the implications for radiocarbon dating. *Archaeometry* 33:43–50.

Bird MI, Grocke DR. 1997. Determination of the abundance and carbon isotope composition of burnt carbon in sediments. *Geochimica Cosmochimica Acta* 61: 3413–23.

Bird MI, Ayliffe LK, Fifield LK, Cresswell R, Turney CSM, Barrows TT and David B. 1999. Radiocarbon dating of 'old' charcoal using a wet oxidation-stepped combustion procedure. *Radiocarbon* 41(1):127–40.

Bocquet-Appel J-P and Demars P-Y. 2000. Population Kinetics in the Upper Palaeolithic in Western Europe. *Journal of Archaeological Science* 27:551–70.

Bowdler S. 1990. 50,000 year old site in Australia – is it really that old? *Australian Archaeology* 31:93.

Bowler JM. 1998. Willandra Lakes revisited: environmental framework for human occupation. *Archaeology in Oceania* 33:120–55.

Bowler JM, Magee JW. 2000. Redating Australia's oldest skeleton: a sceptic's view. *Journal of Human Evolution* 38:719–26.

Bowler JM, Price DM. 1998. Luminescence dates and stratigraphic analyses at Lake Mungo: review and new perspectives. *Archaeology in Oceania* 33:156–68.

Bowler JM, Thorne AG. 1976. Human remains from Lake Mungo: discovery and excavation of Mungo 3. In: Kirk RL, Thorne AG, editors. *The origin of the Australians*. Canberra: Australian Institute of Aboriginal Studies. p 127–38.

Bowler JM, Thorne AG, Polach HA. 1972. Pleistocene man in Australia: age and significance of the Mungo skeleton. *Nature* 240:48–50.

Bowler JM, Jones R, Allen H, Thorne AG. 1970. Pleistocene human remains from Australia: a living site and human cremation from Lake Mungo, western New South Wales. *World Archaeology* 2: 39–60.

Chappell J. 1991. Late Quaternary environmental changes in eastern and central Australia, and their climatic interpretation. *Quaternary Science Reviews* 10: 377–90.

Chappell J, Head J, Magee J. 1996a. Beyond the radiocarbon limit in Australian archaeology and Quaternary research. *Antiquity* 70:543–52.

Chappell J, Omura A, Esat T, McCulloch M, Pandolfi J, Ota Y, Pillans B. 1996b. Reconciliation of late Quaternary sea levels derived from coral terraces at Huon Peninsula with deep sea oxygen isotope records. *Earth and Planetary Science Letters* 141:227–36.

Chen T-M, Yuan S. 1988. Uranium-series dating of bones and teeth from Chinese Palaeolithic sites. *Archaeometry* 30:59–76.

Clarke SJ. 1999. *The application of the AAR geochronological technique to Late Pleistocene fossil teeth from the Australian megafaunal locality Cuddie Springs*. Unpublished BSc (Hons) thesis. Department of Geosciences, University of Wollongong.

Cooper A, Rambaut A, Macaulay V, Willerslev E, Hansen AJ, Stringer C. 2001. *Science* 292:1655.

Cosgrove R. 1989. Thirty thousand years of human colonization in Tasmania: new Pleistocene dates. *Science* 243:1706–8.

David B. 2002. *Landscapes, rock-art and the dreaming: an archaeology of preunderstanding*. London: Continuum Press. Chapter 8.

David B, Roberts R, Tuniz C, Jones R, Head J. 1997. New optical and radiocarbon dates from Ngarrabullgan Cave, a Pleistocene archaeological site in Australia: implications for the comparability of time clocks and for the human colonization of Australia. *Antiquity* 71: 183–8.

Dodson J, Fullagar R, Furby J, Prosser I. 1993. Humans and megafauna in a Late Pleistocene environment at Cuddie Springs, northwestern New South Wales. *Archaeology in Oceania* 28:93–9.

Dortch CE. 1979. 33,000 year old stone and bone artifacts from Devil's Lair, Western Australia. *Records of the Western Australian Museum* 7:329–67.

Dortch CE, Dortch J. 1996. Review of Devil's Lair artefact classification and radiocarbon chronology. *Australian Archaeology* 43:28–32.

Dortch CE, Merrilees D. 1973. Human occupation of Devil's Lair, Western Australia during the Pleistocene. *Archaeology and Physical Anthropology in Oceania* 8:89–115.

Field J, Boles WE. 1998. Genyornis newtoni and Dromaius novaehollandiae at 30,000 BP in central northern New South Wales. *Alcheringa* 22:177–88.

Field J, Dodson J. 1999. Late Pleistocene megafauna and archaeology from Cuddie Springs, southeastern Australia. *Proceedings of the Prehistoric Society* 65:275–301.

Fifield K, Allen GL, Ophel TR, Head J. 1992. Accelerator mass spectrometry of ^{14}C at the Australian National University. *Radiocarbon* 34(3):452–7.

Fifield LK, Bird MI, Turney CSM, Hausladen PA, Santos GM and di Tada ML. 2001. Radiocarbon dating of the human occupation of Australia prior to 40 ka BP – successes and pitfalls. *Radiocarbon* 43(2B):1139–45.

Fullagar R, Field J. 1997. Pleistocene seed-grinding implements from the Australian arid zone. *Antiquity* 71: 300–7.

Fullagar RLK, Price DM, Head LM. 1996. Early human occupation of northern Australia: archaeology and thermoluminescence dating of Jinmium rock shelter, Northern Territory. *Antiquity* 70:751–73.

Furby JH, Fullagar R, Dodson JR, Prosser I. 1993. The Cuddie Springs bone bed revisited. In: Smith MA, Spriggs M, Fankhauser B, editors. *Sahul in review:*

Pleistocene archaeology in Australia, New Guinea and Island Melanesia. Canberra: Research School of Pacific Studies, Australian National University. p 204–10.

Gillespie R. 1990. On the use of oxidation for AMS sample pretreatment. *Nuclear Instruments and Methods* B52:345–7.

Gillespie R. 1997. Burnt and unburnt carbon: dating charcoal and burnt bone from the Willandra Lakes, Australia. *Radiocarbon* 39(3):225–36.

Gillespie R. 1998. Alternative timescales: a critical review of Willandra Lakes dating. *Archaeology in Oceania* 33:169–82.

Gillespie R, Temple RB. 1973. Sydney University natural radiocarbon measurements II. *Radiocarbon* 15(3): 566–73.

Gillespie R, Horton DR, Ladd P, Macumber PM, Rich TH, Thorne AR, Wright RVS. 1978. Lancefield Swamp and the extinction of the Australian megafauna. *Science* 200:1044–8.

Gillespie R, Hedges REM, Humm MJ. 1986. Routine AMS dating of bone and shell proteins. *Radiocarbon* 28(2A):451–6.

Gillespie R, Roberts RG. 2000. On the reliability of age estimates for human remains from Lake Mungo. *Journal of Human Evolution* 38:727–32.

Groube L, Chappell J, Muke J, Price D. 1986. A 40,000 year old human occupation site at Huon Peninsula, Papua new Guinea. *Nature* 324:453–5.

Groves CP. 1996. Hovering on the brink: nearly but not quite getting to Australia. *Perspectives in Human Biology* 2:83–7.

Grün R, Spooner NA, Thorne A, Mortimer G, Simpson JJ, McCulloch MT, Taylor L, Curnoe D. 2000. Age of the Lake Mungo 3 skeleton, reply to Bowler and Magee and to Gillespie and Roberts. *Journal of Human Evolution* 38:733–41.

Haynes CV. 1969. The earliest Americans. *Science* 166: 709–15.

Hedges REM, Millard AR. 1995. Bones and groundwater: towards the modelling of diagenetic processes. *Journal of Archaeological Science* 22:155–64.

Hiscock P. 1990. How old are the artefacts in Malakunanja II? *Archaeology in Oceania* 25:122–4.

Huxtable J, Aitken MJ. 1977. Thermoluminescent dating of Lake Mungo geomagnetic polarity excursion. *Nature* 265:40–1.

Jones R. 1968. The geographical background to the arrival of man in Australia and Tasmania. *Archaeology and Physical Anthropology in Oceania* 3:186–215.

Kamminga J, Allen HR. 1973. *Report on the archaeological survey. The Alligator Rivers fact-finding study.* Darwin: Government Printer.

Kiernan K, Jones R, Ranson D. 1983. New evidence from Fraser Cave for glacial age man in southwest Tasmania. *Nature* 301:28–32.

McConnell K, O'Connor S. 1997. 40,000 year record of food plants in the southern Kimberley, Western Australia. *Australian Archaeology* 45:20–31.

Martin HA. 1973. Palynology and historical ecology of some cave excavations in the Australian Nullabor. *Australian Journal of Botany* 21:283–305.

Martin PS. 1984. Prehistoric overkill: the global model. In: Martin PS, Klein RG, editors. *Quaternary extinctions: a prehistoric revolution*. Tucson: University of Arizona Press. p 354–403.

Martin PS. 1986. Refuting Late Pleistocene extinction models. In: Eliott DK, editor. *Dynamics of extinction*. New York: John Wiley & Sons. p 107–30.

Meltzer DJ, Mead JI. 1985. Dating late Pleistocene extinctions: theoretical issues, analytical bias, and substantive results. In: Meltzer DJ, Mead JI, editors. *Environment and extinction: man in late glacial North America*. Orono: University of Maine, Center for the Study of Early Man. p 145–73.

Meltzer DJ, Grayson DK, Ardila G, Barker AW, Dincauze DF, Haynes CV, Mena F, Nunez L, Stanford DJ. 1997. On the Pleistocene antiquity of Monte Verde, southern Chile. *American Antiquity* 62:659–63.

Millard AR, Pike AWG. 1999. Uranium-series dating of the Tabun neanderthal: a cautionary note. *Journal of Human Evolution* 36:581–5.

Miller GH, Magee JW, Johnson BJ, Fogel ML, Spooner NA, McCulloch MT, Ayliffe LK. 1999. Pleistocene extinction of Genyornis newtoni: human impact on Australian megafauna. *Science* 283:205–8.

Mulvaney DJ. 1974. Summary report of the first Mungo Project season. *AIAS Newsletter* 1:21–2.

Mulvaney DJ. 1975. *The prehistory of Australia.* 2nd edition. Melbourne: Penguin Books Australia.

Mulvaney DJ, Kamminga J. 1999. *Prehistory of Australia*. Sydney: Allen and Unwin.

Murray TA, editor. 1998. *Archaeology of Aboriginal Australia: a reader.* Sydney: Allen and Unwin.

Murray AS, Roberts RG. 1997. Determining the burial time of single grains of quartz using optically stimulated luminescence. *Earth and Planetary Science Letters* 152:163–80.

O'Connell JF, Allen J. 1998. When did humans first arrive in greater Australia and why is it important to know? *Evolutionary Anthropology* 6:132–46.

O'Connor S. 1995. Carpenter's Gap Rockshelter 1: 40,000 years of Aboriginal occupation in the Napier Ranges, Kimberley, WA. *Australian Archaeology* 40: 58–9.

O'Connor S, Spriggs M, Veth P. 2002. Excavation at Lene Hara Cave establishes occupation in East Timor at least 30,000–35,000 years ago. *Antiquity* 76:45–50.

Oyston B, 1996. Thermoluminescence age determinations for the Mungo 3 human burial, southeastern Australia. *Quaternary Science Reviews (Quaternary Geochronology)* 15:739–49.

Polach HA, Lovering JF, Bowler JM. 1970. ANU radiocarbon datelist IV. *Radiocarbon* 12(1):1–18.

Roberts RG. 1997. Luminescence dating in archaeology: from origins to optical. *Radiation Measurements* 27: 819–92.

Roberts RG, Jones R. 2000. Chronologies of carbon and silica: evidence concerning the dating of the earliest human presence in northern Australia. In: Tobias PV, Moggie-Cecchi J, Raas MA, Doyle GA, editors. *Humanity from African naissence to coming millenia, colloquia in human biology and palaeoanthropology.* Firenze: University Press. p 239–48.

Roberts RG, Jones R, Smith MA. 1990a. Thermoluminescence dating of a 50,000-year-old human occupation site in northern Australia. *Nature* 345:153–6.

Roberts RG, Jones R, Smith MA. 1990b. Stratigraphy and statistics at Malakunanja II: reply to Hiscock. *Archaeology in Oceania* 25:125–9.

Roberts RG, Jones R, Spooner NA, Head MJ, Murray AS, Smith MA. 1994. The human colonization of Australia: optical dates of 53,000 and 60,000 years bracket human arrival at Deaf Adder Gorge, Northern Territory. *Quaternary Science Reviews* 13:573–84.

Roberts RG, Spooner NA, Jones R, Cane S, Olley JM, Murray AS, Head MJ. 1996. Preliminary luminescence dates for archaeological sediments on the Nullabor Plain, South Australia. *Australian Archaeology* 42:7–16.

Roberts R, Bird M, Olley J, Galbraith R, Lawson E, Laslett G, Yoshida H, Jones R, Fullagar R, Jacobsen G, Hua Q. 1998a. Optical and radiocarbon dating at Jinmium rock shelter in northern Australia. *Nature* 393: 358.

Roberts R, Yoshida H, Galbraith R, Laslett G, Jones R, Smith M. 1998b. Single-aliquot and single-grain optical dating confirm thermoluminescence age estimates at Malakunanja II rock shelter in northern Australia. *Ancient TL* 16:19–24.

Roberts RG, Galbraith RF, Olley JM, Yoshida H, Laslett GM. 1999. Optical dating of single and multiple grains of quartz from Jinmium rock shelter, northern Australia: Part II, results and implications. *Archaeometry* 41:365–95.

Roberts RG, Flannery TF, Ayliffe LK, Yoshida H, Olley JM, Prideaux GJ, Laslett GM, Baynes A, Smith MA, Jones R, Smith BL. 2001. New ages for the last Australian megafauna: continent-wide extinction about 46,000 years ago. *Science* 292:1889–92.

Shackleton NJ. 2000. The 100,000 year ice-age cycle identified and found to lag temperature, carbon dioxide and orbital eccentricity. *Science* 289:1897–902.

Shawcross W. 1998. Archaeological excavations at Mungo. *Archaeology in Oceania* 33:183–200.

Shawcross FW, Kaye M. 1980. Australian archaeology: implications of current interdisciplinary research. *Interdisciplinary Science Reviews* 5:112–28.

Simpson JJ, Grün R. 1998. Non-destructive gamma spectrometric U-series dating. *Quaternary Science Reviews (Quaternary Geochronology)* 17:1009–22.

Smith MA. 1987. Pleistocene occupation in arid central Australia. *Nature* 328:710–1.

Smith MA. 1998. The pattern of continental occupation: late Pleistocene colonization of Australia and New Guinea. In: Murray TA, editor. *Archaeology of Aboriginal Australia: a reader.* Sydney: Allen and Unwin. p 41–9.

Smith MA, Prescott JR, Head MJ. 1997. Comparison of ^{14}C and luminescence chronologies at Puritjarra rock shelter, central Australia. *Quaternary Science Reviews (Quaternary Geochronology)* 16:299–320.

Smith MA, Bird MI, Turney CSM, Fifield LK, Santos GM, Hausladen PA, di Tada ML. 2001. New ABOX-SC AMS ^{14}C ages remove dating anomalies at Puritjarra rock shelter. *Australian Archaeology* 53:45–7.

Spooner N. 1998. Human occupation at Jinmium, northern Australia: 116,000 years ago or much less? *Antiquity* 71:173–8.

Spooner NA, McBryde I, Magee JW, Johnston H, Clark P, Questiaux DG, Bird M, Olley JM, Lawson L, Lawson G, Hill NG, Taylor L. Optical dating at the Lake Mungo lunette, Willandra Lakes, Australia. 2001. Optical dating at the Mungo lunette. *Quaternary Science Reviews (Quaternary Geochronology).* Forthcoming.

Stafford TW Jr, Hare PE, Currie L, Jull AJT, Donohue DJ. 1991. Accelerator radiocarbon dating at the molecular level. *Journal of Archaeological Science* 18: 35–72.

Thorne A, Grün R, Mortimer G, Spooner NA, Simpson JJ, McCulloch M, Taylor L, Curnoe D. 1999. Australia's oldest human remains: age of the Lake Mungo 3 skeleton. *Journal of Human Evolution* 36:591–612.

Turney CSM, Bird MI, Fifield LK, Roberts RG, Smith MA, Dortch CE, Grün R, Lawson E, Ayliffe LK, Miller GH, Dortch J, Cresswell RG. 2001. Early human occupation at Devil' Lair, southwestern Australia 50,000 years ago. *Quaternary Research* 55:3–13.

van Huet S, Grün R, Murray-Wallace CV, Redvers-Newton N, White JP. 1998. Age of the Lancefield megafauna: a reappraisal. *Australian Archaeology* 46:5–11.

Watchman AL, Tacon P, Fullagar R, Head L. 2000. Minimum ages for pecked rock markings from Jinmium, northwestern Australia. *Archaeology in Oceania* 35: 1–10.

Webb SG. 1989. *The Willandra Lakes hominids*. Canberra: Department of Prehistory, Australian National University.

Wright RVS. 1971. The archaeology of Koonalda Cave. In: Mulvaney DJ, Golson J, editors. *Aboriginal man and environment in Australia*. Canberra: ANU Press. p 105–13.

Yokoyama Y, Esat T, Lambeck K, Fifield LK. 2000. Last ice age millennial scale climate changes recorded in Huon Peninsula corals. *Radiocarbon* 42(1):383–401.

RADIOCARBON, Vol 44, Nr 2, 2002, p 473–476

RADIOCARBON DATES FROM PALEOLITHIC SITES IN KOREA

Kidong Bae

Department of Anthropology, Hanyang University, Ansan 425-791, Korea. Email: bkd5374@chollian.net.

ABSTRACT. Fewer than 20 radiocarbon dates have been obtained from Paleolithic sites on the Korean Peninsula. It is still unknown how and when Korean Middle Paleolithic stone industries developed, despite the handful of dates older than 40,000 BP obtained from some sites. A lower boundary for the Korean Upper Paleolithic of approximately 30,000 BP can be inferred from the few dates associated with stone blade industries. ^{14}C dates associated with microlithic industries of 24,000 BP are considered too old in light of evidence from other areas of East Asia. Most such assemblages are post-Last Glacial Maximum in age. Improved understanding of the Korean Paleolithic sequence will depend ultimately on the further accumulation of ^{14}C dates, as well as the application of alternative dating techniques and attention to the reconstruction of site formation process.

INTRODUCTION

The past 40 years of research have identified more than 150 Paleolithic sites on the Korean Peninsula and, at the current pace of study, this number is expected to increase dramatically in the near future. More than of these 30 sites have been excavated and several are designated as national historic monuments. Following Western archaeological practices, the Korean Paleolithic is divided into three sub-stages, the Lower, Middle, and Upper Paleolithic. These designations carry chronological and evolutionary implications. They should be treated with caution, however, as there is yet no firm consensus among Korean archaeologists on the chronological boundaries for each stage. Moreover, there are few clear changes in stone industries between so-called Early and Middle Paleolithic industries, bringing into question the utility of these designations.

The construction of a reliable chronology for stone industries on the Peninsula remains a critical issue within Korean Paleolithic archaeology. Radiocarbon dating plays a very important role in this endeavor and, at present, two new AMS ^{14}C labs are operating in southern Korea, one at Seoul National University (SNU) and the other at the National Research Institute of Cultural Properties (KCP). These labs have recently produced several hundred dates for late prehistoric and historic archaeological sites, but only two dates so far for Paleolithic sites. The predominance of acidic soils on the Peninsula and consequent poor organic preservation at most open-air archaeological sites is partly responsible for the slow accumulation of Paleolithic-age ^{14}C dates.

Korean Paleolithic Sites and Radiocarbon Dates

Seventeen ^{14}C dates have been obtained for 8 Paleolithic sites on the Korean Peninsula. Dates obtained from the Sokchangni site in the early 1970s by the Korean Research Institute of Atomic Energy (AERIK) (Sohn 1973) were crucial for demonstrating the presence of Paleolithic stone industries on the Korean Peninsula. However, most of the ^{14}C dates pertaining to the Korean Paleolithic are the result of very recent work. Most of the newly available dates represent the Upper Paleolithic or Microlithic, but some may also represent the late Middle Paleolithic. The oldest date yet obtained is an age greater than from Noeundong. Most of the dates were obtained from charcoal, but some from peat or concentrated organics (see Table 1).

Sokchangni

Sokchagni was the first site in Korea to yield ^{14}C dates and it remains a very important benchmark for regional Paleolithic sequence. The site, situated on the first terrace of the Kumkang river near Kongju city, was found in 1962 and excavated in 1964. A 12-m sequence of alluvial and colluvial deposits contained 12 cultural horizons. Two ^{14}C dates were obtained from charcoal samples col-

Table 1 List of ^{14}C dates from Paleolithic Sites in Korea

#	Site name	Coordinates lat., long.	Sample position	Date (BP)	Lab code	Material	Culture	Reference
1	Janghungri	38.11, 127.17	Layer 2	24,200 ± 600	SNU00-380	Charcoal	Microlithic	Choi et al. 2001
2	Janghungri	38.11, 127.17	Layer 2	24,400 ± 600	SNU00-381	Charcoal	Microlithic	Choi et al. 2001
3	Bongmyoungdong	36.38, 127.23	Cultural layer II	12,260 ± 40	GX-25513	Charcoal	Microlithic	Lee 2000
4	Bongmyoungdong	36.38, 127.23	Cultural layer I	49,860 ± 2710	GX-25897	Charcoal	Middle Paleo. ?	Lee 2000
5	Bongmyoungdong	36.38, 127.23	Cultural layer I	48,450 ± 1370	GX-25515	Charcoal	Middle Paleo. ?	Lee 2000
6	Sokchangni	36.26.35, 127.11.30	Cultural layer 11	30,690 ± 3000	AERIK-5	Charcoal	Upper Paleolithic	Sohn 1973
7	Sokchangni	36.26.35, 127.11.30	Cultural layer 12	20,830 ± 1880	AERIK-8	Charcoal	Microlithic?	Sohn 1973
8	Sokchangni	36.26.35, 127.11.30	Cultural layer 8	50,270	Beta-60807	Charcoal	Middle Paleolithic?	Sohn 1993
9	Suyanggae	36.57, 128.20		18,630	UCR-2078	Charcoal	Upper Paleolithic	Yun 1996
10	Suyanggae	36.57, 128.20		16,400		Charcoal	Microlithic?	Yun 1996
11	Noeundong	36.22, 127.18	Layer 3a	22,870 ± 110		Charcoal	Upper Paleolithic	Han 2000
12	Noeundong	36.22, 127.18		>54,720		Charcoal	Middle Paleolithic	Han 2000
13	Chommal	37.12, 128.14	Depth 78–94 cm	13,700 ± 700	AERIK	Charcoal	Upper Paleolithic?	Lee 1977
14	Sorori	36.41, 127.25	30.8 msl[a]	13,010 ± 190	GX-24334	Peat	Microlithic	Lee et al. 1999
15	Sorori	36.41, 127.25	30.8 msl	14,820 ± 250	GX-25494	Peat	Microlithic	Lee et al. 2000
16	Sorori	36.41, 127.25	30.8 msl	17,310 ± 310	GX-25495	Peat	Microlithic?	Lee et al. 2000
17	Sorori	36.41, 127.25	~36.5 msl	>36,350		Organic	Middle Paleolithic	Lee 2000
18	Sorori	36.41, 127.25	~36.5 msl	>36,210		Organic	Middle Paleolithic	Lee 2000
19	Sorori	36.41, 127.25	32.6–32.13 msl	12,930 ± 400	SNU01-286	Peat	Microlithic?/Neolithic?	Lee &Woo 2001
20	Sorori	36.41, 127.25	32.6–32.13 msl	12,500 ± 200	SNU01-293	Peat	Microlithic?/Neolithic	Lee &Woo 2001
21	Sorori	36.41, 127.25	32.6–32.13 msl	12,780 ± 170	GX-28416	Peat	Microlithic?/Neolithic	Lee &Woo 2001
22	Sorori	36.41, 127.25	32.17–32.10 msl	13,270 ± 180	GX-28417	Peat	Microlithic?/Neolithic	Lee &Woo 2001
23	Sorori	36.41, 127.25	31.76–31.36 msl	13,420 ± 180	GX-28418	Peat	Microlithic?/Neolithic	Lee &Woo 2001
24	Sorori	36.41, 127.25	31.43–31.36 msl	14,020 ± 190	GX-28419	Peat	Microlithic?/Neolithic	Lee &Woo 2001
25	Sorori	36.41, 127.25	31.76–31.69 msl	14,000 ± 190	GX-28420	Peat	Microlithic?/Neolithic	Lee &Woo 2001
26	Sorori	36.41, 127.25	31.43–31.36 msl	13,920 ± 200	SNU01-291	Peat	Microlithic?/Neolithic	Lee &Woo 2001
27	Sorori	36.41, 127.25	31.43–31.36 msl	14,800 ± 210	GX-28421	Peat	Microlithic?/Neolithic	Lee &Woo 2001
28	Sorori	36.41, 127.25	~29.0 msl	17,310 ± 310	GX	Peat	Microlithic?/Neolithic	Lee &Woo 2001
29	Yonghodong	36.23, 127.24	~39.7 msl	38,500 ± 1000		Charcoal	Upper Paleolithic	Han et al. 2000

[a]msl = meters above sea level.

lected from upper most horizons during the early excavations. The first sample, from the 12th cultural layers, was collected from a hearth in a supposed dwelling structure associated with microcores and dated to 20,830 ± 1880 BP. The second charcoal sample, from the 11th cultural layer (associated with blade technology), was dated 30,690 ± 3000 BP. This second date is believed to indicate the lower boundary of the Upper Paleolithic in Korea (Sohn 1973). A third date of greater than 50,270 BP on charcoal collected from the colluvial deposit is thought to provide a limiting age for the 8th cultural layer (Sohn 1993).

Bongmyoung-dong

Paleolithic artifacts were found in 1999 on a hill slope near Bongmyoung-dong in Chongju city as part of salvage excavations. In one area, artifacts were found on a sloping surface mixed with angular and rounded cobbles and are interpreted as having been redeposited from higher geological layers no longer in evidence at this site. On the lower part of this same slope, colluvial deposits of up to 3 m were exposed in test pits. Two cultural layers were identified, a micro-core stone industry in the upper layer and a Middle Paleolithic industry in the lower. Three ^{14}C dates were obtained from charcoal samples collected from the two cultural layers. Charcoal from the upper cultural layer dated to 12,260 ± 40 BP, while two samples from the lower cultural layer yielded ages of 49,860 ± 2710 BP and 48,450 ± 1370 BP (Lee 2000). The latter two dates probably represent minimum ages for the Middle Paleolithic stone industry.

Sorori

Situated on the flat agricultural plain between the Miho-chon river and low mountain range, the Sorori site was found in 1994 and excavated in 1997. Three localities were excavated, one at an elevation approximately 4–5 m below the other two. Three distinct cultural layers were identified within a clay overlying peat deposits. The uppermost cultural layer, represented by a pseudo-microcore industry, was found at all the three localities. Despite the fact that there are no clear differences in the lithic technologies, the lower two cultural layers are thought to represent separate Middle and Upper Paleolithic industries (Lee 2000). These layers were identified only at the two higher elevation localities. Three ^{14}C dates were obtained from the peat deposits at the low elevation locality, 13,010 ± 190 BP, 14,820 ± 250 BP, and 17,310 ± 310 BP, and are stratigraphically consistent. These dates may provide a maximum age for the pseudo-microlithic industry at the site. Maximum ages for the two lower cultural layers may be provided by ^{14}C dates from peat deposits exposed at each of the higher localities, 36,350 BP and 36,210 BP (Lee et al. 2000). No standard deviations are reported for these dates.

Changhungni

This site was found in the early 1980s, but was excavated in 1999 for road construction. Stone artifacts were found in fluvial deposits lying on a basalt plateau. Two ^{14}C dates, 24,200 ± 600 BP and 24,400 ± 600 BP, were obtained at the AMS lab at Seoul National University from charcoal collected from upper most clay layer containing a microlithic industry (Choi 2001). If accurate, they represent the oldest microlithic industry on the Korean Peninsula.

Noeundong

This site was found during the construction of a football stadium for the 2002 World Cup football games in Taejon. Charcoal collected from a paleosol identified by vertical soil cracks dated to 22,870 ± 110 BP (Han 2000). Microlithic tools were found directly above this paleosol. A second radiocarbon date of 54,720 BP was recently announced for a much lower layer, and presumably represents the Middle Paleolithic (Choi 2001).

Suyanggae

At Suyanggae, fluvial terrace deposits of the Namhan River have yielded tens of thousands of stone artifacts. Remains of a stone knapping area were exposed and many artifacts from within this feature were successfully conjoined. While a formal report has not yet been published, preliminary information indicates the presence of three cultural stages, represented from the top of the sequence by microlithic, Upper Paleolithic, and Middle Paleolithic stone industries. It should be noted that a tanged point, technologically similar to knife-type tools in western Japan, was found for the first time in Korea at this site. Two ^{14}C dates, 18,630 BP and 16,400 BP, were obtained from charcoal collected at the site (Lee and Yun 1994). Unfortunately, the provenance of these samples is unclear.

In addition to the sites mentioned above, Chommal Cave and the recently excavated Yonghodong site have produced several new radiocarbon dates. These results are not yet published.

DISCUSSION AND CONCLUSION

In spite of the large number of known sites of apparent Paleolithic age in Korea, few have been systematically dated using the ^{14}C technique. The exceptions generally are associated only with single dates, which presents some problems for evaluating the reliability of the age determinations. Ages obtained for so-called Middle Paleolithic assemblages, some of which approach 50,000 BP, are still highly questionable. These dates likely represent only minimum ages. In contrast, the small sample of dates presently available points to a maximum age for the Upper Paleolithic on the Korean Peninsula of approximately 30,000 BP. ^{14}C age estimates for the earliest appearance of microlithic technologies are not substantially younger at approximately 24,000 BP. The majority of ^{14}C dates associated with Korean microlithic industries are terminal Pleistocene in age, however, which is consistent with the accepted age range for these technologies in greater Northeast Asia.

To resolve these outstanding questions, there is an immediate necessity for intensive dating programs focused on Paleolithic stone industries. In this regard, the recent dramatic increase in the number of ^{14}C-dated Paleolithic sites in Korea is encouraging. It is important to recognize, however, that ^{14}C dating offers a partial solution to the problems at hand because of the widespread distribution of acidic soils on the Korean Peninsula and the consequent poor organic preservation at most Paleolithic sites. It will be necessary therefore to employ alternative dating tools, including relative chronological methods and strict attention to site formation processes, to provide a complete chronological picture of the Paleolithic sequence. To date, little attention has focused on the geochronology of Korean Paleolithic sites.

REFERENCES

Choi BK, Choi SY, Lee HY, Cha JH. 2001. *Jangheungri Paleolithic site*. Kangwon Provincial Government and Institute of Archaeological Research of Kangwon University.

Choi SY. 2001. Paleolithic Sites in the Kumkang River Basin. *Paleolithic Culture in Korea*. Lecture Series of the Yonsei University Museum.

Han CK. 2000. *Preliminary report of the excavation of the Yongho-dong Paleolithic site, Taejon* (mimeo, unpub.).

Lee Y. 1977. Paleolithic Age, *Hankuksa*. Vol. 1 (History of Korea). Kuksapy'onchanwiwonhoe (National Committee for Compilation Korean History). Suyanggae site, Korea. Paper presented in "The Origin and Dispersal of the Microblade Technique in Northern Eurasia". Sapporo Univ.

Lee Y, Hong MY, Han CK, Park HH. 2000. *Sorori Paleolithic site.* Chungbuk National University.

Sohn PK. 1973. Upper Paleolithic settlement of Sokchangni site, *Hankuksayongu* (Studies of Korean History). Volume 19. Hankuksayonguhoe (Society of Korean History Studies). p 5–59.

Sohn PK. 1993. *Sokchangni Paleolithic site*. The Donga Publishing Co.

RADIOCARBON, Vol 44, Nr 2, 2002, p 477–494

RADIOCARON DATES AND ARCHAEOLOGY OF THE LATE PLEISTOCENE IN THE JAPANESE ISLANDS

Akira Ono[1,2] • Hiroyuki Sato[3] • Takashi Tsutsumi[4] • Yuichiro Kudo[1]

ABSTRACT. We discuss the radiocarbon chronology of Late Pleistocene archaeology in the Japanese islands. In sum, 429 samples from more than 100 archaeological sites were compiled and then divided into three periods and four stages. The Early Upper Paleolithic, characterized by Trapezoid industries, lasted during approximately 34–26 ka. The Late Upper Paleolithic period includes both the backed-blade stage and point-tool stage, the latter appearing chronologically later than the former. This stage covers ~25–15 ka. The Final Upper Paleolithic and Incipient Jomon are distinguished by the appearance of microblade industries and the emergence of pottery at the end of this period. This period covers approximately 14–12 ka. The microblade tradition, in the broadest sense, is strongly connected to the background of peopling of the New World. New data on the transitional stage from the Middle to the Upper Paleolithic are also discussed in regards to three archaeological sites. Issues on the application of the ^{14}C calibration to the whole Japanese Upper Paleolithic are critically evaluated.

INTRODUCTION

The intent of this paper is to clarify the background of the peopling of the New World in relation to the archaeological records, with particular emphasis on radiocarbon dates from the Japanese islands. Chronometric foundations of the Japanese Upper Paleolithic have been developed during the last three decades. Compilation of ^{14}C dates, together with the stratigraphic sequence of lithic industries, illustrates the board-spectrum of the background of the topic (Kuzmin et al. 1998).

Some framework should be noted. First, we discuss the Japanese Upper Paleolithic in as simplified a way as possible in an attempt to summarize and focus on the relevant subjects. Second, we limit the geographical area within the Japanese islands. Although this area reflects only the boundaries of the present nation state, we have kept this framework because most of the Japanese Paleolithic research has been carried out in this field since 1949. Third, the time range of this paper covers the final phase of the Middle Paleolithic to the entire Upper Paleolithic and Incipient Jomon, i.e., the latter half of OIS3 to the end of OIS2. The criterion for the subdivision of the Japanese Paleolithic are controversial in regards to whether they should be divided into three or two periods (Sato 2001). The term used here, "final phase of the Middle Paleolithic" indicates in any case a phase before the emergence of the blade technique. Fourth, the ^{14}C results cited in this paper are uncalibrated dates despite the conventional or accelerator mass spectrometry (AMS) determinations. Prior to the advent of AMS, conventional ^{14}C dates for the Upper Paleolithic in Japanese islands were of variable quality.

THE PRESENT STATE OF RADIOCARBON DATING

The number of Pleistocene sites in the Japanese islands has been estimated at 4500. Each year, more than 100 additional sites are excavated. However, not many of these sites have been dated by the ^{14}C method (see Table 1 in Appendix).

Almost all Japanese Late-Pleistocene archaeological sites belong to the Upper Paleolithic with the exception of some Middle Paleolithic sites (Ono et al. 1992; Japan Association for Quaternary Research 1987). The reasons why there are few examples of ^{14}C dating in the Late Pleistocene of the Japanese islands are as follows.

[1]Archaeology Laboratory, Tokyo Metropolitan University, Minami-Osawa 1-1, Hachioji, Tokyo, Japan
[2]Corresponding author. Email: ono@bcomp.metro-u.ac.jp.
[3]Department of Archaeology, University of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo, Japan
[4]Archaeological Heritage Section, Miyota Board of Education, Miyota-machi 2663-2, Kitasaku, Nagano Prefecture, Japan

First, the establishment of the local chronology within the Japanese islands has to be mentioned. Many Upper Paleolithic sites have been excavated since the first Paleolithic excavation was carried out at the Iwajuku site in Gunma Prefecture in 1949. The massive volcanic eruptions in the Pleistocene are traceable in many archaeological layers. Extensive studies of the tephrochronology have clarified the distinctive cultural layers in thick loam with many marker-tephra (Machida and Arai 1992). Widely distributed key tephra covered almost all the Japanese islands and they functioned as the time-marker. Archaeological artifacts from different areas have been combined and given exact chronological positions (Machida et al. 2000). At the same time, the archaeological chronology of each area has been completed by the progression of techno-typological studies of lithic artifacts.

Second, the persistent condition of carbonized materials for ^{14}C dating in the Japanese Late Pleistocene under the periglacial environment provides fewer advantages for preservation. Cultural layers consist of acid soils that originated from volcanic ash, and no organic materials such as wood or bone are preserved at all. In the early period of ^{14}C dating, results often conflicted with the archaeological chronology. At that time, the effectiveness of ^{14}C dating was questioned by many archaeologists because of the inconsistency of sampling bias and preservation issues before the 1970s.

Third, Japanese Paleolithic research began in pursuit of the regional chronology, and comparative studies between neighboring Asian countries were not active before the 1980s. Over the past two decades, research developments in China, Korea, and the Russian Far East have forwarded the development of intercontinental chronological comparison both by morpho-typological and ^{14}C dating.

KEY RADIOCARBON DATES OF THE UPPER PALAEOLITHIC

Chronology of the Upper Paleolithic in the Japanese Islands

Upper Paleolithic chronological studies have been advanced in most areas that have well-stratified thick loam layers made up of volcanic ash, aeolian dust/or loess from China, and fine sand blown in from river terraces near the studied area. In the central part of the Japanese islands, and in the Tokyo area in particular, detailed chronologies have been established both on a stratigraphic and a morpho-typological basis. The widely distributed key marker tephra provides excellent chronological synchronicity among separated areas. The basic chronological sequence of the Upper Paleolithic follows four stages: 1) in the early phase, trapezoid industries covered whole Japanese islands; 2) backed-blade industries became common and stable during the early-to-later phase of the Upper Paleolithic; 3) point-tool industries have developed particularly in Central Japan; and 4) microblade industries have successfully spread over the Japanese islands until the emergence of incipient Jomon cultural elements.

The distinction between the Early and Late Upper Paleolithic is characterized as the formation of local varieties of lithic assemblage and social change, reflecting settlement patterns, and this occurred in the middle phase of the backed-blade sequence.

The huge volcanic eruption occurred from the Aira caldera, south Kyushu, in the following sequence. The eruption spread volcanic ash over most of the Japanese islands as well as the Korean peninsula, a part of east China, and southern Primorye in the Russian Far East. This key tephra is called Aira-Tn tephra (AT), which is critically important for the Upper Palelithic chronology. Recent AMS determination of the AT-tephra was found to be 25–24 ka (Japan Association for Quaternary Research 2000). This time range coincides well with the transition from OIS3 to OIS2, which includes LGM period. Key ^{14}C dates are compiled in Table 1. The table lists 429 samples from more than 100 archaeological sites. Figure 1 shows the chronology of Upper Paleolithic development of lithic assemblage.

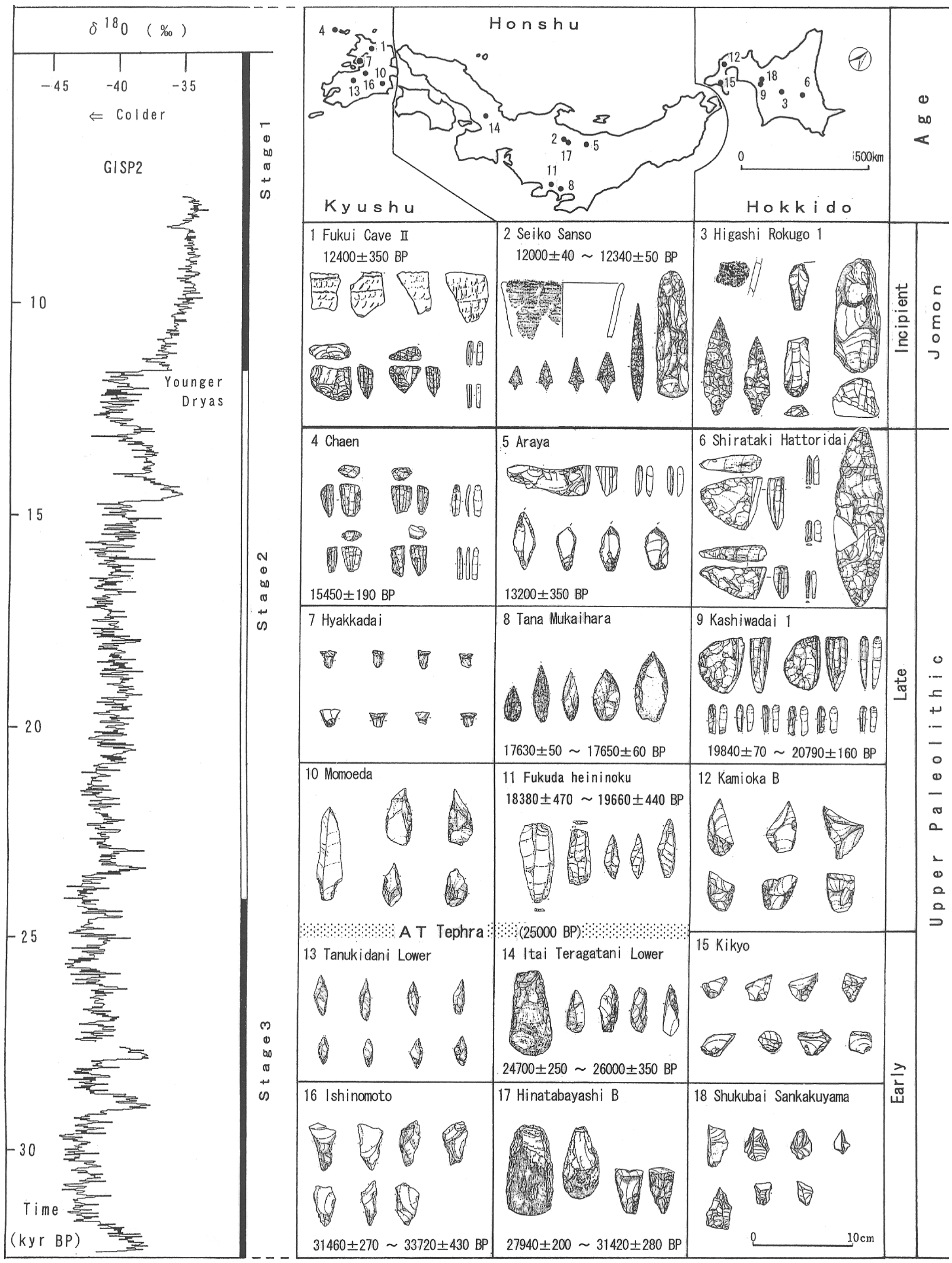


Figure 1 Chronology and ^{14}C dates of the Upper Paleolithic and Incipient Jomon in the Japanese islands. Left: climatic change shown by the δ^{18}O record of the GISP2 ice core (after Stuiver and Grootes 2000). Note that the ^{14}C dates of archaeological sites are uncalibrated AMS measurements.

Early Upper Paleolithic: ~34–26 ka

The earliest period of the Upper Paleolithic is distinguished by trapezoidian lithic industries of in which trapezoids and edge-round stone tools were used (Sato 1992). One of the representative sites from the Kyushu, the Ishinomoto site (Figure 1:16), is AMS dated to 31,460 ± 270 ~ 33,720 ± 430 BP (Ikeda 1999). Sixty edge-ground stone tools (axes) and many trapezoids have also been excavated from the early Upper Paleolithic site Hinatabayashi B (Figure 1:17) in north-central Japan. Its AMS determination was 27,940 ± 200 ~ 31,420 ± 280 BP (Tsuchiya and Tani 2000). These ^{14}C dates suggest that the beginning of the Japanese Upper Paleolithic is older than 30 ka.

In the later phase of the early period of the Upper Paleolithic, Hatsunegahara, a unique open-air site, explicitly showed that 56 trap-pits with almost 1.5-m depths have been unearthed beneath the AT tephra horizon. These provide key evidence for re-evaluating the site function as well as the hunting system in the Upper Paleolithic. ^{14}C dates detected from the bottom of one of these pits show 27,200 BP and 29,750 ± 210 BP (Suzuki and Maejima 1999). The foundation of these trap-pits can therefore be suggested between 27 ka and 25 ka.

In the western part of the Japanese islands, an industry from the lower cultural horizon of the Itai-Teragatani site is a representative one that belongs to the later phase of early Upper Paleolithic. ^{14}C dates from this site were 24,700 ± 250 BP and 26,000 ± 350 BP (Yamaguchi and Kishimoto 1991). Though the edge-ground stone tools (axes) and backed-blades have been excavated from this site, a specific "Setouchi technique," characterized by an oblong blade-detaching or a side-blow flaking technique, in western Japan in particular, had already emerged in its germinal stage.

The foundation of the "Setouchi technique" could threfore suggest that it can be set back to 26–25 ka. Contrary to the "Setouchi side-blow technique", the blade technique was developed in the latter half of the early Upper Paleolithic in eastern Japan.

Late Upper Paleolithic: ~25–15 ka

After the huge AT ash fall, i.e., in the latter half of the Upper Paleolithic, the upper cultural layer of the Itai-Teragatani site contains backed blades and many denticulated points (*Kakusuijo-sekki*). ^{14}C measurement of the peat layer, which is included these lithic industries, indicates 22,700 ± 330 BP and 20,400 ± 260 BP. The Tomizawa site in northern Japan also belongs to the latter Upper Paleolithic. A buried forest was discovered at this site with backed-blades and a fireplace. This is a unique hunting site that has great potential for reconstructing the paleoenvironment and human activities in the Upper Paleolithic (Ota 1992). ^{14}C dates from the site are 23,870 ± 860 BP and 19,430 ± 400 BP, and these fall in the LGM period. In the same horizon around Tomizawa, the sub-arctic coniferous buried forest of *Picea* has been excavated. There, droppings of Shika deer (*Cervus nippon*) and the fossils of insects that lived in the aquatic environment have been found.

After backed-blades diminished in the later Upper Paleolithic, point-tool industries came about mainly in central Japan. These bifacially retouched leaf shape points are usually about 10 cm long. Two dwelling structures were recently excavated at the Kogure-Higashi-Arayama site in Gunma Prefecture and at the Tana-Mukaihara site in Kanagawa Prefecture. The two dwelling sites belong to the point-tool industry and AMS determination indicates that the former is 17,950 ± 60 BP (Hosono 1999), and the latter are 17,650 ± 60 and 17,630 ± 50 BP (Tsuji 2000). As a result of these measurements, point-tool industries can be dated back to about 18–17 ka.

Final Upper Paleolithic and the Incipient Jomon: ~14–12 ka

The microblade industry represents the final period of the Upper Paleolithic in the Japanese islands. The sites of Yasumiba 14,300 ± 700 BP (Sugihara and Ono 1965), Araya (Figure 1:5) 13,200 ± 350 BP (Serizawa 1959), and Tsukimino-Kamino 13,570 ± 410 BP (Aida 1986) offer key ^{14}C dates for this period. Contrary to these dates, recent AMS determination at the Kashiwadai site (Figure 1:9) in Hokkaido reveals 20,790 ± 160 ~ 19,840 BP. These results imply that the microblade industry in Hokkaido, at the northern extreme of the Japanese islands, begins with about 21–20 ka, and this means a few thousand years earlier than Honshu area (Fukui and Koshida 1999). In Chaen at the extreme southern tip of the Kyushu (Figure 1:4), an early microblade industry dated to 15,450 ± 190 BP (Kawamichi and Araki 1998).

The duration of microblade industries in Kyushu covers approximately 15–12 ka, and in the latter phase of this period nail-patterned incipient Jomon pottery had already been associated with the microblade technique at the Fukui cave site Layer II (Figure 1:1). A ^{14}C date at Fukui cave is 12,400 ± 350 BP (Kamaki and Serizawa 1965).

New AMS dates have recently become available for the terminal Upper Paleolithic and/or the incipient phase of Jomon. The earliest undecorated pottery and the Mikoshiba-type axe, with its humped cross-section and points, have been excavated at the Odai-Yamamoto site in the northern extreme of the Japanese main island Honshu. Carbon adhesions on pottery fragments were dated by AMS and the results are shown as 13,780 ± 170 ~ 12,680 ± 140 BP (Taniguchi 1999). Furthermore, carbon adhesions on linear-relief pottery from the Seiko-Sanso site in central-northern Japan have also been tested by AMS, and the results are 12,340 ± 50 ~ 12,000 ± 40 (Tsuchiya and Nakajima 2000). Direct AMS dating of carbon adhesions on the earliest potsherds shows that the emergence of pottery in the Japanese islands dates from ~13,000 BP.

It should be emphasized that the Upper Paleolithic of the Japanese islands began before ~30 ka and developed for over 20,000 years before diminishing in the transition to the Jomon age at about 13 ka.

DISCUSSION

The Origin of Blade and Microblade Technology in Hokkaido: Kashiwadai 1 Site

Hokkaido is located at the northern tip of the Japanese islands. The soil formation there was not well developed in the later Pleistocene. Lithic artifacts from different periods, therefore, were sometimes unearthed from the same layer. Recently, however, the result of good carbonized materials of AMS determination from fireplaces allows one to re-examine the chronology of the microblade industry that had been established mostly by typological classification of cores and reduction technology.

In the case of the Kashiwadai 1 site, Chitose City in Hokkaido, the carbonized materials of 13 samples were found in fireplaces associated with lithic concentrations and Rankoshi-type microblade cores. AMS results are 20,790 ± 160 to 19,840 ± 70 BP. The mean value is ~20,500 BP (Hokkaido Center for Archaeological Operations 1999). This indicates the Rankoshi-type microblade core is older than the Shirataki type.

The detaching face of the Rankoshi type is set on the long axis, but the Shirataki type is set on the minor axis. This change so far seemed to be caused by gradual evolution of the effective utilization of raw materials. Furthermore, the blade technique is evident in the initial flaking stage of the Rankoshi micro core production in Kashiwadai 1 Site. Therefore, the emergence of the blade technique in Hokkaido suggested that it was older than 20 ka. The first appearance of microblade industry in

Hokkaido, in this context, seems to show no large time discrepancy compared to East Siberia, and inflow of microblade industries to Hokkaido was comparatively earlier than in other parts of the Japanese islands. Hokkaido microblade industries might have shared the same cultural traditions of East Siberia. These cultural traditions, in the broadest sense, are strongly connected to the theme of peopling the New World crossover to the Beringia.

New Data on the Transitional Stage from Middle to Upper Paleolithic

The Lake Nojiri Site Group

Lake Nojiri in central north Japan lies in the flat highland of the northern Fossa Magna at 654 m above sea level. The Nojiriko Formation is divided into three members: the Lower, Middle, and Upper, with marked inconformities. Furthermore, each member is subdivided into three or four parts. The chronometric framework of the Nojiri-ko Formation can be attributed as follows by AMS determination: the Lower Member covers ~50,000–42,000 BP, the Middle Member covers ~42,000–35,000 BP, and the Upper Member covers ~35,000–12,000 BP (Sawada et al. 1992). The Tategahana site on the shore of Lake Nojiri is, in particular, is unique with well-preserved organic materials.

Most of the mammal fossils are made up of two species. Bones of Naumann's elephant (*Palaeoloxodon naumanni*) represent 91.9%, and Yabe's giant deer (*Sinomegaceros yabei*) form 7.9% of the total mammal fossils. This faunal assemblage suggests that the selective big game hunting by Paleolithic hunters reflected the composition of the faunal remains. Lithic tools and flakes such as scrapers and drills have been excavated with bone materials in the same layer. In the Middle Nojiri-ko, Member I in particular, a bone cleaver and refitted bone flake with retouched base, and refitted bone chips were also found at same concentration. All bone tools were made by direct flaking, but the so-called "groove and splinter technique" had not yet appeared (Ono 2001). These pieces of evidence suggest that the site functioned as a killing and butchering place on a lake shore in the final stage of Middle Paleolithic (Nojiri-ko Excavation Research Group 1984, 1994; Ono and the Nojiri-ko Excavation Research Group 1991).

Ishinomoto Site

A recent investigation of South Kyushu reveals new aspects of the early Upper Paleolithic. More than 3000 lithic artifacts have been unearthed at the Ishinomoto site in Kumamoto Prefecture. This industry includes many trapezoids that have distinguishing features of the early Upper Paleolithic viewed from the techno-typology (Sato 1992). AMS dates (33,720 ± 430 and 31,460 ± 270 BP) are reported (Ikeda 1999), and these are good examples of the beginning of the Upper Paleolithic.

Trapezoid industries are possible to evaluate as an index of the early Upper Paleolithic from Kyushu to Hokkaido. At the same time, some characteristic industries were discovered from Kyushu as shown below.

Yokomine C, Tachikiri, and Ushiromuta Sites

At Tanegashima island, in the ocean to the south of Kyushu, three pebble clusters, some pounding stones, and pebble tools were excavated from the early Upper Paleolithic cultural layer I (Dogome 1998). AMS dates for carbonized materials from the pebble clusters are 31,280 ± 690 and 29,670 ± 540 BP. Another AMS determination from cultural layer II is 30,490 ± 590. The stratigraphic level of this horizon is just above the Tane IV volcanic ash, and found three pebble clusters and anvil stones, pounding stones, grinding stones, and flakes (Sakaguchi and Dogome 2000).

The same chronological layer to the culture layer I of Yokomine C site, a pebble cluster, two pits, 14 fire places, and about 50 stone tools were excavated from Tachikiri site. An AMS date for this site is 30,480 ± 210 BP.

The Ushiromuta site also has many grinding and pounding stones from culture layer III, and four AMS dates are available from 30,290 ± 200 to 28,900 ± 150 BP (Sato 1999). These industries are very different from other parts of Japan (Tachibana 1999) and they suggest that the early Upper Paleolithic people had adapted to the plant resource acquisition strategy. This should be a key to discuss the possibilities of a southern route of peopling modern humans to the Japanese islands.

CONCLUSION

We discussed mainly the determination of the chrono-stratigraphic sequence of the Upper Paleolithic of the Japanese islands by ^{14}C dating. Recent progress and the increasing number of AMS dates bring about a new horizon in ^{14}C dating for a whole range of the Upper Paleolithic. High-precision ^{14}C dates and their calibration lead us to new critical issues with particular reference not only to the framework of the Pleistocene/Holocene transition, but the Paleolithic/Jomon transition. In this paper, ^{14}C dates have been discussed with uncalibrated ones. When the calibration applied to the earliest pottery such as the Odai-Yamamoto I site, the dates calculate between 16,500 and 16,000 cal BP. This suggests that the earliest potteries in East Asia are preceded by the Oldest Dryas period in terms of northwest Europe. ^{14}C dating is widely applicable among different disciplines. Correlations between high-precision dating, calibration, exact sampling from the sound archaeological context and their interpretations are, therefore, more critically evaluated.

ACKNOWLEDGMENTS

We are greatful to Dr T Soda of the Palaeoenvironment Research Laboratory, Maebashi, Japan, for constructive comments on the marker-tephra.

RERERENCES

Aida K, editor. 1986. Kamino site Location 1 in the Tukimino site group. *Archaeological Research Reports of Yamato City*, No. 21. Yamato City Board of Education. In Japanese.

Dogome H. 1998. Paleolithic culture in Tanegashima Island. In: *Proceedings of the annual meeting of the Japanese Archaeological Association.* p 17–26. In Japanese.

Fukui J, Koshida K, editors. 1999. Kashiwadai 1 Site: Hokkaido. *Hokkaido Archaeological Research Center. Research Reports,* No. 138. Hokkaido Archaeological Research Center. In Japanese.

Hokkaido Center for Archaeological Operations. 1999. *Kashiwadai 1 Site.* In Japanese.

Hosono T. 1999. Excavations at Kogure-Higashi-Arayama site. In: *The 11th Meeting for Paleolithic Culture Research in Nagano Prefecture*. Abstracts. In Japanese.

Ikeda T, editor. 1999. Ishinomoto site group (II). Kumamoto. *Archaeological Research Rreports of Kumamoto Prefecture,* No. 178. Kumamoto Prefectural Board of Education. In Japanese.

Japan Association for Quaternary Research, editors. 1987 *Quaternary Maps of Japan*. University of Tokyo Press: Tokyo. In Japanese.

Japan Association for Quaternary Research, editors. 2000. *^{14}C ages of the Japanese Prehistory.*

Kamaki Y, Serizawa C. 1965. The rock-shelter of Fukui, Nagasaki prefecture. *Kokogaku Syukan* 3(1):1–14. In Japanese.

Kawamichi H, Araki N, editors. 1998. Chaen site. *Kishiku town board of education archaeological research reports,* No. 3. Nagasaki. Kishiku town Board of Education. In Japanese.

Kuzmin YV, Ono A, Sato H, et al. 1998. *Radiocarbon chronology of the stone age of northeast Asia*. Vladivostok.

Machida H, Arai F. 1992. *Atlas of Tephra in and around Japan*. Tokyo: University of Tokyo Press. In Japanese.

Machida H, Arai F, Moriwaki H. 2000. *Basics of stratigraphy.* Tokyo: Tokyo-Bijutsu. In Japanese.

Nojiri-ko Excavation Research Group. 1984. The Lake Nojiri Excavation 3. *The Association for the Geological Collaboration in Japan, Monograph* 27: 267. In Japanese with English abstract.

Nojiri-ko Excavation Research Group. 1994. The Late

Quaternary environment around Lake Nojiri in central Japan. *Proceedings of the 29th International Geological Congress, Part B*:269–77.

Ono A, Harunari H, Oda S, editors. 1992. *Atlas of Japanese archaeology.* Tokyo: University of Tokyo Press. In Japanese.

Ono A. 2001. *Flaked bone tools: an alternative perspective on the Palaeolithic.* Tokyo: Tokyo University Press. 290 p. In Japanese with English abstract.

Ono A, the Nojiri-ko Excavation Research Group. 1991. Archaeology of Lake Nojiri: a kill-butchering site of central north Japan in Later Pleistocene. In: Harding JL, editor. *The INQUA International Symposium on Stratigraphy and Correlation of Quaternary Deposits of the Asian and Pacific Regions*. CCOP/TP 22:159–66.

Ota A, editor. 1992. Tomizawa site. *Sendai city board of education research reports,* No. 160. Miyagi : Sendai city Board of Education. In Japanese with English abstract.

Sakaguchi K, Dogome H, editors. 2000. *Yokomine C site.* Kagoshima: Minamitane-cho Board of Education. In Japanese.

Sato H. 1992. *Structure and evolution of Japanese Paleolithic culture*. Tokyo: Kashiwa-Shobo. In Japanese.

Sato H. 1999. The transition from Middle to Late Paleolithic in southwestern Japan. In: *From Souzudai to Kamitakamori: world Views on the Early and Middle Palaeolithic in Japan*. Sendai: Tohoku Fukushi University. p 73–8. In Japanese.

Sato H. 2001. Do the Lower and Middle Paleolithic present in Japan after the Fujimura's scandal? *Kagaku* 71(4):5. In Japanese.

Sawada K, Arita Y, Nakamura T, Akiyama M, Kamei T, Nakai N. 1992. ^{14}C dating of the Nojiri-ko Formation using accelerator mass spectrometry. *Earth Science* 46(2):133–42. In Japanese with English abstract.

Serizawa C. 1959. A new Microblade industry discovered at the Araya site and the Araya-type Graver. *The Quaternary Research* 1(5):174–81. In Japanese.

Stuiver M, Grootes PM. 2000. GISP2 oxygen isotope ratios. *Quaterrnary Research* 53:277–84.

Sugihara S, Ono S. 1965. Microblade culture from the Yasumiba site in Shizuoka Prefecture. *Kokogaku Shukan* 3(2):1–33.

Suzuki T, Ito T, Maejima H, editors. 1999. *Hatunegahara site*. Shizuoka: Mishima City Board of Education. In Japanese.

Tachibana M. 1999. The Paleolithic culture in southern Kyushu: recent researche on the early upper Paleolithic in Kagoshima prefecture. *Kagoshima-Kouko* 33:59–73. In Japanese.

Taniguchi Y, editor. 1999. *Archaeological research at the Odai Yamamoto I site: inquiry into the question of the end of the Palaeolithic culture and the beginning of the Jomon culture*. Aomori: Odai Yamamoto I Site Excavation Team. In Japanese with English abstract.

Tsuchiya T, Nakajima E, editors. 2000. Seiko Sanso A, Seiko Ssansou B, Nishioka A, Kanoki, Uenohara, Okubo-minami, Higashiura, Uranoyama, Harinoki, Odaira B, Hinatabayasi A, Hinatabayasi B, Nanatsuguri and Fukoda sites. *Nagano archaeological research center research reports,* No. 49. Nagano: Nagano Prefectural Archaeological Research Center. In Japanese.

Tsuchiya T, Tani K, editors. 2000. Hinatabayashi B, Hinatabayashi A, Nanatsuguri, and Ohira B sites. *Nagano archaeological research center research reports,* No. 15. Nagano: Nagano Archaeological Research Center. In Japanese.

Tsuji S. 2000. From radiocarbon dates to calender years: for the estabilishment of chronologies in 21st century. In: Kawai N, editor. *A chronicle of archaeology 2000*. Asahi Shinbun.

Yamaguchi T, Kishimoto K. 1991. Itai-Teragatani site. *Archaeological reports of Hyogo prefecture*, No. 96. Hyogo: Hyogo Prefectural Board of Education. In Japanese.

APPENDIX

REFERENCES FOR TABLE 1

(J)= in Japanese. (J/E) = in Japanese with English abstract.
[1] Akashi H, Goto Y, editors. 1978. *Kamiitaira site*. Obihiro city Board of Education. (J)
[2] Oba T, Matsushita W. 1965. Preceramic age of Hokkaido. *The Archaeology of Japan.*Vol.1. Kawade-shobo. (J)
[3] Ueno S, Miyatsuka Y. 1981. *Mosanru site*. Shimokawa-cho Board of Education. (J)
[4] Shirataki Research Group. 1963. *Study of the Shirataki site*. (J)
[5] Goto T, Tomikawa T. 1983. *Obihirokuko-minami A site*. Tokachi Shicho. (J)
[6] Yoshizaki M. 1974. *Shukubai-sankakuyama*. Chitose city Board of Education. (J)
[7] Miya H, editor. 1985. Hirosato 8 site (II). Kitami city Board of Education. (J)
[8] Yamahara T, editor. 1992. Kyoei 3 site. In *Kamishimizu 2, Kyoei 3, Higashi matsuzawa 2, and Komyo 1 site*. Hokkaido Archaeological Research Center. (J)
[9] Sato N, Kitazawa M, editors. 1985. *Obihiro-Akatsuki site*. Obihiro city Board of Education. (J)
[10] Sato N, Kitazawa M, editors. 1986. *Obihiro-Akatsuki site 2*. Obihiro city Board of Education. (J)
[11] Sato N, Kitazawa M, editors. 1987. *Obihiro-Kamiitaira site 2*. Obihiro city Board of Education. (J)
[12] Sato N, Kitazawa M, editors. 1986. *ObihiroKuko-minami B site*. Obihiro city Board of Education. (J)
[13] Kitazawa M, Yamahara T, editors. 1995. *Obihiro Minamimachi site*. Obihiro city Board of Education. (J)
[14] Tamura T, editor. 1994. *Excavation in the Marukoyama site*. Obihiro city Board of Education. (J)
[15] Oshima Y, editor. 1997. *Osatsu 16 site(2).* Hokkaido Association for Cultural Properties. (J)
[16] Terasaki Y. 1990. *Kamioka 2 site*. Imakane city Board of Education. (J)
[17] Naganuma T, editor. 1985. *Pirika 1 site.* Hokkaido Archaeological Research Center. (J)
[18] Naganuma T, editor. 1988. *Isikawa 1 site*. Hokkaido Archaeological Research Center. (J)
[19] Onuma T, Chiba E, Endo K, Tachikawa T, Kumaya H, Hanaoka M. 1988. *Shinmichi 4 site.* Hokkaido Archaeological Research Center. (J)
[20] Tsuji H, editor. 1985. *Oribe 16 site in Oribe site group.* Kamishihoro-choBoard of Education. (J)
[21] Naganuma T, Koshida M, Sato T, editors. 1999. *Nitto site*. Hokkaido Archaeological Research Center. (J)
[22] Fukui J, Koshida K, editors. 1999. *Kashiwadai 1 site.* Hokkaido Archaeological Research Center. (J)
[23] Sagawa S, Nakata Y, Kageura O, Hanaoka M, editors. 2000. *Miyako site*. Hokkaido Archaeological Research Center. (J)
[24] Kitazawa M, Yamahara T, Kondo Y, Warashina T, editors. 1998. *Obihiro-Kawanishi C site.* Obihiro city Board of Eduation. (J)
[25] Kitazawa M, Sasajima K, Warashina T, editors. 2000. *Obihiro-Kawanishi C site 2.* Obihiro city Board of Eduation. (J)
[26]Yamahara T. 1999. *Obihiro-Ochiai site 2.* Obihiro city Board of Eduation.(J)
[27]Kitahara M. 2001. *Obihiro-Beppu 1 site*. Obihiro city Board of Eduation. (J)
[28] Taniguchi Y, editor. 1999. *Archaeological research at the Odai Yamamoto I site.* Odai Yamamoto I site Excavation team. (J/E).
[29] Takahashi Y, Kikuchi K, editors. 1999. *Tougeyamabokujyo 1 site, A area*. Iwate Archaeological Research Center. (J)
[30] Kikuchi K, Hashiba N, Takahashi Y, editors. 1996. *Kashiyamatate-ato Archaeological Research Reports*. Iwate Prefectural Archaeological Research Center. (J)
[31] Murakami T, editor. 1999. *Mimitori 1 site, B area.* Iwate Prefectural Archaeological Research Center. (J)
[32] Assosiation for Field Archaeologist Network. 1996. *Archaeology and Numerical Dates*. (Abstracts and Data) 40th Meeting at Takatsuki, 17&18. August 1996. (J)
[33] Japan Association for Quaternary Research. 2000. *14C ages of the Japanese Prehistory.*
[34] Kondo N, Kobayashi H, editors. 1992. *Simomouchi site.* Nagano Prefectural Center for Archaeological Research . (J)
[35] Suto T. editor. 1999. *Happusan site group.* Saku city Board of Education.(J)
[36] Tani K. editor. 2001. *Kosakayama site.* Nagano Prefectural Archaeological Research Center. (J)
[37] Tsuchiya S, Tani K, editors. 2000. *Hinatabayashi B, Hinatabayashi A, Nanatsuguri and Ohira B site.* Nagano prefectural Archaeological Research Center. (J)
[38] Tani, k. (ed.) 2000 *Uranoyama, Higashiura, Okuominami and Uenohara site*. Nagano Prefectural Archaeological Research Center. (J)
[39] Tsuchiya S, Otake N, Tani K, Nakajima E, Totani Y, editors. 2000. *Kannoki and Nishioka A site.* Nagano Prefectural Archaeological Research Center. (J)
[40] Tsutiya S, Nakajima E, editors. 2000. *Seiko Sansou A, Seiko Ssansou B, Nishioka A, Kannoki, Uenohara, Okubo-minami, Higashiura, Uranoyama, Harinoki, Odaira B, Hinatabayasi A, Hinatabayasi B, Nanatsuguri and Fukoda site.* Nagano Prectural Archaeological Research Center. (J)
[41] Muraishi M, editor. 2000. *Yokohari-maekubo, Yoneyama and Yokohari-nakayama site.* Yamanashi prefectural archaeological research center. (J)

[42] Hosono T. 1999. *Excavations at Kogure-Higashi-Arayama site.* 11th Meeting for Palaeolithic Cultures Resarch in Nagano Prefecture. (Abstracts)(J)

[43] Nakatsu Y, Kobiki H. 1992. *Tanashi Minami-cho site.* Excavation committee for sites on Tokyo public school ground. (J)

[44] Oda S. 1980. *Nishinodai Loc. B*. Tokyo Metoropolitan Board of Education. (J)

[45] Suzuki Site Publication Committee. 1978. *Suzuki site I*. Suzuki Site Publication Committee. (J/E)

[46] Excavation group for Tokyo Astronomical Observatory site. 1983. *TokyoÅ@Astronomical Observatory site.* Excavation group for Tokyo Astronomical Observatory site. (J)

[47] Sakairi T, Ito F, Orikasa A. 1977. *Takaidohigashi-chushajo-nishi site*. Tokyo: Takaido Higashi Chushajo Nishi Site Excavation Project. (J)

[48] Itano S, editor. 1999. *Hikageyama site*. Site research association of Nishi-Kokubunji area. (J)

[49] Kurihara N, editor. 1998. *Carbonized wood embedded in the loam layer from the site group among Yoda by-path project*. KANAGAWA Archaeology Foundation. (J)

[50] Tsuji S. 2000. From radiocarbon dates to calender years: for the estabilishment of chronologies in 21st century. In *A chronicle of archaeology 2000*. Kawai, N. (ed.) Asahi Shinbun.

[51] Ichikawa M, Suzuki J, Yoshida M, editors. 1998. Kitahara (No. 10, 11 North) site. in *The Miyagase site group.* KANAGAWA Archaeology Foundation. (J)

[52] Suzuki J, Ichikawa M, Sanpei Y, editors. 1997. Nakappara and Ueppara site. in *The Miyagase site group*. KANAGAWA Archaeology Foundation. (J)

[53] Ikeda O, Sunada Y, editors. 2000. *Heiwazaka site*. KANAGAWA Archaeology Foundation. (J)

[54] Mine O, Hatanaka T, Izeki F, editors. 1999. *Fukudaheininoku site.* KANAGAWA archaeology Foundation. (J)

[55] Suzuki T, Ito T, Maejima H, editors. 1999. *Hatunegahara site*. Mishima city board of education. (J)

[56] Togashi T, Watase O, Sato K, Kasai M, Morinaga H, Yamashita H, editors. 1998. *Takamigaoka (III, IV) site.* Shizuoka Prefectural Archaeological Research Center. (J)

[57] Sasahara Y. 1999. Nishibora site, B area. Numazu city Board of Education. (J)

[58] Kawamichi H, Araki N, editors. 1998. *Chaen site*. Kishiku town Boardof Education. (J)

[59] Murasaki T, editor. 1998. *Mimikiri site*. Kumamoto Board of Education. (J)

[60] Ikeda T, editor. 1999. *Ishinomoto site group (II)*. Kumamoto Board of Education. (J)

[61] Association for Field Archaeologist Network. 1987. *Issues of Tephra and Archeology.* (J)

[62] Dogome H. 1998. Upper Paleolithic Culture in Tanegashima Island. Annual Meeting of the Japanese Archaeological Association held in Okinawa, 1998. *(Abstract)* (J)

[63] Dogome H, editor. 2000 . *Yokomine C site.* Minamitane town Board of education.(J)

[64] Dogome H. 1998. Upper Paleolithic Culture in Tanegashima Island. Annual Meeting of the Japanese Archaeological Association held in Okinawa, 1998.*(Abstract)* (J)

[65] Sato H. 1999. The transition from Middle to Late Paleolithic in southwestern Japan. in *From Souzudai to Kamitakamori: World Views on the Early and Middle Palaeolithic in Japan.* :73-78, Tohoku Fukushi University:Sendai.(J)

[66] Nagano T. 2000. *Chyochi site*. Kiiri-cho Board of Education. (J)

Table 1 Radiocarbon dates for the Upper Paleolithic and Incipient Jomon. Dates are uncalibrated.

	NO	Site name	Coordinates Latitude	Longitude	Sample position	Measured C14 age	Conventional C14 age	Lab Code and No.	Material dated	Cultural affiliation	β AMS	Reference
1	1	Kamiitaira	42° 43'	143° 14'	Cultural layer	11410±440	—	GaK-7076	charcoal	Microblade industry	β	[1]
2					Cultural layer	12530±490	—	GaK-7075	charcoal	Microblade industry	β	[1]
3					stone heap	32500±inf,-12000	—	KSU-1336	charcoal	Upper Paleolithic	β	[11]
4	2	Kitakami B	43° 46'	143° 52'	Cultural layer?	10300±1300	—	GaK-331	charcoal	Microblade industry	β	[2]
5	3	Mosanru	44° 19'	142° 43'	Cultural layer	13270±420	—	GaK-8722	charcoal	Upper Paleolithic	β	[3]
6					Cultural layer	15080±450	—	GaK-8723	charcoal	Upper Paleolithic	β	[3]
7					Cultural layer	14430±350	—	GaK-8724	charcoal	Upper Paleolithic	β	[3]
8	4	Shirataki 31	43° 52'	143° 08′	depth 3.4m	15820±400	—	GaK-212	peat	Microblade industry	β	[4]
9					depth 3.77m	15800±400	—	GaK-160	wood	Microblade industry	β	[4]
10					depth 3.38m	14800±330	—	GaK-210	wood	Microblade industry	β	[4]
11	5	Obihirokuko Minami A	42° 43′	143° 13′	Cultural layer	23850±4480/-2850	—	GaK-10747	charcoal	Upper Paleolithic	β	[5]
12					Cultural layer	19420±1770	—	GaK-10746	charcoal	Upper Paleolithic	β	[5]
13	6	Shukubai Sankakuyama	42° 50′	141° 11′	Cultural layer	21450±750	—	GaK-4346	charcoal	Upper Paleolithic	β	[6]
14	7	Hirosato 8	43° 45′	143° 48′	Cultural layer	13560±360	—	GaK-11568	charcoal	Upper Paleolithic	β	[7]
15	8	Kyoei 3	42° 57′	142° 55′	Cultural layer	＞18000	—	KSU-2167	charcoal	Upper Paleolithic	β	[8]
16					Cultural layer	＞18000	—	KSU-2168	charcoal	Upper Paleolithic	β	[8]
17	9	Akatsuki	42° 55′	143° 12′	Cultural layer	14700±250	—	KSU-717	charcoal	Microblade industry	β	[9]
18					Cultural layer	14700±130	—	KSU-718	charcoal	Microblade industry	β	[9]
19					Cultural layer	10900±500	—	KSU-889	charcoal	Microblade industry	β	[10]
20	10	Obihirokuko Minami B	42° 43′	143° 14′	Cultural layer	9150±600	—	KSU-890	charcoal	Microblade industry	β	[12]
21					Cultural layer	9500±650	—	KSU-891	charcoal	Microblade industry	β	[12]
22	11	Minamimachi 2	42° 54′	143° 10′	fireplace	13790±190	—	GaK-18247	charcoal	Microblade industry	β	[13]
23					fireplace	19610±270	—	GaK-18248	charcoal	Upper Paleolithic	β	[13]
24	12	Maruokayama	42° 52′	141° 42′	Cultural layer	—	21940±250	NUTA-2801	charcoal	Upper Paleolithic	AMS	[14]
25	13	Osatsu 16	42° 50′	141° 35′	pit	14590±200	—	GaK-19469	charcoal	Microblade industry	β	[15]
26					pit	10600±8650	—	GaK-19468	charcoal	Microblade industry	β	[15]
27	14	Kamioka 2	42° 25′	139° 59′	Cultural layer	9130±50	—	KSU-1995	charcoal	Upper Paleolithic	β	[16]
28	15	Pirika 1	42° 28′	140° 13′	Cultural layer Ⅰ	20100±335	—	N-4937	charcoal	Microblade industry	β	[17]
29					Cultural layer Ⅰ	20900±260	—	KSU-689	charcoal	Microblade industry	β	[17]
30					Cultural layer ⅡB	19800±380	—	KSU-687	charcoal	Microblade industry	β	[17]
31					Cultural layer ⅢA	18200±230	—	N-4936	charcoal	Point industry	β	[17]
32					Cultural layer ⅢA	17500±200	—	KSU-688	charcoal	Point industry	β	[17]
33	16	Ishikawa 1	41° 50′	140° 44′	Cultural layer	13400±160	—	KSU-1652	charcoal	Microblade industry	β	[18]
34	17	Shinmichi 4	41° 40′	140° 25′	Cultural layer	8320±280	—	KSU-1430	charcoal	Microblade industry	β	[19]
35	18	Oribe 16	43° 13′	143° 22′	Cultural layer	5630±90	—	KSU-759	charcoal	Microblade industry	β	[20]
36					Cultural layer	5300±550	—	KSU-760	charcoal	Microblade industry	β	[20]
37					Cultural layer	23600±700	—	KSU-761	charcoal	Microblade industry	β	[20]
38	19	Nitto	43° 50′	142° 47′	Cultural layer	16940±80	16940±80	Beta-136453	charcoal	Microblade industry	AMS	[21]
39					Cultural layer	980±40	980±40	Beta-136454	charcoal	Microblade industry	AMS	[21]
40					Cultural layer	16570±120	16560±120	Beta-136455	charcoal	Microblade industry	AMS	[21]
41	20	Kashiwadai 1	42° 48′	141° 41′	Layer Ⅰ	22190±210	22210±210	Beta-112913	charcoal	—	AMS	[22]
42					Layer Ⅰ	19650±130	19660±130	Beta-112915	charcoal	—	AMS	[22]
43					Layer Ⅳ	20910±190	20900±190	Beta-126178	charcoal	—	AMS	[22]
44					Layer Ⅰ	20200±120	20180±120	Beta-112919	charcoal	Microblade industry	AMS	[22]
45					fireplace	31350±330	31350±330	Beta-126182	charcoal	Microblade industry	AMS	[22]
46					Layer Ⅱ～Ⅲ	20700±210	20680±210	Beta-112922	charcoal	Microblade industry	AMS	[22]
47					Layer Ⅳ	20500±160	20510±160	Beta-112920	charcoal	Microblade industry	AMS	[22]
48					Layer Ⅳ～Ⅴ	20500±130	20490±130	Beta-112921	charcoal	Microblade industry	AMS	[22]
49					Layer Ⅳ	20570±160	20580±160	Beta-126167	charcoal	Microblade industry	AMS	[22]
50					fireplace	20140±150	20130±150	Beta-126170	charcoal	Microblade industry	AMS	[22]
51					fireplace	20790±160	20790±160	Beta-126175	charcoal	Microblade industry	AMS	[22]
52					fireplace	20600±160	20610±160	Beta-126184	charcoal	Microblade industry	AMS	[22]
53					fireplace	19850±70	19840±70	Beta-120881	charcoal	Microblade industry	AMS	[22]
54					fireplace	20370±70	20370±70	Beta-120883	charcoal	Microblade industry	AMS	[22]
55					fireplace	20700±150	20700±150	Beta-126176	charcoal	Microblade industry	AMS	[22]
56					fireplace	18840±150	18830±150	Beta-126177	charcoal	Microblade industry	AMS	[22]
57					fireplace	22340±170	22340±170	Beta-126168	charcoal	Endscraper	AMS	[22]
58					fireplace	22300±180	22300±180	Beta-126169	charcoal	Endscraper	AMS	[22]
59					fireplace	22550±180	22550±180	Beta-126171	charcoal	Endscraper	AMS	[22]

	NO	Site name	Coordinates Latitude	Longitude	Sample position	Measured C14 age	Conventional C14 age	Lab Code and No.	Material dated	Cultural affiliation	β AMS	Reference
60					Layer II~III	20600±120	20570±120	Beta-112914	charcoal	Endscraper	AMS	[22]
61					fireplace	22330±200	22340±200	Beta-126173	charcoal	Endscraper	AMS	[22]
62					Layer I	20300±150	20320±150	Beta-112916	charcoal	Endscraper	AMS	[22]
63					fireplace	21790±230	21790±230	Beta-126174	charcoal	Endscraper	AMS	[22]
64					fireplace	22180±170	22200±170	Beta-126183	charcoal	Endscraper	AMS	[22]
65					fireplace	20410±70	20390±70	Beta-120880	charcoal	Endscraper	AMS	[22]
66					fireplace	21000±100	21000±100	Beta-120881	charcoal	Endscraper	AMS	[22]
67					Layer V	33020±540	33030±540	Beta-126181	charcoal	—	AMS	[22]
68					Layer VI	28200±480	28200±480	Beta-112918	charcoal	—	AMS	[22]
69					Layer VII	32500±360	32490±360	Beta-126180	charcoal	—	AMS	[22]
70					Layer X	37350±550	37350±550	Beta-126179	charcoal	—	AMS	[22]
71	21	Miyako	43° 3′	140° 49′	Layer	37610±350	37590±430	Beta-138112	organic sediment	?	AMS	[23]
72	22	Kawanishi C	42° 52′	143° 11′	fireplace	21800±90	21780±90	Beta-106506	charcoal	Upper Paleolithic	AMS	[24]
73					fireplace	21420±190	21400±190	Beta-107731	charcoal	Upper Paleolithic	AMS	[24]
74					Cultural layer	13070±40	13020±40	Beta-126150	charcoal	Microblade industry	AMS	[25]
75					pebble cluster	16940±50	16920±50	Beta-126151	charcoal	Microblade industry	AMS	[25]
76					Cultural layer	12920±50	12900±50	Beta-127399	charcoal	Microblade industry	AMS	[25]
77	23	Ochiai	42° 53′	143° 11′	Layer	18570±140	18590±140	Beta-111832	charcoal	Upper Paleolithic	AMS	[26]
78	24	Beppu 1	42° 51′	143° 9′	Cultural layer	13460±70	13400±70	Beta-149443	charcoal	Upper Paleolithic	AMS	[27]
79					Cultural layer	3730±40	3750±40	Beta-149444	charcoal	Upper Paleolithic	AMS	[27]
80	25	Odaiyamamoto I	43° 3′	140° 33′	pottery	—	13210±160	NUTA-6515	charcoal	Incipient Jomon	AMS	[28]
81					pottery	—	13030±170	NUTA-6507	charcoal	Incipient Jomon	AMS	[28]
82					pottery	—	12720±160	NUTA-6509	charcoal	Incipient Jomon	AMS	[28]
83					pottery	—	12680±140	NUTA-6506	charcoal	Incipient Jomon	AMS	[28]
84					pottery	—	13780±170	NUTA-6510	charcoal	Incipient Jomon	AMS	[28]
85					Layer III	—	13480±70	Beta-125550	charcoal	Incipient Jomon	AMS	[28]
86	26	Togeyamabokujyo I A	39° 17′	140° 50′	Layer IIb	30550±1190	—	Gak-18479	charcoal	Upper Paleolithic	β	[29]
87	27	Kashiwayamatate-ato	39° 10′	141° 05′	Layer IIa	12150±950	—	Gak-18460	charcoal	Upper Paleolithic	β	[30]
88					Layer IIa~IIb	17010±1210	—	Gak-18461	charcoal	Upper Paleolithic	β	[30]
89	28	Mimitori I B	39° 17′	140° 50′	Layer II 1	13650±60	13630±60	Beta-89465	charcoal	Point industry	AMS	[31]
90	29	Odaino	39° 40′	141° 05′	Cultural layer II	18500±450	—	GaK-3780	charcoal	Upper Paleolithic	β	[32]
91	30	Kanedori	39° 10′	141° 20′	Cultural layer II	23580±450	—	GaK-13090	charcoal	Upper Paleolithic	β	[32]
92	31	Hanaizumi	38° 40′	141° 05′	Cultural layer	24670±1310	—	GaK-14565	wood	Upper Paleolithic	β	[32]
93					Cultural layer	>35770	—	GaK-14566	charcoal	Upper Paleolithic	β	[32]
94					Cultural layer	11690±360	—	GaK-14567	wood	Upper Paleolithic	β	[32]
95					Cultural layer	24920±810	—	GaK-14568	charcoal	Upper Paleolithic	β	[32]
96					Cultural layer	13890±270	—	GaK-14569	wood	Upper Paleolithic	β	[32]
97					Cultural layer	12220±180	—	GaK-14571	wood	Upper Paleolithic	β	[32]
98					Cultural layer	12700±190	—	GaK-14572	wood	Upper Paleolithic	β	[32]
99					Cultural layer	12500±140	—	GaK-14573	wood	Upper Paleolithic	β	[32]
100					?	18470±660	—	GaK-15798	bovid tooth	Upper Paleolithic	β	[32]
101					?	21430±1260	—	GaK-15893	elephant tooth	Upper Paleolithic	β	[32]
102	32	Owatari 2	39° 18′	140° 45′	?	13830±220	—	GaK-16961	wood	Upper Paleolithic	β	[32]
103					?	18940±370	—	GaK-16962	wood	Upper Paleolithic	β	[32]
104					?	26490±910	—	GaK-16963	wood	Upper Paleolithic	β	[32]
105					Cultural layer	24740±600	—	GaK-17720	charcoal	Upper Paleolithic	β	[32]
106					Cultural layer	26000±760	—	GaK-17721	charcoal	Upper Paleolithic	β	[32]
107					Cultural layer	21500±470	—	GaK-17722	charcoal	Upper Paleolithic	β	[32]
108					Cultural layer	17740±270	—	GaK-17723	charcoal	Upper Paleolithic	β	[32]
109					Cultural layer	27740±920	—	GaK-17724	charcoal	Upper Paleolithic	β	[32]
110					Cultural layer	26150±900	—	GaK-17725	charcoal	Upper Paleolithic	β	[32]
111					Cultural layer	27780±1060	—	GaK-17726	charcoal	Upper Paleolithic	β	[32]
112					Cultural layer	22750±430	—	GaK-17727	charcoal	Upper Paleolithic	β	[32]
113					Cultural layer	27330±970	—	GaK-17728	charcoal	Upper Paleolithic	β	[32]
114					Cultural layer	24560±450	—	GaK-17729	charcoal	Upper Paleolithic	β	[32]
115					Cultural layer	22710±480	—	GaK-17730	charcoal	Upper Paleolithic	β	[32]
116					?	11510±150	—	GaK-17731	peat	Upper Paleolithic	β	[32]
117					?	23090±590	—	GaK-17732	peat	Upper Paleolithic	β	[32]
118	33	Matsukidai 3	39° 40′	140° 15′	?	22750±620	—	GaK-12702	charcoal	Upper Paleolithic	β	[32]

	NO	Site name	Coordinates Latitude	Longitude	Sample position	Measured C14 age	Conventional C14 age	Lab Code and No.	Material dated	Cultural affiliation	β AMS	Reference
119	34	Kamonokodai	40° 05′	139° 50′	?	8420±380	—	GaK-15404	charcoal	Upper Paleolithic	β	[32]
120	35	Tomizawa	38° 13′	140° 52′	Cultural layer	21110±590	—	GaK-13766	wood	Upper Paleolithic	β	[32]
121					Cultural layer	21670±750	—	GaK-13767	wood	Upper Paleolithic	β	[32]
122					Cultural layer	23770±760	—	GaK-13768	wood	Upper Paleolithic	β	[32]
123					Cultural layer	19500±560	—	GaK-13769	wood	Upper Paleolithic	β	[32]
124					Cultural layer	23870±870	—	GaK-13770	wood	Upper Paleolithic	β	[32]
125					Cultural layer	21760±490	—	GaK-13860	wood	Upper Paleolithic	β	[32]
126					Cultural layer	19430±400	—	GaK-13861	wood	Upper Paleolithic	β	[32]
127					Cultural layer	20590+600/-560	—	NU-119	wood	Upper Paleolithic	β	[32]
128					Cultural layer	19730+440/-410	—	NU-120	wood	Upper Paleolithic	β	[32]
129					Cultural layer	19470+470/-440	—	NU-121	wood	Upper Paleolithic	β	[32]
130					Cultural layer	27300+1810/-1480	—	NU-122	charcoal	Upper Paleolithic	β	[32]
131					Cultural layer	23300+1400/-1190	—	NU-123	charcoal	Upper Paleolithic	β	[32]
132					Cultural layer	19970+930/-840	—	NU-124	charcoal	Upper Paleolithic	β	[32]
133					Cultural layer	23270+700/-640	—	NU-125	wood	Upper Paleolithic	β	[32]
134					Cultural layer	23610+730/-670	—	NU-126	wood	Upper Paleolithic	β	[32]
135					Cultural layer	23010+940/-840	—	TH-1442	wood	Upper Paleolithic	β	[32]
136					Cultural layer	20380±290	—	GaK-16925	wood	Upper Paleolithic	β	[32]
137					Cultural layer	20420±280	—	GaK-16926	wood	Upper Paleolithic	β	[32]
138					Cultural layer	18270±210	—	GaK-16927	wood	Upper Paleolithic	β	[32]
139					Cultural layer	14500±320	—	GaK-16928	wood	Upper Paleolithic	β	[32]
140					Cultural layer	22180±1330	—	GaK-16929	conifer	Upper Paleolithic	β	[32]
141					?	20530±360	—	NU-670	wood	Upper Paleolithic	β	[32]
142					?	24610±490	—	NU-671	wood	Upper Paleolithic	β	[32]
143					?	22620±425	—	NU-672	wood	Upper Paleolithic	β	[32]
144					?	20850+710/-650	—	NU-673	charcoal	Upper Paleolithic	β	[32]
145	36	Owatari	37° 40′	140° 55′	Cultural layer	>26000	—	?	charcoal	Upper Paleolithic	β	[32]
146	37	Sanganchi	37° 50′	140° 50′	?	19470±400	—	GaK-13136	wood	Upper Paleolithic	β	[32]
147	38	Araya	37° 16′	138° 52′	Cultural layer	13200±350	—	GaK-948	charcoal	Microblade industry	β	[32]
148	39	Osaka Uemachi	37° 40′	139° 10′	Cultural layer	26810±970	—	GaK-17474	charcoal	Upper Paleolithic	β	[32]
149	40	Uenotaira	37° 45′	139° 10′	peat	>38280	—	GaK-17472	wood	Upper Paleolithic	β	[32]
150					peat	36070±2250	—	GaK-17473	wood	Upper Paleolithic	β	[32]
151	41	Tategahana	37° 00′	138° 10′	Upper Nojiri-ko Member I	—	34500±670	NUTA-1281	elephant molar tooth	Middle Paleolithic	AMS	[33]
152					Upper Nojiri-ko Member I	—	38820±1580	NUTA-1263	elephant molar tooth	Middle Paleolithic	AMS	[33]
153					Upper Nojiri-ko Member I	—	38310±1400	NUTA-1262	elephant molar tooth	Middle Paleolithic	AMS	[33]
154					Upper Nojiri-ko Member I	—	42540±1420	NUTA-1317	elephant molar tooth	Middle Paleolithic	AMS	[33]
155					Upper Nojiri-ko Member I	—	31920±700	NUTA-1299	elephant molar tooth	Middle Paleolithic	AMS	[33]
156					Upper Nojiri-ko Member I	—	30580±1290	NUTA-1194	bone fragment of giant deer	Middle Paleolithic	AMS	[33]
157					Upper Nojiri-ko Member I	—	33660±1850	NUTA-1190	antler fragment of giant deer	Middle Paleolithic	AMS	[33]
158					Middle Nojiri-ko Member II	—	40700±1200	NUTA-1280	elephant molar tooth	Middle Paleolithic	AMS	[33]
159					Middle Nojiri-ko Member II	—	41700±1260	NUTA-1294	elephant molar tooth	Middle Paleolithic	AMS	[33]
160					Middle Nojiri-ko Member II	—	40130±1080	NUTA-1296	elephant molar tooth	Middle Paleolithic	AMS	[33]
161					Middle Nojiri-ko Member II	—	40560±1500	NUTA-1261	antler fragment of giant deer	Middle Paleolithic	AMS	[33]
162					Middle Nojiri-ko Member I	—	40860±1170	NUTA-1231	elephant molar tooth	Middle Paleolithic	AMS	[33]
163					Middle Nojiri-ko Member I	—	41520±1020	NUTA-1282	elephant molar tooth	Middle Paleolithic	AMS	[33]
164					Middle Nojiri-ko Member I	—	35570±790	NUTA-1077	elephant tusk	Middle Paleolithic	AMS	[33]
165					Middle Nojiri-ko Member I	—	35410±1550	NUTA-1195	bone fragment of giant deer	Middle Paleolithic	AMS	[33]
166					Lower Nojiri-ko Member IIIB3	—	45120±1350	NUTA-1267	elephant molar tooth	Middle Paleolithic	AMS	[33]
167					Lower Nojiri-ko Member IIIB3	—	45810±1290	NUTA-1279	elephant molar tooth	Middle Paleolithic	AMS	[33]
168					Lower Nojiri-ko Member IIIB3	—	35140±910	NUTA-1232	elephant tusk	Middle Paleolithic	AMS	[33]
169					Lower Nojiri-ko Member IIIB3	—	37420±910	NUTA-630	elephant tusk	Middle Paleolithic	AMS	[33]
170					Lower Nojiri-ko Member IIIB2	—	45100±1190	NUTA-1252	elephant molar tooth	Middle Paleolithic	AMS	[33]
171					Lower Nojiri-ko Member IIIB2	—	42670±1120	NUTA-1269	elephant molar tooth	Middle Paleolithic	AMS	[33]
172					Lower Nojiri-ko Member IIIB2	—	42250±990	NUTA-1283	elephant molar tooth	Middle Paleolithic	AMS	[33]
173					Lower Nojiri-ko Member IIIB2	—	33540±620	NUTA-631	elephant tusk	Middle Paleolithic	AMS	[33]
174					Lower Nojiri-ko Member IIIB1	—	48800±1950	NUTA-1278	elephant molar tooth	Middle Paleolithic	AMS	[33]
175					Lower Nojiri-ko Member IIIB1	—	42420±1500	NUTA-1254	elephant molar tooth	Middle Paleolithic	AMS	[33]
176					Lower Nojiri-ko Member IIIB1	—	30540±1430	NUTA-1192	elephant molar tooth	Middle Paleolithic	AMS	[33]
177					Lower Nojiri-ko Member IIIB1	—	43350±1160	NUTA-1340	elephant molar tooth	Middle Paleolithic	AMS	[33]

	NO	Site name	Coordinates Latitude	Longitude	Sample position	Measured C14 age	Conventional C14 age	Lab Code and No.	Material dated	Cultural affiliation	β AMS	Reference
178					Lower Nojiri-ko Member IIIB1	—	41250±1190	NUTA-1316	antler fragment of giant deer	Middle Paleolithic	AMS	[33]
179					Lower Nojiri-ko Member IIIA2	—	43520±1340	NUTA-1295	elephant molar tooth	Middle Paleolithic	AMS	[33]
180					Lower Nojiri-ko Member IIIA1	—	43310±1200	NUTA-1268	elephant molar tooth	Middle Paleolithic	AMS	[33]
181					Lower Nojiri-ko Member IIIA1	—	37250±1280	NUTA-1230	elephant tusk	Middle Paleolithic	AMS	[33]
182					Lower part of Lower Nojiri-ko Member III	—	41770±1470	NUTA-1329	elephant molar tooth	Middle Paleolithic	AMS	[33]
183					Lower part of Lower Nojiri-ko Member III	—	43460±1630	NUTA-1330	elephant molar tooth	Middle Paleolithic	AMS	[33]
184					Lower part of Lower Nojiri-ko Member III	—	46230±2430	NUTA-1328	elephant molar tooth	Middle Paleolithic	AMS	[33]
185					Botom of Lower Nojiri-ko Member III	—	39180±1370	NUTA-1251	elephant molar tooth	Middle Paleolithic	AMS	[33]
186					Botom of Lower Nojiri-ko Member III	—	43640±920	NUTA-1189	elephant molar tooth	Middle Paleolithic	AMS	[33]
187					J-line Formation	—	8260±140	NUTA-1298	wood	Middle Paleolithic	AMS	[33]
188					Upper Nojiri-ko Member III	—	17460±340	NUTA-1391	wood	Middle Paleolithic	AMS	[33]
189					Upper Nojiri-ko Member III	—	16860±250	NUTA-1392	wood	Middle Paleolithic	AMS	[33]
190					Upper Nojiri-ko Member II	—	28350±350	NUTA-1305	wood	Middle Paleolithic	AMS	[33]
191					Upper Nojiri-ko Member I	—	32750±490	NUTA-1297	wood	Middle Paleolithic	AMS	[33]
192					Upper Nojiri-ko Member I	—	38490±520	NUTA-1240	wood	Middle Paleolithic	AMS	[33]
193					Upper Nojiri-ko Member I	—	39290±480	NUTA-1237	wood	Middle Paleolithic	AMS	[33]
194					Middle Nojiri-ko Member I	—	39420±950	NUTA-1239	wood	Middle Paleolithic	AMS	[33]
195					Lower Nojiri-ko Member IIIB2	—	42550±530	NUTA-1242	wood	Middle Paleolithic	AMS	[33]
196					Lower Nojiri-ko Member IIIA2	—	43070±570	NUTA-1241	wood	Middle Paleolithic	AMS	[33]
197					Lower part of Lower Nojiri-ko Member III	—	47150±810	NUTA-1273	wood	Middle Paleolithic	AMS	[33]
198					Botom of Lower Nojiri-ko Member III	—	49410±970	NUTA-1274	wood	Middle Paleolithic	AMS	[33]
199					Botom of Lower Nojiri-ko Member III	—	51260±1150	NUTA-1276	wood	Middle Paleolithic	AMS	[33]
200	42	Shimomouchi	36° 24′	138° 38′	Chltural layer	16250±180	—	NUTA-1515	charcoal	Upper Paleolithic	AMS	[34]
201	43	Kannoki	36° 49′	138° 12′	Chltural layer	35050±90	—	GaK-4985	wood	Upper Paleolithic	β	[32]
202	44	Nakamachi	36° 50′	138° 13′	Chltural layer	32200	—	GaK-5638	wood	Upper Paleolithic	β	[32]
203					Chltural layer	31140+2790/-2060	—	GaK-5639	wood	Upper Paleolithic	β	[32]
204					Chltural layer	22860±840	—	GaK-5640	wood	Upper Paleolithic	β	[32]
205					Chltural layer	22140±760	—	GaK-5641	peat	Upper Paleolithic	β	[32]
206	45	Sugikubo	36° 30′	138° 10′	Chltural layer	17700±500	—	GaK-812	peat	Upper Paleolithic	β	[32]
207					Chltural layer	15100±300	—	GaK-813	wood	Upper Paleolithic	β	[32]
208					Chltural layer	32540	—	GaK-6920	wood	Upper Paleolithic	β	[32]
209					Chltural layer	13660±310	—	GaK-6921	wood	Upper Paleolithic	β	[32]
210					Chltural layer	18640±530	—	GaK-6922	wood	Upper Paleolithic	β	[32]
211					Chltural layer	16760±490	—	GaK-6923	wood	Upper Paleolithic	β	[32]
212	46	Happusan II	36° 16′	138° 36′	Cultural layer	34840±250	31860±250	Beta-86229	charcoal	Backed blade industry	AMS	[35]
213					Cultural layer	32220±260	32240±260	Beta-86230	charcoal	Backed blade industry	AMS	[35]
214					Cultural layer	31380±230	31360±230	Beta-86231	charcoal	Backed blade industry	AMS	[35]
215					Cultural layer	32200±260	32190±260	Beta-86232	charcoal	Backed blade industry	AMS	[35]
216					Cultural layer	32180±260	32180±260	Beta-86233	charcoal	Backed blade industry	AMS	[35]
217	47	Happusan IV	36° 16′	138° 36′	Cultural layer	12230±240	—	JAS212	charcoal	Point industry	β	[35]
218					Cultural layer	11020±290	—	JAS203	charcoal	Point industry	β	[35]
219	48	Kosakayama	36° 16′	138° 36′	Cultural layer	31650±190	31860±250	Beta-109376	charcoal	Backed blade industry	AMS	[36]
220					Cultural layer	30950±170	30950±170	Beta-109377	charcoal	Backed blade industry	AMS	[36]
221					Cultural layer	30570±160	30510±160	Beta-109378	charcoal	Backed blade industry	AMS	[36]
222					Cultural layer	31630±180	31630±180	Beta-109379	charcoal	Backed blade industry	AMS	[36]
223	49	Hinatabayashi B	36° 48′	138° 14′	Cultural layer	—	29870±250	Beta-120858	charcoal	Backed blade industry	AMS	[37]
224					Cultural layer	—	31420±280	Beta-120859	charcoal	Backed blade industry	AMS	[37]
225					Cultural layer	—	2500±50	Beta-120860	charcoal	Backed blade industry	AMS	[37]
226					Cultural layer	—	19600±100	Beta-120861	charcoal	Backed blade industry	AMS	[37]
227					Cultural layer	—	27950±210	Beta-120862	charcoal	Backed blade industry	AMS	[37]
228					Cultural layer	—	28230±210	Beta-120863	charcoal	Backed blade industry	AMS	[37]
229					Cultural layer	—	29820±250	Beta-120864	charcoal	Backed blade industry	AMS	[37]
230					Cultural layer	—	28400±210	Beta-120865	charcoal	Backed blade industry	AMS	[37]
231					Cultural layer	—	29640±240	Beta-120866	charcoal	Backed blade industry	AMS	[37]
232					Cultural layer	—	27940±210	Beta-120867	charcoal	Backed blade industry	AMS	[37]
233					Cultural layer	—	28540±220	Beta-120868	charcoal	Backed blade industry	AMS	[37]
234					Cultural layer	—	27940±200	Beta-120869	charcoal	Backed blade industry	AMS	[37]
235	50	Higashiura	36° 48′	138° 12′	Layer 15	29330±1060	—	GaK-17715	wood	Backed blade industry	β	[38]
236					Layer 4	17290±330	—	GaK-17716	wood	Backed blade industry	β	[38]

	NO	Site name	Coordinates Latitude	Longitude	Sample position	Measured C14 age	Conventional C14 age	Lab Code and No.	Material dated	Cultural affiliation	β AMS	Reference
237					Layer 6	18130±330	—	GaK-17717	wood	Backed blade industry	β	[38]
238					Layer 4	17430±240	—	GaK-17718	soil	Backed blade industry	β	[38]
239					Layer 4	21830±480	—	GaK-17719	soil	Backed blade industry	β	[38]
240	51	Kannoki	36° 49′	138° 11′	Layer Vc	33050±530	33040±530	Beta-82577	charcoal	Upper Paleolithic	AMS	[39]
241					Layer Va	5450±50	5430±50	Beta-82578	charcoal	Upper Paleolithic	AMS	[39]
242					Layer Va	3060±60	3040±60	Beta-82579	charcoal	Upper Paleolithic	AMS	[39]
243					Layer Vb	33090±540	33070±540	Beta-82580	charcoal	Upper Paleolithic	AMS	[39]
244					Layer IV	—	32260±590	Beta-109414	charcoal	Upper Paleolithic	AMS	[39]
245					Layer Va	—	32110±610	Beta-109415	charcoal	Upper Paleolithic	AMS	[39]
246					Layer Va	—	8020±80	Beta-109416	charcoal	Upper Paleolithic	AMS	[39]
247					Layer Vb	—	30510±510	Beta-109417	charcoal	Upper Paleolithic	AMS	[39]
248					Layer Vb	—	160±50	Beta-109418	charcoal	Upper Paleolithic	AMS	[39]
249					Layer Vc	—	32410±340	Beta-109419	charcoal	Upper Paleolithic	AMS	[39]
250	52	Seko-sanso B	36° 49′	138° 11′	pottery	—	12340±50	Beta-133847	charcoal	Incipient Jomon	AMS	[40]
251					pottery	—	12000±40	Beta-133848	charcoal	Incipient Jomon	AMS	[40]
252					pottery	—	12160±40	Beta-133849	charcoal	Incipient Jomon	AMS	[40]
253	53	Yokohari-maekubo	35° 50′	138° 22′	Cultural layer	39900±1300	39930±1300	Beta-124569	charcoal	Backed blade industry	AMS	[41]
254					Cultural layer	29720±190	29720±190	Beta-132116	charcoal	Backed blade industry	AMS	[41]
255					Cultural layer	41140±800	41140±800	Beta-132117	charcoal	Backed blade industry	AMS	[41]
256					Cultural layer	27800±290	27810±290	Beta-136079	charcoal	Backed blade industry	AMS	[41]
257	54	Kogure-higashiarayama	36° 27′	139° 6′	pit	17930±60	17950±60	Beta-121133	charcoal	Point industry	AMS	[42]
258	55	Goshinden	36° 45′	139° 55′	Cultural layer	17800±190	—	GaK-13013	loam	Upper Paleolithic	β	[32]
259	56	Fujioka Kitayama B	36° 20′	138° 50′	Cultural layer	—	20420±330	NUTA-2528	charcoal	Upper Paleolithic	AMS	[32]
260					Cultural layer	—	19880±330	NUTA-2482	charcoal	Upper Paleolithic	AMS	[32]
261					Cultural layer	—	19260±490	NUTA-2526	charcoal	Upper Paleolithic	AMS	[32]
262					Cultural layer	—	19940±340	NUTA-2483	charcoal	Upper Paleolithic	AMS	[32]
263					Cultural layer	—	19450±290	NUTA-2527	charcoal	Upper Paleolithic	AMS	[32]
264	57	Tanashi Minamicho	35° 45′	139° 32′	Cultural layer	10060±340	—	GaK-14430	charcoal	Upper Paleolithic	β	[43]
265	58	Nishinodai B	35° 42′	139° 31′	Cultural layer	24740±1330	—	I-8794	charcoal	Upper Paleolithic	β	[44]
266	59	Suzuki	35° 43′	139° 30′	Cultural layer V	21200±355	—	N-2997	humic acid	Upper Paleolithic	β	[45]
267					Cultural layer IX	25500±500	—	N-2998	humic acid	Upper Paleolithic	β	[45]
268					Cultural layer X	17900±270	—	N-3090	humic acid	Upper Paleolithic	β	[45]
269					Cultural layer V	17300±185	—	N-2999	humic acid	Upper Paleolithic	β	[45]
270					Cultural layer X	18000±240	—	N-3006	humic acid	Upper Paleolithic	β	[45]
271	60	Tokyo Tenmondai Konai	35° 41′	139° 31′	Cultural layer VI	23500±300	?	TK-468	charcoal	Upper Paleolithic	β	[46]
272					Cultural layer VI	23900±300	?	TK-469	charcoal	Upper Paleolithic	β	[46]
273					Cultural layer X	28300±600	?	TK-471	charcoal	Upper Paleolithic	β	[46]
274	61	Takaido Higashi	35° 41′	139° 37′	Cultural layer IX	21160±820	—	GaK-6435a	humus	Upper Paleolithic	β	[47]
275					Cultural layer IX	22340±1310	—	GaK-6435b	humic acid	Upper Paleolithic	β	[47]
276					Cultural layer IX	32150±2549	—	GaK-6435	humic acid	Upper Paleolithic	β	[47]
277					Cultural layer X	23210±1680	—	GaK-6437	charcoal	Upper Paleolithic	β	[47]
278					Cultural layer X	29000±925	—	N-2651	charcoal	Upper Paleolithic	β	[47]
279					Cultural layer X	25000+2050/-1650	—	N-2652	humic acid	Upper Paleolithic	β	[47]
280	62	Hikageyama	35° 41′	139° 28′	Layer IVa	16680±120	16660±120	Beta-119975	charred material	Backed blade industry	AMS	[48]
281	63	Hashimoto	35° 20′	139° 20′	Cultural layer	13500±290	—	N-4680	loam	Upper Paleolithic	β	[32]
282					Cultural layer	13200±365	—	N-4681	loam	Upper Paleolithic	β	[32]
283					Cultural layer	15100±890	—	N-4682	loam	Upper Paleolithic	β	[32]
284					Cultural layer	23600+1580/-1320	—	N-4683	loam	Upper Paleolithic	β	[32]
285					Cultural layer	25200+1200/-1050	—	N-4684	loam	Upper Paleolithic	β	[32]
286					Cultural layer	24900+1550/-1310	—	N-4685	loam	Upper Paleolithic	β	[32]
287	64	Daikanyama	35° 25′	139° 30′	Cultural layer VI	26840±1200	—	GaK-12429	soil	Upper Paleolithic	β	[32]
288					Cultural layer IX	18750±420	—	GaK-12430	soil	Upper Paleolithic	β	[32]
289	65	Kamisoyagi	35° 27′	139° 25′	Cultural layer	19410±530	—	GaK-10134	charcoal	Upper Paleolithic	β	[32]
290					Cultural layer	18820±720	—	GaK-10136	charcoal	Upper Paleolithic	β	[32]
291					Cultural layer	14400±590	—	GaK-10137	charcoal	Upper Paleolithic	β	[32]
292	66	Tsukimino Kamino	35° 30′	139° 30′	Cultural layer IV	16370±680	—	GaK-10532	charcoal	Upper Paleolithic	β	[32]
293					Cultural layer IV	15060±1530	—	GaK-10537	charcoal	Upper Paleolithic	β	[32]
294					Cultural layer IV	14480±650	—	GaK-10533	charcoal	Upper Paleolithic	β	[32]
295					Cultural layer IV	15510±490	—	GaK-10534	charcoal	Upper Paleolithic	β	[32]

	NO	Site name	Coordinates Latitude	Coordinates Longitude	Sample position	Measured C14 age	Conventional C14 age	Lab Code and No.	Material dated	Cultural affiliation	β AMS	Reference
296					Cultural layer IV	16380±730	—	GaK-10535	charcoal	Upper Paleolithic	β	[32]
297					Cultural layer IV	16470±470	—	GaK-10536	charcoal	Upper Paleolithic	β	[32]
298					stone heap	15840±640	—	GaK-10440	charcoal	Upper Paleolithic	β	[32]
299					stone heap	15510±1060	—	GaK-10541	charcoal	Upper Paleolithic	β	[32]
300					stone heap	19710±680	—	GaK-10546	charcoal	Upper Paleolithic	β	[32]
301					Cultural layer	24140±1750	—	GaK-10544	charcoal	Upper Paleolithic	β	[32]
302	67	Shimotsuruma Nagahori	35° 27′	139° 25′	Cultural layer	17570±440	—	GaK-8957	charcoal	Upper Paleolithic	β	[32]
303					Cultural layer	18040±510	—	GaK-8595	charcoal	Upper Paleolithic	β	[32]
304					Cultural layer	18040±520	—	GaK-8594	charcoal	Upper Paleolithic	β	[32]
305					Cultural layer	14530±350	—	GaK-8598	charcoal	Upper Paleolithic	β	[32]
306					Cultural layer	14900±1300	—	GaK-8593	charcoal	Upper Paleolithic	β	[32]
307					Cultural layer	15860±340	—	GaK-8596	charcoal	Upper Paleolithic	β	[32]
308					Cultural layer	14230±430	—	GaK-8599	charcoal	Upper Paleolithic	β	[32]
309					Cultural layer	17670±460	—	GaK-8600	charcoal	Upper Paleolithic	β	[32]
310	68	Miyagase Sazaranke	35° 30′	139° 15′	fire place	17460±330	—	GaK-18281	charcoal	Upper Paleolithic	β	[32]
311					Cultural layer III	15470±290	—	GaK-18282	charcoal	Upper Paleolithic	β	[32]
312					stone heap	18780±370	—	GaK-18283	charcoal	Upper Paleolithic	β	[32]
313	69	Hayakawa Tenjinmori	35° 26′	139° 25′	Cultural layer	22150±1600	—	GaK-10370	charcoal	Upper Paleolithic	β	[32]
314					Cultural layer	20460±450	—	GaK-10371	charcoal	Upper Paleolithic	β	[32]
315	70	Miyakubo	35° 25′	139° 25′	Cultural layer	21520±550	—	GaK-17605	peat	Upper Paleolithic	β	[32]
316	71	Toriimae	35° 24′	139° 25′	Layer B1	—	19440±220	NUTA-5102	charcoal	Backed blade industry	AMS	[49]
317					Layer B1	—	19540±170	NUTA-5103	charcoal	Backed blade industry	AMS	[49]
318					Layer B1	—	19390±170	NUTA-5104	charcoal	Backed blade industry	AMS	[49]
319					Layer B1	18730±170	—	NUTA-5109	charcoal	Backed blade industry	AMS	[49]
320					Layer B1	—	18360±170	NUTA-5110	charcoal	Backed blade industry	AMS	[49]
321					Layer B1	—	19350±170	NUTA-5127	charcoal	Backed blade industry	AMS	[49]
322	72	Tanamukaihara	35° 30′	139° 22′	dwelling pit No.2	—	17650±60	Beta-127792	charcoal	Point industry	AMS	[50]
323					dwelling pit No.4	—	17630±50	Beta-127793	charcoal	Point industry	AMS	[50]
324	73	Miyagase Kitahara	35° 30′	139° 14′	Cultural layer I	13070±80	13060±80	Beta-105398	charcoal	Incipient Jomon	AMS	[51]
325					Cultural layer I	9660±0	9480±80	Beta-105399	charcoal	Incipient Jomon	AMS	[51]
326					Cultural layer I	13020±80	13050±80	Beta-105400	charcoal	Incipient Jomon	AMS	[51]
327					Cultural layer I	13170±100	13060±100	Beta-105401	charcoal	Incipient Jomon	AMS	[51]
328					Cultural layer I	13030±80	13020±80	Beta-105402	charcoal	Incipient Jomon	AMS	[51]
329					Cultural layer I	13060±80	13050±80	Beta-105403	charcoal	Incipient Jomon	AMS	[51]
330	74	Miyagase Nakappara	35° 31′	139° 13′	fireplace	18950±100	18920±100	Beta-97116	charcoal	Backed blade industry	AMS	[52]
331	75	Miyagase Ueppara	35° 31′	139° 13′	fireplace	19270±100	19240±100	Beta-97117	charcoal	Backed blade industry	AMS	[52]
332					pebble cluster	19500±100	19470±100	Beta-97118	charcoal	Backed blade industry	AMS	[52]
333	76	Heiwazaka	35° 29′	139° 23′	Layer	14630±70	14610±70	Beta-134486	charcoal	Upper Paleolithic	AMS	[53]
334	77	Fukudaheininoku	35° 26′	139° 27′	CL II pebble cluster	—	19440±430	Tka-11591	charcoal	Backed blade industry	AMS	[54]
335					CL II pebble cluster	—	18970±440	Tka-11598	charcoal	Backed blade industry	AMS	[54]
336					CL II pebble cluster	—	19240±700	Tka-11601	charcoal	Backed blade industry	AMS	[54]
337					CL II pebble cluster	—	18770±330	Tka-11602	charcoal	Backed blade industry	AMS	[54]
338					Cultural layer II	—	19220±330	Tka-11603	charcoal	Backed blade industry	AMS	[54]
339					Cultural layer II	—	19460±350	Tka-11605	charcoal	Backed blade industry	AMS	[54]
340					Cultural layer I	—	18100±210	Tka-11607	charcoal	Backed blade industry	AMS	[54]
341					Cultural layer I	—	17880±220	Tka-11666	charcoal	Backed blade industry	AMS	[54]
342					Cultural layer I	—	18960±480	Tka-11525	charcoal	Backed blade industry	AMS	[54]
343					Cultural layer I	—	19410±250	Tka-11594	charcoal	Backed blade industry	AMS	[54]
344					Cultural layer I	—	19480±490	Tka-11608	charcoal	Backed blade industry	AMS	[54]
345					Cultural layer I	—	18380±470	Tka-11609	charcoal	Backed blade industry	AMS	[54]
346					Cultural layer I	—	18820±290	Tka-11597	charcoal	Backed blade industry	AMS	[54]
347					CL II pebble cluster	—	19300±270	Tka-11611	charcoal	Backed blade industry	AMS	[54]
348					CL II pebble cluster	—	19660±440	Tka-11537	charcoal	Backed blade industry	AMS	[54]
349					CL I pebble cluster	—	17920±320	Tka-11612	charcoal	Backed blade industry	AMS	[54]
350					Layer L2	—	19340±350	Tka-11548	charcoal	Upper Paleolithic	AMS	[54]
351					Layer L2	—	18900±270	Tka-11595	charcoal	Upper Paleolithic	AMS	[54]
352	78	Teradani	34° 25′	137° 40′	Cultural layer III	9540±190		GaK-?	soil	Upper Paleolithic	β	[32]
353					Cultural layer IV	18090±550		GaK-?	soil	Upper Paleolithic	β	[32]
354					?	16300±1000	—	KSU-334	ash	Upper Paleolithic	β	[32]

	NO	Site name	Coordinates Latitude	Longitude	Sample position	Measured C14 age	Conventional C14 age	Lab Code and No.	Material dated	Cultural affiliation	β AMS	Reference
355	79	Hironokita	34° 25′	137° 40′	stone heap	22300+800/−700	—	KSU-671	charcoal	Upper Paleolithic	β	[32]
356					stone heap	22100+800/−700	—	KSU-672	charcoal	Upper Paleolithic	β	[32]
357					stone heap	25300+3500/−2000	—	KSU-673	charcoal	Upper Paleolithic	β	[32]
358	80	Shimizuyanagi Kita	35° 10′	138° 50′	Cultural layer	22980±2540	—	GaK-13712	?	Upper Paleolithic	β	[32]
359					Cultural layer	27860±1710	—	GaK-13713	?	Upper Paleolithic	β	[32]
360					Cultural layer	28300±930	—	GaK-13714	?	Upper Paleolithic	β	[32]
361	81	Yamadahara 2	34° 50′	137° 40′	Cultural layer	9190±175	—	N-4844	charcoal	Upper Paleolithic	β	[32]
362					Cultural layer	8070±280	—	N-4845	charcoal	Upper Paleolithic	β	[32]
363					stone heap	9520±350	—	N-4846	charcoal	Upper Paleolithic	β	[32]
364					Cultural layer	10000±325	—	N-4847	soil	Upper Paleolithic	β	[32]
365	82	hatunegahara	35° 07′	135° 58′	pit	29720±210	29750±210	Beta-104086	charcoal	Upper Paleolithic	AMS	[55]
366					Cultural layer	18600±295	—	N-5447	soil	Backed blade industry	β	[55]
367					Cultural layer	23400±405	—	N-5448	soil	Upper Paleolithic	β	[55]
368					Cultural layer	20200±355	—	N-5449	soil	Upper Paleolithic	β	[55]
369					Cultural layer	21700±400	—	N-5450	soil	Upper Paleolithic	β	[55]
370					pit	22500±415	—	N-5451	soil	Upper Paleolithic	β	[55]
371					pit	24100±435	—	N-5452	soil	Upper Paleolithic	β	[55]
372	83	Takamigaoka Ⅲ	34° 44′	137° 50′	pebble cluster	12900±60	12850±60	Beta-92768	charcoal	Backed blade industry	AMS	[56]
373					Layer	12870±60	21810±60	Beta-92769	charcoal	Backed blade industry	AMS	[56]
374					Cultural layer	12950±70	12940±70	Beta-106411	charcoal	Backed blade industry	β	[56]
375					Cultural layer	18520±70	18480±70	Beta-92767	charcoal	Backed blade industry	AMS	[56]
376					pit	13160±100	13120±100	Beta-106416	charcoal	Backed blade industry	AMS	[56]
377					Cultural layer	22680±520	22660±510	Beta-106414	charcoal	Backed blade industry	β	[56]
378					pebble cluster	22090±470	22090±470	Beta-106413	charcoal	Backed blade industry	β	[56]
379					Cultural layer	25460±670	25430±670	Beta-106415	charcoal	Backed blade industry	β	[56]
380					Cultural layer	12570±1180	12560±180	Beta-106412	charcoal	Backed blade industry	β	[56]
381	84	Takamigaoka Ⅳ	34° 44′	137° 50′	Cultural layer	13060±60	13020±60	Beta-93765	charcoal	Backed blade industry	AMS	[56]
382					Cultural layer	17020±60	17000±60	Beta-92766	charcoal	Backed blade industry	AMS	[56]
383					pit	39460±460	39460±460	Beta-92767	charcoal	Backed blade industry	AMS	[56]
384	85	Kannonbora	35° 10′	139° 00′	fire place	23700±680	—	N-5605	?	Upper Paleolithic	β	[32]
385					fire place	24400±570	—	N-5605	?	Upper Paleolithic	β	[32]
386	86	Kagebora	35° 10′	139° 00′	Cultural layer	17100±470	—	N-5443	?	Upper Paleolithic	β	[32]
387					Cultural layer	14200±190	—	N-5444	?	Upper Paleolithic	β	[32]
388	87	Nishibora B	35° 09′	138° 51′	Cultural layer BBⅥO	30200±360	30200±360	Beta-122043	charcoal	Upper Paleolithic	AMS	[57]
389					Cultural layer BBⅥO	29700±210	29690±210	Beta-122044	charcoal	Upper Paleolithic	AMS	[57]
390					Cultural layer BBⅥO	30400±230	30390±230	Beta-122045	charcoal	Upper Paleolithic	AMS	[57]
391	88	Itaiteragatani	35° 10′	135° 00′	Cultural layer	25100±360	—	KSU-1139	soil	Upper Paleolithic	β	[32]
392					Cultural layer	26000±350	—	KSU-1140	soil	Upper Paleolithic	β	[32]
393					Cultural layer	25000±1100	—	KSU-1141	soil	Upper Paleolithic	β	[32]
394					Cultural layer	24700±250	—	KSU-1142	soil	Upper Paleolithic	β	[32]
395	89	Nanokaichi	35° 10′	135° 10′	Cultural layer	23970+460/−440	—	GS-213	soil	Upper Paleolithic	β	[32]
396	90	Hase	35° 30′	133° 45′	Cultural layer	23340±650	—	GaK-17163	charcoal	Upper Paleolithic	β	[32]
397					Cultural layer	23610±1320	—	GaK-17164	charcoal	Upper Paleolithic	β	[32]
398	91	Yokotani	35° 30′	133° 45′	pyroclastic flow	20420±420	—	GaK-19091	?	Upper Paleolithic	β	[32]
399					Cultural layer	9150±310	—	GaK-19100	?	Upper Paleolithic	β	[32]
400	92	Todani	35° 17′	133° 12′	Cultural layer	23400±500	—	KSU-612	?	Upper Paleolithic	β	[32]
401	93	Fukui Cave	33° 10′	129° 40′	Cultural layer Ⅳ	13600±600	—	GaK-949	charcoal	Upper Paleolithic	β	[32]
402					Cultural layer ⅩⅤ	>31900	—	GaK-949	charcoal	Upper Paleolithic	β	[32]
403	94	Hyakkadai Higashi	32° 50′	130° 05′	Cultural layer Ⅲ	10200±60	—	KSU-1603	soil	Upper Paleolithic	β	[32]
404					Cultural layer Ⅶ	24400±230	—	KSU-1604	soil	Upper Paleolithic	β	[32]
405	95	Chaen	32° 44′	128° 46′	Layer Ⅴ	15470±190	15450±190	Beta-107730	charcoal	Microblade industry	AMS	[58]
406	96	Yanoharu	32° 35′	131° 30′	Cultural layer Ⅷ	24290±680	—	GaK-?	soil	Upper Paleolithic	β	[32]
407					Cultural layer Ⅸ	21850±530	—	GaK-?	soil	Upper Paleolithic	β	[32]
408	97	Kurata	32° 35′	131° 30′	Cultural layer Ⅶ	15190±220	—	GaK-?	soil	Upper Paleolithic	β	[32]
409	98	Mimikiri	33° 7′	131° 5′	Layer	9500±60	9600±60	Beta-116660	soil	Point industry	β	[59]
410					Layer	23200±220	23290±230	Beta-116661	soil	Backed blade industry	β	[59]
411	99	Ishinomoto Ⅱ	32° 50′	130° 48′	Layer Ⅳb	32750±1060	32740±1060	Beta-84289	charcoal	Backed blade industry	β	[60]
412					Layer Ⅳb	33710±430	33720±430	Beta-84290	charcoal	Backed blade industry	β	[60]
413					Layer Ⅳb	33180±560	33140±550	Beta-84291	charcoal	Backed blade industry	β	[60]

	NO	Site name	Coordinates		Sample position	Measured	Conventional	Lab Code and No.	Material dated	Cultural affiliation	β AMS	Reference
			Latitude	Longitude		C14 age	C14 age					
414					Layer IVb	31600±270	31460±270	Beta-84292	charcoal	Backed blade industry	β	[60]
415	100	Shimonjo	33° 9′	131° 4′	?	13700±200	—	N-3718	?	?	β	[61]
416	101	Yokomine C	30° 26′	130° 52′	Cultural layer I	>30260	—	GaK-16775	charcoal	Upper Paleolithic	β	[62]
417					pebble cluster	>31080	—	GaK-16776	charcoal	Upper Paleolithic	β	[62]
418					pebble cluster	>28110	—	GaK-16777	charcoal	Upper Paleolithic	β	[62]
419					Cultural layer I	31290±690	31280±690	Beta-102399	charcoal	Upper Paleolithic	AMS	[62]
420					Cultural layer I	29660±540	29670±540	Beta-102400	charcoal	Upper Paleolithic	AMS	[62]
421					Cultural layer II	30480±590	30490±590	Beta-102401	charcoal	Upper Paleolithic	AMS	[62]
422					Cultural layer II	29300±520	29300±520	Beta-102402	charcoal	Upper Paleolithic	AMS	[63]
423	102	Tachikiri	30° 26′	130° 52′	Cultural layer	30500±210	30480±210	Beta-114267	charcoal	Upper Paleolithic	AMS	[64]
424	103	Ushiromuta	32° 12′	131° 30′	Layer 8 Middle	28920±150	28900±150	Beta-131409	charcoal	Upper Paleolithic	AMS	[65]
425					Layer 7b Lower	29540±160	29520±160	Beta-142857	charcoal	Upper Paleolithic	AMS	[65]
426					Layer8	29440±150	29470±150	Beta-142856	charcoal	Upper Paleolithic	AMS	[65]
427					Layer 10a	22660±80	22640±80	Beta-142855	charcoal	Upper Paleolithic	AMS	[65]
428					Layer 10 Upper	30310±200	30290±200	Beta-142854	charcoal	Upper Paleolithic	AMS	[65]
429	104	Chochi	31° 18′	130° 33′	Layer 17	24550±130	24690±130	Beta-105068	soil	Upper Paleolithic	AMS	[66]

RADIOCARBON, Vol 44, Nr 2, 2002, p 495–502

PEOPLING OF WESTERN JAPAN, FOCUSING ON KYUSHU, SHIKOKU, AND RYUKYU ARCHIPELAGO

Hiroto Takamiya

Sapporo University, 3-7 Nishioka, Toyohira-ku, Sapporo 062-8520, Japan. Email: takamiya@sapporo-u.ac.jp.

Hiromi Obata

Maizo Bunka zai Chosa-shitsu, Kumamoto University, 2-39-1 Kurokami, Kumamoto City 860-8555, Japan

ABSTRACT. The discovery of the Iwajuku site in Japan is the beginning of the study of the first Paleolithic cultures in the region. In this paper we examine the timing of the earliest colonization of southern Japan, especially focusing on the areas of Kyushu, Shikoku, and the Ryukyu archipelago. Osteological studies have proposed the ultimate origin of these western Japanese Paleolithic populations in Southeast Asia. If this hypothesis is correct, Native Americans may be remotely related to the populations of this region. Greater attention to data from areas such as Japan is necessary to understand the timing and nature of New World colonization.

INTRODOUCTION

Homo sapiens sapiens did not evolve in the region now known as Japan. They, and possibly archaic hominids at some point in time, migrated from the nearby continent to the Japanese islands. It was not until 1949 that Pleistocene human occupation of Japan was recognized, most notably at the Iwajuku site (Aizawa 1969). Before this discovery, most archaeologists believed that the Japanese islands were colonized at the beginning of the Jomon period (Early Neolithic), arguing that the region was inhospitable during the Pleistocene due to active volcanism. The discovery of the Iwajuku site not only proved the presence of the Paleolithic cultures in this region, but also suggested the next question: When did earliest human colonization occur?

The examination of the timing of human colonization to Japan is extremely important not only for the prehistory of the region, but also that of the New World. Data from Japan may provide clues as to the possibility and nature of early archaeological sites in the New World. Here, we examine the timing of colonization of western Japan, focusing especially on Kyushu, Shikoku, and the Ryukyu archipelago. This geographic focus is significant because the peopling of Japan may have taken place through Korea to Kyushu, and/or from farther south through the Ryukyu archipelago to Kyushu. Radiocarbon dates from Paleolithic period sites were collected to assess the timing of colonization of these areas. However, the ages of most Paleolithic sites in the region have been established by relative dating (i.e. tephra stratigraphy) and morphological characteristics of lithic artifacts. Only and handful of sites have been directly ^{14}C dated. Consequently, we provide both a brief introduction to these alternative dating methods and a discussion of the available ^{14}C-dated sites. We then examine possible routes through which the Japanese archipelago was colonized, and attempt to relate these observations to the study of the peopling of the New World.

BRIEF BACKGROUND AND RADIOCARBON DATES

Kyushu Region

The search for the presence of Paleolithic sites in Kyushu began with the excavation of the Fukui Cave site in 1960 (Serizawa 1976, 1979). By 1965, 42 sites were reported as Paleolithic in age (Kamaki and Makabe 1965). According to Obata and Miyata (1999:55), at least 800 Paleolithic sites are now known from this island alone. Of these, 530 belong to the late Upper Paleolithic and the transition between the Paleolithic and Jomon periods. Most of the Paleolithic sites on Kyushu have been dated stratigraphically in relation to volcanic tephras of known age. Here we describe briefly the five tephras used as key age markers for establishing an Upper Paleolithic chronology in Kyushu (Tachibana 2000; Fujimoto 2000). The Aera Caldera, the most important tephra, is dated to between 24,000 and 25,000 BP. The Black Band tephra is estimated to date to approximately 28,000 BP. These two ash layers are widely distributed not only on Kyushu, but also most areas of Japan. The next three ash layers are found only in restricted areas on Kyushu, but are significant in establishing local chronology. The Tane IV tephra is distributed in southern Kyushu and on Tane Island, and dates to 30,000 BP. The distribution of the Kirishima Iwaokoshi (Kr-lw) tephra is limited to Southern and eastern Kyushu, dating also to 30,000 BP. The Kokonoe-Daiichi- Karuishi So (Kjp-1) tephra, dating to 40,000 BP, is found in eastern Kyushu. Finally, the Aso 4 ash layer (Aso-4), dating to 80,000–90,000 BP, is an important tephra for establishing Middle Paleolithic chronology (Tachibana 2000:1–3; Fujimoto 2000:12).

Did archaic hominids colonize Kyushu during the Lower or Middle Paleolithic periods? Tachibana (2000) believes that such sites are present but undiscovered because thick ash layers cover the sedimentary deposits of appropriate ages to contain Lower or Middle Paleolithic occurrences (see also Shimaoka 2000). Several sites have been purported to belong to the Middle Paleolithic, such as Tsujita, Yokota, Matsuo, Ushiromuta, and Kamishimoda (Tachibana 2000:3; Shimaoka 2000:9). The first four sites, while yielding lithic assemblages that clearly differ from the Upper Paleolithic, are not associated with tephras of known age and have not yielded chronometric dates. The last site is also said to have produced a Middle Paleolithic-like lithic assemblage. Although the Aso-4 tephra (80,000–90,000 BP) is reported at the site, stratigraphic association between the tephra and archaeological materials is not yet clear. Regarding the early colonization of Kyushu, Obata and Miyata (1999:59) conclude that "the lithic assemblages which are said to date prior to the Upper Paleolithic were collected in isolation or obtained through site excavation, but detailed reports have not been published. In short, they cannot be readily accepted as the Middle and/or Lower Paleolithic sites."

Only one possible Middle Paleolithic assemblage, from Layer 15 at Fukui Cave, is associated with a ^{14}C date. The wood charcoal sample yielded and age of 31,900 BP (Serizawa 1976, 1979; Kawamichi 2000:17; Nakamura et al. 2000). Serizawa first announced that Layer 15 belonged to the Lower Paleolithic, but later suggested that it is Middle Paleolithic (Serizawa 1999 cited from Kawamichi 2000:17).

While the status of the Lower and Middle Paleolithic cultures on Kyushu is still debated, it is clear that initial Upper Paleolithic human populations were present in the region by 30,000 BP. Several sites have yielded radiocarbon dates from this time period. On Kyushu, the Ishinomoto site in Kumamoto prefecture yielded four radiocarbon dates ranging from 33,720 ± 430 BP to 31,460 ± 270 BP (Kumamoto Prefecture Board of Education 1999a). The Ushiromuta site in Miyazaki prefecture has been dated to 29,520 ± 180 BP and 29,470 ± 150 BP (Shimaoka 2000). Finally, the Kawahara No.14 site in Kumamoto prefecture have yielded ^{14}C dates of 29,370 ± 360 BP and 28,790 ± 350 BP (Kumamoto University 2000).

Three sites belonging to the early Upper Paleolithic period have been ^{14}C dated. The Chouchi site locating in Kagoshima prefecture has yielded three ^{14}C dates of 22,390 ± 1200 BP, 24,690 ± 130 BP, and 25,110 ± 210 BP. The Nihongi site, also located in Kagoshima prefecture, has ^{14}C dated to be 25,330 ± 880 BP. A date of 24,400 ± 230 BP has been obtained from the Hyakkadai site in Nagasaki prefecture.

There are only three sites ^{14}C dated to the late part of the Upper Paleolithic sites. The Kiriki and Mimitori sites are both from Kagoshima prefecture. The former has yielded four ^{14}C dates ranging from 24,270 ± 180 BP to 22,960 ± 170 BP (Nagano 2000). Only one sample has been ^{14}C dated from the latter, resulted in an age estimate of 24,030 ± 110 BP (Nagano 2000). The Mimikiri site, located in Kumamoto prefecture, also has a date of 23,200 ± 220 BP (Kumamoto Prefecture Board of Education 1999b).

Only two terminal Paleolithic sites have been ^{14}C dated at the present time. The Chaen site in Nagasaki prefecture produced a date of 15,450 ± 190 BP (Kishiku Town Board of Education 1998). The Fukui Cave site, also in Nagasaki prefecture, contained five terminal Paleolithic cultural layers, with dates ranging from 14,000 ± 400 BP to 10,700 ± 300 BP. It should be mentioned that Fukui Cave contains the oldest remains of pottery in the world, found in association with microblade cores. Radiocarbon dates place the appearance of ceramic technology at 12,400 ± 350 BP and 12,700 ± 500 (Nakamura et. al 2000).

Shikoku Region

Fujino (personal communication 2001) estimates that there are 200–300 known Paleolithic sites in Shikoku. This number will certainly grow given that Paleolithic research in the region is in its infancy (Kimura 1994:1). According to Fujino, no Middle Paleolithic or earlier sites are yet known on Shikoku. Rather, the earliest known sites date to the later part of the Upper Paleolithic. Fujino believes, based on his summary of Paleolithic sites in western Japan, that the beginning of the Upper Paleolithic in Shikoku is two or three thousand years later than on Chugoku and Kyushu (Fujino 1999). To best of our knowledge, the only ^{14}C dated site on Shikoku is Kamikuroiwa Rock Shelter in Ehime Prefecture. This site is one of the most important in all of Japan because it covers the transitional period between the Paleolithic and Jomon. The lower layer (Layer IX) yielded tanged points and no pottery. The upper layer (Layer V) produced one of the earliest known assemblages of pottery, associated with arrow points but without tanged points. Importantly, it appears that the transition from the Paleolithic to the Jomon at Kamikuroiwa Rock Shelter occurred later than at Fukui Cave: Layer IX (terminal Paleolithic) at Kamikuroiwa has been ^{14}C dated to 12,165 ± 650 BP and Layer V (Jomon) to 10,085 ± 320 BP (Nakamura et al. 2000).

Ryukyu Archipelagos

The islands linearly distributed between Kyushu and Taiwan are collectively known as the Ryukyu archipelago. The archipelago can be divided into three regions in terms of geological and cultural characteristics: the Northern, Central, and Southern Ryukyus (e.g. Kokubu 1972). Northern Ryukyu consists of Yaku, Tane, and their satellite islands. Central Ryukyu consists of Amami, Okinawa, and their satellite islands. Southern Ryukyu consists of Miyako, Ishigaki and their satellite islands

The presence of Pleistocene human populations in the Ryukyu archipelago was first suggested by Tokunaga as early as 1936. He recognized that modified deer bones recovered from Gadabaru cave site, in Central Ryukyu, were potentially human artifacts. In the 1960s and 1970s, several additional sites yielded modified deer bones, and were believed to be bone “artifacts” based on Tokunaga’s original observation. By 1977, having analyzed these bone “artifacts”, Kato (1977) reached conclusion that the modifications were made by deer chewing and not by humans. Most scholars today support Kato’s conclusion. This leaves open the question of when humans first colonized Ryukyu.

Central Ryukyu provides earliest evidence for presence of *Homo sapiens sapiens* during the Late Pleistocene. In 1968, the Yamashita-cho No.1 cave site yielded fragmentary remains of a human child estimated to have been 6 years old at time of death. Unfortunately, the remains of this immature individual provide only limited information on the physical characteristics of the resident human population (Takamiya 1994:327). However, wood charcoal associated with the fossil astonished the academic community: At 32,000 ± 650 BP the Yamashita-cho No.1 fossil is the earliest remains of *Homo sapiens sapiens* in East Asia (Baba and Narasaki 1991; Matsu'ura and Kondo 2000; Takamiya 1983). At about same time, the Minatogawa site yielded human remains representing at least 5 or 6 adult male and female individuals. The analysis of these remains have contributed greatly to our understanding of the origins of the Japanese (Hanihara 1991). The site has been ^{14}C dated to 18,000 ± 650 BP and 16,600 ± 300 BP (Suzuki 1975). In addition, 6 other sites in Central Ryukyu have yielded human skeletal remains (Matsu'ura and Kondo 2000). While the precise ages of these later sites are not known, the radiometric dates from Yamashita-cho No.1 and Minatogawa demonstrate the presence of *Homo sapiens sapiens* in the region during the late Pleistocene.

In Southern Ryukyu, the only known Pleistocene site is the Pinzaabu site, which produced fossil human remains but no lithic technology. The site has been ^{14}C dated to 25,800 ± 900 BP and 26,800 ± 1,300 BP (Hamada 1985).

Until recently, very little was known about the Paleolithic in the region North of Okinawa, namely Northern Ryukyu through the Amami archipelago. In 1986, the stone artifacts of clear human manufacture were reported for the first time from the Tsuchihama Yaya site on Amami Island. The site was radiocarbon dated to >21,400 BP (Kagoshima Prefecture Board of Education 1986). Two years later, the Kishikawa site yielded Paleolithic artifacts with a finite radiocarbon age of 25,250 ± 790 BP (Tamura and Ikeda 1995). In 1992, the presence of Pliestocene human populations in Northern Ryukyu was demonstrated at the Yokomine C site, on the Tane island. The site was first excavated by the Minami Tane Town Board of Education in 1992, resulting in a collection of Paleolithic artifacts and three wood charcoal dates of >30,260 BP, >31,080 BP, and >28,110 BP (Minami Tane Town Board of Education 1993). The site was re-excavated in 1995 and 1996 and this time produced four finite ^{14}C ages of 31,280 ± 690 BP, 29,670 ± 540 BP, 30,490 ± 590 BP, and 29,300 ± 520 BP (Minami Tane Town Board of Education 2000). At the Tachikiri site, also on Tane Island, Paleolithic artifacts have been ^{14}C dated to 30,480 ± 210 BP (Dogome 2000). These lines of evidence demonstrate that *Homo sapiens sapiens* occupied the Northern Ryukyu archipelago at least as early as the main island of Kyushu.

DISCUSSION

We conclude that there is as yet no unequivocal Middle (or Lower) Paleolithic site known in Kyushu, Shikoku, or the Ryukyu archipelago. The one possible exception is Layer 15 at Fukui Cave. By approximately 30,000 years ago, however, *Homo sapiens sapiens* were present on both Kyushu and the Ryukyu archipelago. Shikoku may have been settled from Kyushu or western Chugoku area several thousand years later.

From which region (or regions) were Kyushu and the Ryukyu archipelago colonized? Unfortunately, no human remains dating to the Paleolithic Period have been found on Kyushu. Archaeological data provide the only available information on the origin of Paleolithic Kyushu populations. According to Oda (1999), the early Upper Paleolithic in the region is characterized by "knife type" lithic artifacts. This artifact category seems to be closely related to finds on the Korean Peninsula (Obata and Miyata 2000). Thus, the Korean Peninsula would seem to be the most likely region from where *Homo sapiens sapiens* spread into Kyushu.

On the other hand, the Ryukyu archipelago, especially Central and Southern Ryukyu, have produced relatively abundant human skeletal remains belonging to the Paleolithic Period. Only 3 sites on mainland Japan have yielded unquestionable Paleolithic human remains, whereas 9 sites in Central and Southern Ryukyu have produced fossilized skeletal remains (Matsu'ura and Kondo 2000).

While skeletal remains recovered from mainland Japan are all fragmentary, the Minatogawa site in Okinawa has yielded well preserved human remains. Consequently, the Minatogawa remains have been the subject of intensive study and comparisons with other *Homo sapiens sapiens* fossils from East Asia. The results demonstrate that the Minatogawa populations are morphologically closer to the "Liujin Man" remains from in South China than the Zhoukoudian Upper Cave skeletal remains recovered from Northern China (Hanihara 1991). Accordingly, it has been suggested the Southern and Central Ryukyu regions were populated from the South (Hanihara 1991).

As mentioned above, lithic artifacts belonging to the Paleolithic period have been recovered recently from the Northern and Central Ryukyu regions. Kato (1996) believes that the lithic complex from Northern Ryukyu is affiliated with that found on Kyushu, and the complex from Central Ryukyu with that from Taiwan or further South. Oda (1999) seems to agree with Kato (1996). Okamura (1998) suggests further that the lithic complex represented in Central Ryukyu may have ultimately expanded to Northern Ryukyu. If their analysis is correct, the origin of these Ryukyu Paleolithic populations may be sought in southern areas including Southeast Asia. However, more detailed study of the lithic complexes is necessary to accept this hypothesis (Obata and Miyata 2000).

Archaeological data from Kyushu and Shikoku indicate that once these regions were colonized, about 30,000 years ago, both were continuously occupied into the Holocene (Serizawa 1976). For example, the Fukui Cave site in Kyushu contains an archaeological sequence beginning around 31,900 BP (layer 15) and continuing through the appearance of the earliest pottery in the world at approximately 12,000 BP. These early pottery sherds were associated with formal microblades, which are diagnostic implements of the later part of the Upper Paleolithic period in Japan. The layer below contained only stone artifacts, and the layer above other pottery types and microcores (Serizawa 1976). The Kamikuroiwa Rock Shelter site documents a similar late Upper Paleolithic-Jomon transition on Shikoku. Together, these sites indicate that Kyushu and Shikoku, once settled, were continuously occupied through to the Jomon period (Serizawa 1976). In contrast, human populations seem to have had a hard time maintaining occupations on the Ryukyu archipelago. There are no sites known from Southern Ryukyu after Pinzaabu until approximately 3000 years ago. In Central Ryukyu, detailed studies of paleogeography and paleodemography have revealed that the Minatogawa and other Paleolithic populations moved out, or died out by the end of the Pleistocene (e.g., Takamiya 1996). Similar phenomena seem to characterize Northern Ryukyu, although further detailed research is needed.

The most important questions issuing from the above presentations are the following: Where did the Paleolithic Japanese populations ultimately originate from? Can anything be said about the peopling of the Americas from this study? As we have discussed, the initial Kyushu Paleolithic populations seem to have originated on the Korean Peninsula, while the contemporaneous Ryukyu populations originated from the South. In an intensive study of Asian populations, Turner (1987) recognized two dental morphology types; a more generalized tooth morphology he terms *sundadont*, and a more specialized tooth morphology he terms *sinodont*. The former type is distributed mainly in Southeast Asia and Oceania and the latter in Northeast Asia. He believes that the generalized *sundadont* morphology is ancestral to contemporary Asian populations. More specifically, as *sundadont* populations moved north, the more specialized *sinodont* type emerged (Turner 1987). According to this hypothesis, the ancestors of both Kyushu and Ryukyu Paleolithic populations ultimately originated in Southeast Asia. One group moved from Southeast Asia to the Ryukyu archipelago directly, while the other group first migrated from Southeast to Northeast Asia and then entered Kyushu via the Korean Peninsula. Turner (1987) believes that these Asian populations eventually colonized the New World, implying Southeast Asia is the ultimate point of origin of native Americans.

Omoto (1999) opposes Turner's hypothesis, disagreeing with the fundamental assumption that things (in this case tooth morphology) necessarily evolve from simple to complex. Omoto (1999) further argues that Turner's conclusion are not supported by genetic data. Omoto and Saitou (1997) have analyzed 26 human groups on the basis of 20 genetic markers. Their results indicate that there is much more diversity among Asians, Pacific Islanders, and Native Americans than previously thought. Like Turner, they suggest the East Asian population can be placed genetically into two groups: Southeast and Northeast Asians. However, Omoto (1999) speculates that these two groups existed in East Asia independently: The former migrated into Southeast Asia through a corridor South of the Himalayas and the latter through a corridor North of the Tibetan massif. Both populations originated in West Asia. Surprisingly enough, the Ainu, who are thought to be the descendants of the Southeast Asian Paleolithic populations by Turner (1987) and Hanihara (1991), belong genetically to Northeast Asian populations (Omoto and Saitou 1997). Thus, the Paleolithic Ryukyu population may have originated in Southeast Asia, while the contemporaneous Kyushu population may have an colonized from independent Northeast Asian population. In this case, Southeast Asians may have nothing to do directly with the origins of native Americans. It would suggest that the focus should be on Northeast Asians to understand the peopling of the New World.

SUMMARY AND CONCLUSION

This paper has dealt with the peopling of western Japan, more specifically Kyushu, Shikoku, and the Ryukyu archipelago. While several hundred Paleolithic sites have been identified in Kyushu and Shikoku, only a handful of these sites have been ^{14}C dated. Although some sites on Kyushu are claimed to be Middle Paleolithic period occupations, a consensus has not been obtained. By 30,000 years ago, however, Kyushu and Ryukyu were both settled by *Homo sapiens sapiens*. Archaeological data indicate that Shikoku was first occupied by human population several thousand years later. In terms of artifact complexes, Kyushu, Northern Ryukyu, and Shikoku seem to belong to the same culture tradition. In contrast, Central Ryukyu—and possibly Southern Ryukyu, though no artifacts has yet been recovered—formed different cultural tradition. The evidence suggests that this cultural tradition is related to regions farther south.

Human skeletal remains belonging to the Paleolithic period are known in detail only from the Central and Southern Ryukyu regions. One of the sites, the Minatogawa site dating to 18,000 years ago, has produced fossil remains very important to understanding the origins of the Japanese (Hanihara 1991; Matsu'ura and Kondo 2000). These remains have been analyzed intensively, resulting in the suggestion that the population represented originated in the South. This result supports suggestions made by some archaeologists including Oda (1999), Kato (1996), and Okamura (1998). While no skeletal remains are known from Kyushu or Shikoku (and Northern Ryukyu according to Obata and Miyata [2000]), lithic assemblages suggest these people may have migrated from the Korean Peninsula.

Osteological studies have proposed the ultimate origin of these western Japanese Paleolithic population in Southeast Asia. If this hypothesis is correct, Native Americans may be remotely related to the populations of this region. Geneticists such as Omoto (1999) reject this hypothesis, however, and suggest a dual structure to East Asian populations, both of which originated in West Asia. The process by which these two groups formed hinges on the separate routes they followed on their way to East Asia. If this hypothesis is correct, the ancestors of native Americans should be genetically more related to Northeast than to Southeast Asians.

While the peopling of the New World has been an important theme in anthropology, investigation of the processes by which colonization occurred has suffered from a lack comparisons across the

Pacific. Additional data from areas such as Japan is necessary to understand the timing and nature of New World colonization. The fact that much of the ^{14}C data presented in this paper was obtained in recent years indicates that Japanese archaeologists are now more aware and more interested in radiocarbon dating. With increased chronological resolution made possible by continued radiocarbon dating we may soon be able to provide more detailed conclusions about the relationships between the peopling of the Japanese archipelago and the peopling of the New World.

ACKNOWLEDGMENTS

Dr Fujino from Hiroshima University has provided information on the Paleolithic period in Shikoku Island. Dr Toizumi from Waseda University provided radiocarbon dates from several important sites in Japan, including Kaimkuroiwa Rock Shelter and Fukui Cave. We sincerely thank them. We also thank Drs Yaroslav Kuzmin and P Jeffrey Brantingham for inviting us to contribute to this issue. Finally, we would like to thank archaeologists in Kyushu, Shikoku, and Ryukyu archipelago who have worked hard to obtain the data presented in this paper.

REFERENCES

Aizawa T. 1969."Iwajuku no Hakken" (The Discovery of the Iwajuku site). Kodansha: Tokyo.

Baba H, Narasaki S. 1991. Minatogawa Man, the oldest type of modern *Homo sapiens sapiens* in East Asia. *Quaternary Research* 30:221–30.

Dogome H. 2000. Kagoshima-ken ni okeru Koki Kyusekki jidai bunka no seiritsu (The Emergence of the Upper Paleolithic Period and Culture in Kagoshima Prefecture). Kyushu Bunka Kenkyukai, editor. Kumamoto: Kyushu Bunka Kenkyukai. p 23–8.

Fujimoto M. 2000. Miyazaki-ken Ushiromuta Iseki Gakujutsu Chosa (On the excavation of the Ushiromuta site, Miyazaki). Kyushu Bunka Kenkyukai, editor. Kumamoto: Kyushu Bunka Kenkyukai. p 9–11.

Fujino T. 1999. Hiroshima-ken ni okeru Kyusekkijidai Sekkigun (The Paleolithic Stone Assemblages in Hiroshima Prefecture). In: Geibi Tomo no Kai, editor. *Kokogaku kara mita Chiiki Bunka*. Hiroshima: Keisuisha. p 9–30.

Hanihara K. 1991. Dual structure model for the population history of the Japanese. *Japan Review* 2:1–33.

Hamada T. 1985. ^{14}C Nendai Sokutei (The radiocarbon dates). In: Pinzaabu, editor. Okinawa Okinawa: Prefecture Board of Education. 180 p.

Kagoshima Prefecture Board of Education. 1988. *Tsuchihama Yaya Iseki (The Tsuchihama Yaya site)*. Kagoshima: Kagoshima Prefecture Board of Education.

Kamaki Y, Makabe T. 1965. Kyushu Chihou no Sen-doki Jidai (The Pre-Ceramic Ages in Kyushu Region). In: Sugihara S, editor. *Nihon no Kokogaku.* Tokyo: Kawaide-shobo. p 303–22.

Kato S. 1977. Okinawa no Iwayuru Sajo Kokki (On so-called fork shaped bone artifacts from Okinawa). *Kokogaku Janaru* 167:72–5.

Kato S. 1996. Nansei Shotou eno Kyusekki Bunka no Kakusan (On the dispersion of Paleolithic culture to the Southwest Islands). *Journal of Geography* 105(3): 372–83.

Kawamichi H. 2000. Nagasaki-ken ni okeru AT kai Sekkigun (The Lithic assemblages below the AT ash layer in Nagasaki Prefecture). In: Kyshu Bunka Kenkyukai, editor. *Kyushuni okeru Kyusekki Jidai no Seiritsu.* Kumamoto: Kyushu Kyusekki Bunka Kenkyu Kai. p 17–22.

Kimura T. 1994. Kouchi-ken no Kyusekki-nansei Shikoku wo Chushin to shite (The Paleolithic in Kouchi Prefecture, focusing on southwestern Shikoku). In: Chu/Shikoku Kyusekki Bunka Danwa Kai, editor. Kochi: Chu/Shikoku Kyusekki Bunka Danwa Kai. p 1–3.

Kishiku Town Board of Education. 1998. *Chaen Iseki (The Chaen Site)*. Nagasaki: Kishiku Town Board of Education.

Kokubu N. 1972. *Nanto Senshi Jidai no Kenkyu (Research on the Prehistoric Southern Islands)*. Tokyo: Keiyu-sha.

Kumamoto Prefocture Board of Education. 1999a. *Ishinomoto Iseki-gun II (The Ishinomoto Site II)*. Kumamoto Kumamoto Prefocture Board of Education.

Kumamoto Prefocture Board of Education. 1999b. *Mimikiri Iseki (The Mimikiri Site).* Kumamoto: Kumamoto Prefocture Board of Education.

Kumamoto University. 2000. Koukogaku Kenkyu-shitsu Hokoku dai 35 shu (The Archaeological Report, Kumamoto University Vol. 35). Kumamoto: Kumamoto University.

Minami Tane Town Board of Education. 1993. *Yokomine Iseki (The Yokomine site)*. Kagoshima: Minami Tane Board of Education.

Minami Tane Town Board of Education. 2000. *Yokomine C Iseki (The Yokomine C Site)*. Kagoshim: Minami Tane Board of Education.

Nagano S. 2000. Kyusekki Jidai no Jintai-gata Sekiseihin-Mimitori Iseki (The Stone Figurine of the

Paleolithic Period Recovered from the Mimitori Site). *Kokogaku Janaru* 467:27–9.

Nakamura T, Tsuji S, Toizumi G, Tsumura H, Harunari H, editors. 2000. *^{14}C ages of the Japanese prehistory.* Tokyo: Japan Association for Quaternary Research.

Naka Tane Town Board of Education. 1999. *Kyozuka Tachikiri (Kyozuka Tachikiri)*. Kagoshima: Naka Tane Town Board of Education.

Obata H, Eiji M. 1999. Kyushu-chihou/Nansei-shoto (Kyushu Region and Southwest Archieplago). *Kyusekki Kokogaku* 58:58–63.

Oda S. 1999. Ryukyu Retto Kyusekki Bunka no Waku Gumi ni tsuite (Marginal Zone: Upper Paleolithic Cultures around the Ryukyu Islands). *Jinruishi Kenkyu* 11:29–46.

Okamura M. 1998. *Rekishi Hakkutsu 1 Sekki no Seisui (Study of history 1: development and decline of lithics).* Tokyo: Kodan-sha.

Okamura M. 2000. *Nihon no Rekishi 10 Jomon no Seikatsu-shi (History of Japan 10: Life in the Jomon Period)*. Tokyo: Kodan-sha.

Omoto K. 1999. *Bunshi-Jinrui-gaku kara mita Nihonjin no Kigen (Origin of Japanese: molecular biological perspective)*. In: Sahara M, Tanaka M, editors. *Kodaishi no Ronten 6.* Tokyo: Shogakkan. p 39–70.

Omoto K, Saitou S. 1997. Genetic origins of the Japanese: a partial support for the "dual structure hypothesis". *American Journal of Physical Anthropology* 102:437–46.

Serizawa C. 1976. The Stone Age of Japan. *Asian Perspectives* XIX(1):1–14.

Serizawa C. 1979. The Paleolithic Age of Japan. Paper presented for the Richard K Beardsley Symposium on Japanese Archaeology and Prehistory, at the Center for Japanese Studies, the University of Michigan, Ann Arbor, Michigan.

Shimaoka T. 2000. Miyazaki-ken Jito-gun Kawaminami-cho Ushiromuta Iseki no dai1~4ji chosa ni tsuite (On the excavation of the first to fourth excavation field years at the Ushiromuta site, Kawakmimami-cho, Jito-gun, Miyazaki). In: Kyushu Bunka Kenkyukai, editor. *Kyushu niokeru Koki Kyusekki Jidai Bunka no Seiritsu*. Kumamoto: Kyushu Kyusekki Bunka Kenkyu Kai. p 9–11.

Suzuki H. 1975. Discoveries of the Fossil Man from Okinawa Island (in Japanese). *Journal of the Anthropological Society of Nippon* 83(2):113–24.

Tachibana M. 2000. Kyushu ni okeru Chuki Kyusekki Jidai to Kouki Kyusekki jidai Seiritsu zengo no Sekkigun (The lithic complex during the Middle Paleolithic and emerging period of the Upper Paleolithic in Kyushu). *Beppu Daigaku Hakubutsu kan Kenkyu Hokoku* 20:1–33.

Takamiya H. 1983. Okinawa no Kodai Bunka wo megutte (On the ancient culture in Okinawa). In: Obayashi T, Tanigawa K, Mori K, editors. *Okinawa no Kodai Bunka.* Tokyo: Shogakkan. p 59–86.

Takamiya H. 1994. *Okinawa no Senshi Iseki to Bunka (Archaeological Sites and Cultures in Okinawa)*. Tokyo: Daiichi Shobo.

Takamiya H. 1996. Initial colonization, and subsistence adaptation processes in the late prehistory of the island of Okinawa. *Indo-Pacific Prehistory Association Bulletin* 15:143–50.

Tamura K, Ikeda O. 1995. Kishikawa Iseki (Kishikawa Site). *Aoyama Shigaku* 14:1–64.

Tokunaga S. 1936. Bone artifacts used by ancient man in the Ryukiyu Islands. *Proceedings of the Imperial Academy* XII(10):352–4.

Turner C II. 1987. Late Pleistocene and Holocene population history of East Asia based on dental variation. *American Journal of Physical Anthropology* 73:305–21.

RADIOCARBON, Vol 44, Nr 2, 2002, p 503–530

RADIOCARBON-BASED CHRONOLOGY OF THE PALEOLITHIC IN SIBERIA AND ITS RELEVANCE TO THE PEOPLING OF THE NEW WORLD

Sergey A Vasil'ev[1] • Yaroslav V Kuzmin[2] • Lyubov A Orlova[3] • Vyacheslav N Dementiev[4]

ABSTRACT. The territory of Siberia is of crucial importance for the study of early human dispersal and the peopling of the New World. A Siberian Paleolithic Radiocarbon Database has been compiled. The Database allows us to compile a chronolgical framework for human colonization of Northern Asia. There are 446 ^{14}C dates for 13 Middle and 111 Upper Paleolithic sites older than around 12,000 BP. Seventeen percent of the dates were obtained by the accelerator mass spectrometry (AMS) technique, and the remaining 83% are conventional. From the viewpoint of the spatial distribution of the ^{14}C-dated sites, the majority of these are located at the Yenisey River Basin, Transbaikal, and the Altai Mountains. The general outline of the Upper Paleolithic colonization of Siberia is given here. The earliest traces of modern human occupation are dated to around 43,000–39,000 BP in the southern part of Siberia. It seems that by around 13,000 BP, almost all of northern Asia, including the extreme northeastern Siberia had been colonized by modern humans. We discuss some controversial problems that have provoked heated debates in current Russian archaeology. Notable among these are the surprisingly early AMS dates for the Early Upper Paleolithic, the age of the Dyuktai culture of Yakutia, the problem of human presence in Siberia at the time of the Last Glacial Maximum (20,000–18,000 BP), and the timing of the initial settling of the Chukchi Peninsula and northeastern Siberia.

INTRODUCTION

The territory of Siberia (or northern Asia; Figure 1) has attracted the attention of students of prehistory for many years. This area is of crucial importance to questions regarding the first entry of people to the New World, human–land relationship in periglacial environments, and prehistoric culture contacts in the northern Pacific. In light of new data, we discuss here the peopling of Siberia and the timing of the initial human entry into the Americas. We also discuss the controversial subject of the age of the Dyuktai culture of Yakutia.

The establishment of a firm chronological framework for the Paleolithic in Siberia is of direct relevance to the complicated issue of the initial peopling of the New World. In this work, we use radiocarbon (^{14}C) dates obtained mostly on the Upper Paleolithic sites (and few Middle Paleolithic ones) in Siberia since 1960. Several summaries of Siberian prehistoric ^{14}C dates have been published in English (see, e.g., Henry 1984; Kuzmin 1994; Kuzmin and Tankersley 1996; Kuzmin and Orlova 1998). The recent Russian monograph on the ^{14}C chronology of the Paleolithic of Russia includes 423 dates from Siberia (Lisitsyn and Svezhentsev 1997). Because the New World in general, and Alaska in particular, was already colonized at minimum around 12,000 BP (cf., West 1996), we excluded Siberian Paleolithic and Initial Neolithic ^{14}C dates younger than around 12,000 BP compared with previously published summaries (Lisitsyn and Svezhentsev 1997; Kuzmin and Orlova 1998; Orlova et al. 2000b, Kuzmin 2000).

In this paper, we present the updated ^{14}C Database of the Siberian Paleolithic with values earlier than around 12,000 BP (Table 1). One should bear in mind that in a number of cases the assemblages included in our roster (the Elenev Cave, Layer 18 and underlying deposits; Novoselovo 6, Maynin-

[1]Institute for the Material Culture History, Russian Academy of Sciences, 18 Dvortsovaia Emb., St.-Petersburg 191186, Russia. Email: anna@neuro.pri.pu.ru
[2]Pacific Institute of Geography, Far Eastern Branch of the Russian Academy of Sciences, 7 Radio St., Vladivostok 690041, Russia. Email: ykuzmin@tig.dvo.ru
[3]Institute of Geology, Siberian Branch of the Russian Academy of Sciences, 3 Koptyug Ave., Novosibirsk 630090, Russia. Email: orlova@uiggm.nsc.ru
[4]Center for GIS Technologies, Siberian Branch of the Russian Academy of Sciences, 3 Koptyug Ave., Novosibirsk 630090, Russia. Email: dementev@uiggm.nsc.ru

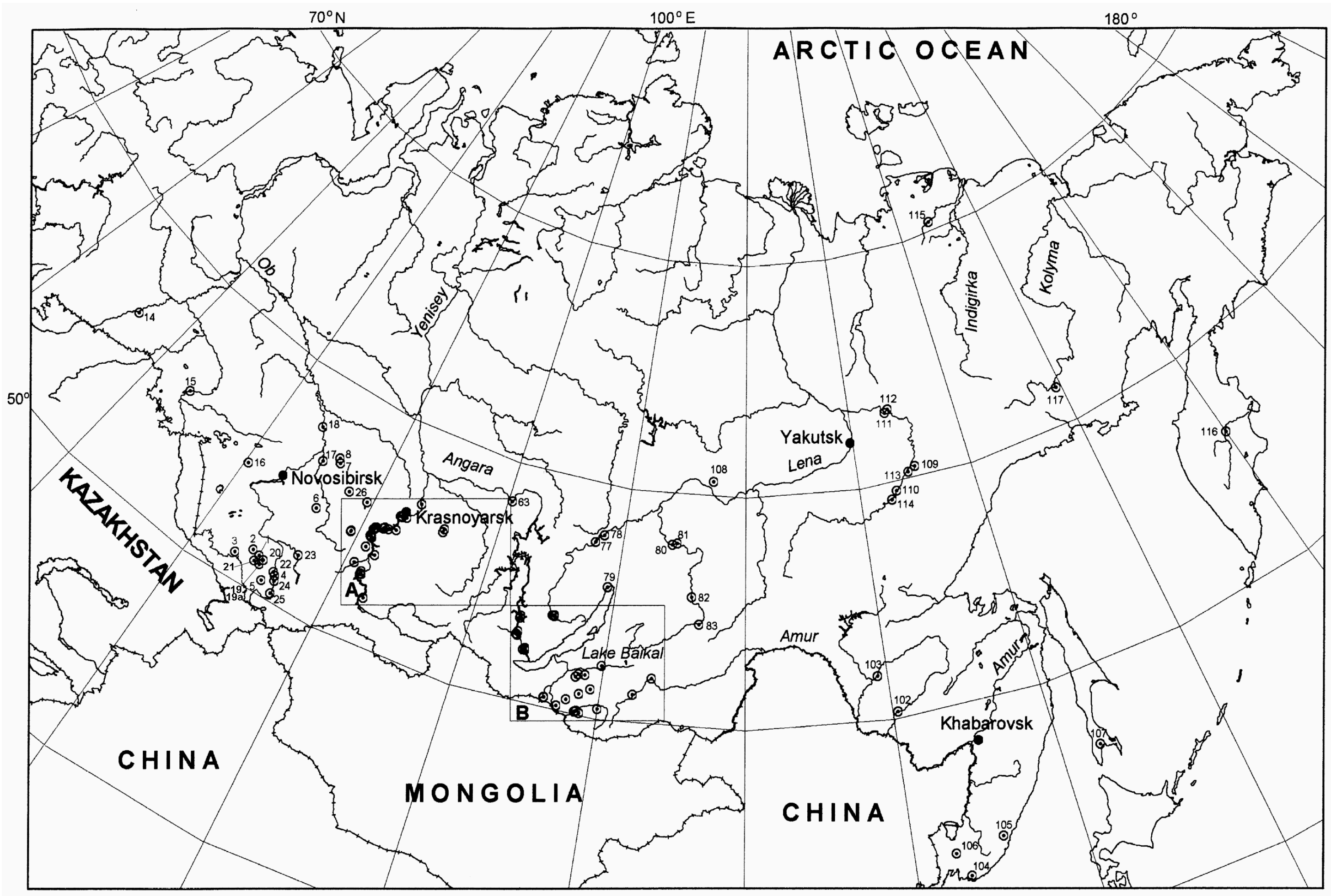


Figure 1 Radiocarbon-dated Paleolithic occurrences in Siberia

skaya, Layers A1-A3; Bolshoi Yakor 1, Layers 5 and 6; Ust'-Kyakhta 17; Studenoe 1; Malye Kuruktachi; Berelekh; Ushki; Siberdik, Layer 3), also produced dates younger than 12,000 BP, some of which are not included to the Table 1 (see appendix). Data presented are as of May 2001. In the columns "Latitude" and "Longitude", the geographic coordinates are given as decimal values (i.e., 70.50 means 70°30′) for using the Geographic Information System software, such as ARC/VIEW and ARC/INFO.

^{14}C DATABASE OF THE SIBERIAN PALEOLITHIC

Discussion of Siberian Paleolithic chronology in this paper is based on the ^{14}C dates directly associated with the Paleolithic assemblages. Thus, we omitted dates from paleontological localities without clear evidence of human presence, and dates from geological cross-sections located near the Paleolithic sites. For example, for the site of Berelekh in northeastern Siberia only ^{14}C dates from the cultural layer of the habitation site are included in the list (Table 1). The same is true for dates from archaeological occurrences run on samples lacking direct association with artifacts, for instance Filimoshki (Kuzmin 1996:138). At the same time, some dates included in the list (Afontova 2, GIN-117; Kashtanka 1, GrN-24482 and GrN-24481; Kunaley, GIN-6124; Gorbatka 3, SOAN-1922; and Ust'-Mil 2, LE-955) were run on samples lying below the artifact-bearing strata, thus providing only lower temporal limit for the assemblages. Some dubious Pleistocene-age ^{14}C dates of the apparently Holocene (Neolithic and Bronze Age) cultural strata, mostly from the Transbaikal (cf., Konstantinov 1994), are excluded. The ^{14}C dates, mentioned in the literature without indication of laboratory numbers and/or standard deviation, are also omitted. Finally, there are a lot of disappointing inaccuracies in individual data presentation in literature. Thus, we use the ^{14}C dates as these appeared in first publications.

As a result of careful dates selection, we roster 13 Middle and 111 Upper Paleolithic localities, which produced 446 dates (Table 1). Slightly more than 17% of the dates were obtained using accelerator mass spectrometry (AMS) technique; others are conventional. Largest ^{14}C datasets are known from the Shestakovo (21 values); Malta (19); Mayninskaya and Bolshoi Yakor 1 (15 for each one); Ust'-Karakol 1, and Ikhine 2, and Afontova Gora 2 (13 for each one); Geographical Society Cave (11); Kara-Bom and Kamenka 1 (10 for each one) sites. From the geographical viewpoint, the distribution of sites is no less uneven (Figure 1). The majority of the ^{14}C-dated sites locate in the Yenisey River drainage area and adjacent regions (33%) (Figure 2), Altai Mountains and the Kuznetsky Basin (19%), Transbaikal (14%), and areas around the Lake Baikal (9%) (Figure 3). At the same time, some areas extremely rich in prehistoric remains, such as the Angara and Upper Lena River valleys, yielded insufficient data compared to the number of sites (only 11% of total dates). Vast territories of the southern part of Northeastern Siberia (6%), the Russian Far East (less than 6%) and the West Siberian Plain (3%) produced only a few dates.

^{14}C DATING OF BONE COLLAGEN FROM SIBERIAN PALEOLITHIC SITES

The reliability of ^{14}C dates, made on animal and human bones, has been a complicated problem for decades (cf., Taylor 1997:87–91). There is a clear skepticism from some sources about the accuracy of bone ^{14}C dates made in Russian laboratories (cf., Goebel 1993:139–40). However, we are quite confident that the technique of collagen extraction developed in Russia (Arlsanov 1987:137–43; Sulerzhitsky 1997) is very reliable. The general idea is that slow dissolution of the mineral part of whole pieces of bones in diluted hydrochloric acid allows one to extract non-contaminated collagen, and to see the degree of preservation of initial fiber-like internal collagen structure after demineralization. This is different from widely accepted Longin's (1971) technique of collagen extraction,

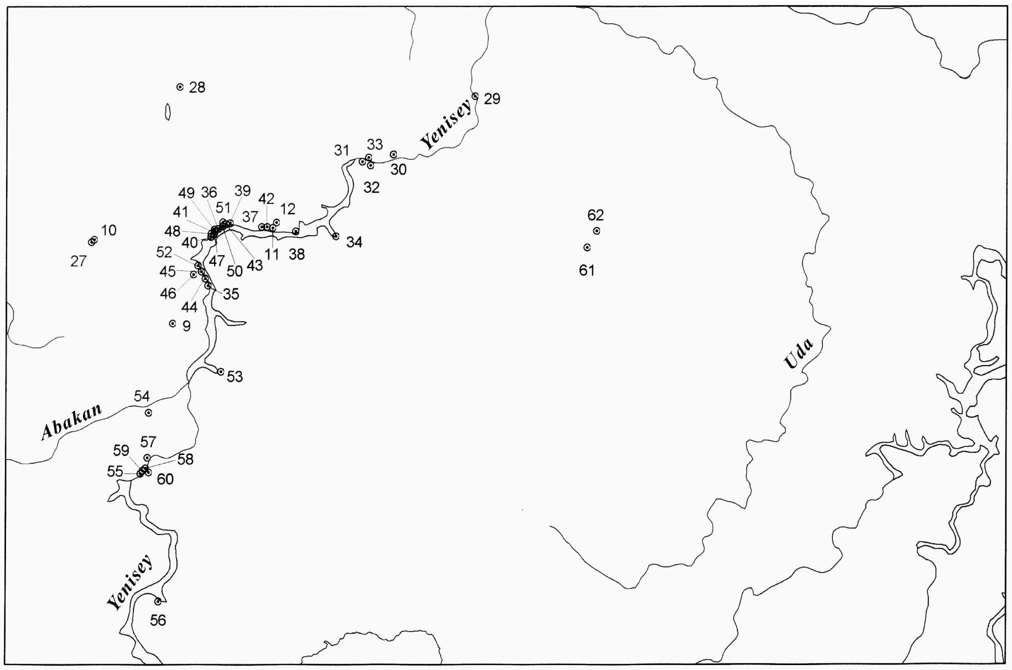


Figure 2 Radiocarbon-dated Paleolithic occurrences near the Yenisey River

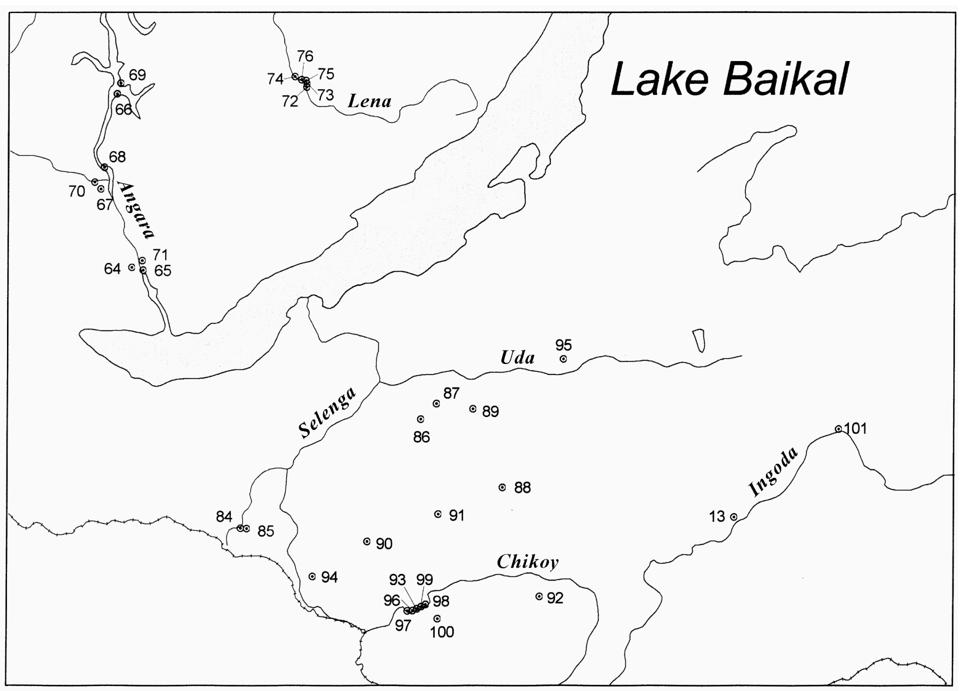


Figure 3 Radiocarbon-dated Paleolithic occurrences near Lake Baikal

where bone material is powdered before demineralization. The reliability of the slow dissolution technique for collagen extraction is supported by parallel dating of the same pieces of bone in Moscow (Geological Institute, Russian Academy of Sciences), and in the NSF-Arizona AMS Facility at the University of Arizona (Tucson, Arizona, USA) (Vasil'chuk et al. 2000) and Beta Analytic, Inc. (Miami, Florida, USA) (MacPhee et al. 2002).

The following technique of collagen extracted has been used at the Novosibirsk ^{14}C laboratory (lab code SOAN) since 1985. The pieces of bones 10–20 cm long, once cleaned of any surface compounds, are demineralized by 5% HCl solution (the proportion is 7–8 L of solution for 1 kg of bones) under a temperature of 2–3 °C, usually in a refrigerator. As the surface layer becames soft, once every few days it was scraped with a knife, and the demineralization continued until the mineral part of bone was completely dissolved; sometimes this may take 1–2 weeks. Finally, the extracted gelatin-like collagen is thoroughly washed by distilled water. To remove the humic acids, the collagen is treated by a 0.1 N solution of NaOH for several hours. The remaining collagen is again washed by distilled water, dried, and carbonized by heating on 800 °C in oxygen-free environment. To remove the phosphorous compounds, carbonized collagen is treated with a mixture of HNO_3 and HCl ("aqua regia"). Finally, the cleaned collagen is washed by distilled water, dried, and used for benzene preparation.

In some laboratories (such as Geological Institute, Moscow, lab code GIN) centrifuging is used for separation of humic acids from collagen (acceleration of 2500–3000 g). As for any bacterial contamination remaining after collagen extraction, repeated washing by distilled water ensures the removal of all possible bacteria (L D Sulerzhitsky, personal communication 2000).

Thus, the extracted collagen and the ^{14}C dates run on it seem to be very reliable, and there have been no serious arguments so far against the accuracy of the extraction technique. The key issue is that if collagen is already degraded before sampling, there is no way to obtain reliable material for dating, even if separate amino acids are being used as a source of ^{14}C (cf., Stafford et al. 1991). As one can observe after bone demineralization by cold HCl, well-preserved collagen keeps the fiber-like structure but the degraded collagen usually has "amorphic" appearance.

Several examples of the reliability of such collagen extraction may be found in Sulerzhitsky (1997: 186–8). One of the best cases is dating of several woolly mammoth bones from Taymyr Peninsula (extreme northern Siberia), collected on the surface and partly covered with moss. After mechanical removal of moss and collagen extraction as described above, the Late Glacial ^{14}C ages (around 12,000 BP) were obtained. This clearly shows that well-preserved collagen is very resistant to any kind of contamination.

EVALUATION OF ^{14}C DATES IN SIBERIAN PALEOLITHIC GEOARCHAEOLOGY

The critical evaluation of a large series of ^{14}C dates has put forward the concept of "practicable accuracy" of ^{14}C dating of archaeological assemblages (Krenke and Sulerzhitsky 1992; see for details Kuzmin and Orlova 1998:24–5). The limit in accuracy of ^{14}C dating of the Paleolithic sites, being a part of the "practicable accuracy" concept, has been empirically estimated as 3000–4000 ^{14}C years (Krenke and Sulerzhitsky 1992). However, some archaeologists and geoarchaeologists are still disappointed by relatively large difference in ^{14}C date series from the same (and supposedly uniform) cultural layer. Recent examples for Siberia may be found in Goebel et al. (2000:572), and Goebel and Waters (2000).

We argue that the age difference of several hundreds or even thousands of ^{14}C years should be expected *a priori* in the series of ^{14}C dates from Paleolithic sites due to the complex taphonomic nature of organic material (charcoal, uncarbonized wood, bones, etc.) to be dated. This essentially means that a large (up to 3000–4000 ^{14}C years) difference in the date series from single cultural layer of a Paleolithic site should not confuse archaeologists, because it was observed on many well-dated sites with non-disturbed stratigraphy.

It seems that Paleolithic humans collected and brought to habitation sites wood (including fossil one), bones, antlers, tusks, and teeth of different (from the view of ^{14}C dating) ages. The dates found on mammoth bones and/or tusk should be considered with extreme caution, taking into account the possibility that the prehistoric inhabitants of a site collected these pieces from natural bone accumulations (deathsites or so-called "mammoth cemeteries"). The best controversial example is the date of around 43,000 BP obtained for the site of Druzhinikha at the Yenisey River basin of apparently Final Pleistocene age based on geological data. It should be added that some other dates included in our roster (Sabanikha, Shlenka, Pervomaiskoe 1, and Ulug-Bil') were also run on bones collected from the surface, thus these dates are controversial. In other cases, the faunal assemblages from the cave sites seem to be produced mostly by natural agencies, and the degree of human involvement is dubious (Proskuriakov Rockshelter and the Geographical Society Cave).

The site of Shestakovo in western Siberia (Zenin et al. 2000b, 2000d; Derevianko et al. 2000b) yielded evidence on scavenging of mammoth bones and teeth from the natural accumulation, and as a result ^{14}C mammoth dates show wide variation within one cultural layer, from 20,480 ± 180 BP to 22,340 ± 180 BP. Multiple human occupations of the site resulted in a wide range of ^{14}C ages of charcoal, from 20,800 ± 450 BP to 23,250 ± 110 BP. Another example of large variation in ^{14}C date series was obtained from the upper component of the Kostenki 1 site in central Russia, where 16 dates from the same dwelling unit vary from 20,800 ± 300 BP to 24,100 ± 500 BP (Praslov and Sulerzhitsky 1997).

Thus, we should expect that in the Paleolithic ^{14}C date series the range of dates might be quite wide, and it is almost impossible to judge which date is more reliable. This applies especially to sites where only woolly mammoth bones have been ^{14}C-dated. The general approach is that charcoal ^{14}C dates taken from hearth-like features could give us the age values most closely corresponding to the time of human occupation. However, such examples from Siberia are rare. Unfortunately, Paleolithic cultural layers could not be regarded as "snapshots" in terms of the age of organics recovered during the excavations and later ^{14}C-dated. Careful evaluation of ^{14}C data should be given when scientists are trying to find out the timing of human occupation of the Paleolithic sites.

CONTROVERSIES IN ^{14}C CHRONOLOGY OF THE UPPER PALEOLITHIC IN SIBERIA

It is far beyond our scope here to discuss the chronology of the Upper Paleolithic in Siberia in full detail (see e.g. Larichev et al. 1988, 1990, 1992; Vasil'ev 1993; West 1996; Derevianko 1997; Kuzmin and Orlova 1998; Kuzmin et al. 1998a, 1998b; Goebel and Slobodin 1999; Orlova et al. 2000b; Kuzmin 2000). Here we wish only to mention some controversial problems connected with the problem of ^{14}C chronology of the Dyuktai culture of Yakutia, which provokes hot debates in current Russian Paleolithic archaeology.

The timing of the Dyuktai culture has been discussed several times (e.g., Abramova 1979c; Yi and Clark 1985). This issue is important because the Dyuktai culture is considered to be directly related to the initial peopling of the New World (e.g. West 1996). Mochanov (1977) proposed the age of the earliest Dyuktai sites, Ust'-Mil 2, Ezhantsy, and Ikhine 2, to be as old as around 35,000 BP

(Table 1). Several scholars disagree with such an early age of typical microblade industry in remote northeast Siberian territory (Abramova 1979c; Kashin 1983; Yi and Clark 1985; Kuzmin and Orlova 1998). To re-evaluate the ^{14}C chronology of the earliest Dyuktai sites, we use both ^{14}C and palynological records from archaeological sites and geological Late Pleistocene sections in eastern and northeastern Siberia.

Through all the Late Pleistocene sections in northern part of Siberia, the distinct feature is the predominance of arboreal (tree) pollen in deposits dated to around 30,000–25,000 BP, and predominance of non-arboreal pollen (grasses) and spores in deposits dated to around 33,000–30,000 BP and around 22,000–18,000 BP (cf. Kind 1974). The most complete record of climatic fluctuations in the second part of Late Pleistocene in northern Siberia was obtained from the Molotkovsky Kamen section in the lower stream of the Kolyma River (latitude 68°00′N, longitude 163°00′E), based on palynological and ^{14}C data (Kaplina and Lozhkin 1982; Kaplina and Giterman 1983; Giterman 1985). In total, about 15 ^{14}C dates and about 70–80 pollen spectra were obtained for the Molotkovsky Kamen section. Two warm climatic episodes with a predominance of arboreal pollen (up to 40–60% of the total amount of pollen and spores) were ^{14}C-dated to around 43,000–34,500 BP and around 28,000–24,500 BP. Vegetation during those times was represented by birch-larch forests. Two cold episodes with an increase in non-arboreal pollen and spore content (up to 80% of the total amount) were ^{14}C-dated to around 34,000–28,000 BP and around 24,000–18,000 BP. Vegetation was presented by tundra, with small admixture of larch (sparse forest-tundra associations). The same features in the pollen spectra were recognized in the records from Chuiskoye and Vilyi cross-sections in Central Yakutia (Shofman et al. 1977; Alekseev et al. 1986).

Several early Dyuktai sites, such as Ust'-Mil 2, Ikhine 2, and Ezhantsy, also produced pollen records (Savvinova et al. 1996). At Ust'-Mil 2, in the lower (i.e. pre-cultural) part of the section at a depth of 4.00 m, ^{14}C-dated to 35,600 ± 900 BP (LE-965), the amount of arboreal pollen is about 11–39%. In the upper part of section with the Dyuktai culture artifacts at a depth of 1.75–2.50 m, ^{14}C-dated to around 23,500–30,000 BP, the amount of arboreal pollen decreases dramatically, and does not exceed 5–10% of total pollen and spores content. This fact could be interpreted as a reflection of the climatic deterioration. The next increase in arboreal pollen content on the Ust'-Mil 2 pollen diagram (up to 70% of total pollen and spores) is ^{14}C-dated to 12,200 ± 170 BP (LE-953).

Thus, in the Ust'-Mil 2 pollen records the time interval between around 33,000 BP and around 23,500 BP corresponds to a cold climatic event. However, in the Molotkovsky Kamen sequence this time is characterized by dominance of arboreal pollen, which reflects climatic amelioration. Only in the upper part of the Molotkovsky Kamen section, ^{14}C-dated between around 24,500 BP and around 10,000 BP, the dominance of non-arboreal pollen is noted. It should be stressed that similar features of very low arboreal pollen content are observed on the pollen diagrams of Ezhantsy, Ikhine 1, and Ikhine 2 (Savvinova et al. 1996). ^{14}C dates for those sites are more than around 16,600 BP (Ikhine 1), around 17,200 BP (Ezhantsy), and around 31,200 BP to 24,300 BP (Ikhine 2).

On the basis of pollen and ^{14}C records obtained from the Late Pleistocene sections in northern Siberia, along with critical re-examination of the Dyuktai culture records, we can assume that the portion of Ust'-Mil 2 section with low content of arboreal pollen corresponds to the final Karginsky Interglacial, ^{14}C-dated to around 30,000–24,000 BP (see details in Kuzmin and Orlova 1998: 35-39). The use of driftwood from older deposits by the earliest Dyuktai culture bearers could result in distortion of the ^{14}C age determinations of *human occupation* (sic!) (cf. Kuzmin and Orlova 1998).

In this case, bone material might be more reliable in the age estimation of the Dyuktai culture rather than driftwood, which can be re-deposited from older sediments of the Aldan River. The most suitable ^{14}C value from the Ikhine 2 site seems to be 26,030 ± 200 BP (IM-239) (Figure 4). However, the wood sample from the same depth yielded very close ^{14}C date, 26,500 ± 540 BP (IM-202). Nevertheless, the older ^{14}C values from the depth of 0.90–1.20 m between around 31,200 BP and around 27,400 BP could be considered as less reliable. The youngest wood ^{14}C date, 24,500 ± 480 BP (IM-203), might be more reliable.

MODERN HUMAN DISPERSAL IN NORTHERN ASIA: AN OUTLINE

The earliest known Upper Paleolithic occurrences in Siberia are dated to around 43,000–38,500 BP (Table 1). These are concentrated mostly at two areas in southern Siberia, at the Altai Mountains (Kara-Bom, Kara-Tenesh, Ust'-Karakol 1, etc.) and the Transbaikal (Tolbaga, Kamenka 1, etc.). At the same time, some occurrences at the Yenisey, Angara, and Upper Lena River basins witness the occupation of the whole southern Siberia. It seems to be premature to analyze the problem of the Upper Paleolithic genesis, associated with early *Homo sapiens sapiens* migration on the basis of the scanty data at hand. The earliest Upper Paleolithic traditions of Siberia share a lot of features in common with preceding Mousterian, thus demonstrating an apparent continuity between the Middle and Upper Paleolithic (Goebel et al. 1993). At the same time, these traditions evidenced the appearance of such typical Upper Paleolithic culture manifestations as mobile art objects, sophisticated bone technology, and personal ornaments. The southwestern way for early *Homo sapiens sapiens* migration seems to be plausible, and the Early Upper Paleolithic sites dated to the second part of the Karginsky Interglacial, around 40,000–25,000 BP, are identified at Altai Mountains, Angara River basin, and Transbaikal.

The data at hand indicate the sparse traces of humans during the final phase of the Karginsky Interglacial, around 30,000–25,000 BP. This scarcity of data could be explained by the large-scale erosion and cryoturbation of deposits during the advent of the Sartan Glaciation at around 25,000–22,000 BP. Meanwhile, we could argue about the permanent colonization of south Siberian mountainous areas, from the Altai to the Transbaikal, during the Early Upper Paleolithic.

The accidental discovery of the Upper Paleolithic artifacts in such a remote area as the northern part of the Chukchi Peninsula (Laukhin et al. 1989) led to speculation about human settlement in extreme northeastern Siberia during the warm phases of the Karginsky Interglacial. However, the age estimates and stratigraphic situation for the Kymyneikei site in the northern Chukchi Peninsula remains unclear (Goebel and Slobodin 1999:125; Orlova et al. 2000b:407–8). More data have been obtained for the Yakutia. Taking into consideration the age estimates for the Dyuktai culture, we can assume that modern people settled at this territory at least at around 18,000 BP (Verkhne-Troitskaya), and perhaps earlier, about around 25,000 BP (Ikhine 2).

The data referring to the Early Sartan Glaciation, around 25,000–22,000 BP, are more numerous. Unfortunately, all these data seem to be insufficient for a reconstruction of human dispersal in details. The idea of depopulation of Siberia under the harsh climatic conditions of the peak of Sartan Glaciation at around 19,000–16,000 BP was first put forward by Tseitlin (1979), and later by Goebel (1999). In spite of inevitable decrease of an area inhabited and population movements southwards, we could argue that even during the Late Glacial Maximum, around 20,000–18,000 BP, the occupation of southern Siberia and the Russian Far East was not interrupted. Stratigraphic columns of such sites as Shlenka, Ui 1, Krasny Yar 1, Varvarina Gora, etc. provide evidence. Also, at least 14 well-studied Upper Paleolithic sites in northern Asia have ^{14}C dates within time interval of around 20,000–18,000 BP (Table 1).

The Final Pleistocene provides evidence of dense population at all main drainage basins in southern Siberia. Beyond more familiar areas of the Altai Mountains—Yenisey, Angara, and Upper Lena River basins, and Transbaikal—the Late Sartan time span saw human dispersal in the southern portion of the West Siberian Plain, and along the Yenisey River valley downstream from modern Krasnoyarsk. Certainly, the most important event was human dispersal in northeastern Asia along the main rivers of Yakutia. Even such remote areas as the Indigirka River basin were inhabited in the Final Pleistocene (Berelekh site). This important movement resulted in peopling of Beringia at around 12,000 BP (see below), thus continuing the general trend of human movement in northern Eurasia from southwest to northeast.

BERINGIA AND THE PEOPLING OF AMERICA

In spite of numerous efforts to search for direct ancestors of Paleoindians in northeastern Asia carried out from radically different viewpoints (cf., Mochanov 1984; Dikov 1985; Yi and Clark 1985), there is a lot to be desired in the problem of timing and tracing of the first human entry to the New World. Before discussing the archaeological evidence on Pleistocene occupation of Beringia, let us look at paleoenvironmental data relevant to the Final Sartan, i.e. the time span that is thought to witness the peopling of the New World (Kozhevnikov and Zheleznov-Chukotskii 1995). It seems that the glaciation of Chukotka was restricted by mountainous areas and glaciers could not hamper faunal and human migrations. The Bering Land Bridge existed during the entire Final Pleistocene. From 13,000 to 12,000 BP the land bridge was a vast smooth plain, whereas from 11,000 BP its area began to decrease. First, the Anadyr Strait between Chukotka and St Lawrence Island was formed; later the Bering Strait appeared. It seems that around 10,500 BP the waters of the Pacific and Arctic Oceans joined (Elias et al. 1997). Meanwhile, even after the submerging of the land bridge, the Bering Strait could not be considered as an important barrier hampering human contacts, which were possible by boats as well as on ice during winters.

The territory of Alaska was not covered by ice. Cordilleran glaciation touched parts of the Aleutian and Alaska Ranges to the south (Glaciation Park McKinley) and the modern Aleutian Islands as well as a dry shelf. The glacial lobes were oriented mostly in a southern direction, but occasional mountain glaciers penetrated the upper parts of the Yukon tributaries valleys, including the Nenana River.

The favorable conditions for animal and human dispersal existed from 11,800 to 10,500 BP during the intermediary period between glacial advances McKinley III and IV (or Riley Creek III and IV, according to the old schemes). This time span was even labeled the "Critical Millennium" of the Pleistocene. It is followed by the Park McKinley IV Phase, correlated with Younger Dryas, but persisted as late as 9500 BP.

The northern part of the area demonstrates more restricted glaciation, mostly touched the central portion of the Brooks Range (Itkillik II Phase). The last glacial advance in this region is dated around 12,800 BP, later glaciers only retreated and the time span around 11,500 BP saw significant decrease of glaciated areas. Small glaciers existed in the mountains of the southern part of the Seward Peninsular, Kuskokwim Mountains, and Yukon-Tanana Highlands. Thus the central interior Alaska, the area with intense loess deposition at Final Pleistocene, rested open for animal and human migrations (Péwé 1975; Ten Brink 1984; Bigelow 1991).

Most scholars tend to argue that cold dry steppes with sagebrush—grasses and isolated willow stands—dominated the Bering Land Bridge, while woodland refuge (willow, birch) could survive along rivers. Numerous discoveries of Pleistocene fauna (horse, bison, reindeer, wild sheep, elk, etc.) indicate that Beringia provided a favorable place for large herds of ungulates, especially during the so-called "Birch Zone", which evidenced a climate amelioration from 14,000 to 10,000 BP. This time span seems to correspond to the presumed human entry to the New World. The dwarf birch area gradually widened from 14,300 to 13,500 BP, across the Alaskan territory. Starting in the western portion of the Peninsular, birch distributed along the Yukon from 12,500–12,000 BP. The mountains were woodland-free with patches of herbaceous tundra. From around 11,000 BP (the late phase of the "Birch Zone") the territory saw the gradual decrease of glaciated areas and expansion of forest—poplar along river valleys, and aspen on south-facing mountain slopes. Meanwhile, herbaceous tundra still dominated the landscape. A short-term cold spell corresponding to the Younger Dryas, between 10,500 and 10,200 BP, is marked by the appearance of grass tundra in the place of bush tundra in central Alaska (Elias 2001).

As seen above, pieces of archaeological evidence relevant to prehistoric human occupation of western Beringia (the extreme northeastern Asia) are far from numerous. It has been demonstrated that central Yakutia (the Lena and Aldan valleys) were inhabited from around 24,500 to 18,000 BP. What is known is the fact that the dispersal of the Dyuktai-type culture in the central (and probably also northern) portion of Yakutia, while Berelekh evidenced human movement northwards, to the Arctic Ocean coastline around 13,000–12,000 BP.

It is more difficult to argue about the settlement of Kolyma, Kamchatka, and Chukotka, due to scarcity. The sites attributed to the Dyuktai Complex, but located beyond the core area of the culture, at the Okhotsk Sea coastal zone or the Kolyma River basin (Maiorych and Kukhtui III) are dubious. The last site is even referred to as Neolithic. In other cases, the unambiguous dates are lacking and it is difficult to judge if the sites could be referred to the Final Pleistocene or Early Holocene as in the case of the lower component of Kheta. Some sites are claimed as Paleolithic (Druchak-Vetrenyi and Uptar) received the Early Holocene ^{14}C dates. The age of the unique presumable Pleistocene site at the Kamchatka Peninsular–Ushki, remains enigmatic. There are many disappointing inaccuracies in numerous writings by Dikov on the enumeration of cultural horizons, provenance of samples for ^{14}C determinations, etc. (for latest versions see Dikov 1996a, 1996b). It seems hardly possible to make a judgement about the so-called "Ushki culture/s" that share no element in common with Siberia, as well as with North American Pleistocene assemblages. One should bear in mind that several sites (Bolshoi Elgakhchan I and II at the Omolon River, surface scatters at the Chukotka Peninsular) were referred to the Paleolithic exclusively based on the morphological similarity of the lithics found to Ushki. The age and character of the occurrences with the so-called "Pebble-tool" industries at Kamchatka and Chukotka (Orlovka II, Lopatka IV, etc.) remain far from clear. Frankly speaking, in spite of long-term research activity in the area, we have no direct evidence of the Late Pleistocene human colonization of the vast areas adjacent to the submerged portions of the Bering Land Bridge, i.e. at the Chukotka Peninsular, in the Kolyma, Omolon, and Anadyr River valleys (see the recent review in Slobodin 1999). Even now we have no assemblages comparable to the Alaskan ones from the chronological viewpoint.

So far, we have one more site in extreme northeastern Siberia—Siberdik in the Kolyma River headwaters (Dikov 1977:213–21; 1979:90–100) (Figure 1, Nr 117). There are several age estimates for the lowermost cultural layer 3, range from around 13,200 BP to around 7900 BP (Kuzmin and Tankersley 1996:580; Kuzmin and Orlova 1998:17; Kuzmin 2000:123), and this fact is well known in spite of skepticism expressed by Goebel and Slobodin (1999:155). Unfortunately, no details about the degree of association between ^{14}C-dated charcoal and artifacts from layer 3 were given by Dikov (personal communication to Kuzmin, September 1994). But we cannot simply reject the earliest ^{14}C value of the layer 3 on Siberdik, 13,225 ± 230 BP (MAG-916) (Lozhkin and Trumpe 1990:178), as was done by Goebel and Slobodin (1999:114) without any discussion. Until there are new site excavations and dating, this age of the Siberdik still should be taken into account as the tentative evidence of human occupation of the Kolyma headwaters around 13,000 BP. Thus, we can conclude that at least at around 13,000 BP humans already settled the extreme northeastern Siberia, the "forepost" of the peopling of the New World, and the Berelekh, Siberdik, and Ushki might represent the earliest Paleolithic sites there.

Leaving aside faunal occurrences with more or less dubious evidence of human involvement (Old Crow, Trail Creek, and the Lime Hills 1 Caves) and sites with artifactual material but ambiguous stratigraphic resolution (unit B at the Bluefish Caves nos. 1 and 2), it could be said with confidence that the earliest human traces in Alaska are associated with the Nenana and Denali Complex sites, located in the Central Interior Alaska (West 1996). The oldest Nenana assemblages (Components 1 at Owl Ridge, Walker Road, and Dry Creek, Cultural Zones 4 and 3 at Broken Mammoth, Layer 1 at Moose Creek) are dated by ^{14}C from around 11,800–11,100 to 9000 BP. The age of the oldest Denali assemblages is generally slightly younger, around 10,700–9000 BP (Components 2 at Dry Creek and Moose Creek). Recent discoveries revealed more the complex character of the culture development in Beringia with early appearance of microblade industry as evidenced by the lowermost horizons at Swan Point, dated around 11,600 BP.

Assuming Nenana and Denali were separate culture traditions, the Alaskan sites could therefore be regarded as a reflection of two different migration waves from Asia. The oldest seems to be represented by the Nenana assemblages dated from around 12,000–11,000 BP. The second, presumably reflecting the spread of the Dyuktai populations in north-eastward direction, are represented by Denali and dated between 11,000 and 10,000 BP (West 1996).

Apart from these traditions, the northern Paleoindian is represented by the sites with projectile points located in northern and western portions of Alaska. The earliest dates are between around 11,700 and 9700 BP for Mesa, around 10,500 BP for Bedwell, 10,300 BP for Hilltop, and around 11,000 BP for Tuluaq (Bever 2000; Rasic and Gal 2000).

The revision of old data and a search for new data are needed. The achievements along these lines could be only possible through the development of cooperation between Russian and American scholars. There is little doubt that the frozen ground lands of northeastern Asia should contain the traces of the ancestors of the first Americans. The current surge in joint research allows us to see the future of our studies in favorable perspective.

CONCLUSION

More close collaborative efforts of archaeologists and scientists specializing in ^{14}C dating, Quaternary geology, and geomorphology are necessary for the solution of the problems mentioned above. There is a lot of discordance in publication of ^{14}C dates, especially in terms of laboratory numbers, cultural layer identifications and contexts, and the development of a standard general database is called for. Recently, the Siberian Paleolithic Radiocarbon Database has been compiled (see the website of the Institute of Geology, the Siberian Branch of the Russian Academy of Sciences [www.giscenter.ru]). This paper should be cited as a primary source of the ^{14}C dates for the Paleolithic of Siberia included in the Database.

ACKNOWLEDGMENTS

We are deeply grateful to Zoia A Abramova, Sergey N Astakhov, Galina V Sinitsyna, Anatoly P Derevianko, Ruslan S Vasil'evskii, Valery T Petrin, Sergey V Markin, Yuri P Kholiushkin, Michael

V Shun'kov, Yuri V Grichan, Pavel V Volkov, Andrey V Tabarev, Arthur L Kungurov, Nikolay I Drozdov, Nikolay D Ovodov, Elena V Akimova, Nikolay P Makarov, Alexander S Vdovin, German I Medvedev, Michael P Aksenov, Nicholas A Savel'ev, Anatoly G Generalov, Tagir A Abdulov, Irina L Lezhnenko, Victor M Vetrov, Eugene M Ineshin, Nathalie A Berdnikova, Sergey N Perzhakov, Oleg V Zadonin, Liudmila V Lbova, Yuri A Mochanov, Nicholas M Cherosov, Igor I Kirillov, Michael V Konstantinov, Alexander V Konstantinov, Victor K Kolosov, Sergey G Vasil'ev, Oleg K Kuznetsov, Nina A Kononenko, Alexander A Krupianko, Anatoly M Kuznetsov, Valery A Lynsha, Sergey B Slobodin, and many other scholars for friendly discussions and easy access to all kinds of data. The Central European University Research Support Scheme (grant nr 609/1991), the Fulbright Scholar Program (grants nrs 22246 and 21230), the Russian Foundation for Basic Sciences (grant nrs 99-06-80348, 00-06-80376, and 00-06-80410), the Regional Scholar Exchange Program, and the Russian Foundation for Humanities (grant nr 99-01-12010) have supported this research. The first draft of the paper was presented by the senior author at the 2nd Russian Quaternary Conference held in St Petersburg in 1998.

REFERENCES

Abramova ZA. 1979a. *Paleolit Yeniseya: Afontovskaya kul'tura* (Paleolithic of the Yenisey: The Afontova culture). Novosibirsk: Nauka Publ. 157 p.

Abramova ZA. 1979b. *Paleolit Yeniseya: Kokorevskaya kul'tura* (Paleolithic of the Yenisey: The Kokorevo culture). Novosibirsk, Nauka Publ. 200 p.

Abramova ZA. 1979c. O vozraste paleolita Aldana (On the dating of the Paleolithic of Aldan). *Sovetskaya arkheologiya* 4:5–14.

Abramova ZA. 1989. Paleolit Severnoi Azii (The Paleolithic of Northern Asia). In: Boriskovskiy PI, editor. *Paleolit mira. Paleolit Kavkaza i Severnoi Azii*. Leningrad: Nauka Publ. p 144–243.

Abramova ZA, Astakhov SN, Vasil'ev SA, Lisitsyn NF, Ermolova NM. 1991. *Paleolit Yeniseya* (The Paleolithic of the Yenisey). Leningrad: Nauka Publ. 158 p.

Akimova EV. 1998. Istoriya antropologicheskoi nakhodki so stoyanki Listvenka (The story of anthropological finding from the Listvenka site) In: Derevianko AP, editor. *Paleoekologiya pleistotsena i kul'tury kamennogo veka Severnoi Azii i sopredel'nykh territoryi*. Part 1. Novosibirsk: Institute of Archaeology and Ethnography Press. p 298–300.

Akimova EV, Gorelchenkova OA, Poplevchenko NA. 2000a. Priemy pervichnogo razschepleniya v 19-m kul'turnom sloe stoyanki Listvenka (Lithic technology of the Layer 19 of Listvenka). In: Drozdov NI, editor. *Paleogeografiya kamennogo veka. Korrelyatsya prirodnykh sobytyi i arkheologicheskikh kul'tur paleolita Severnoi Azii i sopredel'nykh territoryi*. Krasnoyarsk: Krasnoyarsk State Pedagogical University. p 7–9.

Akimova EV, Stasiuk IV, Tomilova EA, Maklaeva YM, Andrenko OV, Gulyaev AA, Zykin VS, Zykina VS, Orlova LA. 2000b. Kompleksnoye izuchenie pozdnepaleoliticheskogo mestonakhozhdeniya Derbina 5 na Krasnoyarskom vodokhranilische (The multidisciplinary study of the Late Paleolithic site of Derbina 5 at the Krasnoyarsk Reservoir). In: Drozdov NI, editor. *Paleogeografiya kamennogo veka. Korrelyatsya prirodnykh sobytyi i arkheologicheskikh kul'tur paleolita Severnoi Azii i sopredel'nykh territoryi.* Krasnoyarsk: Krasnoyarsk State Pedagogical University. p 10–11.

Aksenov MP. 1993. Doneoliticheskie mestonakhozhdeniya Verkhnei Leny (Pre-Neolithic sites at the Upper Lena). In: Derevianko AP, editor. *Istorichesky opyt osvoeniya vostochnykh raionov Rossii.* Part 1. Vladivostok: Far Eastern Branch of the Russian Academy of Sciences. p 67–70.

Aksenov MP. 1996. Doneoliticheskie stoyanki Kachugsko-Verkholenskogo uchastka doliny Verkhnei Leny (Pre-Neolithic sites at the Kachug-Upper Lena portion of the Upper Lena valley). In: Medvedev GI, editor. *Arkheologicheskoye nasledie Baikalskoi Sibiri*. Part 1. Irkutsk: Center for Cultural Heritage Preservation. p 12–22.

Alekseev MN, Golubeva LV, Liskun IG, Sokolovskaya VT. 1986. Klimatostratigrafiya chetvertichnykh otlozhenyi severa Vostochnoi Sibiri (Climatostratigraphy of the Quaternary deposits of the northern Eastern Siberia). *Bulleten' Komissii po izucheniyu chetvertichnogo perioda* 55:14–26.

Arslanov HA. 1987. *Radiouglerod: geokhimiya i geochronologiya* (Radiocarbon: geochemistry and geochronology). Leningrad: Leningrad State University Press. 300 p.

Arslanov HA, Svezhentsev YS, Markov YN. 1981. Uluchschennye metody radiouglerodnogo datirovaniya iskopaemykh kostei (Advanced methods of the radiocarbon dating of fossil bones). In: Kurvits YA, editor. *Izotopnye i geokhimicheskie metody v biologii, geologii i arkheologii*. Tartu: Estonian Academy of Sciences. p 12–15.

Astakhov SN. 1986. *Paleolit Tuvy* (The Paleolithic of Tuva). Novosibirsk: Nauka Publ. 174 p.

Astakhov SN, Zubareva GY, Lisitsyn NF, Yamskikh AF. 1993. Paleoliticheskaya stoyanka Shlenka (The Paleolithic site of Shlenka). *Rossiiskaya arkheologiya* 3: 140–8.

Bazarov DB, Konstantinov MV, Imetkhenov AB, Bazarova LD, Savvinova VV. 1982. *Geologiya i kul'tura drevnikh poselenyi Zapadnogo Zabaikalya* (The geology and culture of the ancient settlements of the western Transbaikal). Novosibirsk: Nauka Publ. 164 p.

Belousov VM, Ineshin EM, Sulerzhitsky LD, Teten'kin AV. 1997. Nekotorye aspekty sozdaniya dinamicheskoi modeli razvitiya rel'efa v Mamakanskom geoarkheologicheskom mikroraione (Some aspects of the construction of dynamic model of relief formation in the Mamakan geoarchaeological region). In: Derevianko AP, Molodin VI, editors. *Problemy arkheologii, etnografii, antropologii Sibiri i sopredel'nykh territoryi*. Vol. 3. Novosibirsk: Institute of Archaeology and Ethnography Press. p 19–23.

Bever MR. 2000. *Paleoindian lithic technology and landscape use in Late Pleistocene Alaska: a study of the Mesa Complex.* Unpublished PhD dissertation. Dallas: Southern Methodist University.

Bigelow NH. 1991. *Analysis of Late Quaternary soils and sediments in the Nenana Valley, central Alaska.* Unpublished MA dissertation. Fairbanks: University of Alaska-Fairbanks.

Buerachny EV, Lbova LV. 2000. Osobennosti tekhnologii pazschepleniya industrii Kamenka-A (Peculiarities of the lithic technology from the assemblage of Kamenka-A). In: Drozdov NI, editor. *Paleogeografiya kamennogo veka. Korrelyatsya prirodnykh sobytyi i arkheologicheskikh kul'tur paleolita Severnoi Azii i sopredel'nykh territoryi.* Krasnoyarsk: Krasnoyarsk State Pedagogical University. p 22–4.

Cherosov NM. 1988. Stoyanki kamennogo veka tsentral'noi chasti Lenskogo Plato (Stone Age sites of the central part of the Lena Plateau). In: Alekseev AN, editor. *Arkheologiya Yakutii*. Yakutsk: Yakutsk State University. p 54–71.

Derevianko AP, editor. 1997. *The Paleolithic of Siberia*. Urbana: The University of Illinois Press. 406 p.

Derevianko AP, Agadzhanian AK, Baryshnikov GF, Dergacheva MI, Dupal TA, Malaeva EM, Markin SV, Molodin VI, Nikolaev SV, Orlova LA, Petrin VT, Postnov AV, Ul'ianov VA, Fedeneva IN, Foronova IV, Shun'kov MV. 1998. *Arkheologiya, geologiya i paleogeografiya pleistozena i golozena Gornogo Altaya* (Archaeology, geology, and paleogeography of the Pl;eistocene and Holocene of the Mountainous Altai). Novosibirsk: Institute of Archaeology and Ethnography Press. 174 p.

Derevianko AP, Bolikhovskaya NS, Markin SV, Sobolev VM. 2000a. Paleogeografiya finala pleistozena srednegornoi zony Severo-Zapadnogo Altaya po dannym izucheniya razrezov peschery Kaminnoi (Paleogeography of the Final Pleistocene in the middle range of northwestern Altai Mountains according to the study of the Kaminnaya Cave sections). In: Markin SV, editor. *Problemy rekonstruktsii klimata i prirodnoi sredy golozena i pleistozena Sibiri*. Vol. 2. Novosibirsk: Institute of Archaeology and Ethnography Press. p 154–61.

Derevianko AP, Drozdov NI, Chekha VP, editors. 1992. *Arkheologiya, geologiya i paleogeografiya paleoliticheskikh pamyatnikov yuga Srednei Sibiri* (Archaeology, geology and paleogeography of the Paleolithic sites of southern Central Siberia). Krasnoyarsk: Institute of Archaeology and Ethnography Press. 130 p.

Derevianko AP, Zenin VN. 1995a. Paleoliticheskaya stoyanka Shestakovo: osobennosti industrii shestogo kulturnogo sloya (The Paleolithic site of Shestakovo: peculiarities of the industry from the sixth cultural layer). In: Kiriushin YF, editor. *Problemy zaschity, izucheniya i okhrany kul'turnogo naslediya na Altaye*. Barnaul: Altai State University. p 38–9.

Derevianko AP, Zenin VN. 1995b. *Paleolit Selemdzha* (The Paleolithic of Selemdga). Novosibirsk: Institute of Archaeology and Ethnography Press. 159 p.

Derevianko AP, Zenin VN, Leshchinsky SV, Mashchenko EN. 2000b. Peculiarities of mammoth accumulation at Shestakovo site in West Siberia. *Archaeology, Ethnology, and Anthropology of Eurasia* 1(3):42–55.

Dikov NN. 1977. *Arkheologicheskie pamyatniki Kamchatki, Chukotki i Verkhnei Kolymy* (Archaeological sites on Kamchatka, Chukotka, and Upper Kolyma). Moscow: Nauka Publ. 391 p.

Dikov NN. 1979. *Drevnie kul'tury Severo-Vostochoi Azii* (Ancient cultures of Northeast Asia). Moscow: Nauka Publ. 352 p.

Dikov NN. 1985. The Paleolithic of Northeast Asia and its relations to the Paleolithic of Ameriaround *Inter-Nord* 17:173–7.

Dikov NN. 1996a. The Ushki sites, Kamchatka Peninsula. In: West FH, editor. *American Beginnings: The Prehistory and Palaeoecology of Beringia*. Chicago: The University of Chicago Press. p 244–50.

Dikov NN. 1996b. Rannie etapy kamennogo veka: paleolit i mezolit (The early stages of the Stone Age: Paleolithic and Mesolithic) In: Dikov NN, editor. *Severo-Vostok Rossii ot pervobytnogo vremeni do sovremennosti: novyie vzglady na istoriyu.* Magadan: Northeastern Interdisciplinary Research Institute. p 13–22.

Drozdov NI. 1992. *Etapy razvitiya kamennogo veka v pleistotsene Srednei Sibiri* (Stages of the development of the Stone Age in the Pleistocene Central Siberia). An abstract of doctoral dissertation. Novosibirsk: Institute of Archaeology and Ethnography. 54 p.

Drozdov NI, Artem'ev EV. 1997. *Novye dostizheniya v izuchenii paleolita Afontovoi Gory* (New achievements in the study of the Paleolithic of Afontova Gora). Moscow: INQUA. 56 p.

Drozdov NI, Chekha VP, Artem'ev EV, Haesaerts P, Orlova LA. 2000. *Chetvertichnaya istoriya i arkheologicheskie pamyatniki Severo-Minusinskoi kotloviny* (Quaternary history and archaeological sites of the northern Minusinsk Basin). Krasnoyarsk: Krasnoyarsk State Pedagogical University. 76 p.

Drozdov, NI, Chekha VP, Laukhin SA, Kol'tsova VG, Akimova EV, Ermolaev AV, Leont'ev VP, Vasil'ev SA, Yamskikh AF, Demidenko GA, Artem'ev EV, Vikulov AA, Bokarev AA, Foronova IV, Sidoras SD. 1990. *Khronostratigrafiya paleoliticheskikh pamyatnikov Srednei Sibiri* (Chronostratigraphy of the Paleolithic sites of Central Siberia). Novosibirsk: Institute of History, Philology, and Philosophy. 185 p.

Drozdov NI, Chlachula J, Chekha VP. 1999. Pleistocene environments and Paleolithic occupation of the northern Minusinsk Basin, southern Krasnoyarsk Region. *Anthropozoikum* 23:141–56.

Elias SA. 2001. Beringian paleoecology: results from the 1997 workshop. *Quaternary Science Reviews* 20:7–13.

Elias SA, Short SK, Birks HH. 1997. Late Wisconsin environments of the Bering Land Bridge. *Palaeogeography, Palaeoclimatology, Palaeoecology* 136:293–308.

Firsov LV, Panychev VA, Orlova LA. 1985. *Katalog radiouglerodnykh dat* (The catalogue of radiocarbon dates). Novosibirsk: Institute of Geology and Geophysics. 88 p.

Generalov AG. 2000. *Geoarkheologichesky ob'ekt Strizhovaya Gora* (Geoarchaeological object of the Strizhovaya Gora). Irkutsk: Irkutsk State University Press. 153 p.

Gening VF, Petrin VT. 1985. *Pozdnepaleoliticheskaya epokha yuga Zapadnoi Sibiri* (The Late Paleolithic epoch of the southern West Siberia). Novosibirsk: Nauka Publ. 89 p.

Giterman RE. 1985. *Istoriya rastitel'nosti Severo-Vostoka SSSR v pliozene i pleistozene* (The history of the vegetation of the Northeast USSR in the Pliocene and Pleistocene). Moscow: Nauka Publ. 95 p.

Goebel T. 1993. *The Middle to Upper Paleolithic transition in Siberia*. Unpublished PhD dissertation. Fairbanks: University of Alaska-Fairbanks.

Goebel T. 1999. Pleistocene human colonization of Siberia and peopling of the Americas: an ecological approach. *Evolutionary Anthropology* 8(6):208–27.

Goebel T, Aksenov M. 1995. Accelerator radiocarbon dating of the initial Upper Paleolithic in southeast Siberia. *Antiquity* 69:349–57.

Goebel T, Derevianko AP, Petrin VT. 1993. Dating the Middle-to-Upper Paleolithic transition of Kara-Bom. *Current Anthropology* 34(4):452–8.

Goebel T, Slobodin SB. 1999. The colonization of western Beringia: technology, ecology, and adaptations. In: Bonnichsen R, Turnmire KL, editors. *Ice Age people of North America: environments, origins, and adaptations of the first Americans.* Corvallis: Oregon State University Press. p 156–99.

Goebel T, Waters MR. 2000. New AMS ^{14}C ages for the Tolbaga Upper Paleolithic site, Transbaikal, Siberia. *Current Research in the Pleistocene* 17:32–4.

Goebel T, Waters MR, Buvit I, Konstantinov MV, Konstantinov AV. 2000. Studenoye-2 and the origins of microblade technologies in the Transbaikal, Siberia. *Antiquity* 74:567–75.

Henry M. 1984. Absolute chronologies of Late Pleistocene and Early Holocene cultures of Northeast Asia. *Arctic Anthropology* 21(1):1–68.

Ineshin EM. 1993. Deyatelnostnyi podkhod k izucheniiu planigrafii arkheologicheskogo pamytnika Bolshoi Yakor (Behavioral approach to the study of the spatial structure of the archaeological site of Bol'shoi Yakor). In: Derevianko AP, editor. *Istorichesky opyt osvoeniya vostochnykh raionov Rossii.* Part 1. Vladivostok: Far Eastern Branch of the Russian Academy of Sciences. p. 67–74.

Kaplina TN, Giterman RE. 1983. Molotkovsky Kamen – oporny razrez otlozhenyi pozdnego pleistozena Kolymskoi nizmennosti (The Molotkovsky Kamen – an key section of the Late Pleistocene of the Kolyma Lowland). *Izvestiya AN SSSR. Seriya geologicheskaya* 6:79–83.

Kaplina TN, Lozhkin AV. 1982. Vozrast "ledovogo kompleksa" Primorskikh nizmennostei Yakutii (The age of the "Ice Complex" of the coastal Yakutain lowlands). *Izvestiya AN SSSR. Seriya geologicheskaya* 2: 84–95.

Kashin VA. 1983. Istoriya issledovaniya i rezul'taty izucheniya paleolita Yakutii (History of research and results of the studies of the Paleolithic of Yakitia). In: Vasil'evsky RS, editor. *Paleolit Sibiri.* Novosibirsk: Nauka Publ. p 111–23.

Kind NV. 1974. *Geokhronologiya pozdnego antropogena po izotopnym dannym* (Geochronology of the Late Anthropogene according to isotopic data). Moscow: Nauka Publ. 255 p.

Kind NV, Sulerzhitsky LD, Vinogradova SN. 1976. Radiouglerodnye datirovki GIN AN SSSR. Soobshchenie 8 (Radiocarbon dates of GIN AN SSSR, report No. 8). *Bulleten' Komissii po izucheniyu chetvertichnogo perioda* 46:169–85.

Kirillov II, Cherenshchikov OY. 1996. Netraditsionnye izdeliya iz kamnya s mnogosloinoi stoyanki Sukhotino 4 (Non-traditional lithic artifacts from the multicomponent Paleolithic site of Sukhotino 4). In: Lezhnenko IL, editor. *Arkheologiya, paleoekologiya i etnografiya Sibiri i Dal'nego Vostoka.* Part 1. Irkutsk: Irkutsk State University. p 125–30.

Kirillov II, Kasparov AK. 1990. Arkheologiya Zabaikal'a: problemy i perspektivy (epokha paleolita) (Archaeology of the Transbaikal: problems and perspectives of the Paleolithic period). In: Derevianko AP, editor. *Khronostratifraphiya paleolita Severnoi, Centralnoi i Vostochnoi Azii i Ameriki*. Novosibirsk:

Institute of History, Philology, and Philosophy. p 194–8.

Klement'ev AM. 2000. Krupnye mlekopitayuschie paleolita Zabaikal'ya (Large mammals from the Paleolithic of Transbaikal). In: Drozdov NI, editor. *Paleogeografiya kamennogo veka. Korrelyatsya prirodnykh sobytyi i arkheologicheskikh kul'tur paleolita Severnoi Azii i sopredel'nykh territoryi.* Krasnoyarsk: Krasnoyarsk State Pedagogical University. p 68–70.

Konstantinov MV. 1994. *Drevnie pamyatniki kamennogo veka Baikalskoi Azii* (The Stone Age archaeological sites of the Baikal Asia). Chita: Chita State Teacher Training College Press. 180 p.

Kostiukevich VV, Degtiareva GP, Ivanov IE, Nesterenko SA. 1977. Radiouglerodnye daty laboratorii Instituta merzlotovedeniya SO AN SSSR (Radiocarbon dates of the laboratory, Permafrost Research Institute SO AN SSSR. *Bulleten' Komissii po izucheniyu chetvertichnogo perioda* 47:145–52.

Kostiukevich VV, Dneprovskaya OA, Ivanov IE. 1984. Radiouglerodnye datirovki laboratorii Instituta merzlotovedeniya (Radiocarbon dates of the Laboratory of Permafrost Research Institute). *Bulleten' Komissii po izucheniyu chetvertichnogo perioda* 53:172–4.

Kostiukevich VV, Ivanov IE, Nesterenko SA. 1980. Spisok radiouglerodnykh dat laboratorii geokhimii Instituta merzlotovedeniya SO AN SSSR (A roster of radiocarbon dates of the geochemistry laboratory, Permafrost Research Institute SO AN SSSR). *Bulleten' Komissii po izucheniyu chetvertichnogo perioda* 50:193–6.

Kozhevnikov YP, Zheleznov-Chukotsky NK. 1995. *Berigniya: istoriya i evolutsiya* (Beringia: history and evolution). Moscow: Nauka Publ. 383 p.

Krenke NA, Sulerzhitsky LD. 1992. Arkheologiya i realnaya tochnost radiouglerodnogo metoda (Archaeology and the real accuracy of radiocarbon method). In: Chichagova OA, Punning J-M, Kind NV, editors. *Geokhronologiya chetvertichnogo perioda.* Moscow: Nauka Publ. p 169–74.

Krupianko AA, Tabarev AV. 2001. *Arkheologicheskie kompleksy epokhi kamnya v Vostochnom Primorye* (Archaeological complexes of the Stone Age in eastern Maritime Province). Novosibirsk: Siberian University Publ. 104 p.

Kuzmin YV. 1994. Prehistoric colonization of Northeastern Siberia and migration to America: radiocarbon evidence. *Radiocarbon* 36(3):367–376.

Kuzmin YV. 1996. Palaeoecology of the Palaeolithic of the Russian Far East. In: West FH, editor. *American beginnings: the prehistory and palaeoecology of Beringia*. Chicago & London: University of Chicago Press. p 136–46.

Kuzmin YV. 2000. Geoarchaeology of the Lower, Middle, and early Upper Palaeolithic of Siberia: a review of current evidence. *The Review of Archaeology* 21(1): 32–40.

Kuzmin YV, Jull AJT, Orlova LA, Sulerzhitsky LD. 1998a. ^{14}C chronology of the Stone Age cultures, Russian Far East. *Radiocarbon* 40(2):675–86.

Kuzmin YV, Orlova LA. 1998. Radiocarbon chronology of the Siberian Paleolithic. *Journal of World Prehistory* 12(1):1-53.

Kuzmin YV, Orlova LA, Sulerzhitsky LD, Jull AJT. 1994. Radiocarbon dating of the Stone and Bronze Age sites in Primorye (Russian Far East). *Radiocarbon* 36(3):359–66.

Kuzmin YV, Tankersley KB. 1996. The colonization of Eastern Siberia: an evaluation of the Paleolithic age radiocarbon dates. *Journal of Archaeological Science* 23(4):577–85.

Kuzmin YV, Vasilevsky AA, O'Malley JM, Jull AJT. 1998b. The age and environment of the Paleolithic occupation of Sakhalin Island, the Russian Far East. *Current Research in the Pleistocene* 15:134–6.

Kuz'mina I, Sinitsyna G. 1995. Importance of faunistic remains for the chronology of multilayered Biryusa site in the Middle Yenisei area. In: Baryshnikov G, Kuzmina I, Saunders J, editors. *First International Mammoth* symposium. St Petersburg: Russian Academy of Sciences. p 682–3.

Kuznetsov AM. 1992. *Pozdny paleolit Primorya* (The Late Paleolithic of the Maritime Territory). Vladivostok: Far Eastern State University Press. 240 p.

Larichev V, Kholiushkin Y, Laricheva I. 1988. The Upper Paleolithic of Northern Asia: achievements, problems and perspectives (I) – western Siberia. *Journal of World Prehistory* 2(4):359–96.

Larichev V, Kholiushkin Y, Laricheva I. 1990. The Upper Paleolithic of Northern Asia: achievements, problems and perspectives (II) – central and eastern Siberia. *Journal of World Prehistory* 4(3):347-385.

Larichev V, Kholiushkin Y, Laricheva I. 1992. The Upper Paleolithic of northern Asia: achievements, problems and perspectives (III) – northeastern Siberia and Russian Far East. *Journal of World Prehistory* 6(4):441–76.

Laukhin, SA, Drozdov NI, Panychev VA, Velichko SV. 1989. The date of the last glaciation in northern East Chukotka. *International Geological Review* 31:527–31.

Lbova LV. 1996a. Paleoliticheskoe poselenie Varvarina Gora (The Paleolithic settlement of Varvarina Gora). In: Konstantinov MV, editor. *Novye paleoliticheskie pamyatniki Zabaikalya.* Chita: Chita State Teacher Trainers College. p 11–23.

Lbova LV. 1996b. Paleoliticheskoe mestonakhozhdenie Kamenka (The Paleolithic locality of Kamenka). In: Konstantinov MV, editor. *Novye paleoliticheskie pamyatniki Zabaikalya.* Chita: Chita State Teacher Trainers College. p 24–47.

Lbova LV, Bazarov BA, Buerachny EV. 1997. Mukhor-Tala: perspektivy izucheniya finalnogo paleolita v Buryatii (Mukhor-Tala: perspectives for the study of the Final Paleolithic in Buriatia). In: Vetrov VM, editor. *Dulovskie chteniya – 1997.* Irkutsk: Irkutsk State University. p 19–23.

Lisitsyn NF. 2000. *Pozdny paleolit Chulymo-Eniseiskogo mezhdurechiya* (The Late Paleolithic of Chulym-Yenisey region). St Petersburg: Petersburg Oriental Studies Press. 232 p.

Lisitsyn NF, Svezhentsev YS. 1997. Radiouglerodnaya khronologiya verkhnego paleolita Severnoi Azii (The radiocarbon chronology of the Upper Paleolithic of Northern Asia). In: Sinitsyn AA, Praslov ND, editors. *Radiouglerodnaya khronologiya paleolita Vostochnoi Evropy i Severnoi Azii: problemy i perspektivy.* St Petersburg: Institute of the History of Material Culture. p 67–108.

Longin R. 1971. New method of collagen extraction for radiocarbon dating. *Nature* 230:241–2.

Lozhkin, AV, Trumpe MA. 1990. Sistematizatsiya radiouglerodnykh datirovok arhkeologicheskikh pamyatnikov Magadanskoi oblasti (Systematization of radiocarbon dates of the archaeological sites on the Magadan District). In: Dikov NN, editor. *Drevnie pamyatniki Severa Dalnego Vostoka.* Magadan: Northeastern Interdisciplinary Research Institute. p 176–9.

MacPhee RDE, Tikhonov AN, Mol D, de Marliave C, van der Plicht J, Greenwood AD, Fleming C, Agenbroad L. 2002. Radiocarbon chronologies and extinction dynamics of the Late Quaternary mammalian megafauna of the Taimyr Peninsula, Russian Federation. *Journal of Archaeological Science* 29:1017–42.

Medvedev GI, Berdnikov AM, Fedorenko AB. 1991. Nekotorye voprosy izucheniya dokeramicheskikh mestonakhozhdenii Angaro-Osinskogo raiona (Some aspects of the study of the pre-ceramic localities in the Angara-Osa area). In: Medvedev GI, editor. *Paleoetnologicheskie issledovaniya na yuge Srednei Sibiri.* Irkutsk: Irkutsk State University. p 5–14.

Medvedev G, Cauwe N, Vorob'eva G, Coupe D, Claes L, Lipnina E, Modrie S, Mukharramov S, Osadchy S, Pettitte P, Rebrikov P, Rogovsky E, Sitlivyi V, Sulerzhitsky L, Khenzykhenova D. 1996. *Paleoliticheskoye mestonakhozhdenie Malta* (The Malta Paleolithic locality). Irkutsk: ARCOM Press. 31 p.

Medvedev GI, Savel'ev NA, Svinin VV, editors. 1990. *Stratigrafiya, paleogeografiya i arkheologiya yuga Srednei Sibiri* (Stratigraphy, paleogeography, and archaeology of the southern Central Siberia). Irkutsk: Irkutsk State University Press. 165 p.

Meshcherin MN. 1996. Kharakteristika industryi pozdnekarginskogo – rannesartanskogo vremeni Zapadnogo Zabaikal'ya (Characterization of the Late Karginsky – Early Sartan age industries from the western Transbaikal). In: Kononenko NA, editor. *Pozdny paleolit – ranny neolit Vostochnoi Azii i Severnoi Ameriki.* Vladivostok: Dalpress Publ. p 184–6.

Mochanov YA. 1977. *Drevneishie etapy zaseleniya chelovekom Severo-Vostochoi Azii* (The most ancient stages of human settling of Northeast Asia). Novosibirsk: Nauka Publ. 264 p.

Mochanov YA. 1984. Paleolithic finds in Siberia (resume of studies). In: Kontrimavichus VI, editor. *Beringia in Cenozoic Era*. New Delhi: Amerind Publ. p 694–724.

Muratov VM, Ovodov ND, Panychev VA, Safarova SA. 1982. Obschaya kharakteristika paleoliticheskoi stoyanki Malaya Syia v Khakasii (A general view of the Paleolithic site of Malaia Syia in Khakasiya). In: Konopatsky AK, Khudiakov YS, editors. *Arkheologiya Severnoi Azii.* Novosibirsk: Nauka Publ. p 33–48.

Nokhrina TI, Dergacheva MI, Petrin VT, Nikolaev SV. 2000. Peschernyie stoyanki Biika v doline Srednei Katuni (The Biika Cave sites at the Middle Katun' valley). In: Kiriushin YF, Tishkin AA, editors. *Okhrana i izuchenie kul'turnogo naslediya Altaya*. Volume 11. Barnaul: Altai State University Press. p 77–9.

Okladnikov AP. 1981. *Paleolit Tsentralnoi Azii. Moiltyn Am* (Paleolithic of Central Asia: Moil'tyn Am). Novosibirsk: Nauka Publ. 461 p.

Okladnikov AP, Grigorenko BG, Alexeeva EV, Volkov IA. 1971. Stoyanka verkhnepaleoliticheskogo cheloveka Volchya Griva (A site of Upper Paleolithic man at Volchia Griva). In: Okladnikov AP, editor. *Materialy Dal'nevostochnoi arkheologicheskoi ekspeditsii.* Part 2. Novosibirsk: Institute of History, Philology, and Philosophy. p 87–131.

Okladnikov AP, Kirillov II. 1980. *Iugo-vostochnoe Zabaikalie v epokhu kamnya i rannei bronzy* (The southeastern Transbaikal area in the Stone and Early Bronze Epoch). Novosibirsk: Nauka Publ. 177 p.

Orlova LA. 1979. Radiouglerodny vozrast iskopaemykh ostatkov mamonta na territorii SSSR (Radiocarbon age of the fossil mammoth remains on the USSR territory). *Izvestiya Sibirskogo Otdeleniya AN SSSR. Seriya obschestvennykh nauk* 16(2):89–97.

Orlova LA. 1995. Radiouglerodnoye datirovanie arkheologicheskikh pamyatnikov Sibiri i Dalnego Vostoka. Soobschenie 1 (Radiocarbon dating of archaeological sites from Siberia and the Russian Far East. Report 1). In: Derevianko AP, Kholushkin YP, editors. *Metody estestvennykh nauk v arheologicheskikh rekonstruktsiyakh.* Novosibirsk: Institute of Archaeology and Ethnography Press. p 207–32.

Orlova LA, Kuzmin YV, Volkova VS, Zolnikov ID. 2000b. Mamont (*Mammuthus primigenius* Blum.) i drevny chelovek v Sibiri: sopryazhenny analiz arealov populyatsyi na osnove radiouglerodnykh dannykh (Mammoth (*Mammuthus primigenius* Blum.) and prehistoric humans in Siberia: conjunctive spatial analysis of distributions based on the radiocarbon evidence). In: Markin SV, editor. *Problemy rekonstruktsii klimata i prirodnoi sredy golozena i pleistozena Sibiri*. Volume 2. Novosibirsk: Institute of Archaeology and Ethnography Press. p 383–412.

Orlova LA, Leschinsky SV, Zenin VN, Borisov MA. 2000a. Radiouglerodnye i stratigraficheskie issledovaniya mestonakhozhdeniya Volchya Griva v 2000 godu (Radiocarbon and stratigraphical studies of the Volchya Griva locality in 2000). In: Derevianko AP, Molodin VI, editors. *Problemy arkheologii, etnografii, antropologii Sibiri i sopredel'nykh territoryi*. Vol. 6. Novosibirsk: Institute of Archaeology and Ethnography Press. p 188–91.

Ovodov ND. 1975. Fauna paleoliticheskikh stoyanok Sibiri i problema khronologicheskikh i paleolandschaftnykh tolkovanyi (Fauna of the Paleolithic sites of Siberia and problem of their chronological and environmental interpretations). In: Derevianko AP, editor. *Sootnosheniye drevnikh kul'tur Sibiri s kul'turami sopredel'nykh territoryi*. Novosibirsk: Institute of History, Philology, and Philosophy. p 35–50.

Ovodov ND, Muratov VM, Panychev VA, Orlova LA. 1992. Novye dannye po geologii i teriofaune grota Proskuryakova (New data on the geology and mammalian fauna of the Proskuriakov rockshelter). In: Konstantinov MV, Rudenko YT, Zarubin, VG, editors. *Petr Alexeevich Kropotkin*. Chita: Chita State Teacher Trainers College. p 43–5.

Ovodov ND, Tomilova EA. 1998. Neandertal'tsy na Enisee (The Neanderthals at the Yenisey). In: Derevianko AP, editor. *Paleoekologiya pleistozena i kul'tury kamennogo veka Severnoi Azii i sopredel'nykh territoryi*. Part 1. Novosibirsk: Institute of Archaeology and Ethnography Press. p 379–85.

Petrin VT. 1986. *Paleoliticheskie pamyatniki Zapadno-Sibirskoi Ravniny* (The Paleolithic sites of the West Siberian Plain). Novosibirsk: Nauka Publ. 142 p.

Péwé TL. 1975. *Quaternary Geology of Alaska.* Geological Survey Professional Papers 835. Washington: US Geological Survey.

Praslov ND, Sulerzhitsky LD. 1997. De nouvelles données chronologiques pour le Paléolithique de Kostenki-sur-Don. *Préhistoire Européenne* 11:133–43.

Rasic J, Gal R. 2000. An early lithic assemblage from the Tuluaq site, Northwest Alaska. *Current Research at the Pleistocene* 17:66–8.

Savvinova GM, Mochanov YA, Fedoseeva SA. 1996. Pollen records from archaeological sites in the Aldansky Region, Sakha Republic. In: West FH, editor. *American beginnings: the prehistory and palaeoecology of Beringia.* Chicago: The University of Chicago Press. p 97–107.

Shmygun PE, Filippov AK. 1982. Nizhny komponent Kurlinskikh stoyanok (The lower component of the Kurla sites). In: Generalov AG, editor. *Material'naya kul'tura i drevnee naselenie Vostochnoi Sibiri*. Irkutsk: Irkutsk State University Press. p 15–24.

Shofman IL, Kind NV, Pakhomov MM, Prokopchuk BI, Vinogradova SN, Sulerzhitsky LD, Forova VS. 1977. Novye dannye o vozraste nizkikh terras v basseine reki Vilyi (New data about the age of the lower terraces in the Vilui River valley). *Bulleten' Komissii po izucheniyu chetvertichnogo perioda* 47:100–7.

Slobodin SB. 1999. Northeast Asia in the Late Pleistocene and Early Holocene. *World Archaeology* 30: 484–502.

Stafford TW Jr, Hare PE, Currie L, Jull AJT, Donahue D. 1991. Accuracy of North American human skeleton ages. *Quaternary Research* 34(1):111–20.

Starikov EV, Zhidovlenko VA, Gorozhankina SM. 1991. Radiouglerodnye daty Instituta lesa i drevesiny. Soobshchenie 5 (Radiocarbon dates of the Institute of wood and timber. Information no. 5). *Bulleten' Komissii po izucheniyu chetvertichnogo perioda* 60:143–4.

Sulerzhitsky LD. 1997. Cherty radiouglerodnoi khronologii mamontov Sibiri i severa Vostochnoi Evropy kak substrata dlya rasseleniya cheloveka (Patterns of the radiocarbon chronology of mammoths in Siberia and northern Eastern Europe as sub-stratum for human dispersal). In: Velichko AA, Soffer O, editors. *Chelovek zaselyaet planetu Zemlya*. Moscow: Institute of Geography. p 184–202.

Sulerzhitsky LD, Vinogradova SN, Ryabinin AL, Man'ko RV. 1987. Radiouglerodnye daty Geologicheskogo Instituta AN SSSR. Soobschenie 8 (Radiocarbon dates of the Geological Institute AN SSSR. Report 8). *Bulleten' Komissii po izucheniyu chetvertichnogo perioda* 56:149–54.

Svezhentsev YS, Lisitsyn NF, Vasil'ev SA. 1992. Radiouglerodnaya khronologiya Eniseiskogo paleolita (Radiocarbon chronology of the Paleolithic of Yenisey). In: Derevianko AP, editor. *Khronostratigraphiya paleolita Severnoi, Centralnoi i Vostochnoi Azii i Ameriki*. Novosibirsk: Institute of History, Philology, and Philosophy. p 57–64.

Tashak VI. 1996. *Paleolit i mezolit iuga Buryatii* (The Paleolithic and Mesolithic in the southern part of Buriatia). Abstract of the candidate of science dissertation. Novosibirsk: Institute of Archaeology and Ethnography. 18 p.

Taylor RE. 1997. Radiocarbon dating. In: Taylor RE, Aitken MJ, editors. *Chronometric dating in archaeology.* New York & London: Plenum Press. p 65–96.

Ten Brink NW. 1984. *North Alaska Range Project. Final report on 1978–1982 Geo-archaeological studies.* Allendale: Grand Valley State College.

Tseitlin SM. 1979. *Geologiya paleolita Severnoi Azii* (Geology of Paleolithic of Northern Asia). Moscow: Nauka Publ. 236 p.

Tseitlin SM. 1983. Tomskaya stoyanka (The site of Tomskaya). *Bulleten' Komissii po izucheniyu chetvertichnogo perioda* 52:181–2.

Vasil'chuk YK, Vasil'chuk AC, Long A, Jull AJT, Donahue DJ. 2000. AMS dating mammoth bones: Comparison with conventional dating. *Radiocarbon* 42(2):281–4.

Vasil'ev SA. 1993. The Upper Paleolithic of Northern Asia. *Current Anthropology* 34(1):82–92.

Vasil'ev SA. 1996. *Pozdny paleolit Verkhnego Eniseya* (The Late Paleolithic of the Upper Yenisey). St Petersburg: Petersburg Oriental Studies Press. 224 p.

Vetrov VM. 1995. Stone Age cultures of Upper Vitim. In: Kajiwara H, editor. *The origin of ceramics in the Far East*. Sendai: Tohoku Fukushi University Press. p 31–5.

Vorob'eva GA. 1991. Paleogeograficheskie usloviya osadkonakopleniya i otlozheniya mnogosloinoi stoyanki kamennogo veka Sosnovy Bor (Paleogeographical conditions of sedimentation and deposits of the multicomponent Stone Age site of Sosnovy Bor). In: Medvedev GI, editor. *Paleoetnologicheskie issledovaniya na yuge Srednei Sibiri.* Irkutsk: Irkutsk State Uiversity Press. p 15–25.

Vorob'eva GA, Generalov AG, Zagrafsky SI. 1998. Paleoliticheskie ob'ekty 30-go tysyacheletiya na yuge Srednei Sibiri (Archaeological sites dated to around 30,000 BP in the southern Central Siberia). In: Derevianko AP, editor. *Paleoekologiya pleistozena i kul'tury kamennogo veka Severnoi Azii i sopredel'nykh territoryi*. Part 2. Novosibirsk: Institute of Archaeology and Ethnography Press. p 46–54.

West FH, editor. 1996. *American beginnings. the prehistory and palaeoecology of Beringia*. Chicago: The University of Chicago Press. 576 p.

Yi S, Clark G. 1985. The "Dyuktai culture" and New World origins. *Current Anthropology* 26(1):1–20.

Zadonin OV. 1996. Paleoliticheskoe mestonakhozhdenie Alexeevsk I (Paleolithic locality of Alexeevsk I). In: Medvedev GI, editor. *Arkheologicheskoye nasledie Baikalskoi Sibiri*. Part 1. Irkutsk: Center for Cultural Heritage Preservation. p 23–7.

Zenin VN, Leshchinsky SV, Fedeneva IN, Orlova LA, Borisov MA. 2000a. Novye paleoliticheskie kompleksy Tom'-Eniseiskogo mezhdurechya (New Paleolithic assemblages from the Tom'-Yenisey watershed). In: Drozdov NI, editor. *Paleogeografiya kamennogo veka. Korrelyatsya prirodnykh sobytyi i arkheologicheskikh kul'tur paleolita Severnoi Azii i sopredel'nykh territoryi.* Krasnoyarsk: Krasnoyarsk State Pedagogical University. p 56–8.

Zenin VN, van der Plicht J, Orlova LA, Kuzmin YV, Brantingham PJ. 2000b. Geoarchaeology of the Shestakovo Upper Paleolithic site, Western Siberia: human-mammoth interactions during the Last Glacial Maximum. *Current Research in the Pleistocene* 17: 142–4.

Zenin VN, Orlova LA, van der Plicht J. 2000c. Radiouglerodnoye datirovanie stoyanki Shestakovo (Radiocarbon dating of the site of Shestakovo). In: Drozdov NI, editor. *Paleogeografiya kamennogo veka. Korrelyatsya prirodnykh sobytyi i arkheologicheskikh kul'tur paleolita Severnoi Azii i sopredel'nykh territoryi.* Krasnoyarsk: Krasnoyarsk State Pedagogical University. p 61–2.

Zenin VN, van der Plicht J, Orlova LA, Kuzmin YV. 2000d. AMS ^{14}C chronology of woolly mammoth (*Mammuthus primigenius* Blum.) remains from the Shestakovo Upper Paleolithic site, Western Siberia: timing of human-mammoth interaction. *Nuclear Instruments and Methods in Physics Research* B 172: 745–50.

APPENDIX

Table 1 Results from the updated ^{14}C Database of the Siberian Paleolithic

Site nr	Lat. N	Long. E	Site name, sample position	Material	Lab code	^{14}C date BP	Reference
Mousterian assemblages							
1	51.40	84.67	Denisova Cave, Layer 21	Humic acids	SOAN-2499	39,390±1310	Derevianko et al. 1998
			Denisova Cave, Layer 21	Charcoal	GX-17599	35,140±670*	Kuzmin & Orlova 1998
			Denisova Cave, Layer 21	Humic acids	SOAN-2488	>34,700	Derevianko et al. 1998
			Denisova Cave, Entrance, Layer 9	Charcoal	GX-17602	46,000±2,300*	Kuzmin & Orlova 1998
2	51.67	84.33	Okladnikov Cave, Layer 3	Bone	RIDDL-722	43,300± 1,300/–1,500*	Derevianko et al. 1998
			Okladnikov Cave, Layer 3	Bone	RIDDL-720	40,700± 1,100*	Derevianko et al. 1998
			Okladnikov Cave, Layer 3	Bone	RIDDL-721	32,400±500*	Derevianko et al. 1998
			Okladnikov Cave, Layer 2	Bone	RIDDL-719	37,750±750*	Derevianko et al. 1998
			Okladnikov Cave, Layer 1	Bone	RIDDL-718	33,500±700*	Derevianko et al. 1998
			Okladnikov Cave, Layer 3	Bone	SOAN-2459	28,470±1,250	Derevianko et al. 1998
			Okladnikov Cave, Layer 3	Bone	SOAN-2458	>16,210	Derevianko et al. 1998
3	51.17	83.02	Strashnaya Cave, depth 4 to 3 m (Layer 3/3)	Bone	SOAN-785	>25,000	Orlova 1995
			Strashnaya Cave	Bone	SOAN-3219	31,510±2,615	Kuzmin & Orlova 1998
4	51.17	86.20	Biika 1, Layer 5	Bone	Bln-4981	37,000±1,000	Nokhrina et al. 2000
			Biika 1, Layer 5	Bone	Bln-4980	23,480±300	Nokhrina et al. 2000
5	50.72	85.57	Kara-Bom, Stratum M1	Bone	AA-8894	>44,000*	Derevianko et al. 1998
			Kara-Bom, Stratum M1	Bone	AA-8873	>42,000*	Derevianko et al. 1998
6	54.58	86.37	Mokhovo 2	Bone	SOAN-2861	30,330±445	Orlova 1995
7	56.82	86.23	Aryshevskoe 1, Stratum 2	Humic acids	SOAN-4178	>40,000	Zenin et al. 2000a
			Aryshevskoe 1, Stratum 2	Humic acids	SOAN-4179	>40,000	Zenin et al. 2000a
			Aryshevskoe 1, Stratum 6	Charcoal	SOAN-4180	33,630±995	Zenin et al. 2000a
8	56.87	86.17	Voronino-Yaya, above cultural layer	Bone	SOAN-3837	28,450±850	Zenin et al. 2000a
9	54.13	90.95	Dvuglazka Cave, Layer 7	Bone	LE-4811	27,200±800	Lisitsyn & Svezhentsev 1997
10	54.45	89.47	Proskuriakov Rockshelter	Bone	SOAN-1519	40,770±1,075	Ovodov et al. 1992
			Proskuriakov Rockshelter	Bone	SOAN-1517	40,690±1,150	Ovodov et al. 1992
			Proskuriakov Rockshelter	Bone	SOAN-1518	40,595±875	Ovodov et al. 1992
			Proskuriakov Rockshelter	Bone	SOAN-848	>40,000	Ovodov 1975
11	55.17	91.58	Kurtak 4, Stratum 17	Bone	LE-3638	32,280±280	Svezhentsev et al. 1992
			Kurtak 4, Stratum 17	Charcoal	LE-3352	31,650±520	Svezhentsev et al. 1992
12	55.22	91.65	Ust'-Izhul'	Bone	SOAN-3334	>45,000	Ovodov & Tomilova 1998
			Ust'-Izhul'	Charcoal	AECV-2034C	>42,190	Drozdov et al. 1999
			Ust'-Izhul'	Bone	AECV-1939C	>42,100	Drozdov et al. 1999
			Ust'-Izhul'	Charcoal	AECV-2032C	>41,810	Drozdov et al. 1999
			Ust'-Izhul'	Charcoal	AECV-2033C	>40,050	Drozdov et al. 1999
13	51.25	112.25	Arta 2, up from Layer 5	Charcoal	LE-2967	37,360±2,000	Kirillov & Kasparov 1990
Upper Paleolithic Assemblages							
Western Siberia and Altai Mountanis							
14	56.32	66.37	Shikaevka	Bone	SOAN-2211	18,050±95	This paper

*AMS dates are shown by asterisks; other dates are conventional

Table 1 Results from the updated ^{14}C Database of the Siberian Paleolithic

Site nr	Lat. N	Long. E	Site name, sample position	Material	Lab code	^{14}C date BP	Reference
15	55.50	73.43	Chernoozierye 2, Layers 3 to 2	Charcoal	GIN-122	14,500±50	Gening & Petrin 1985
16	54.65	80.25	Volchiya Griva	Bone	SOAN-111	14,450±110	Firsov et al. 1985
			Volchiya Griva	Bone	SOAN-78	14,200±520	Okladnikov et al. 1971
			Volchiya Griva	Bone	SOAN-111	13,600±230	Lisitsyn & Svezhentsev 1997
			Volchiya Griva	Bone	SOAN-111A	13,600±230	Orlova 1979
			Volchiya Griva	Bone	SOAN-4292	14,280±285	Orlova et al. 2000a
			Volchiya Griva	Bone	SOAN-4293	12,520±150	Orlova et al. 2000a
17	56.48	85.00	Tomsk	Charcoal	GIN-2100	18,300±1,000	Tseitlin 1983
18	57.73	83.55	Mogochino 1, cultural layer	Bone	SOAN-1513	20,150±240	Petrin 1986
			Denisova Cave, Layer 11	Bone	SOAN-2504	>37,235	Derevianko et al. 1998
19	51.38	84.68	Ust'-Karakol 1, Layer 10	Charcoal	SOAN-3259	35,100±2,850	Derevianko et al. 1998
			Ust'-Karakol 1, Layer 9v	Charcoal	SOAN-3257	33,400±1,285	Derevianko et al. 1998
			Ust'-Karakol 1, Layer 9v	Charcoal	SOAN-3358	29,860±355	Derevianko et al. 1998
			Ust'-Karakol 1, Layer 9v	Charcoal	SOAN-3359	29,720±360	Derevianko et al. 1998
			Ust'-Karakol 1, Layer 5	Charcoal	SOAN-3326	30,460±2,035	Kuzmin & Orlova 1998
			Ust'-Karakol 1, Layer 5	Charcoal	SOAN-3356	27,020±435	Derevianko et al. 1998
			Ust'-Karakol 1, Layer 5	Charcoal	SOAN-3357	26,920±310	Derevianko et al. 1998
			Ust'-Karakol 1, Layer 5	Charcoal	SOAN-3261	26,305±280	Derevianko et al. 1998
			Ust'-Karakol 1, Layer 4	Humic acids	SOAN-3356	26,920±310	Kuzmin & Orlova 1998
			Ust'-Karakol 1, Excavation 1, Layer 3	Charcoal	SOAN-2515	31,410±1,160	Derevianko et al. 1998
			Ust'-Karakol 1, Excavation 1, Layer 3	Charcoal	SOAN-2869	31,345±1,275	Derevianko et al. 1998
			Ust'-Karakol 1, Excavation 1, Layer 3	Charcoal	IGAN-837	29,900±2,070	Derevianko et al. 1998
			Ust'-Karakol 1, Excavation 1, Layer 2	Bone	SOAN-2614	28,700±850	Derevianko et al. 1998
19a	51.38	84.68	Ust'-Karakol 2, Layer 3	Bone	IGAN-1077	31,430±1,180	Derevianko et al. 1998
20	51.39	84.66	Anyi 2, Layer 12	Charcoal	IGAN-1425	27,930±1,590	Derevianko et al. 1998
			Anyi 2, Layer 12	Charcoal	SOAN-3005	26,810±290	Derevianko et al. 1998
			Anyi 2, Layer 9	Charcoal	SOAN-2868	27,125±580	Derevianko et al. 1998
			Anyi 2, Layer 8	Charcoal	SOAN-3006	24,205±420	Derevianko et al. 1998
			Anyi 2, Layer 8	Charcoal	SOAN-2862	22,610±140	Derevianko et al. 1998
			Anyi 2, Layer 8	Charcoal	SOAN-2863	20,350±290	Derevianko et al. 1998
			Anyi 2, Layer 6	Charcoal	IGAN-1430	23,431±1,550	Derevianko et al. 1998
			Anyi 2, Layer 4	Charcoal	IGAN-1431	21,502±580	Derevianko et al. 1998
			Anyi 2, Layer 3	Charcoal	SOAN-3007	21,280±440	Derevianko et al. 1998
21	51.28	84.47	Kaminnaya Cave, Layer 14b	Bone	SOAN-3923	15,350±240	Derevianko et al. 2000a
			Kaminnaya Cave, Layer 14a	Bone	SOAN-3922	14,550±230	Derevianko et al. 2000a
			Kaminnaya Cave, Layer 13	Bone	SOAN-3921	14,120±95	Derevianko et al. 2000a
			Kaminnaya Cave, Layer 12	Bone	SOAN-3920	13,870±390	Derevianko et al. 2000a
			Kaminnaya Cave, Layer 11g	Bone	SOAN-3919	13,550±140	Derevianko et al. 2000a
			Kaminnaya Cave, Layer 11v	Bone	SOAN-3918	12,160±225	Derevianko et al. 2000a
22	51.20	86.07	Tyitkesken' 3, Layer 6	Charcoal	SOAN-2989	12,850±205	Derevianko et al. 1998
23	52.45	86.92	Dmitrievka, Strata 4 to 3	Charcoal	SOAN-4233	14,750±250	Sulerzhitskiy et al. 1987
5			Kara-Bom, Layer 6	Charcoal	GX-17597	43,200±1,500*	Derevianko et al. 1998
			Kara-Bom, Layer 5	Charcoal	GX-17596	43,300±1,600*	Derevianko et al. 1998
			Kara-Bom, Layer 4	Charcoal	GX-17595	34,180±640*	Derevianko et al. 1998
			Kara-Bom, Layer 4	Charcoal	GX-17594	33,780±570*	Derevianko et al. 1998
			Kara-Bom, Layer 3	Charcoal	GX-17593	30,990±460*	Derevianko et al. 1998
			Kara-Bom, up from Layer 3	Charcoal	GX-17592	38,080±910*	Derevianko et al. 1998
			Kara-Bom	Charcoal	GIN-5935	33,800±600	Derevianko et al. 1998

Table 1 Results from the updated ^{14}C Database of the Siberian Paleolithic

Site nr	Lat. N	Long. E	Site name, sample position	Material	Lab code	^{14}C date BP	Reference
			Kara-Bom, Layers 4 to 3	Bone	GIN-5934	32,200±600	Derevianko et al. 1998
24	51.05	86.30	Kara-Tenesh	Charcoal	SOAN-2485	42,165±4,170	Derevianko et al. 1998
			Kara-Tenesh	Bone	SOAN-2135	34,760±1,240	Derevianko et al. 1998
			Kara-Tenesh	Bone	SOAN-2486	31,400±410	Derevianko et al. 1998
			Kara-Tenesh	Bone	SOAN-2134	26,875±625	Derevianko et al. 1998
			Kara-Tenesh	Charcoal	SOAN-3646	25,630±430	Derevianko et al. 1998
25	50.42	86.52	Malyi Yaloman Cave, Layer 3	Charcoal	SOAN-2500	33,350±1,145	Derevianko et al. 1998
26	55.90	87.95	Shestakovo, Layer 24	Bone	GrA-13238	25,660±200*	Zenin et al. 2000c
			Shestakovo, Layer 24	Bone	GrA-13239	24,590±110*	Zenin et al. 2000c
			Shestakovo, Layer 22	Bone	GrA-13235	23,330±110*	Zenin et al. 2000c
			Shestakovo, Layer 22	Bone	SOAN-4177	22,500±280	Zenin et al. 2000c
			Shestakovo, Layer 22	Bone	SOAN-3612	22,240±185	Zenin et al. 2000c
			Shestakovo, Layer 21	Bone	SOAN-3611	21,300±420	Zenin et al. 2000c
			Shestakovo, Layer 19	Bone	GrA-10935	24,360±150*	Zenin et al. 2000c
			Shestakovo, Layer 19	Charcoal	GrA-13233	23,250±110*	Zenin et al. 2000c
			Shestakovo, Layer 19	Charcoal	AA-35322	23,290±200*	Zenin et al. 2000c
			Shestakovo, Layer 19	Bone	GrA-13240	22,340±180/170*	Zenin et al. 2000c
			Shestakovo, Layer 19	Charcoal	SOAN-3606	20,800±450	Zenin et al. 2000c
			Shestakovo, Layer 19	Bone	SOAN-3218	20,770±560	Zenin et al. 2000c
			Shestakovo, Layer 19	Bone	SOAN-3607	20,480±180	Zenin et al. 2000c
			Shestakovo, Layer 19	Bone	SOAN-3608	20,360±210	Zenin et al. 2000c
			Shestakovo, Layer 17	Bone	GrA-13234	21,560±100*	Zenin et al. 2000c
			Shestakovo, Layer 17	Bone	SOAN-3609	19,190±310	Zenin et al. 2000c
			Shestakovo, Layer 17	Bone	SOAN-3610	18,040±175	Zenin et al. 2000c
			Shestakovo	Bone	SOAN-1386	22,990±170	Lisitsyn & Svezhentsev 1997
			Shestakovo	Bone	SOAN-1380	22,980±125	Lisitsyn 2000
			Shestakovo	Bone	LU-104	22,410±200	Lisitsyn & Svezhentsev 1997
			Shestakovo	Charcoal	SOAN-1684	20,490±150	Derevianko & Zenin 1995a
The Yenisey River basin and adjacent areas							
27	54.42	89.45	Malaya Syia	Bone	SOAN-1286	34,500±500	Muratov et al. 1982
			Malaya Syia	Bone	SOAN-1287	34,420±360	Muratov et al. 1982
			Malaya Syia	Bone	AA-8876	29,450±420*	Kuzmin & Orlova 1998
			Malaya Syia	Bone	LE-4918	25,250±1,200	Lisitsyn 2000
			Malaya Syia	Charcoal	SOAN-1124	20,300±350	Derevianko et al. 1992
28	55.85	89.57	Berezovyi Ruchei I	Bone	LE-4895	15,310±560	Lisitsyn 2000
29	56.80	93.52	Druzhinikha, a surface finding	Bone	LE-4894	43,580±8,800	Lisitsyn 2000
30	56.00	92.85	Afontova Gora 2, lower humified lenses	Charcoal	GIN-117	20,900±300	Tseitlin 1979
			Afontova Gora 2, below Layer 5	Charcoal	GrA-5554	14,180±60*	Drozdov & Artem'ev 1997
			Afontova Gora 2, below Layer 5	Charcoal	GrA-5555	12,400±60*	Drozdov & Artem'ev 1997
			Afontova Gora 2, Layer 5	Bone	SOAN-3251	15,130±795	Kuzmin & Orlova 1998
			Afontova Gora 2, Layer 4	Charcoal	SOAN-3075	14,070±110	Drozdov & Artem'ev 1997
			Afontova Gora 2, Layer 4	Charcoal	GIN-7541	13,930±80	Drozdov & Artem'ev 1997
			Afontova Gora 2, Layer 4	Charcoal	GIN-7540	13,650±70	Drozdov & Artem'ev 1997
			Afontova Gora 2, up from Layer 4	Charcoal	GrN-22275	13,390±260*	Drozdov & Artem'ev 1997
			Afontova Gora 2, Layer 3b	Charcoal	SOAN-3077	14,330±95	Drozdov & Artem'ev 1997
			Afontova Gora 2, Layer 3b	Charcoal	GrN-22274	13,990±110*	Drozdov & Artem'ev 1997
			Afontova Gora 2, Layer 3	Charcoal	GIN-7539	13,350±60	Drozdov & Artem'ev 1997

Table 1 Results from the updated ^{14}C Database of the Siberian Paleolithic

Site nr	Lat. N	Long. E	Site name, sample position	Material	Lab code	^{14}C date BP	Reference
			Afontova Gora 2, Layer 2	Charcoal	GrA-5556	14,200±60*	Drozdov & Artem'ev 1997
			Afontova Gora 2, Layer 2	Charcoal	GIN-7542	13,330±140	Drozdov & Artem'ev 1997
31	55.95	92.40	Listvenka, Layer 19	Charcoal	SOAN-3734	16,640±350	Akimova et al. 2000a
			Listvenka, Layer 19	Bone	GIN-6093	16,300±600	Drozdov 1992
			Listvenka, Layer 12	Charcoal	Beta-58391	19,000±60*	Akimova 1998
			Listvenka, Layer 12	Charcoal	GIN-6965	13,100±410	Drozdov 1992
			Listvenka, Layer 9	Charcoal	GIN-6967	14,170±80	Drozdov 1992
			Listvenka, Layer 8	Charcoal	IGAN-1078	12,750±140	Drozdov 1992
			Listvenka, Layer 7	Charcoal	GIN-6092	14,750±250	Drozdov 1992
			Listvenka, Layer 6	Charcoal	SOAN-3463	13,850±485	Kuzmin & Orlova 1998
			Listvenka, Layer 6	Charcoal	IGAN-1079	13,580±350	Drozdov 1992
32	55.95	92.53	Bolshaya Slizneva, Layer 8	Charcoal	SOAN-3315	13,540±500	Kuzmin & Orlova 1998
			Bolshaya Slizneva, Layer 7	Bone	SOAN-3009	12,930±60	Kuzmin & Orlova 1998
33a	55.87	92.20	Biruisa 1, Layer 4	Bone	LE-4962	14,700±270	Kuz'mina & Sinitsyna 1995
			Biruisa 1, Layer 4	Bone	LE-4910	14,680±400	Kuz'mina & Sinitsyna 1995
			Biruisa 1, Layer 4	Bone	GIN-8077	14,200±70	Lisitsyn & Svezhentsev 1997
			Biruisa 1, Layer 4	Bone	GIN-8075	13,840±90	Lisitsyn & Svezhentsev 1997
			Biruisa 1, Layer 3a	Bone	LE-3777	14,480±400	Kuz'mina & Sinitsyna 1995
33b	55.97	92.48	Eleneva Cave, Section no. 1	Bone	SOAN-3333	13,665±90	Kuzmin & Orlova 1998
			Eleneva Cave, Section no. 2	Charcoal	SOAN-3307	12,050±325	Kuzmin & Orlova 1998
			Eleneva Cave, Section no. 2	Charcoal	SOAN-3308	12,040±160	Kuzmin & Orlova 1998
			Eleneva Cave, Section no. 2	Charcoal	SOAN-3309	12,085±105	Kuzmin & Orlova 1998
			Eleneva Cave, Layer 18	Bone	SOAN-3252	12,040±150	Orlova et al. 2000b
9			Dvuglazka Rockshelter, Layer 4	Bone	LE-4808	26,580±520	Lisitsyn 2000
			Dvuglazka Rockshelter	Bone	LE-1433	22,500±600	Arslanov et al. 1981
			Dvuglazka Rockshelter	Bone	LE-1433	20,190±140	Arslanov et al. 1981
			Dvuglazka Rockshelter	Bone	LE-1433	19,880±200	Arslanov et al. 1981
34	55.32	92.50	Derbina 5	Charcoal	SOAN-4201	32,430±1,540	Akimova et al. 2000b
			Derbina 5	Charcoal	SOAN-4200	29,230±940	Akimova et al. 2000b
35	54.58	91.07	Sabanikha, a surface finding	Antler	LE-3747	25,950±500	Lisitsyn 2000
			Sabanikha	Charcoal	LE-4796	25,440±450	Lisitsyn 2000
			Sabanikha	Charcoal	LE-3611	22,930±350	Svezhentsev et al. 1992
			Sabanikha	Charcoal	LE-4701	22,900±480	Svezhentsev et al. 1992
11			Kurtak 4, Strata 12 to 11	Charcoal	LE-2833	27,470±200	Svezhentsev et al. 1992
			Kurtak 4, Stratum 11	Bone	LE-3357	24,890±670	Svezhentsev et al. 1992
			Kurtak 4, Stratum 11	Charcoal	GIN-5350	24,800±400	Svezhentsev et al. 1992
			Kurtak 4, Stratum 11	Charcoal	LE-3351	24,170±230	Svezhentsev et al. 1992
			Kurtak 4, Stratum 11	Bone	LE-4156	24,000±2,950	Svezhentsev et al. 1992
			Kurtak 4, Stratum 11	Charcoal	LE-4155	23,800±900	Svezhentsev et al. 1992
			Kurtak 4, Stratum 11	Charcoal	LE-2833	23,470±200	Svezhentsev et al. 1992
36	54.97	90.95	Novoselovo 13, Layer 3	Charcoal	LE-3739	22,000±700	Svezhentsev et al. 1992
			Novoselovo 13, Layer 1	Bone	LE-4896	15,030±620	Lisitsyn 2000
			Novoselovo 13, Layer 1	Bone	LE-4805	13,630±200	Lisitsyn 2000
37	55.15	91.55	Kashtanka 1, buried soils (below cultural layer)	Charcoal	GrN-24482	36,130±510*	Drozdov et al. 2000
			Kashtanka 1, buried soils (below cultural layer)	Charcoal	GrN-24481	28,320±190*	Drozdov et al. 2000
			Kashtanka 1, below the main layer	Charcoal	GIN-6999	29,400±400	Derevianko et al. 1992

Table 1 Results from the updated ^{14}C Database of the Siberian Paleolithic

Site nr	Lat. N	Long. E	Site name, sample position	Material	Lab code	^{14}C date BP	Reference
			Kashtanka 1, below the main layer	Charcoal	IGAN-1048	24,400±1,500	Derevianko et al. 1992
			Kashtanka 1, below the main layer	Charcoal	IGAN-1050	23,830±850	Derevianko et al. 1992
			Kashtanka 1, Main Layer	Charcoal	SOAN-2853	24,805±425	Derevianko et al. 1992
			Kashtanka 1, Main Layer	Charcoal	IGAN-1049	21,800±200	Derevianko et al. 1992
			Kashtanka 1, Main Layer	Charcoal	GIN-6968	20,800±600	Derevianko et al. 1992
38	55.22	91.95	Shlenka, a surface finding	Tusk	GIN-2863	20,100±100	Astakhov et al. 1993
			Shlenka, a surface finding	Tusk	GIN-2862	18,600±2,000	Astakhov et al. 1993
39	55.05	91.05	Tarachikha, Loc. 1, a surface finding	Bone	LE-3821	19,850±180	Lisitsyn 2000
			Tarachikha, Loc. 1, a surface finding	Bone	LE-3834	18,930±320	Lisitsyn 2000
40	54.93	90.93	Kokorevo 4A, Layers 5 to 3	Charcoal	LE-469	14,320±330	Abramova 1979a
41	54.94	90.93	Kokorevo 2	Charcoal	GIN-90	13,300±100	Abramova 1979a
			Kokorevo 2	Bone	LE-4812	12,090±100	Lisitsyn 2000
42	55.16	91.57	Kurtak 3	Charcoal	GIN-2102	16,900±700	Abramova et al. 1991
			Kurtak 3	Charcoal	GIN-2101	14,600±200	Abramova et al. 1991
			Kurtak 3	Charcoal	LE-1456	14,390±100	Abramova et al. 1991
			Kurtak 3	Charcoal	LE-1457	14,300±100	Abramova et al. 1991
43	55.03	91.00	Divnyi 1	Bone	LE-4806	13,220±150	Lisitsyn 2000
44	54.60	91.02	Tashtyk 1, Layer 1	Bone	LE-4980	12,880±130	Lisitsyn 2000
			Tashtyk 1, Layer 1	Charcoal	LE-771	12,180±120	Abramova 1979a
45	54.61	91.01	Tashtyk 2, Layer 2	Bone	LE-4801	13,550±320	Lisitsyn 2000
46	54.58	91.00	Tashtyk 4	Charcoal	GIN-262	14,700±150	Abramova 1979a
47	54.93	90.94	Kokorevo 3	Charcoal	LE-629	12,690±140	Abramova 1979a
48	54.93	90.92	Kokorevo 1, Layer 3	Charcoal	IGAN-104	15,900±250	Abramova 1979b
			Kokorevo 1, Layer 3	Charcoal	LE-628	14,450±150	Abramova 1979b
			Kokorevo 1, Layer 3	Charcoal	GIN-91	13,300±50	Abramova 1979b
			Kokorevo 1, Layer 3	Bone	IGAN-102	13,000±50	Abramova 1979b
			Kokorevo 1, Layer 2	Charcoal	IGAN-105	15,200±200	Abramova 1979b
			Kokorevo 1, Layer 2	Bone	IGAN-103	13,100±500	Abramova 1979b
			Kokorevo 1, Layer 2	Charcoal	LE-526	12,940±270	Abramova 1979b
49	54.95	90.93	Kokorevo 4B, the lower layer	Bone	LE-540	15,460±320	Abramova 1979a
50	55.03	90.97	Novoselovo 6	Bone	LE-4807	18,090±940	Lisitsyn 2000
			Novoselovo 6	Bone	LE-5045	13,570±140	Lisitsyn 2000
51	55.03	90.98	Novoselovo 7	Bone	LE-4802	15,950±120	Lisitsyn 2000
			Novoselovo 7	Charcoal	GIN-402	15,000±300	Abramova 1979b
			Novoselovo 7	Bone	LE-4803	14,220±170	Lisitsyn 2000
52	54.63	90.90	Pervomaiskoe 1, a surface finding	Bone	LE-4893	12,870±140	Lisitsyn 2000
53	53.95	91.83	Pritubinsk, Layer 3	Charcoal	SOAN-2854	15,600±495	Orlova 1995
54	53.22	90.80	Ulug-Bil', a surface finding	Bone	LE-1404	15,020±150	Lisitsyn 2000
55	52.97	91.43	Ui 1, Layer 2	Charcoal	LE-4189	22,830±530	Vasil'ev 1996
			Ui 1, Layer 2	Bone	LE-4257	19,280±200	Vasil'ev 1996
			Ui 1, Layer 2	Bone	LE-3359	17,520±130	Vasil'ev 1996
			Ui 1, Layer 2	Bone	LE-3358	16,760±120	Vasil'ev 1996
56	52.08	92.35	Nizhny Idzhir 1	Charcoal	LE-1984	17,200±140	Astakhov 1986
57	53.08	91.42	Oznachennoye 1	Bone	LE-1404	15,020±150	Astakhov 1986
			Oznachennoye 1	Bone	LE-1404	14,100±150	Svezhentsev et al. 1992
58	52.97	91.45	Mayiniskaya, Layer 5	Bone	LE-2135	16,540±170	Vasil'ev 1996
			Mayiniskaya, Layer 5	Bone	LE-2135	16,176±180	Vasil'ev 1996
			Mayiniskaya, Layer 4	Bone	LE-4251	13,690±390	Vasil'ev 1996
			Mayniskaya, Layer 4	Bone	LE-2133	12,910±100	Vasil'ev 1996
			Mayiniskaya, Layer 3	Bone	LE-2149	14,070±150	Vasil'ev 1996
			Mayiniskaya, Layer 3	Bone	LE-2149	13,900±150	Vasil'ev 1996
			Mayiniskaya, Layer 3	Bone	LE-2149	12,330±150	Vasil'ev 1996

Table 1 Results from the updated ^{14}C Database of the Siberian Paleolithic

Site nr	Lat. N	Long. E	Site name, sample position	Material	Lab code	^{14}C date BP	Reference
			Mayiniskaya, Layer 3	Bone	LE-4252	12,120±650	Vasil'ev 1996
			Mayiniskaya, Layer 2-2	Charcoal	LE-2378	10,800±200	Vasil'ev 1996
			Mayiniskaya, Layer 2-1	Bone	LE-2300	12,280±150	Vasil'ev 1996
			Mayiniskaya, Layer 2-1	Bone	LE-2300	12,120±120	Vasil'ev 1996
			Mayiniskaya, Layer 1	Bone	LE-2299	15,500±150	Vasil'ev 1996
			Mayiniskaya, Layer B	Charcoal	LE-2383	15,200±150	Vasil'ev 1996
			Mayiniskaya, Layers A3 to A1	Bone	LE-3019	11,700±100	Vasil'ev 1996
			Mayiniskaya, Layer A1	Bone	LE-4255	12,110±220	Vasil'ev 1996
59	52.97	91.44	Ui 2, Layer 6	Charcoal	LE-3717	14,310±3,600	Lisitsyn 2000
60	52.98	91.52	Golubaya 1, Layer 3	Charcoal	LE-1101d	13,650±180	Astakhov 1986
			Golubaya 1, Layer 3	Charcoal	LE-1101a	13,050±90	Astakhov 1986
			Golubaya 1, Layer 3	Bone	LE-1101b	12,900±150	Astakhov 1986
			Golubaya 1, Layer 3	Bone	LE-1101c	12,980±140	Astakhov 1986
61	56.03	95.88	Brazhnoe	Bone	GIN-8481	>31,000	Vorob'eva et al. 1998
62	56.18	95.92	Strizhovaya Gora, Layer 18	Bone	GIN-5326	14,000±1,500	Generalov 2000
			Strizhovaya Gora, Layer 16 to 14	Bone	GIN-5820	12,250±150	Generalov 2000
			Strizhovaya Gora, Layer 16 to 14	Bone	GIN-5822	12,090±120	Generalov 2000
			Strizhovaya Gora, Layer 16 to 14	Bone	GIN-5821	12,000±150	Generalov 2000
The Angara River basin and the Lena River headwaters							
63	58.30	100.33	Ust'-Kova, Lower Component	Charcoal	GIN-5929	34,300±900	Drozdov et al. 1990
			Ust'-Kova, Lower Component	Charcoal	SOAN-1690	>32,850	Drozdov et al. 1990
			Ust'-Kova, Lower Component	Charcoal	GIN-1741	30,100±150	Drozdov et al. 1990
			Ust'-Kova, Lower Component	Charcoal	SOAN-1875	28,050±670	Drozdov et al. 1990
			Ust'-Kova, Lower Component	Charcoal	SOAN-1900	19,540±90	Drozdov et al. 1990
			Ust'-Kova, Middle Component	Charcoal	KRIL-381	23,920±310	Drozdov et al. 1990
			Ust'-Kova, Middle Component	Bone	LE-3820	13,860±680	Lisitsyn 2000
			Ust'-Kova, Upper Component	Charcoal	LE-1372	14,220±110	Drozdov et al. 1990
			Ust'-Kova, depth 1.5 m	Charcoal	KRIL-621	18,035±180	Starikov et al. 1991
64	52.30	104.17	Mamony 2, Layer 4	Bone	GIN-8480	31,400±150	Vorob'eva et al. 1998
65	52.30	104.32	Voenny Hospital	Bone	GIN-4410	29,700±500	Medvedev et al. 1990
66	53.58	103.42	Igeteisky Log I, Stratum 6	Bone	GIN-4327	24,400±100	Medvedev et al. 1990
			Igeteisky Log I, Stratum 4	Charcoal	IM-405	23,760±1,100	Medvedev et al. 1990
			Igeteisky Log I, Stratum 4	Charcoal	LE-1592	23,508±250	Medvedev et al. 1990
			Igeteisky Log I, Stratum 4	Charcoal	LE-1590	21,260±240	Medvedev et al. 1990
67	52.83	103.53	Malta, Stratum 6	Bone	OxA-6189	43,100±2,400*	Medvedev et al. 1996
			Malta, gravel	Bone	GIN-7707	41,100±1,500	Medvedev et al. 1996
			Malta, contact between Strata 7 and 3	Bone	OxA-6190	25,760±260*	Medvedev et al. 1996
			Malta, Stratum 8	Bone	OxA-6191	21,700±160*	Medvedev et al. 1996
			Malta, Stratum 8	Bone	GIN-7708	21,600±200	Medvedev et al. 1996
			Malta, Stratum 8	Bone	GIN-8475	21,600±170	Medvedev et al. 1996
			Malta, Stratum 8	Bone	OxA-6193	21,340±340*	Medvedev et al. 1996
			Malta, Stratum 8	Bone	GIN-7704	21,300±300	Medvedev et al. 1996
			Malta, Stratum 8	Bone	GIN-7702	21,300±110	Medvedev et al. 1996
			Malta, Stratum 8	Bone	GIN-7703	21,100±150	Medvedev et al. 1996
			Malta, Stratum 8	Bone	GIN-7706	21,000±140	Medvedev et al. 1996

Table 1 Results from the updated ^{14}C Database of the Siberian Paleolithic

Site nr	Lat. N	Long. E	Site name, sample position	Material	Lab code	^{14}C date BP	Reference
			Malta, Stratum 8	Bone	GIN-7710	20,800±140	Medvedev et al. 1996
			Malta, Stratum 8	Bone	OxA-6192	20,340±320*	Medvedev et al. 1996
			Malta, Stratum 8	Bone	GIN-7705	19,900±800	Medvedev et al. 1996
			Malta, washed sediments	Bone	GIN-7709	20,700±150	Medvedev et al. 1996
			Malta, Stratum 9	Tusk	GIN-8476	14,720±190	Medvedev et al. 1996
			Malta, main cultural layer	Bone	GIN-4367	20,900±200	Medvedev et al. 1996
			Malta, main cultural layer	Bone	GIN-4367	20,800±200	Medvedev et al. 1996
			Malta	Bone	GIN-87	14,750±120	Tseitlin 1979
68	53.00	103.50	Buret’	Bone	SOAN-1680	21,190±100	Abramova 1989
69	53.67	103.43	Krasny Yar 1, Layer 6	Bone	GIN-5330	19,100±100	Medvedev et al. 1991
70	52.87	103.43	Sosnovy Bor, Layer 3b	Bone	GIN-5328	12,060±120	Vorob’eva 1991
			Sosnovy Bor, Layer 4	Bone	AA-38038	12,090±110*	This paper
71	52.37	104.28	Verkholenskaya Gora 1, Layer 3d	Charcoal	Mo-441	12,570±180	Medvedev et al. 1990
72	54.00	105.82	Makarovo 4, Layer 3a	Bone	AA-8800	>39,000*	Goebel & Aksenov 1995
			Makarovo 4, Layer 3a	Bone	AA-8878	>38,000*	Goebel & Aksenov 1995
			Makarovo 4, Layer 3a	Bone	AA-8879	>38,000*	Goebel & Aksenov 1995
73	54.02	105.80	Makarovo 3	Bone	GIN-7067b	31,200±500	Aksenov 1993
74	54.02	105.67	Shishkino 8	Bone	AA-8882	21,190±175*	Aksenov 1993
75	54.03	105.82	Makarovo 2, Layer 4	Charcoal	GIN-481	11,950±50	Medvedev et al. 1990
76	54.03	105.78	Shishkino 2, Layer 3	Charcoal	GIN-5634	13,900±200	Aksenov 1996
77	57.48	107.77	Balyshevo 3, Layer 2	Bone	LE-3950	25,100±940	Lisitsyn & Svezhentsev 1997
78	57.83	108.37	Alexeevsk 1	Charcoal	LE-3931	22,415±480	Zadonin 1996
79	55.65	109.35	Kurla 3, Layer 2	Charcoal	SOAN-1397	24,060±5,700	Shmygun & Filippov 1982
			Kurla 3, Layer 1	Bone	SOAN-1396	15,200±1,250	Shmygun & Filippov 1982
			Kurla 3, Layer 1	Bone	SOAN-1396	13,160±350	Ineshin 1993
			Kurla 6	Charcoal	SOAN-1398	14,150±960	Shmygun & Filippov 1982
80	57.83	114.00	Bolshoi Yakor 1, Layer 9	Charcoal	GIN-8470	12,700±400	Belousov et al. 1997
			Bolshoi Yakor 1, Layer 8	Charcoal	GIN-6468	12,630±230	Belousov et al. 1997
			Bolshoi Yakor 1, Layer 7	Bone	GIN-6467	12,380±250	Belousov et al. 1997
			Bolshoi Yakor 1, Layer 7	Charcoal	GIN-6466	12,330±250	Belousov et al. 1997
			Bolshoi Yakor 1, Layer 6	Charcoal	GIN-7712	15,900±270	Belousov et al. 1997
			Bolshoi Yakor 1, Layer 6	Charcoal	LE-4172	12,400±150	Belousov et al. 1997
			Bolshoi Yakor 1, Layer 6	Bone	GIN-6425	12,380±200	Belousov et al. 1997
			Bolshoi Yakor 1, Layer 5	Charcoal	GIN-7711	17,840±290	Belousov et al. 1997
			Bolshoi Yakor 1, Layer 5	Charcoal	GIN-8470	12,700±140	Belousov et al. 1997
			Bolshoi Yakor 1, Layer 5	Charcoal	GIN-8473	12,700±90	Belousov et al. 1997
			Bolshoi Yakor 1, Layer 5	Charcoal	GIN-7713	12,530±90	Belousov et al. 1997
			Bolshoi Yakor 1, Layer 5	Charcoal	GIN-8471	12,200±80	Belousov et al. 1997
			Bolshoi Yakor 1, Layer 5	Charcoal	GIN-8472	12,050±120	Belousov et al. 1997
			Bolshoi Yakor 1, Layer 3v	Charcoal	GIN-6460A	12,080±220	Belousov et al. 1997
			Bolshoi Yakor 1, Layer 3v	Charcoal	GIN-6460	12,000±250	Belousov et al. 1997
81	57.83	114.09	Avdeikha, depth 0.8 to 1.2 m	Charcoal	IM-236	15,200±300	Kostiukevich et al. 1977
			Avdeikha, depth 0.8 to 1.2 m	Charcoal	GIN-1022	12,900±300	Kind et al. 1976
82	55.63	115.87	Nizhniaya Dzhilinda 1, Layer 7	Charcoal	GIN-6466	12,330±250	Kuzmin & Tankersley 1996
83	54.47	116.52	Ust'-Karenga 12, Layer 8	Bone	GIN-8668	16,430±240	Vetrov 1995
			Ust'-Karenga 12, Layer 8	Bone	GIN-8070	13,560±1,950	Vetrov 1995
			Ust'-Karenga 12, Layer 8	Bone	GIN-6469	12,880±130	Vetrov 1995
			Ust'-Karenga 12, Layer 8	Bone	GIN-8069	12,710±380	Vetrov 1995
The Transbaikal							
84	50.53	106.30	Ust'-Kyakhta 4, Layer 2	Bone	SOAN-1553	12,595±150	Okladnikov 1981

Table 1 Results from the updated ^{14}C Database of the Siberian Paleolithic

Site nr	Lat. N	Long. E	Site name, sample position	Material	Lab code	^{14}C date BP	Reference
85	50.53	106.32	Ust'-Kyakhta 17, Layer 5	Bone	GIN-8493b	12,230±100	Tashak 1996
			Ust'-Kyakhta 17, Layer 5	Bone	GIN-8493a	12,100±80	Tashak 1996
86	51.63	108.17	Varvarina Gora	Bone	AA-8893	>35,300*	Goebel & Aksenov 1995
			Varvarina Gora	Bone	AA-8875	>34,050*	Goebel & Aksenov 1995
			Varvarina Gora	Bone	SOAN-1524	34,900±780	Bazarov et al. 1982
			Varvarina Gora	Bone	SOAN-850	30,600±500	Bazarov et al. 1982
			Varvarina Gora, Layer 2	Bone	SOAN-3054	29,895±1,790	Lbova 1996a
			Varvarina Gora, Layer 1	Bone	SOAN-3053	17,035±400	Lbova 1996a
87	51.77	108.33	Kamenka 1, Component A	Bone	AA-26743	40,500±3,800*	Buerachnyi & Lbova 2000
			Kamenka 1, Component A	Charcoal	SOAN-3133	31,060±530	Lbova 1996b
			Kamenka 1, Component A	Bone	SOAN-3354	30,460±430	Lbova 1996b
			Kamenka 1, Component A	Bone	SOAN-2903	28,060±475	Lbova 1996b
			Kamenka 1, Component A	Bone	SOAN-3353	26,760±265	Lbova 1996b
			Kamenka 1, Component A	Bone	SOAN-3355	25,540±300	Kuzmin & Orlova 1998
			Kamenka 1, Component A	Bone	SOAN-3031	24,625±190	Lbova 1996b
			Kamenka 1, Component C	Bone	SOAN-3052	30,220±270	Lbova 1996b
			Kamenka 1, Component B	Bone	SOAN-2904	35,845±695	Lbova 1996b
			Kamenka 1, Component B	Bone	SOAN-3032	28,815±150	Lbova 1996b
88	51.22	109.33	Tolbaga, Stratum 4	Bone	SOAN-1522	34,860±2,100	Bazarov et al. 1982
			Tolbaga, Stratum 4	Bone	SOAN-1523	27,210±300	Bazarov et al. 1982
			Tolbaga, Stratum 4	Bone	AA-8874	25,200±260*	Goebel & Waters 2000
			Tolbaga, Stratum 4	Bone	AA-26740	29,200±1,000*	Goebel & Waters 2000
			Tolbaga, Stratum 4	Bone	SOAN-3078	26,900±225	Sinitsyn & Praslov 1997
			Tolbaga, Stratum 3	Bone	SOAN-840	15,100±520	Bazarov et al. 1982
89	51.78	108.80	Mukhor-Tala 7	Charcoal	SOAN-3468	11,630±300	Lbova et al. 1997
90	50.62	107.80	Kunalei, below Layer 3	Humic acids	GIN-6124	21,100±300	Konstantinov 1994
91	50.93	108.60	Kandabaevo	Bone	SOAN-1625	38,460±1,100	Orlova 1995
92	50.43	110.00	Masterov Kliych, Layer 4	Bone	AA-8888	24,360±270*	Meshcherin 1996
93	50.18	108.55	Priiskovaya	Bone	AA-8891	25,825±290*	Kuzmin & Orlova 1998
94	50.27	107.23	Podzvonkaya	Bone	AA-26741	38,900±3,300*	Klement'ev 2000
			Podzvonkaya	Bone	AA-26742	>36,800*	Klement'ev 2000
			Podzvonkaya	Bone	SOAN-3404	26,000±1,000	Tashak 1996
			Podzvonkaya	Bone	SOAN-3350	22,675±265	Kuzmin & Orlova 1998
95	52.28	109.83	Khotyk 3, Layer 2	Charcoal	AA-32669	26,220±550*	This paper
96	50.17	108.50	Studenoe 1, Layer 19/1	Charcoal	GIN-6139	12,330±60	Konstantinov 1994
			Studenoe 1, Layer 18/2	Charcoal	GIN-2947	12,800±400	Konstantinov 1994
			Studenoe 1, Layer 18/1	Charcoal	LE-2061	13,430±150	Konstantinov 1994
			Studenoe 1, Layer 18/1	Charcoal	GIN-2935	12,110±150	Konstantinov 1994
			Studenoe 1, Layer 17	Charcoal	GIN-2934	12,140±150	Konstantinov 1994
			Studenoe 1, Layer 17	Charcoal	GIN-2934a	12,130±150	Konstantinov 1994
			Studenoe 1, Layer 15	Charcoal	GIN-2931	14,900±2,000	Konstantinov 1994
			Studenoe 1, Layer 15	Charcoal	LE-2062	12,290±130	Konstantinov 1994
			Studenoe 1, Layer 14	Charcoal	GIN-2925	12,300±700	Konstantinov 1994
97	50.17	108.49	Studenoe 2, Layer 5	Charcoal	AA-23657	17,165±115*	Goebel et al. 2000
			Studenoe 2, Layer 4/5	Bone	AA-26739	18,830±300*	Goebel et al. 2000
			Studenoe 2, Layer 4/5, hearth 1	Charcoal	AA-23653	17,885±120*	Goebel et al. 2000
			Studenoe 2, Layer 4/5, hearth 2	Charcoal	AA-23655	17,225±115*	Goebel et al. 2000
98			Ust'-Menza 2, Layer 21	Charcoal	GIN-5464	17,600±250	Konstantinov 1994
			Ust'-Menza 2, Layer 21	Charcoal	GIN-5464A	17,190±120	Konstantinov 1994
			Ust'-Menza 2, Layer 20	Charcoal	GIN-5465	16,980±150	Konstantinov 1994

Table 1 Results from the updated ^{14}C Database of the Siberian Paleolithic

Site nr	Lat. N	Long. E	Site name, sample position	Material	Lab code	^{14}C date BP	Reference
			Ust'-Menza 2, Layer 17	Charcoal	GIN-6117	16,900±500	Konstantinov 1994
			Ust'-Menza 2, Layer 17	Charcoal	GIN-5478	15,400±400	Konstantinov 1994
			Ust'-Menza 2, Layer 11	Charcoal	GIN-6116	14,830±390	Konstantinov 1994
99	50.21	108.62	Ust'-Menza 1, Layer 14	Charcoal	GIN-7161	11,820±120	Konstantinov 1994
100	50.13	108.82	Kosaya Shivera 1, Layer 14	Charcoal	GIN-6123	12,070±300	Konstantinov 1994
13			Arta 2, Layer 3	Charcoal	LE-2966	23,200±2,000	Kirillov & Kasparov 1990
101	52.02	113.43	Sokhatino 4, Layer 8	Bone	LE-3653	16,970±720	Lisitsyn & Svezhentsev 1997
			Sokhatino 4, Layer 7	Bone	LE-3647	16,820±390	Kirillov & Cherensh-chikov 1996
			Sokhatino 4, Layer 6	Bone	LE-3652	15,820±300	Lisitsyn & Svezhentsev 1997
			Sokhatino 4	Charcoal	SOAN-1138	26,110±150	Okladnikov & Kirillov 1980
The Russian Far East							
102	50.30	130.32	Malye Kuruktachi	Charcoal	SOAN-3287	14,200± 130	Kuzmin et al. 1998a
			Malye Kuruktachi	Charcoal	AA-13399	13,815± 150*	Kuzmin et al. 1998a
			Malye Kuruktachi	Charcoal	AA-13398	13,310 ±105*	Kuzmin et al. 1998a
			Malye Kuruktachi	Charcoal	AA-17212	12,485± 80*	Kuzmin et al. 1998a
			Malye Kuruktachi	Charcoal	AA-23128	12,010± 75*	Kuzmin et al. 1998a
103	51.92	129.30	Ust'-Ulma 1, Layer 2	Charcoal	SOAN-2619	19,360±65	Derevianko & Zenin 1995b
104	42.92	133.05	Geographical Society Cave	Bone	AA-37070	>40,000*	This paper
			Geographical Society Cave	Bone	AA-37068	>39,000*	This paper
			Geographical Society Cave	Bone	AA-37071	>38,000*	This paper
			Geographical Society Cave	Bone	AA-34074	>38,000*	This paper
			Geographical Society Cave	Bone	AA-37072	>37,000*	This paper
			Geographical Society Cave	Bone	AA-37073	>36,000*	This paper
			Geographical Society Cave	Bone	AA-37069	35,100±1,900*	This paper
			Geographical Society Cave	Bone	AA-38230	34,510±1,800*	This paper
			Geographical Society Cave	Bone	AA-37183	34,400±1,800*	This paper
			Geographical Society Cave	Bone	AA-38229	34,300±1,700*	This paper
			Geographical Society Cave	Bone	IGAN-341	32,570±1,510	Kuz'min 1994
105	44.27	135.30	Suvorovo 4	Charcoal	AA-9463	15,105±100*	Krupianko & Tabarev 2001
			Suvorovo 4	Charcoal	Ki-3502	15,300±140	Krupianko & Tabarev 2001
			Suvorovo 4	Charcoal	AA-36625	15,340±90*	Krupianko & Tabarev 2001
			Suvorovo 4	Charcoal	AA-36626	15,900±120*	Krupianko & Tabarev 2001
106	43.95	132.40	Gorbatka 3 (below cul-tural layer)	Organics	SOAN-1922	13,500±200	Kuznetsov 1992
			Ogonki 5, Layer 2b	Charcoal	AA-20864	19,320±145*	Kuzmin et al. 1998b
			Ogonki 5, Layer 2b	Charcoal	AA-25434	18,920±150*	Kuzmin et al. 1998b
107	46.78	142.43	Ogonki 5, Layer 2b	Charcoal	AA-23137	17,860±120*	Kuzmin et al. 1998b
The Yakutia and Northeastern Siberia							
108	59.99	117.35	Khaergas Cave, Layer 6	Bone	IM-887	16,000±300	Cherosov 1988
109	60.52	135.13	Ezhantsy, Layer 3 (depth 0.6 to 1.0 m)	Bone	IM-459	17,150±345	Kostiukevich et al. 1980
110	59.65	133.12	Ust'-Mil 2, Stratum 5 (below cultural layer)	Wood	LE-955	35,600±900	Mochanov 1977

Table 1 Results from the updated ^{14}C Database of the Siberian Paleolithic

Site nr	Lat. N	Long. E	Site name, sample position	Material	Lab code	^{14}C date BP	Reference
			Ust'-Mil 2, Stratum 4, middle part	Wood	LE-954	35,400±600	Mochanov 1977
			Ust'-Mil 2, Stratum 4, middle part	Wood	LE-1000	33,333±500	Mochanov 1977
			Ust'-Mil 2, Stratum 4, middle part	Wood	LE-1101	30,000±500	Mochanov 1977
			Ust'-Mil 2, Stratum 4, upper part	Wood	LE-999	23,500±500	Mochanov 1977
			Ust'-Mil 2, Stratum 3	Wood	LE-953	12,200±170	Mochanov 1977
111	63.12	133.60	Ikhine 1, Layer 2	Bone	IM-452	16,660±270	Kuzmin & Orlova 1998
112	63.12	133.62	Ikhine 2, Layer 2g	Wood	IM-206	27,800±500	Mochanov 1977
			Ikhine 2, Layer 2v	Wood	GIN-1020	31,200±500	Mochanov 1977
			Ikhine 2, Layer 2v	Wood	IM-201	26,600±900	Mochanov 1977
			Ikhine 2, Layer 2v	Wood	IM-201	26,500±900	Mochanov 1977
			Ikhine 2, Layer 2v	Bone	IM-239	26,030±200	Mochanov 1977
			Ikhine 2, Layer 2b	Wood	GIN-1019	30,200±300	Mochanov 1977
			Ikhine 2, Layer 2b	Wood	IM-205	27,400±800	Mochanov 1977
			Ikhine 2, Layer 2b	Wood	IM-155	24,600±380	Mochanov 1977
			Ikhine 2, Layer 2b	Wood	IM-203	24,500±480	Mochanov 1977
			Ikhine 2, Layer 2b	Wood	LE-1131	24,330±200	Mochanov 1977
			Ikhine 2, layer unknown	Bone	SOAN-3185	20,080±150	Kuzmin & Orlova 1998
			Ikhine 2, layer unknown	Bone	SOAN-3186	19,695±100	Kuzmin & Orlova 1998
			Ikhine 2, layer unknown	Bone	SOAN-3187	15,780±70	Orlova et al. 2000b
113	60.35	134.45	Verkhne-Troitskaya, Layer 6	Wood	LE-905	18,300±180	Mochanov 1977
			Verkhne-Troitskaya, Layer 6 (above artifacts)	Wood	LE-906	17,680±250	Mochanov 1977
			Verkhne-Troitskaya, Layer 6 (above artifacts)	Charcoal	GIN-626	15,950±250	Mochanov 1977
			Verkhne-Troitskaya, Layer 6 (above artifacts)	Wood	LE-864	14,530±160	Mochanov 1977
114	59.30	132.60	Dyuktai Cave, Depth 2.7 m	Bone	IM-462	12,520±259	Kostiukevich et al. 1984
			Dyuktai Cave, Layer 7v	Wood	LE-908	13,110±90	Mochanov 1977
			Dyuktai Cave, Layer 7b	Charcoal	GIN-404	14,000±100	Mochanov 1977
			Dyuktai Cave, Layer 7b	Charcoal	LE-784	13,070±90	Mochanov 1977
			Dyuktai Cave, Layer 7b	Charcoal	LE-860	12,960±120	Mochanov 1977
			Dyuktai Cave, Layer 7a	Charcoal	GIN-405	13,200±250	Mochanov 1977
			Dyuktai Cave, Layer 7a	Wood	IM-462	12,520±260	Mochanov 1977
			Dyuktai Cave, Layer 7a	Wood	LE-907	12,100±120	Mochanov 1977
115	70.43	143.95	Berelekh	Wood	IM-152	13,420±200	Mochanov 1977
			Berelekh	Wood	GIN-1021	12,930±80	Mochanov 1977
116	56.17	159.97	Ushki 1, Layer 7	Charcoal	GIN-167	14,300±200	Dikov 1996a
			Ushki 1, Layer 7	Charcoal	GIN-167	13,600±250	Dikov 1977
			Ushki 1, Layer 6a	Charcoal	LE-4185	13,800±600	Lisitsyn & Svezhentsev 1997
117	61.63	149.52	Siberdik, Layer 3	Charcoal	MAG-916	13,225±230	Lozhkin & Trumpe 1990

RADIOCARBON, Vol 44, Nr 2, 2002, p 531–540

NEW RADIOCARBON DATES FROM THE BALKANS (DUBENE-SAROVKA): APPROACH TO THE EARLY BRONZE ABSOLUTE CHRONOLOGY IN UPPER THRACE

Lolita Nikolova

International Institute of Anthropology, PO Box 112065, Salt Lake City, Utah 84117-2065 USA, and Prehistory Foundation, 30 Krivolac, Karlovo 4300, Bulgaria; Adjunct-Associate Professor at University of Utah, Salt Lake City, Utah, USA. Email: lnikolova@iianthropology.org.

Jochen Görsdorf

Deutsches Archäologisches Institut, Eurasien-Abteilung, Postfach 330014, 14191 Berlin, Germany. Email: 14C@dainst.de.

ABSTRACT. This paper addresses the absolute chronology of the earlier Yunatsite and Ezero cultures in Upper Thrace (South Bulgaria), from Early Bronze I and the beginning of Early Bronze II. The two newly obtained radiocarbon dates from Early Bronze Dubene-Sarovka (the Upper Stryama Valley) are published and discussed in a detailed stratigraphic and comparative Early Bronze I–Early Bronze II context. Date Bln-5233 (3490–3120 cal BC) is the first ^{14}C date from the Upper Maritsa valley from Early Bronze I with well-defined stratigraphic context and values earlier than 3100 BC. This date adds new arguments to the discussion of the ^{14}C dates from Yunatsite 15 and Plovdiv–Nebet Tepe, and addresses the question of the comparative chronology of Yunatsite I and Ezero I cultures from the late fourth millennium BC.

The sample of the date Bln-5231 (2870–2620 cal BC) comes from a level on the border between Early Bronze I and Early Bronze II. On one hand, its values preceded the values of the earlier-obtained ^{14}C dates from IIB layer and confirmed the stratigraphic sequence at Dubene-Sarovka tell. On the other hand, the calibrated values seem to be later than the vast comparative chronology of the end of the Dubene IIA—the beginning of Dubene IIB (ca. 3000 BC). Similar problems occur with dates from Yunatsite and Ezero. The published new dates from Dubene-Sarovka are part of the project on complex elaborating of the Early Bronze absolute chronology in the Balkans, and especially on contextual analysis of the ^{14}C dates.

INTRODUCTION

Our objective here is to provide two new radiocarbon dates with their stratigraphic context from the newly investigated tell in the Upper Stryama valley–Dubene-Sarovka, to consider their interrelations, and to put them together in the newly considered EB I-II comparative chronology of Upper Thrace.

The Middle and Upper Maritsa (Upper Thrace, central south and southeast Bulgaria) and its tributaries (e.g. the Stryama) are a key region for the elaboration of the Early Bronze (EB) ^{14}C chronology of the Balkans. The archaeological sites from this region have provided a solid record foundation—long stratigraphic sequences, numerous ^{14}C dates, and contact data with close and distant cultures (Nikolova and Görsdorf 1998; Nikolova 1999a). Nevertheless, recent interpretations of the ^{14}C dates from the eastern and western parts of Upper Thrace have resulted in contradictory hypotheses about the absolute chronology of the Early Bronze cultures in the region (Ezero and Yunatsite cultures, respectively). The main reason is the difference in the ^{14}C dates from both key sites—Ezero and Yunatsite tells. Then, it has become apparent that we need to complete the EB absolute chronology of the different micro-regions in the Maritsa valley, to include them in the comparative characteristics of the mentioned popular sites in order to compile a detailed EB absolute chronology of Upper Thrace cultures.

Dubene-Sarovka: Stratigraphy and Relative Chronology

Dubene-Sarovka is a low tell in northwest Thrace at 315 m above sea level. It is situated on the left side of the valley of the Upper Stryama, one of the biggest tributaries of the Maritsa River (Figure 1), in the Karlovo Hollow, which is divided from the Maritsa basin by the middle ranges of the Sredna Gora Mountains. Passes of the western Sredna Gora Mountains connect the Karlovo Hollow with

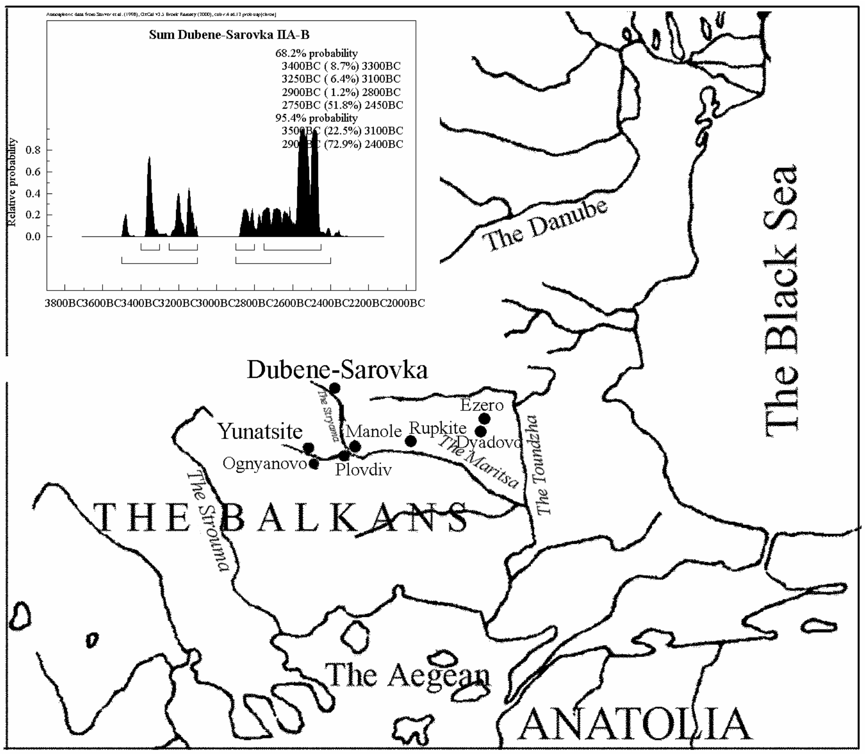


Figure 1 Map of the Balkans showing the main sites studied here. Inset: chart of the sum-probability of Dubene-Sarovka IIA-B ^{14}C dates (n=4).

Sofia Field in southwest Bulgaria and farther with the Morava valley in eastern Serbia, while to the east there are small interrelated hollows connecting the upper Stryama valley with the vast Upper Toudzha valley.

The systematic excavations of the Dubene-Sarovka tell began in 1992[1]. During eight seasons, the site was recovered over more than 4000 m^2 at a depth of 0.50–1.00 m below the surface, while control trenches reached the subsoil at about −2.00 m from the datum. As a result, thick cultural layers from Late Copper (Karanovo VI culture) and Early Bronze I-II (Yunatsite culture I-II) have been documented (Nikolova 1999b). The stratigraphic data were supplemented by a bountiful ceramic record and by archaeomagnetic (Kovacheva et al. 1995; also excavation campaign 1999) and ^{14}C samples (Nikolova and Görsdorf 1998). The complex results from these sites contributed considerably to the modern Early Bronze chronology of the Balkans (Nikolova 1999a, 1999b).

The Early Bronze levels at Dubene-Sarovka have been divided into two main stages, IIA and IIB, respectively. The surface data and some pits documented a third stage (IIC), from Early Bronze III, characterized by pointed-bottom cups and plain pottery. The levels of that stage had been destroyed during the agricultural activity over the tell area.

[1]Since 1992, the excavations at Dubene-Sarovka have been directed by Dr Lolita Nikolova. In 1993 and 1994 Dr Alexander Bonev was the first director who continued to participate in the following campaigns as a supervisor of the excavations. The investigations in 1999–2000 were executed thanks to the volunteer assistance of undergraduate students from the Department of Archaeology at Veliko Turnovo University (Bulgaria).

Dubene-Sarovka IIB (EB II) is, for now, the best-excavated layer on the tell. House structures with a horizontal and vertical stratigraphic correlation have been excavated. The IIB layer is about 1 m thick and comprises three to six house levels preserved in different sectors of the tell. Characteristic of the IIB levels is the encrusted pottery that defines the ceramic style of most of the Early Bronze II Balkan cultures. The superimposed house levels along with ceramic data infer three phases: Dubene-Sarovka IIB1-3, which corresponds to Yunatsite 14-9, Ezero 10-4, Pernik II, Coţofeni II-III, Sitagroi Va, Kostolac, and Vučedol[2], etc., dated from the Early Bronze II (Nikolova 1999b: 62-70). There are two ^{14}C dates from Dubene-Sarovka IIB (Nikolova and Görsdorf 1998):

Bln-4903 4003 ± 36 BP, 2570–2470 cal BC (68.2% confidence), 2630–2450 cal BC (95.4% confidence)[3] (Layer IIB1)
Bln-4900 3993 ± 36 BP, 2565–2465 cal BC (68.2% confidence), 2620–2400 cal BC (95.4% confidence) (Layer IIB2)

In general, the values of the dates confirm the contemporaneous occupation of Dubene-Sarovka IIB1 and Yuntasite 14-13, and Dubene-Sarovka IIB2–Yunatsite 12-11 within the first half of the third millennium BC (see the discussion in Nikolova 1999b:64–5), although we need additional samples for a precise chronology of the levels to which they belonged.

The Dubene-Sarovka IIA layer is comprised of pottery typical of Early Bronze I in the Balkans—mostly plain burnished with emblematic channels and initiated encrusted ceramics. For the time being, the thickest sector cultural layer is about 1 m and consists of four house levels.

The Early Bronze I layer has been initially documented by a house on the southern steep periphery of the tell, as well as by a pit near that house (P15-93). The pottery from that stage has parallels at Yunatsite 17-15, Ezero 13-11, Baden, Cernavoda, Sitagroi IV, etc., dated from Early Bronze I. In 1999, the control trench (H18-4) in the northern central part of the tell (Nikolova 1999b:43–5, Figure 1.1) documented several levels that stratigraphically and ceramically corresponded to the IIA phase, as well as to the transition from IIA to the IIB phase. The last is represented by a hearth floor structure at a depth of 1.44 m from the date over which a burnt level has been documented with fragments of saucer; below there was another level with a published zigzag encrusted bowl (Nikolova 1999b: Figure 2.3). One ^{14}C sample was obtained from the level at a depth of –1.44 m (Bln-5231). The ceramics have analogies at Yunatsite 15-14, but the stratigraphic situation infers that the levels belonged to the end of Early Bronze I, and was contemporaneous with Yunatsite 15, respectively with the end of Pernik I, Baden, Coţofeni I, Ezero 11, and Sitagroi IV, as well as with earlier Cernavoda II and Pit Grave Culture in the Balkans. However, calibrated values of the ^{14}C date point to later chronology (see below).

In the sector under discussion, three more levels, characterized by plain and channel pottery have been recovered in depth, below being a layer with mixed and sparsely distributed Karanovo VI and Yunatsite I sherds. The second new ^{14}C sample from Dubene-Sarovka (Bln-5233) was obtained from the last layer. Hence, the sample has very clear stratigraphic characteristics—below the lowest floor from Early Bronze I in the excavated area. The absence of ^{14}C dates from Yunatsite 16-17, as well as the calibrated values of that ^{14}C date (see below) considerably increases the recent results from Dubene-Sarovka excavations.

[2]See the radiocarbon dates for these cultures in Nikolova 1999a: Table A, Srdoć D et al. 1987; Srdoć D et al. 1989.

[3]Cp. the calibrated values with 3.0 version of Oxcal in Nikolova 1999b: Table A (2850-2450 cal BC). In the context of the comparative chronology, the end of IIB1 phase at Dubene-Sarovka to which the sample belongs, is ca. 2850–2800 cal BC.

The New Radiocarbon Dates

Chemical pretreatment of the samples was completed through AAA treatment (Mook and Streurman 1983). The dating was performed with gas proportional counters of the Houtermans-Oeschger type using methane at 133.3 kPa pressure as filling gas. Measurement control and data processing was executed using computers (Görsdorf 1990). Modern electronics have been used in such a way that the preamplifier, pulse amplifier, comparator, pulse shape and anti-coincidence units were located in a box (19 cm × 10 cm × 5 cm) directly connected to the counter. To reach measurement accuracy, detection of the variations of environmental radiation and the inspection of the long-term stability of the electronics was necessary (Görsdorf 2000).

The $\delta^{13}C$ determinations have been studied at the Leibniz-Labor at the University of Kiel, Germany and reported in permil relative to PDB-standard. Using the measured $\delta^{13}C$ values, the datings are correct for isotopic fractionation, while the ^{14}C ages are calibrated by the OxCal program, version 3.5 (Ramsey 1995, 1998, 2000) and employing the decadal calibration curve (Stuiver et al. 1998) as a first approximation for all samples. The calibration intervals are represented with a confidence of 68.2% and are rounded off to 10 years. Table 1 shows the dating results together with locations. The relatively large calibration intervals of both dates are due to the wiggle shape of the calibration curve.

Table 1 Radiocarbon dates from Dubene-Sarovka (Upper Thrace) and their calibrated individual distribution (68.2% probability)

Lab nr Sample	Dubene-Sarovka site (Stratigraphic data)	$\delta^{13}C$ (PDB ‰)	^{14}C age	Calibrated age ranges (68.2% probability)	Calibrated age ranges (95.4% probability)
Bln-5233 Charcoal	H18-4 Depth: −1.90–2.46 m (+313.10/312.54 m)	−26.8‰	4571 ± 32 BP	3490 BC (1.4%) 3470 BC 3370 BC (35.0%) 3330 BC 3220 BC (14.2%) 3180 BC 3160 BC (17.5%) 3120 BC	3500 BC (8.0%) 3460 BC 3380 BC (40.7%) 3300 BC 3240 BC (46.7%) 3100 BC
Bln-5231 Charcoal	Sq. H18-4 Depth: −1.44 m (+313.56 m)	−26.2‰	4145 ± 29 BP	2870 BC (13.4%) 2830 BC 2820 BC (4.5%) 2800 BC 2780 BC (1.0%) 2770 BC 2760 BC (39.8%) 2660 BC 2650 BC (9.5%) 2620 BC	2880 BC (93.7%) 2620 BC 2610 BC (1.7%) 2590 BC
Bln-4903 Charcoal	Sq. K12 Depth: −1.39 (+313.61)	−24.95‰	4003 ± 36 BP	2570 BC (44.0%) 2515 BC 2500 BC (24.2%) 2470 BC	2630 BC (95.4%) 2450 BC
Bln-4900 Grain	Sq. F16 Depth: −1.10 m (+313.90 m)	−24.52‰	3993 ± 36 BP	2565 BC (40.8%) 2520 BC 2500 BC (27.4%) 2465 BC	2620 BC (94.0%) 2450 BC 2420 BC (1.4%) 2400 BC

DISCUSSION AND CONCLUSIONS

The long stratigraphy of Dubene-Sarovka, the numerous contact data in the context of rich and well-stratified archaeological material, the vast excavated area, and the interacted method of recording including archaeological and natural sciences all contribute to the elaboration of an accurate and complete chronology of the region. This gives reason for the ^{14}C dates to have a high recording value even though for the time being there is sole such evidence from the different levels.

Conclusions based on new stratigraphic and ^{14}C data from Dubene-Sarovka concern two periods in the Balkans—Early Bronze I, as well as the beginning of Early Bronze II. For these periods in Upper Thrace, there are ^{14}C dates from Dubene-Sarovka, Yunatsite, Plovdiv-Nebet Tepe, and possibly Manole (Yunatsite culture), and from Rupkite-Kaleto, Ezero, and Dyadovo tell (Ezero culture)

Table 2 Radiocarbon dates from Early Bronze I and earlier Early Bronze II in Upper Thrace[a]

Site	Lab nr	Sample type	^{14}C age (BP)	Comments (see calibrated values in Figure 2)
Yunatsite Culture (Western Upper Thrace)				
Dubene-Sarovka IIA	Bln-5233	Charcoal	4571 ± 32	EB I. From a cultural level with a few EB I and Late Copper (Karanovo VI culture) sherds.
Dubene-Sarovka IIA/B	Bln-5231	Charcoal	4145 ± 29	End of EB I, or beginning of EB II according to the calibrated values. Hearth.
Yunatsite 15	Bln-3675	Grain & seed	4280 ± 60	End of EB I. The only date from the level that corresponds to the comparative chronology.
Yunatsite 15	Bln-3677	Grain & seed	4080 ± 70	End of EB I. The calibrated values correspond to EB II.
Yunatsite 15	Bln-3678	Grain & seed	4050 ± 50	
Yunatsite 15	Bln-3676	Grain & seed	4030 ± 70	
Plovdiv-Nebet Tepe “10”	Bln-4353	Charcoal	4610 ± 80	The steep character of the terrain might have resulted in imprecise stratigraphy; the pottery from the site (unpublished) comprises typical EB I shapes and ornamentation.
Plovdiv-Nebet Tepe 11	Bln-4355	Charcoal	4280 ± 55	The date corresponds to the end of EB I – EB II. But see the next note.
Plovdiv-Nebet Tepe 11	Bln-4330	Charcoal	4070 ± 40	Later EB II, cp. above and the note on the stratigraphic problems of the site.
Manole-Razkopanitsa 4	Bln-813	Grain & seed	4350 ± 100	According to the diagnostic published pottery, the tell is from EB III and later periods; the published stratigraphy is not precise and the material is not completely published; among the published finds is a figurine that can be dated from EB I.
Ezero Culture (Eastern Upper Thrace)				
Rupkite-Kaleto	Bln-3429	Charcoal	4790 ± 60	Both dates are from ditches; among the preliminary published material there is typical of EB I pottery.
Rupkite-Kaleto	Bln-3773	Charcoal	4250 ± 150	

Table 2 Radiocarbon dates from Early Bronze I and earlier Early Bronze II in Upper Thrace[a] (*Cont'd.*)

Site	Lab nr	Sample type	^{14}C age (BP)	Comments (see calibrated values in Figure 2)
Ezero 13	Bln-1840	Charcoal	4590 ± 100	EB I. All the samples are from a depth of 3.20–3.45 m from the date. Some of the dates with low values originate from similar context with one of the dates that have the highest values. But for instance, Bln-905 and Bln-1838 from a depth of 3.20 m may indicate longer occupation of the level and just partially overlapping of the different houses. Nevertheless, even this interpretation cannot accept the values after 3100 BC which is the latest possible dating of the end of Ezero 13.
Ezero 13	Bln-1920B	Charcoal	4500 ± 50	
Ezero 13	Bln-1786	Charcoal	4450 ± 85	
Ezero 13	Bln-1843	Charcoal	4430 ± 50	
Ezero 13	Bln-1841	Charcoal	4420 ± 50	
Ezero 13	Bln-1837	Charcoal	4415 ± 40	
Ezero 13	Bln-1920	Charcoal	4390 ± 50	
Ezero 13	Bln-1158	Charcoal	4363 ± 100	
Ezero 13	Bln-1838	Charcoal, grain & seed	4305 ± 65	
Ezero 13	Bln-1256	Charcoal	4300 ± 80	
Ezero 13	Bln-904	Charcoal	4143 ± 100	
Ezero 13	Bln-905	Charcoal	4113 ± 100	
Ezero 13	Bln-1159	Charcoal	4099 ± 100	
Ezero 12	Bln-1836	Charcoal	4160 ± 55	EB I. The calibrated values are later than the comparative chronology of the level.
Ezero 12	Bln-903	Charcoal	3935 ± 100	
Ezero 11	Bln-902	Charcoal	4360 ± 100	End of EB I.
Ezero 10	Bln-727	Grain & seed	4315 ± 100	Beginning of EB II.
Ezero 10	Bln-726	Grain & seed	4285 ± 100	
Ezero 10	Bln-1835	Grain & seed	4260 ± 45	
Ezero 10	Bln-725	Grain & seed	4120 ± 100	
Dyadovo 10	Gak-20464	Charcoal	4510 ± 60	EB I. Unpublished ceramics from that level excavated by the Bulgarian team; the date corresponds to EB I, and to Ezero 13 in particular.
Dyadovo 10 Floor A	Gak-20465	Charcoal	4340 ± 60	EB I. The published pottery by the Japanese team has analogy at Ezero 13. But some typical of the last level ornamentation motifs are missing in light of recent limited evidence.
Dyadovo 10 Floor B	Gak-20466	Charcoal	4490 ± 60	
Dyadovo 10 Pithos 1	Gak-20467	Charcoal	4530 ± 120	

[a]Comments: All dates are calibrated with Oxcal 3.5 by Bronk Ramsey (2000). Reference to the original publications of the dates see in Nikolova 1999. References: Nikolova (1999a); Sekime and Kamuro (2000: tables 6 & 7).

(Nikolova 1999a[4]; Sekime and Kamuro 2000). The comments in Table 2 reflect the complexity of the problems that face the stratigraphic analyses of the ^{14}C dates. Figure 2 shows the calibrated values of their individual distribution (n=36) and the sum-probability that covers the very long period from approximately 3400 to 2550 BC (by 68.2% probability).

As Figure 2 shows, Bln-5233 preceded all the values from Early Bronze at Yunatsite 15, however, it is close to one date without a clear stratigraphy from Plovdiv-Nebet Tepe, the main site from the Yunatsite culture in the recent Plovdiv region. The Dubene-Sarovka sample indirectly confirms that the Plovdiv-Nebet Tepe ^{14}C date originated from Early Bronze I level. In comparison to the Ezero

[4]See in the cited monograph the reference to the original publications of the ^{14}C dates compiled in Table 2.

culture, Bln-5233 is close to some dates from Ezero 13 (Nikolova 1999a: Table A), as well as from earlier dates from EB Dyadovo (Sekine and Kamuro 2000). In this group of dates, Bln-5233 is noteworthy as it is considered that the genesis of the Yunatsite culture was before 3300 BC (based on comparative stratigraphy and chronology) and possibly confirms the legacy of the disputed dates such as the one from Plovdiv-Nebet Tepe. Of special importance is the fact that the values of the radiocarbon date completely verify the contemporaneous process of genesis of the Early Bronze I cultures in Upper Thrace. It is an objective of further investigation to determine more precise comparative characteristics of the beginning of the different Early Bronze I sites in Upper Thrace. At this time, it can be assumed that the beginning of Dubene-Sarovka IIA had preceded Yunatsite 17 (the earliest Early Bronze documented horizon on the tell).

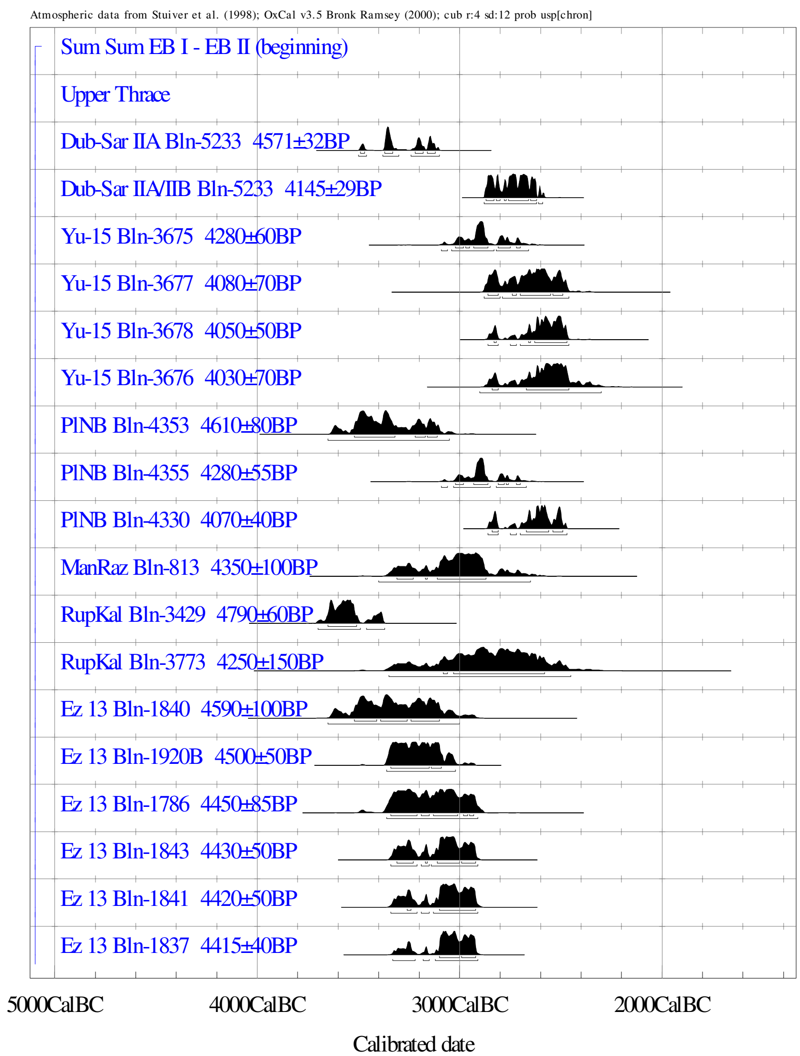


Figure 2A Individual distribution and sum probability of the calibrated ^{14}C dates from Upper Thrace. Early Bronze I to the beginning of Early Bronze II (n = 36). Data from Table 2.

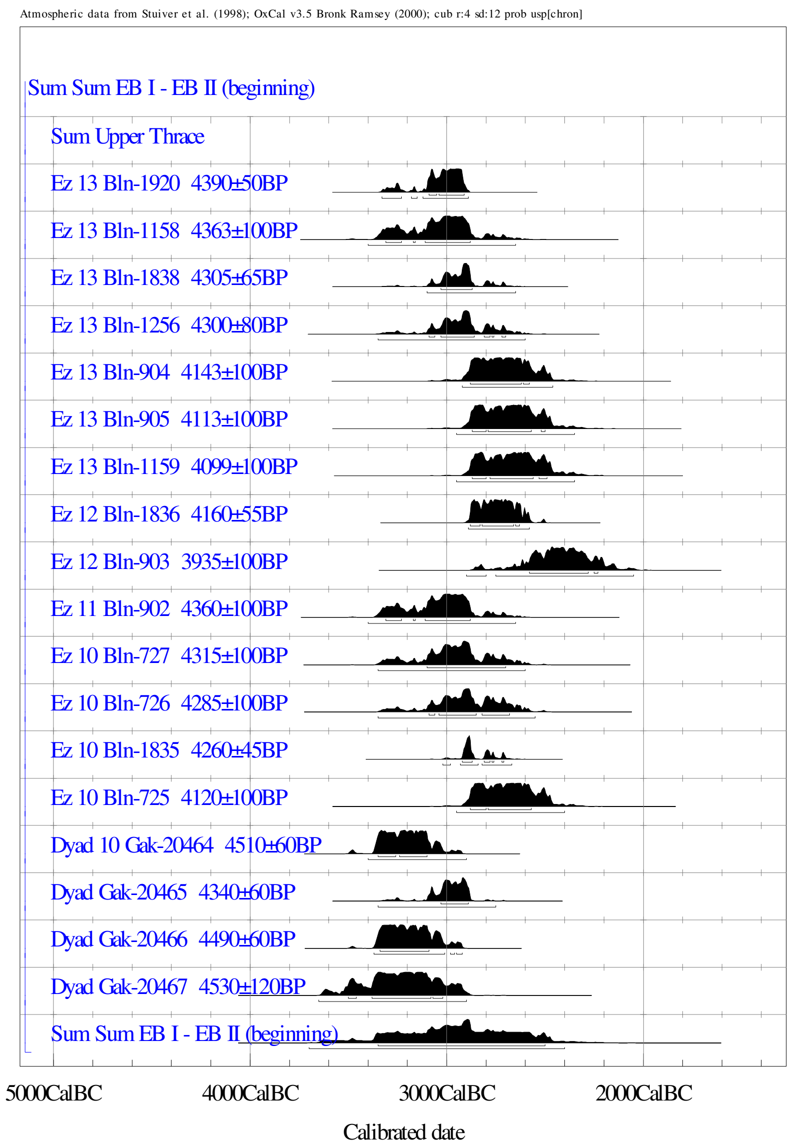


Figure 2B See Figure 2A

The next point concerns the interrelation between the duration of the Early Bronze I sites and the thickness of the cultural layers. The thickness of the stratigraphic levels from Dubene-Sarovka IIA does not exceed 1 m, according to the recent investigation, and is similar to that of Ezero 13-11. In addition, a clear development of the ceramic style is documented at Dubene-Sarovka, which makes it difficult to believe there was an existence of sensitive temporary hiatus during that stage. The accumulation of Early Bronze I on Yunatsite 17-15 is about 1.50 m. It is thicker than Dubene-Sarovka IIA in trench H18-4. The problem requires continued discussion, but for now, the suggestion is that there is a complex interrelation between the different accumulated strata of the prehistoric tells (respectively multilevel settlement); the thickness of those strata cannot be used for any straightforward chronological conclusions. The multilevel settlements combine many characteristics not only of the vertical but also of the horizontal stratigraphy and a variety of accumulation processes.

Furthermore, Bln-5231 concerns the beginning of Early Bronze II in Thrace and in the Balkans. Based on recent complex data, it is dated from around 3000 BC (Nikolova 1999a). The calibrated values of Bln-5231 correspond to such chronology that they date the end of level about 2800–2870 BC (as the earliest possible), but stratigraphically and ceramically, level 1 in H18-4 is closer to the end of EB I. Similar problems have posed the other ^{14}C dates from Dubene-Sarovka IIB and especially those from Yunatsite 13 and 11, as well as some of the dates from early Ezero, in particular Ezero 12. Further ^{14}C dates from Upper Thrace will probably better explain the reason for this controversy.

As far as earlier the Early Bronze age in Upper Thrace is concerned, with 68.2% confidence, the values of the ^{14}C dates in Figure 2 are distributed in the period between 3400 and 2550 BC, hence, it covers EB I and the whole EB II (see Nikolova 1999a). That statistical situation corresponds to the peculiarities of many of the individual dates, which have relatively low values. With 95.4% confidence, the earliest possible chronological border of the beginning of EB I is even 3700 BC. But the radiocarbon dates from Early Bronze I are again still not enough for more detailed considerations.

In conclusion, the Dubene-Sarovka excavations have been accomplished as an integrative project for excavation of the prehistoric site, the goal of which has been employing the different opportunities of the archaeological and natural sciences with interrelated and coordinated tasks and levels of investigations. After the terrain achievement of documenting precise stratigraphy and obtaining different kinds of samples from one and the same levels, the results of the integration at the theoretical level of research confirms that the absolute chronology requires complex interactive research.

ACKNOWLEDGMENTS

We gratefully acknowledge Dr H Erlenkeuser and colleagues (Leibniz-Labor, University of Kiel) for δ^{13}C measurements. Thanks are extended to E Lau and D Teckenburg for assistance in the preparation and measurement of samples in the Berlin Lab (German Institute of Archaeology, Eurasian-Department). Last but not least we thank the two anonymous reviewers for their comments on the manuscript submitted for publication, which helped to improve clarity.

REFERENCES

Bronk Ramsey C. 1995. Radiocarbon calibration and analysis of stratigraphy: the OxCal program. *Radiocarbon* 37(2):425–30.

Bronk Ramsey C. 1998. Probability and dating. *Radiocarbon* 40(1):461–74.

Bronk Ramsey C. 2000. The OxCal Program v.3.5. http://www.rlaha.ox.ac.uk/orau/06_01.htm.

Görsdorf J. 1990 Die Interpretation von ^{14}C-Datierungen im Berliner ^{14}C-Labor. *Zeitschrift für Archäologie* 24: 27–34.

Görsdorf J. 2000 Datierungen im Berliner ^{14}C-Labor. *Berliner Beiträge zur Archäometrie*, Band 17: 121–31.

Kovacheva M, Jordanova D, Jordanova J. 1995. Archaeomagnetic study of the Early Bronze settlement Sarovka near Dubene, Karlovo District. *Reports of Prehistoric Research Projects* 1(1):32–43.

Mook WG, Streurman HJ. 1983. Physical and chemical aspects of radiocarbon dating. *Journal of the European Study Group on Physical, Chemical and Mathematical Techniques Applied to Archaeology.* PACT 8: 31–55.

Nikolova L. 1999a. *The Balkans in later prehistory.* British Archaeological Reports, International Series 791. Oxford: British Archaeological Reports.

Nikolova L. 1999b. *The Yunatsite culture. Periodization, chronology and synchronization*. Reports of Prehistoric Research Projects 2–3, 33–97.

Nikolova L, Görsdorf J. 1998. Stratigraphic sequence and ^{14}C-dates from Dubene-Sarovka Tell in the context of the Early Bronze Balkans. *Eurasia Antiqua* 4: 11–8.

Sekime T, Kamuro H, editors. 2000. *Djadovo excavation 1999. A Preliminary Report on the 13th Excavation at*

Dyadovo, Bulgaria. Tokai: Tokai University Thracian Expedition (*Dyadovo Studies* 3).

Srdoč D, Obelić B, Sliepčević A, Krajcar Bronić I, Horvatinčić N. 1987 Rudjer Bošković Institute Radiocarbon Measurements X. *Radiocarbon* 29(1):135–47.

Srdoč D, Obelić B, Horvatinčić N, Krajcar Bronić I, Sliepčević A. 1989 Rudjer Bošković Institute Radiocarbon Measurements XI. *Radiocarbon* 31(1):85–98.

Stuiver M, Reimer PJ, Bard E, Beck JW, Burr GS, Hughen KA, Kromer B, McCormac FG, van der Plicht J, Spurk M. 1998. INTCAL98 radiocarbon age calibration, 24,000–0 cal BP. *Radiocarbon* 40(3):1041–83.

RADIOCARBON, Vol 44, Nr 2, 2002, p 541–547

RADIOCARBON DATES FROM THE JEWISH CATACOMBS OF ROME

Leonard V Rutgers

Faculty of Theology, Utrecht University, POB 80105, 3508 TC Utrecht, The Netherlands. Email: lrutgers@theo.uu.nl.

Arie F M De Jong • Klaas van der Borg

Faculty of Physics and Astronomy, Utrecht University, POB 80000, 3508 TA Utrecht, The Netherlands

ABSTRACT. This paper reports on the first chronological assessment of the Jewish Catacombs of the ancient Rome performed by accelerator mass spectrometry (AMS) dating of small-size charcoal fragments scattered in the mortar used for sealing off the graves in the Villa Torlonia Catacomb complex. The significance of the obtained ^{14}C readings has been carefully evaluated by taking into consideration the known technologies of quicklime production during Roman and recent times. The new data are of great concern for providing evidence that the Jewish catacombs were used for burial since the first century AD, thus some two centuries prior to the period traditionally believed to be the starting point of burial in the Jewish catacombs of ancient Rome. Such a significant aging of the Jewish catacombs could result in a deep re-examination of the current understanding of the beginning and the evolution of the custom of catacomb burial in both Jewish and early Christian communities in Rome.

INTRODUCTION

The dating of the Jewish catacombs of ancient Rome has been a controversial issue for 400 years (Rutgers 1995) and even today has not yet been accomplished satisfactorily due to several interconnected constraints. Difficulties arise because neither materials suitable for isotope dating nor archaeological findings with impressed age (e.g. coins and/or dated inscriptions) were so far uncovered in the Jewish catacombs. Archaeological analysis has shown that the 255 identified and dated brick and tile stamps represent reused artifacts. Therefore, they can only provide us with a *terminus post quem* (Rutgers 1998).

So far, any attempt of dating the Jewish catacombs of Rome relied on the standard archaeological method of relative chronology, viz., typological comparison of the findings from the catacombs with those from other archaeological contexts, that is the same approach also applied in studying the analogous Christian underground monuments in Rome (Deckers 1992; Guyon 1994). The results of such a relative dating, however, are highly problematic inasmuch as they depend on the tentative assumption that evolution patterns and stylistic traits did develop coherently and continuously through a sequence of well recognizable steps (Borbein 2000). The above mentioned assumption, however, has to be rejected, particularly in the case of late antique wall paintings (Fèvrier 1989).

A reliable dating of the Jewish catacombs is also severely hampered because the archaeological findings are not uncovered in significant, well-sealed stratigraphic sequences (Rutgers 2000). As a rule, the considered archaeological features are located in subterranean galleries, subjected to continuous frequentation over some centuries and frequently, as indicated by damaged graves, pillaged by robbers for both valuables and building materials. Later on, late antique and early medieval lime burners in search of raw materials conceivably joined the ranks of the previous grave robbers (*Codex Theodosianus* 9.17.2 of 349 AD), as did subsequent visitors (Lanciani 1967; Osborne 1985). In more recent times, the dilapidation of the catacombs resulting from neglect and crude research methods by pre-modern scholars destroyed or at least overshadowed the original archaeological context of many archaeological and epigraphic features.

In an attempt to break the deadlock resulting from earlier studies and research methodologies and to circumvent the constraints posed by subsequent disturbances of the archaeological record, a survey was carried out in the Villa Torlonia catacomb complex in 1997 in the framework of a dedicated project. The monument was selected for representing an ideal case study suitable to afford insight into the intriguing matter of dating the Jewish catacombs of Rome. It is the largest still surviving Jewish catacomb in Rome and since its discovery in 1919 has been the subject of various investigations, including a thorough archaeological campaign in the years 1973–1974 (Fasola 1976). Previous accounts on the catacomb complex, used by Jews exclusively, provided evidence that it consists of two catacombs lying at different depth, interconnected subsequently, possibly because of a collapse in area C1/E1 (Figure 1). Despite all this previous research, however, the important task of dating the catacombs was not accomplished adequately. Scholars just assigned the Jewish Villa Torlonia complex to the third/fourth centuries AD, thus roughly contemporary to the Christian catacombs of Rome. However, such a chronological assignment was not based on sound evidence.

We aim here to establish the age of the Jewish catacombs in Rome by means of AMS ^{14}C dating of small charred vegetal remnants isolated from the mortar used to seal the graves. Although charcoal enclosed in mortar has been successfully used to run ^{14}C dating of Medieval buildings in Ireland (Berger 1992), so far the method was neither applied to Jewish nor Christian catacombs.

METHOD AND DESCRIPTIVE BACKGROUND

Most of the graves in the Villa Torlonia catacombs are of the *loculus* type, that is simple, rectangularly shaped, aligned along both walls of the subterranean galleries, averaging 180 and 50 cm in length and depth, respectively and ranging between 40 and 60 cm in height. The graves were sealed according to the following three distinct techniques, by using: 1) stone plaques, 2) (reused) tiles placed contiguously and vertically, and 3) small walls made up of bricks and rubble covered by a smooth layer of whitish, fine mortar suitable for painting the observed red colored funerary inscriptions (Figure 2). A careful inspection revealed some rare small bits of charcoal encased into the mortar plastered onto the latter variety of grave closure. For being scarce and randomly distributed only in a limited number of graves, it appears that these charcoal occurrences are merely occasional rather than resulting from systematic additions in the course of mortar preparation. It is likely that the charcoal bits derive from the firing of the limekiln and, far subordinately, while slackening the quicklime and mixing it up with the mineral aggregate needed to prepare the mortar.

From the mortar on the surface of five distinct graves distributed in both catacombs of the complex, single charcoal fragments were collected and submitted to ^{14}C dating. Their identifiers (Table 1) provide the location on the catacombs map (Figure 1): as an example the charcoal labeled “B4-E7-1” comes from gallery B4, seventh row of graves along the Eastern gallery wall, first *loculus* from the bottom.

The graphite targets, analyzed at the Utrecht AMS facility (van der Borg et al. 1997), were prepared with the CO_2 obtained by burning the charcoal samples previously submitted to the acid-alkali-acid chemical pretreatment. The carbon weight yielded by the samples was some 2 mg with the exception of sample C2-S1-III, which lower carbon content (0.7 mg) resulted in a relatively higher analytical uncertainty.

RESULTS AND DISCUSSION

Table 1 lists the results of radiocarbon dating for the five analyzed samples. The reported calibrated ages ($\pm 1\ \sigma$) were calculated with the computer program Calib 4.3 (Stuiver and Reimer 1993). Four out of five ages range from 1983 to 1735 BP, thus bracketing the calibrated time span BC 40–AD 340. By contrast, the age of sample UtC-6719 (2144 ± 46 BP, which calibrates to BC 349–94) is obviously too old to be consistent with the framework of the studied archaeological site and it can be accounted for only by invoking a serious “old wood” effect.

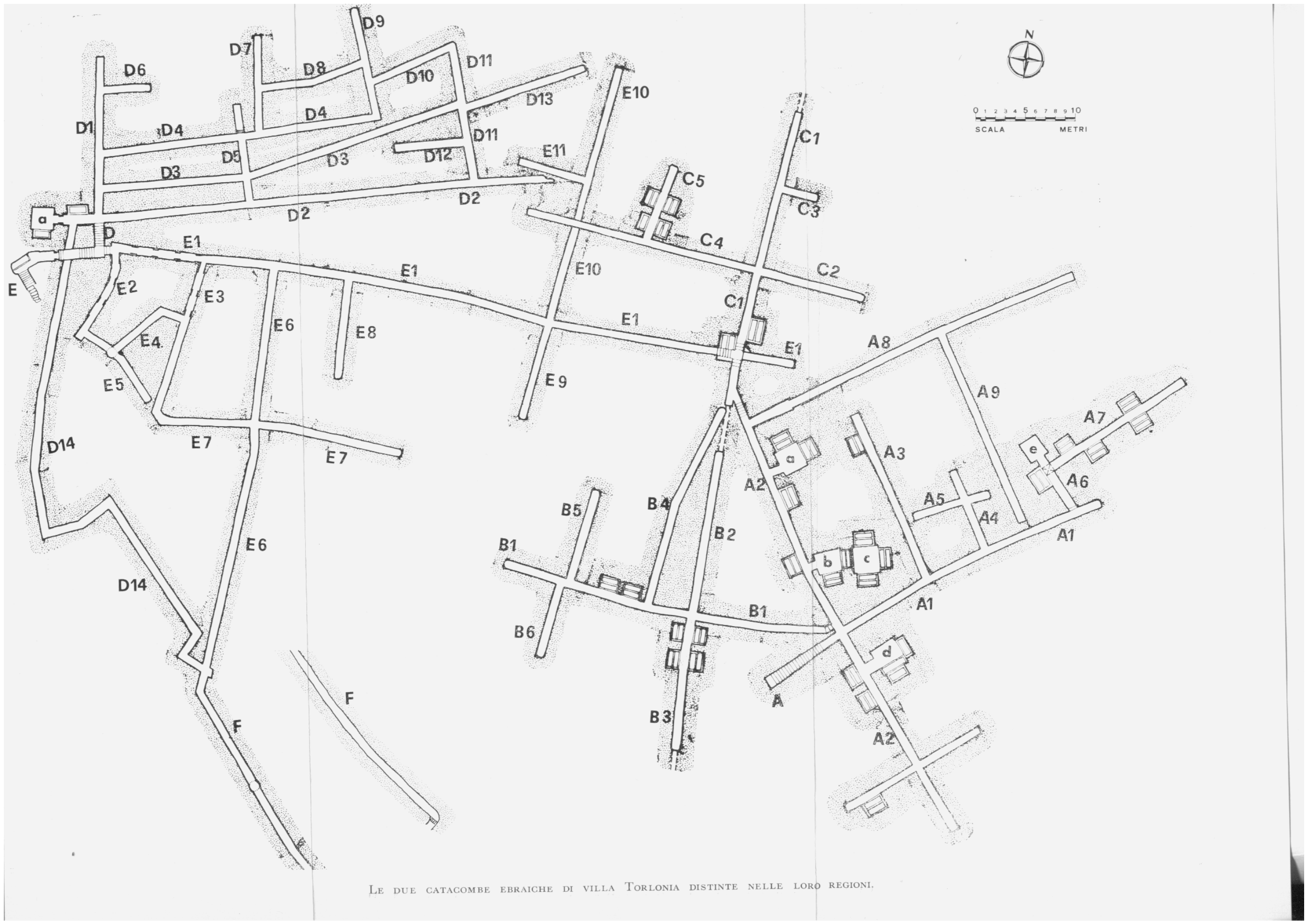


Figure 1 Plan of the Villa Torlonia Catacomb. Gallery complexes A, B, and C represent the upper catacomb; gallery complexes D and E the lower catacomb.

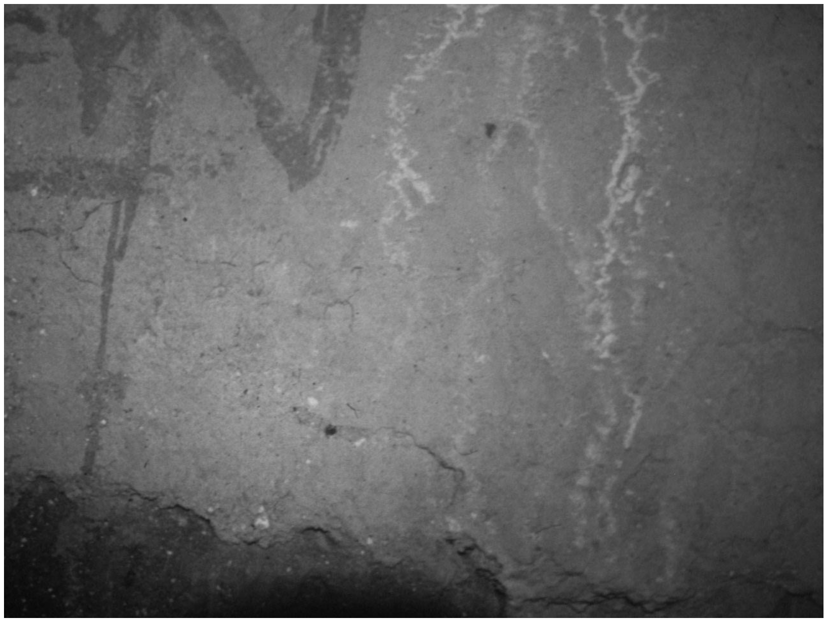


Figure 2 Loculus closure in the Villa Torlonia Catacomb, consisting of a tuff blocks kept in place with mortar. Its exposed surface, plastered by a thin, smooth, whitish layer of fine mortar, shows remnants of a red colored funerary inscription.

Table 1 Data from catacomb charcoal fragments

Sample identifier	$\delta^{13}C$ (‰)	Age (BP)	Lab code (UtC-)	1σ-calendar age[a] (yr)
B4-E7-1	−24.6	1753 ± 33	6718	cal AD 241–263, 274–339
C2-S1-III	−25.2	2144 ± 46	6719	cal BC 349–318, 228–221, 206–94
Entrance-E1-ceiling	−25.4	1983 ± 33	6720	cal BC 37–32, 20–12, 0–34 cal AD, 36–60
D10-N1-II	−25.2	1831 ± 30	6721	cal AD 133–163, 168–204, 204–223
D14-E11-II	−25.2	1915 ± 29	6722	cal AD 66–94, 96–127

[a]Calibrated with the program Calib, version 4.3 (Stuiver and Reimer 1993).

The results of the present investigation are of great concern in that the obtained consistent set of ^{14}C dates urges us to reconsider the current chronological assignment of the Villa Torlonia Jewish catacombs and, consequently, some notable historical assumptions. However, prior to drawing any archaeological/historical conclusion we need to evaluate the reliability of the new dates by discussing to what extent the two events we associate—viz., the origin of the dated charcoal samples and the sealing of the graves—could have been actually coeval.

It has been previously noted that the inclusions of charcoal bits in the mortar were rare, randomly distributed, and that they occurred only accidentally. Most likely, they derive from the process of firing the carbonate rocks to prepare quicklime. In ancient Rome the huge need for quicklime and its hydrated lime derivative (Lanciani 1975, Lega 1999) was mostly satisfied by professional lime burners with dedicated, technologically evolved plants (limekilns) comparable, for example, to those reported from the sites of Iversheim (Sölter 1970), Vuippens (Spycher et al. 1981), Weekley (Jackson 1973), and Sagalassos (Poblome 2000). However, quicklime in subordinate amounts was also occasionally obtained on-site with the less sophisticated “mixed layers pit” technique (Michalowski

1962; Dix 1982; Uscatescu and Martín-Bueno 1997; Lavergne and Suméra 2000)—a simple, inexpensive method to prepare home-made quicklime was still popular at the beginning of the last century throughout most of the Italian countryside. According to the demographic evidence for the studied Jewish catacombs (Rutgers, forthcoming) less than two dozen graves per year were sealed, only in part with mortar: therefore such mortar could have been easily provided by a quick, small-scale preparation on-site. Still, it cannot be ruled out that the mortar was made with professionally fired and slacked quicklime, since a community of the Roman Jews was named after its economic activity, "*Calcarenses*," which is the Latin term for the people dealing with mortar, its ingredients, preparation, etc. (Noy 1995, nos. 69, 98, 165, 558, and 584; Lega 1999).

By accepting that, independently from the firing technique, the dated bits of charcoal strictly record the quicklime production, a proper evaluation of the ^{14}C readings compels us to consider the characteristics of the wood used as a fuel. According to the first account in the *Historia Plantarum* (5.9.4) of Theophrastus (372–287 BC), limekilns were customarily fired with brushwood, since this allows one to attain the high temperature required for calcination faster than does large size wood. Archaeological data support such a practice: as an example only charred twigs and branches less than 4 cm in diameter were uncovered in the limekilns excavated at Weekley (Jackson 1973). Further, even today, traditionally operated limekilns are fired with short-lived vegetal matter. Being unsuitable for long storage, such matter is collected shortly before of firing. The most common fuels are thistles and weeds (Canaan 1932; Dalman 1942), and pine cones and olive kernels (Adam 1994), along with a variety of vegetal trimmings (DeLaine 1997).

Based on the above evidence concerning the production of quicklime and assuming that four out of five dated charcoal fragments from the Villa Torlonia catacombs originated from short-lived vegetation, we can argue that the measured ^{14}C dates are reasonably unaffected by "old wood" biases and therefore are a clue for establishing the sealing time of the graves.

In this respect let us stress that the ^{14}C readings are of great concern in that they point out that the Villa Torlonia Catacomb complex was in use since the first century AD instead of the so far popularly supposed third/fourth centuries AD. At first glance, the difference in the aging of the Jewish catacomb complex (some two centuries) could appear quite striking. However, the found shift in age can be reasonably accounted for by the fact that all previous chronological inferences relied on methods plagued by several constraints. In addition, it should be pointed out that the new dating herein proposed is in fair agreement with the overall historical framework, as according to ancient literary sources a permanent Jewish settlement in Rome appeared in the course of the first century BC (Solin 1983). Given that the only Jewish graves known in Rome are those in the Jewish catacombs—that is burial sites traditionally dated to the end of the second and early third century AD at the earliest—scholars have long wondered where the Jews buried their dead prior to the usage of such catacombs. The results of ^{14}C dating herein reported are valuable for solving the above puzzling question in that they point out that the Jews in ancient Rome neither had burial places other than catacombs (Noy 1998) nor their graves disappeared: they were just buried in the catacombs starting in the first century AD.

CONCLUSION

AMS dating of charcoal fragments enclosed in mortar revealed a powerful tool for achieving a sound chronological assessment of the Jewish Catacombs in Rome. The new data herein reported strongly suggest that the traditional dating of the Jewish catacombs at Villa Torlonia needs a careful and comprehensive re-evaluation. If the new ^{14}C chronology of the Villa Torlonia Jewish catacombs will be confirmed by further investigations, it will exert a dramatic impact on our overall knowledge on the relationship between Jewish and Christian catacombs, particularly concerning Jewish influence on early Christian burial customs in Rome. In addition, as a valuable by-product, the new data are a further warning on the limited effectiveness of relative chronology based on tools such as typology of artifacts and/or paleographic features of inscriptions when applied to particular archaeological contexts.

ACKNOWLEDGMENTS

For permission to study the Villa Torlonia materials, thanks are due to the Soprintendenza Archeologica di Roma. Organizational support was provided by the Istituto Olandese, the American Academy, the Union of Italian Jewish Communities—in particular its former president, Mrs T Zevi—the Rabbinate of Rome, the Commissione Bilaterale Ministero per i Beni Culturali and the the Deutsches Archäologisches Institut, Abteilung Madrid. Financial support was provided by the Kress Foundation and by several anonymous donors. For their unstinting support during the project, special thanks are due to Mariarosaria Barbera and Eric M Meyers. We would finally also like to thank the anonymous reviewers of our manuscript.

REFERENCES

Adam J-P. 1994. *Roman building: materials and techniques.* London.

Berger R. 1992. ^{14}C dating mortar in Ireland. *Radiocarbon* 34(3):880–9.

Borbein AH. 2000. Formanalyse. In: Hölscher T, Zanker P, editors. *Klassische Archäologie. Eine Einführung.* Berlin. p 109–28.

Canaan T. 1932. The Palestinian Arab house: its architecture. *The Journal of the Palestine Oriental Society* 12: 223–47.

Dalman G. 1942. *Arbeit und Sitte in Palästina, Bd. 7, Das Haus, Hühnerzucht, Taubenzucht, Bienenzucht.* Gütersloh.

Deckers JG. 1992. Wie genau ist eine Katakombe zu datieren? Das Beispiel SS. Marcellino e Pietro, in Memoria Sanctorum Venerantes. Miscellanea in onore di Mons. Victor Saxer, *Studi di Antichità Cristiana* 48: 217–38.

DeLaine J. 1997. *The Baths of Caracalla.* Porthsmouth.

Dix B. 1982. The Manufacture of lime and its uses in the western Roman provinces. *Oxford Journal of Archaeology* 1(3):331–45.

Fasola UM. 1976. Le due catacombe ebraiche di Villa Torlonia. *Rivista di Archeologia Cristiana* 52: 7–62.

Février P-A. 1989. À propos de la date des peintures des catacombes romaines. *Rivista di Archeologia Cristiana* 65:105–33.

Guyon J. 1994. Peut-on vraiment dater une catacombe? Retour sur le cimetière "Aux deux Lauriers," ou catacombe des saints Marcellin-et-Pierre, sur la via Labicana à Rome. *Boreas* 17:89–103.

Jackson DA. 1973. A Roman lime kiln at Weekley, Northants. *Britannia* 4:128–40.

Lanciani R. 1967. *The destruction of ancient Rome.* New York.

Lanciani R. 1975. *Storia degli scavi di Roma e notizie intorno le collezioni romane di antichità.* Vol. I, Bologna.

Lavergne D, Suméra F. 2000. La fabrication de la chaux: une activité pérenne ou occasionnelle pendant l'Antiquité gallo-romaine? Premiers éléments de réponse, in Pétrequin P. *et al*., eds, *Arts du feu et productions artisanales.* XXe rencontres internationales d'archéologie et d'histoire d'Antibes, Antibes. p 453–72.

Lega C. 1999. Schola: Calcarienses. In: Steinby M, editor. *Lexicon topographicum urbis Romae.* Volume 4. Rome. p 243–4.

Martin R. 1965. *Manuel d'architecture grecque.* Volume 1. *Matériaux et techniques.* Paris.

Michalowski K. 1962. Les fouilles polonaises à Tell Atrib (1957–1959). *Annales du Service des Antiquités de l'Égypte* 57:49–66.

Noy D. 1995. *Jewish inscriptions of Western Europe.* Volume 2. *Western Europe.* Cambridge.

Noy D. 1998. Where were the Jews of the Diaspora buried? In: Goodman, MD, editor. *Jews in a Graeco-Roman World.* Oxford. p 75–89.

Osborne J. 1985. The Roman catacombs in the Middle Ages. *Papers of the British School at Rome* 53:278–328.

Poblome J. et al. 2000. An early Byzantine tile and lime kiln in the territory of Sagalassos. In: Waelkens M, Loots L, editors. *Sagalassos V: report on the survey and excavation campaigns of 1996 and 1997.* Leuven. p 669–83.

Rutgers LV. 1995. *The Jews in late ancient Rome. evidence of cultural interaction in the Roman Diaspora.* Leiden.

Rutgers LV. 1998. Dating the Jewish catacombs of ancient Rome. In: *The hidden heritage of Diaspora Ju-*

daism. Leuven. p 45–71.

Rutgers LV. 2000. *Subterranean Rome. in search of the roots of Christianity in the catacombs of the Eternal City.* Leuven.

Rutgers LV. Forthcoming. *Final report on the Villa Torlonia catacomb project.* Leuven.

Solin H. 1983. Juden und Syrer im westlichen Teil der römischen Welt. *Aufstieg und Niedergang der römischen Welt* 29.2:587–789.

Sölter W. 1970. *Römische Kalkbrenner im Rheinland.* Düsseldorf.

Spycher HP et al. 1981. Der römerzeitliche Kalkbrennofen von Vuippens/La Palaz (Kt. Freiburg, Schwiez). *Jahrbuch des Römisch-Germanischen Zentralmuseums Mainz* 28:171–96.

Stuiver M, Reimer PJ. 1993. Extended ^{14}C database and revised Calib 3.0 ^{14}C age calibration program, *Radiocarbon* 35(1):215–30 (Calib version 4.3 was used here).

Uscatescu A, Martín-Bueno M. 1997. The Macellum of Gerasa (Jerash, Jordan): from a market place to an industrial area. *Bulletin of the American Schools of Oriental Research* 307:67–88.

van der Borg K, Alderliesten CA, de Jong AFM, van der Brink A, de Haas AP, Kersemaekers HJH, Raaymakers JEMJ. 1997. Precision and mass fractionation in the ^{14}C analysis with AMS. *Nuclear Instruments and Methods in Physical Research* B123:97–101.

Viaene W et al. 1997. An archaeometric study of mortars used at Sagalassos. In: Waelkens M, Poblome J, editors. *Sagalassos IV: report on the survey and excavation campaigns of 1994 and 1995.* Leuven. p 405–21.

RADIOCARBON, Vol 44, Nr 2, 2002, p 549–557

RADIOCARBON AND STABLE ISOTOPE ANALYSES ON THE EARLIEST JOMON SKELETONS FROM THE TOCHIBARA ROCKSHELTER, NAGANO, JAPAN

Minoru Yoneda[1,2] • Masashi Hirota[3] • Masao Uchida[4] • Atsushi Tanaka[1] • Yasuyuki Shibata[1] • Masatoshi Morita[1] • Takeru Akazawa[5]

ABSTRACT. This study presents the results of carbon and nitrogen isotopic analyses of six human skeletons excavated from the Tochibara rockshelter (Nagano, Japan). The human skeletons were reported to be accompanied by "Oshigata-mon" type pottery dating to the Earliest Jomon period (8900 BP ~ 6600 BP). A radiocarbon determination from charcoal associated with the human remains was reported to be 8650 ± 180 BP (GaK-1056). However, the depositional context of human skeletons was uncertain because they were recovered by excavations that were dug by prescribed levels. Our results indicated that these skeletons date to the Earliest Jomon period; the ^{14}C determinations place these remains between 8260 ± 100 BP (TERRA-b030799ab38) and 8580 ± 100 BP (TERRA-b011300a35). This coincides with the archaeological evidence that these specimens are some of the oldest Jomon skeletal materials. Furthermore, $\delta^{13}C$ and $\delta^{15}N$ values provide evidence for the first reconstruction of the diet of an inland Earliest Jomon population. Although the distribution of data indicated a possibility that they had exploited small amounts of seafood, the isotopic data point to this group having relied heavily on a terrestrial ecosystem based on C_3 plants.

INTRODUCTION

In the present study, we re-evaluated the skeletal specimens recovered from the Tochibara rockshelter by measuring the carbon and nitrogen isotopes in six human remains. Radiocarbon (^{14}C) dating and dietary reconstruction based on stable carbon and nitrogen isotopes were done.

This skeletal collection from the Tochibara site is representative of an inland population dating to the Earliest Jomon period. From this site, 12 skeletons including two infants and two children were recovered (Kohara et al. 1971; Nishizawa 1978). Two children are suspected to have been killed by a rock fall accident since they were found beneath a fallen rock in the position for running. It is thought to be the oldest evidence of a fatal accident in Japan (Kohara et al. 1971). In the case of the inland Japan, well-preserved human skeletons are very rare because of the soil acidity. Hence, the human skeletons from the Tochibara rockshelter are important for the investigation of morphological characteristics of the Earliest Jomon people residing in the inland region.

However, the depositional context of human remains was not fully defined during the excavation. The site consists of superimposed layers from the Earliest Jomon through Yayoi periods. Stratigraphic data on each individual remain have not been certified since excavations were conducted by the arbitrary level method digging in steps of 10 cm deep, not by following the natural layers of deposit. Previous studies have reported three ^{14}C ages of charcoals at different levels (Nishizawa 1982); 7920 ± 80 BP (GaK-1054), 8650 ± 180 BP (GaK-1056), and 8870 ± 220 BP (GaK-3773). Re-excavations showed that stratigraphic structure of this site was very complex (Oomi 1984), and it has become more important to evaluate the original period of human specimens exactly. Hence, it was aimed in the present study to determine the ^{14}C ages on human remains directly by using the accelerator mass spectrometry (AMS). The chronological placement of this skeletal collection is essential when investigating its anthropological traits, and studying it in terms of regional and temporal variations among the Jomon.

[1]Environmental Chemistry Division, National Institute for Environmental Studies, Onogawa 16-2, Tsukuba, Ibaraki 305-8506, Japan
[2]Corresponding author. Email: myoneda@nies.go.jp.
[3]Institute of Accelerator Analysis, Ltd. Ichiridan 6-270, Shirasaka, Shirakawa, Fukushima 961-0835, Japan
[4]Japan Marine Science and Technology Center, Natsushima-cho 2-15, Yokosuka, Kanagawa 237-0061, Japan
[5]International Research Center for Japanese Studies, Oeyama-cho 3-2, Goryo, Nishikyo-ku, Kyoto 610-1192, Japan

At the same time, stable isotopes of carbon and nitrogen in preserved protein, collagen, can reveal aspects of their dietary habits. Based on isotopic analyses and other archaeological evidence, it has been revealed that the Jomon people were hunter-gatherer-fishers adapting themselves to regional circumstances (Minagawa and Akazawa 1992). However, almost all data for discussion so far have been obtained from coastal populations found in Jomon shell middens. This study presents the first quantitative evaluation on the dietary habits of the inland Earliest Jomon people.

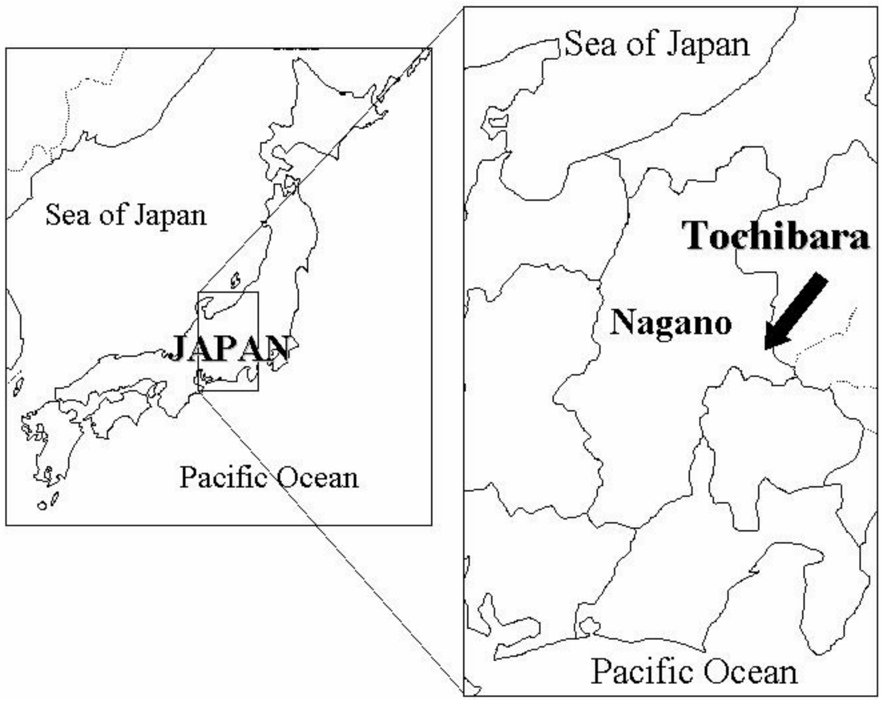


Figure 1 Location of the Tochibara rockshelter, Nagano prefecture, Japan

MATERIALS AND METHODS

The Tochibara rockshelter is located in Kita-Aiki village, Minami-Sakuma county, Nagano prefecture (Figure 1). The rockshelter lies on a palisade facing the Aiki river. In 1965, the first skeleton (KA-1) was found and excavations were then conducted 15 times by Professor M Suzuki of the Department of Medicine, Shinshu University, and his colleagues until 1978 (Oomi 1984). Excavations revealed human skeletons of eight adults, two children, and two infants. As mentioned above, the two children (KA-11 and KA-12) are thought to have been killed by a rockfall (Kohara et al. 1971). The morphological characteristics of the eight adults were reported (Nishizawa 1978). Furthermore, a large amount of artifacts was recovered from deposits believed to date between the Earliest Jomon through the Yayoi period. Most layers yielded the Earliest Jomon pottery. The human remains were accompanied by the "Oshigata-mon" type pottery of the Earliest Jomon period. The typical ^{14}C age for this cultural period is between 8900 BP and 6600 BP in Nagano (Kawasaki 1997).

In this study, six individuals were analyzed for ^{14}C age, δ^{13}C, and δ^{15}N values. KA-1 individual is one of the oldest Jomon people that has a complete facial cranium. KA-1, KA-2, KA-4, and KA-7 were buried closely in the center of the terrace, which were found in the arbitrary level between −150 cm and –200 cm from the surface (see Table 1). For this level, ^{14}C dating of charcoal fragments excavated at a depth of –150 cm to –182 cm gave a date of 8650 ± 180 BP (GaK-1056), but this date has not been corrected for isotopic fractionation (Kunihiko Kigoshi, personal communication). On the other hand, KA-8 was not found in the same area as the four burials, but at the eastern edge of the terrace, and its stratigraphic level and depth were also different, –211 cm. KA-10 was found at the next rockshelter to the east of the main shelter. Even if the burial deposit was primary without any post-depositional disturbance, the correspondence between charcoal ages and skeleton ones has not been confirmed, especially in the cases of KA-8 and KA-10.

Table 1 List of the Tochibara rockshelter specimens analyzed in this study

Sample nr	Sex	Age	Excavated level	Excavation year
KA-1	Male	Adult	–155 cm	1965
KA-2	Male	Adult	–201 cm	1965
KA-4	Female	Adult	–173 cm	1965
KA-7	Female	Adult	No data	1966
KA-8	Female	Adult	–211 cm	1966
KA-10	Female	Adult	No data	1967

For ^{14}C dating, AMS measurement requires a smaller amount of sample (ca. 1 mg of carbon) than the conventional β counting method, since it counts the exact number of ^{14}C atoms. Because of this technical development, it has become possible to measure the ^{14}C age of human bone material without seriously damaging the fossil hominid specimen. Typically, bone pieces of 0.5~1.0 g were taken from a rib bone or other useless bone element. Then the inorganic part was removed by 1 N hydrochloric acid. From the remaining organic matter, the collagen was extracted and purified by the gelatinization method improved from Longin's (1971). The detailed procedure was described elsewhere (Yoneda et al. 1996).

The extracted collagen was analyzed for carbon and nitrogen contents in order to investigate contamination of the extracted collagen. An elemental analyzer (EA; Calro Erba NA 1500, CE Elantech, Inc, Lakewood, New Jersey, USA) was employed, which is combined to an isotope ratio mass spectrometry (IRMS; MAT252, Thermo Finnigan MAT GmbH, Bremen, Germany), for both the elemental analyses and the preparation for isotope analyses. Typically, 0.25 mg of collagen was combusted in the EA and the resulting CO_2 and N_2 were introduced to the IRMS for measuring $^{13}C/^{12}C$ and $^{15}N/^{14}N$. The isotope ratios were usually shown in the δ values in comparison with standard materials, PDB for carbon and AIR for nitrogen. The uncertainty with this system was estimated around 0.25‰ for $\delta^{15}N$ and 0.10‰ for $\delta^{13}C$.

Then, 2.5 mg of collagen was converted to graphite with iron catalysis for the ^{14}C analysis (Kitagawa et al. 1993). Pretreatment of samples, graphitization and ^{14}C measurements were conducted at NIES-TERRA (Tanaka et al. 2000). At least two kinds of standard materials were loaded with unknown samples contemporaneously to calibrate the measured $^{14}C/^{12}C$. The new oxalic acid (NBS RM-4990C), IAEA standard materials, such as C6 (ANU sucrose) and C7 were employed. For each ^{14}C determination, measurements were taken for 10 minutes and repeated three times.

RESULTS

Table 2 shows the results on stable isotopic and elemental analyses. The C/N ratio is employed to certify the purity of extracted gelatin. If a C/N ratio did not show a value between 2.9 and 3.6, the gelatin might be contaminated with foreign organic matter (DeNiro 1985). However, in all the Tochibara samples, the C/N showed reasonable values as pure collagen. Based on this datum, we concluded that the extracted materials principally consist of collagen and that the results of $\delta^{13}C$, $\delta^{15}N$ values, and ^{14}C ages are reliable as the biogenic signals and their original ages without diagenetic effects.

Table 2 Stable isotopic ratios, carbon and nitrogen concentrations, and C/N ratios in collagen extracted from human remains from the Tochibara rockshelter

Sample nr	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C (%)	N (%)	C/N ratio
KA-1	–19.7	7.7	43.1	15.1	3.34
KA-2	–20.4	6.0	44.9	16.2	3.23
KA-4	–19.7	7.6	45.1	15.8	3.33
KA-7	–19.8	7.1	46.2	16.2	3.33
KA-8	–19.8	6.9	46.0	16.7	3.21
KA-10	–19.8	7.4	45.3	16.5	3.21

Their protein sources were estimated by comparing the isotopic values of nutritional groups and the estimated values of dietary protein. Figure 2 shows the isotopic values of typical native foodstuff collected in the Japanese archipelago and the North Pacific (Shimojo 1988; Welch and Parsons 1993; Minami 1995) and reconstructed values of muscle from archaeological mammals (Yoneda unpublished data). As shown in the figure, the source data can be divided into six groups. In general, bone collagen is enriched +4.5‰ for $\delta^{13}C$ and +3.5‰ for $\delta^{15}N$ in comparison with average of absorbed protein, respectively (Ambrose 1993). In Figure 3, the results of human protein sources were plotted in the region of C_3 plants and its consumer. It is clear that they lived on terrestrial foods as main protein sources and it is reasonable that the inland Jomon hunter-gatherer adapted to the terrestrial circumstance.

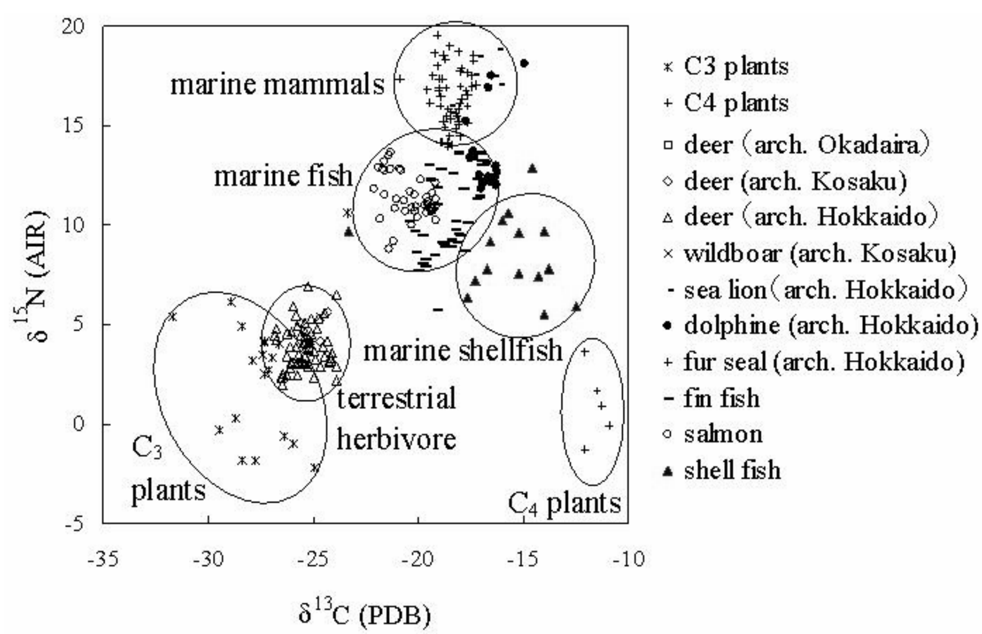


Figure 2 Typical isotopic values of Japanese native foodstuff. For details, see the text.

However, a clear correlation (r = 0.936) observed between $\delta^{13}C$ and $\delta^{15}N$ in human collagen suggests that they exploited two kinds of protein sources dominantly (see Figure 3), and these end-points of the regression line should suggest these two sources theoretically (Schwarcz 1991). In the case of the Tochibara site, it is possible that C_3 plants and terrestrial herbivore are suggested on one end, and marine fish and marine mammals on the other. It is likely that they have exploited some amount of seafood in their daily diet, because faunal remains include chum salmon (*Oncorhynchus keta*) and/or cherry salmon (*Oncorhynchus masou*) and other marine organisms, but the amount of seafood should have been very limited. Furthermore, it is difficult to discriminate the results between plants and herbivore, because the mixture of C_3 plants and seafood yielded the same isotopic features apparently as the terrestrial mammal from the isotopic point of view. That is why we did not try quantitative reconstruction of the prehistoric diet in the present study. Nevertheless, it is possible to say that the reconstructed human diet relied mainly on the protein originating from the terrestrial ecosystem.

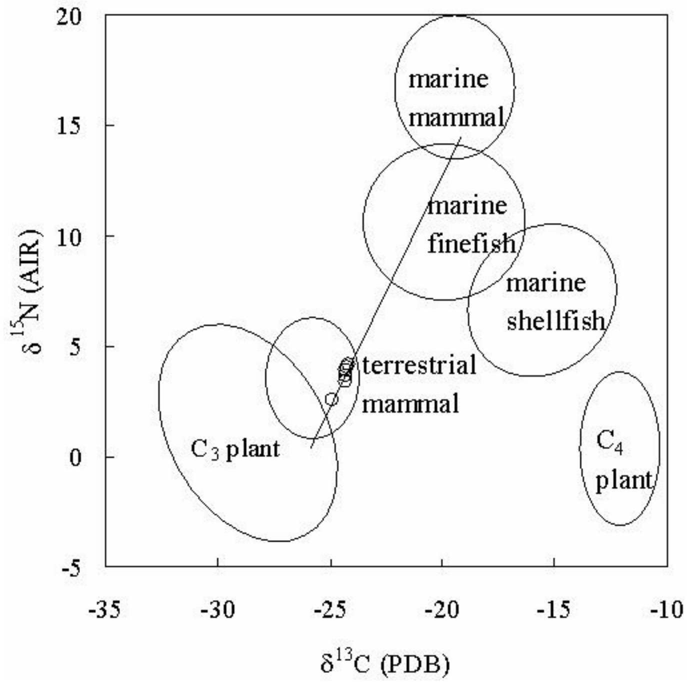


Figure 3 Carbon and nitrogen isotope ratios of the exploited protein by the Tochibara people. Significant correlation is observed between $\delta^{13}C$ and $\delta^{15}N$ values.

Table 3 shows the result of ^{14}C determinations on human bones excavated form the Tochibara rock-shelter. The 1 σ error is cited. They were buried between 8300 BP to 8600 BP, which coincides with the archaeological materials and the previous ^{14}C determination. However, the burials were not contemporary with one another. Even in the case of KA-1, KA-2, and KA-4, which are associated with each other, the three ^{14}C determinations span over 200 ^{14}C yr. However, it seems reasonable amongst the three skeletons, that KA-1 (8370 ± 70 BP), with the highest elevation is slightly younger than KA-2 (8580 ± 100 BP) and KA-4 (8530 ± 80 BP), which are from deeper levels (see Table 1). Although KA-8 was found from the deeper level (–211 cm), its ^{14}C age (8300 ± 80 BP) was similar to KA-1 and younger than KA-2 and KA-4. This discrepancy suggests that the stratigraphic layers declined towards the shelter's opening, and that the elevations at the different positions did not correspond to each other. On the other hand, KA-10 who was found from the different shelter yielded a similar result as others, suggesting that this individual also dates to the Earliest Jomon period and might belong to the same population.

Table 3 Conventional and calibrated ^{14}C ages of the Tochibara specimens

Sample nr	Code nr	Conventional ^{14}C age (BP ± 1σ)			Calibrated age (cal BP)			Probability
KA-1	TERRA-b030799ab17	8370	±	70	9490	–	9280	68.2%
KA-2	TERRA-b011300a35	8580	±	100	9690	–	9470	68.2%
KA-4	TERRA-b030799ab26	8530	±	80	9560	–	9470	65.4%
					9450	–	9440	2.8%
KA-7	TERRA-b030799ab27	8430	±	70	9530	–	9420	62.7%
					9410	–	9400	2.3%
					9340	–	9330	3.2%
KA-8	TERRA-b030799ab28	8300	±	80	9470	–	9450	3.2%
					9430	–	9250	55.8%
					9180	–	9130	9.1%
KA-10	TERRA-b030799ab38	8260	±	100	9420	–	9340	16.2%
					9330	–	9120	49.6%
					9110	–	9090	2.4%

DISCUSSION

In a previous paper, three ^{14}C ages of charcoal samples were reported; 7920 ± 80 BP, 8650 ± 180 BP, and 8870 ± 220 BP at −95 ~ −127 cm, −150 ~ −182 cm, and −534 ~ −535 cm, respectively (Nishizawa 1982). Generally speaking, our results on human ages agree with those of the charcoals, although these previous data have not been corrected for fractionation. Furthermore, this study showed that human individuals were buried within a shorter time frame between 8260 ± 100 BP and 8580 ± 100 BP. In the case of human remains, the ^{14}C reservoir effect should be considered, because they might have exploited organisms derived from a ^{14}C-depleted carbon source, such as seafood (Arneborg et al. 1999; Yoneda et al. 2000, 2001). In the case of coastal Jomon, the marine reservoir effect clearly altered the ^{14}C ages of human remains (Yoneda et al. 2002). However, this effect is negligible for the Tochibara samples since the stable isotopic analyses showed their collagen was originated primarily from terrestrial foods.

Calibration ages in this paper were calculated using the INTCAL98 calibration curve (Stuiver et al. 1998) with the OxCal ver. 3.0 calibration program (Bronk Ramsey 1995). Table 3 shows the calibrated ages of each sample. The calibrated determinations place the skeletons between 9100 cal BP to 9690 cal BP. Some of them show larger uncertainties because the calibration curve turned horizontal at the ranges.

Then, Bayesian methodology was employed for analyzing the series of ^{14}C dates (Bronk Ramsey 1995; Buck et al. 1996). If the six ^{14}C determinations were derived from one phase of human occupation as mentioned in the results, we can calculate the beginning and ending periods of the phase. It is estimated that the series of burials was initiated between 9610 and 9450 cal BP and terminated between 9460 and 9240 cal BP. If more detailed information on their sequence was available, then the calibrated age of each sample could be confined more precisely by using Bayesian methods.

Regarding the subsistence of the Tochibara people, the isotopic reconstruction seems to be consistent with archaeological evidence. Faunal remains contained many kinds of mammals, birds, finfish, and shellfish (Nishizawa 1982). Most frequent mammal species reported were Japanese deer (*Cervus nippon*) and Japanese wild boar (*Sus leucomystax*). Fish remains contained marine, brackish, and freshwater species including northern salmon, pacific abalone (*Nordotis discus discus*), freshwater pearly mussel (*Margaritifera laevis*), and estuary clam (*Corbicula japonica*). Our results showed that a small amount of seafood might be exploited but was almost negligible. It means that the seasonal migration to coastal area and/or the trading of foodstuffs with coastal populations was not common for the Tochibara Jomon people.

In Nagano, carbon isotope data showed that this dietary pattern of depending on terrestrial protein continued to the later Yayoi, Kofun, and Medieval periods (Yoneda et al. 1996). The Middle Jomon population from the Kitamura site (ca. 4500 BP) showed similar isotopic results, while the recent Edo (AD 16C) people exploited some amount of seafood (Figure 4). Kitamura Middle Jomon did not show correlation between two isotopic values, but a wider distribution of $\delta^{13}C$ values. On the other hand, some archaeologists have suggested that the large settlements in the Middle Jomon period were sustained by the C_4 millet agriculture (Fujimoto 1970). It might be possible to interpret that the wider $\delta^{13}C$ variation in the Kitamura was influenced by C_4 plants as a new nutritional resource. However, the differences in $\delta^{13}C$ values were not clear between the Tochibara and Kitamura sites, and do not support the hypothesis that C_4 millets were cultivated as a staple food item.

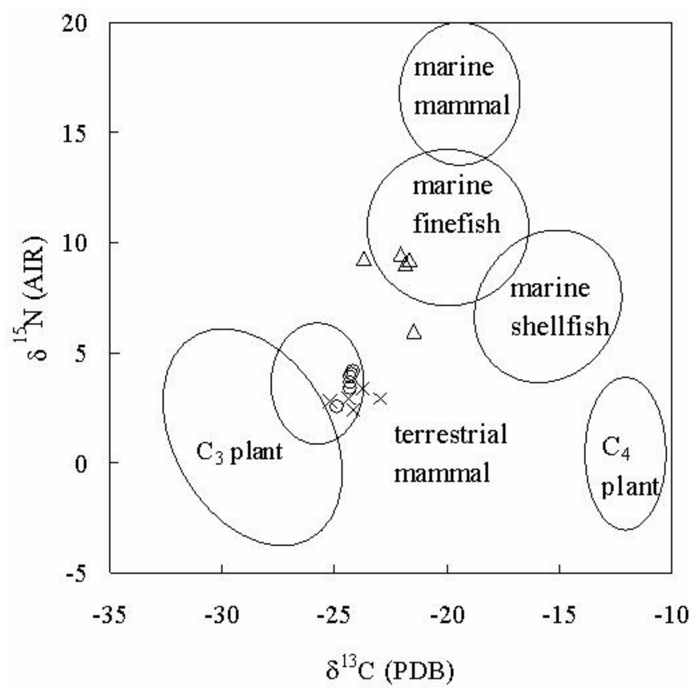


Figure 4 Comparison of dietary habits in Nagano between the Earliest Jomon (Tochibara), the Middle Jomon (Kitamura), and Edo (Hodokubo and Tsuchiya). Tochibara, Kitamura, and Edo people are shown as open circles, cross symbols, and triangles, respectively.

CONCLUSIONS

Six human skeletons excavated from the Tochibara rockshelter were measured for ^{14}C dating and stable isotope analyses. ^{14}C dating indicated that these human skeletons date to the Earliest Jomon period and they are provided as one of rare examples of the oldest skeletal specimens from the inland of Japan. Bayesian statistics suggest that they were buried within shorter time period than suggested by a previous study. This skeletal collection should be re-evaluated from the morphological point of view to understand the structure of the Jomon people and the origin of modern Japanese.

At the same time, the isotopic results indicated that they might have exploited a small amount of seafood, but most of protein in their bodies was derived from the terrestrial ecosystem based on C_3 plants. This is different from the dietary habit of coastal Jomon people who exploited both terrestrial and marine foodstuff substantially (Minagawa and Akazawa 1992). When their morphological characters are to be discussed, this discordance in dietary habits may explain the morphology of inland Japanese.

ACKNOWLEDGMENTS

Dr Y Kohara and Dr T Nishizawa kindly helped us to collect samples. Dr M E Hall of the Niigata Prefectural Museum of History kindly gave useful comments on draft paper and corrected the language thoroughly. Dr K Kigoshi provided information on previous measurements. Anonymous reviewers' comments were useful to improve this paper. The authors also thank Dr H Sekiguchi, Mr C Kobayashi, and Mr T Kobayashi for their assistance in AMS operation and Ms T Kitazaki and Ms S Minoura for their assistance in pretreatments. This study was supported in part by Grant-in-aid for Scientific Research (09740652) from the Ministry of Education, Science, Sports and Culture, Japan.

REFERENCES

Ambrose SH. 1993. Isotopic analysis of paleodiet: methodological and interpretive considerations. In: Sandford MK, editor. *Investigations of ancient human tissue: chemical analyses in anthropology.* Langhorne: Gordon and Breach. p 59–130.

Arneborg J, Heinemeier J, Lynnerup N, Nielsen HL, Rud N, Sveinbjörnsdóttir ÁE. 1999. Change of diet of the Greenland Vikings determined from stable carbon isotope analysis and ^{14}C dating of their bones. *Radiocarbon* 41(2):157–68.

Bronk Ramsey C. 1995. Radiocarbon calibration and analysis of stratigraphy: the program OxCal. *Radiocarbon* 37(2):425–30.

Buck CE, Cavanagh WG, Litton CD. 1996. *Bayesian approach to interpreting archaeological data.* Chichester: John Wiley. 382 p.

DeNiro MJ. 1985. Postmortem preservation and alteration of *in vivo* bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature* 317: 806–9.

Fujimoto E. 1970. *Jomon agriculture*. Tokyo: Gakuseisha. 214 p.

Kawasaki T. 1997. Regarding age determination on sites in Nagano prefecture: comparison and usage of relative age and scientific dating methods. *Journal of Archaeological Society of Nagano Prefecture* 83:1–23. In Japanese.

Kitagawa H, Masuzawa T, Nakamura T, Matsumoto E. 1993. A batch preparation method for graphite targets with low background for AMS ^{14}C measurements. *Radiocarbon* 35(1)**:**295–300.

Kohara Y, Nakamura T, Nishizawa T, Suzuki M. 1971. Human infant remains of the Earliest Jomon period, suffering death by a falling rock. *Journal of Anthropological Society of Nippon* 79(1):55–60. In Japanese with English summary.

Longin R. 1971. New method of collagen extraction for radiocarbon dating. *Nature* 230:241–2.

Minagawa M, Akazawa, T. 1992. Dietary patterns of Japanese Jomon hunter- gatherers: stable nitrogen and carbon isotope analyses of human bones. In: Aikens CM, Rhee SN, editors. *Pacific Northeast Asia in prehistory: recent research into the emergence of huntefisher-gatheres, farmers, and socio-political elites*. Seattle: University Washington Press. p 59–67.

Minami H. 1995. Biogeochemical and ecological studies of 4 species of Procellariidae (Puffinus) in the North Pacific using stable carbon and nitrogen isotope analysis: [dissertation] Sapporo (Japan): Hokkaido University. 155 p. In Japanese with English summary.

Nishizawa T. 1978. Human skeletons from the Tochibara rockshelter site: its burial pattern and physical characters. In: [AANP] Archaeological Association of Nagano Prefecture, editor. *Archaeology of the Central Height.* Nagano: Archaeological Association of Nagano Prefecture. p 94–104. In Japanese.

Nishizawa T. 1982. The Tochihara rockshelter site. In: Nagano Prefecture, editor. *History of Nagano Prefecture (Nagano kenshi), archaeological material 1(2): main sites (northern and eastern Shinshu)*. Nagano: Nagano prefecture. p 559–84. In Japanese.

Oomi Y, editor. 1984. *Excavation report of the Tochibara Rockshelter site in 1983*. Matsumoto: Shinshu University. p 82. In Japanese.

Schwarcz HP. 1991. Some theoretical aspects of isotope paleodiet studies. *Journal of Archaeological Science* 18:261–75.

Shimojo H. 1988. Basic research for the dietary reconstruction of the Okadaira shell midden inhabitant based on carbon and nitrogen stable isotopic ratios [master's thesis]. Tokyo (Japan): University of Tokyo. 71 p. In Japanese.

Stuiver M, Reimer PJ, Bard E, Beck JW, Burr GS, Hughen KA, Kromer B, McCormac G, van der Plicht J, Spurk M. 1998. INTCAL98 radiocarbon age calibration, 24,000–0 cal BP. *Radiocarbon* 40(3):1041–83.

Tanaka A, Yoneda M, Uchida M, Uehiro T, Shibata Y, Morita M. 2000. Recent advances in ^{14}C measurement at NIES-TERRA. *Nuclear Instruments and Methods in Physics Research* B 172:107–11.

Welch DW, Parsons TR. 1993. $\delta^{13}C$-$\delta^{15}N$ values as indicators of trophic position and competitive overlap for Pacific salmon (*Oncorhynchus spp.*). *Fisheries Oceanography* 2:11–23.

Yoneda, M, Yoshida K, Yoshinaga J, Morita M, Akazawa T. 1996. Reconstruction of palaeodiet in Nagano Prefecture based on the carbon and nitrogen isotope analysis and the trace elemental analysis. *The Quaternary Research (Daiyonki-kenkyu)* 35(4):293–303. In Japanese with English summary.

Yoneda M, Kitagawa H, van der Plichit J, Uchida M, Tanaka A, Uehiro T, Shibata Y, Morita M, Ohno T. 2000. Pre-bomb marine reservoir ages in the western North Pacific: preliminary result on Kyoto University collection. *Nuclear Instruments and Methods in Physics Research* B 172:377–81.

Yoneda M, Hirota M, Uchida M, Uzawa K, Tanaka A, Shibata Y, Morita M. 2001. Marine radiocarbon reservoir effect in the western North Pacific observed in archaeological fauna. *Radiocarbon* 43(2A):465–71.

Yoneda M, Uzawa K, Hirota M, Uchida M, Tanaka A, Shibata Y, Morita M. 2002. Radiocarbon marine reservoir effect in human remains from the Kitakogane site, Hokkaido, Japan. *Journal of Archaeological Science* 29(5):529–36.

RADIOCARBON, Vol 44, Nr 2, 2002, p 559–566

^{14}C LEVEL AT MT CHIAK AND MT KYERYONG IN KOREA

J H Park[1,2] • J C Kim[1] • M K Cheoun[1] • I C Kim[1] • M Youn[1] • Y H Liu[1] • E S Kim[3]

ABSTRACT. We have observed $\Delta^{14}C$ concentrations in the northern hemisphere temperate region in the bomb pulse period, using cross-dated tree ring samples. The tree-ring samples were taken from one 70-year-old and two 50-year-old red pines (*Pinus densiflora*) on Mt Chiak, Korea and from a 50-year-old red pine (*Pinus densiflora*) on Mt Kyeryong, Korea. Twenty-two tree-ring samples from four red pines ranging from 1950 to 2000 AD were pretreated to obtain holo-cellulose, combusted to CO_2 by an element analyzer (EA) and converted to graphite for $\Delta^{14}C$ measurement using the accelerator mass spectrometry (AMS) facility at Seoul National University. Our results for $\Delta^{14}C$ showed good agreement with those measured by other researchers at similar latitudes. The observed steady decrease of $\Delta^{14}C$ from 1965 to 2000 AD is described by a single exponential function with a lifetime $\tau = 15.99 \pm 0.43$ yr. This lifetime is similar to that of the high-latitude region in Europe.

INTRODUCTION

Since 1945, nuclear weapons tests have led to an increase in atmospheric $\Delta^{14}C$. The atmospheric $\Delta^{14}C$ concentration in the northern hemisphere has approached a peak value of about twice the natural atmospheric $\Delta^{14}C$ concentration. Since then, the excess atmospheric ^{14}C has diffused into other reservoirs (mainly to the oceans) and, following the Limited Test Ban Treaty of 1963, the excess atmospheric ^{14}C has decreased exponentially (Povinec et al. 1986; Leung et al. 1995). However, the peak value, the time of peak value, and the speed of exponential decay for $\Delta^{14}C$ show differing trends in different latitudes.

Such studies had not been performed in Korea, therefore we obtained $\Delta^{14}C$ data in fresh air regions (Mt Chiak and Mt Kyeryong, Korea) and compared the characteristics of the $\Delta^{14}C$ value, namely the bomb peak value, the time of bomb peak value, and the speed of exponential decay for $\Delta^{14}C$ value with respect to other research results.

We assumed that Mt Chiak and Mt Kyeryong were in a fresh air region and selected tree-ring samples of red pine from those mountains. These tree-ring samples were used to obtain $\Delta^{14}C$ data for Korea for the period 1950–2000 AD.

SAMPLE DESCRIPTION AND DENDROCHRONOLOGY

Tree-Ring Samples from Mt Chiak

Mt Chiak (1288 m asl) is in the eastern part of Korea, 100 km from Seoul. It has a population of about 10 million. We collected red pine tree samples from Guryong temple and Bugok in Mt Chiak. Guryong temple (37°23′N, 128°3′E, 400 m asl) in Mt Chiak, 5 km from the Youngdong expressway, which, having been constructed after 1971 AD, did not influence the tree-ring samples in the the period 1950–1970 AD. However, the sample from 1975 AD (CH75, Table 1) was influenced by the expressway (Figure 1). The Bugok area (37°20′N, 128°4′E, 650 m asl) surrounded by Mt Chiak is 13 km from the Youngdong expressway and 9 km from the Chung-ang expressway still under construction. Moreover, both places are blocked by Mt Chiak, so that Wonju city, whose population is about 260,000, does not affect their tree-ring samples (Figure 1). Therefore, all of the samples except for CH75 (Guryong, Table 1) are safely assumed to be isolated from possible dead carbon sources nearby.

[1]Department of Physics, Seoul National University, Kwanak-ku, Seoul 151-742, Korea
[2]Corresponding author. Email: pjhun77@phya.snu.ac.kr.
[3]Department of Forest Resources, Kookmin University, Seoul 136-702, Korea

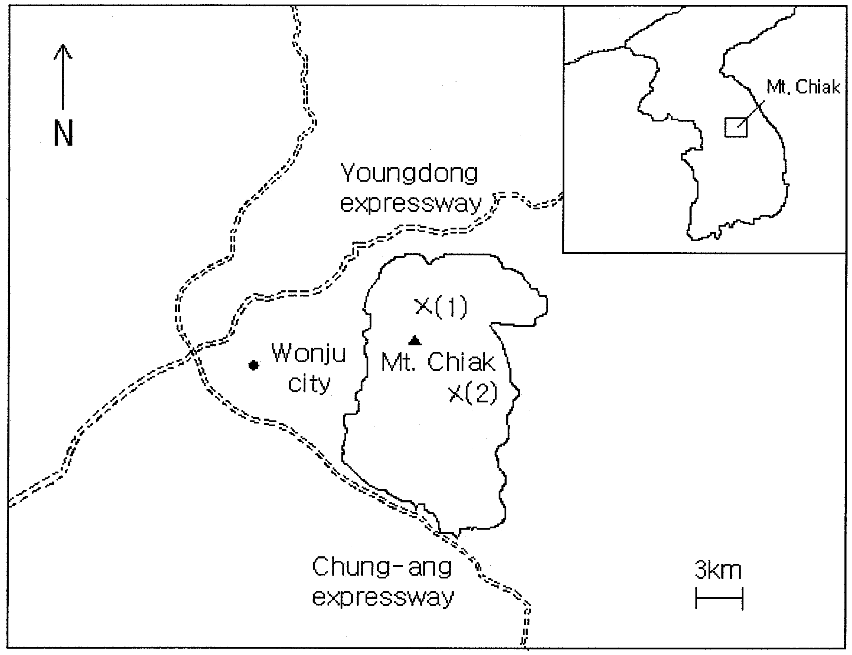


Figure 1 Map of the vicinity of Mt Chaik: (1) Guryong temple, (2) Bugok

Tree-Ring Samples in Mt Kyeryong

Mt Kyeryong (845 m asl) is located in the southern part of Korea at a distance of 140 km from Seoul. We collected red pine tree samples at Baekamdong (36°20′N, 127°13′E, 200 m asl) in Mt Kyeryong. Baekamdong is at a distance of 18 km from Daejeon city, whose population is about 1.5 million, and very near the Honam expressway, but it was also constructed after 1970 AD, so it did not influence the tree-ring samples in the period 1963–1964 AD. Therefore, the tree-ring samples used in this report were reasonably assumed to be collected in fresh air region in Korea.

Dendrochronology

The tree-ring samples were taken using an increment borer. The tree-ring samples showed clear annual ring structures. Each ring width was measured to a resolution of 0.01 mm using a microscope and a sliding linear table interfaced to a personal computer. The width data are presented in Figure 2. In these figures (A, B, and C), we grouped the width data by region. Group A contains the width data of Guryong temple's tree-ring samples, group B contains the width data of Bugok's tree-ring samples, and group C contains the width data of Baekamdong's tree-ring samples. In each group, Chiak-a1 and Chiak-a2, Chiak-d1 and Chiak-d2, and Kyerong-2-1 and Kyerong-2-2's tree rings are taken from the same red pine tree.

At first, we compared the widths of two tree-ring sets from the same red pine tree in each group. Both samples in each group from the same red pine tree show a strong correlation in Figure 2. To study the correlation in detail, we compared both two red pine tree ring sets with another red pine tree ring set. Chiak-c from a different red pine tree at Guryong temple shows a strong correlation with Chaik-a1 and Chaik-a2 in 1998, 1978, 1973, 1968, 1958, 1956, 1954, and 1949 (Figure 2[A]). Chiak-f from a different red pine tree at Bugok also shows a strong correlation with Chaik-d1 and Chaik-d2 in 1998,

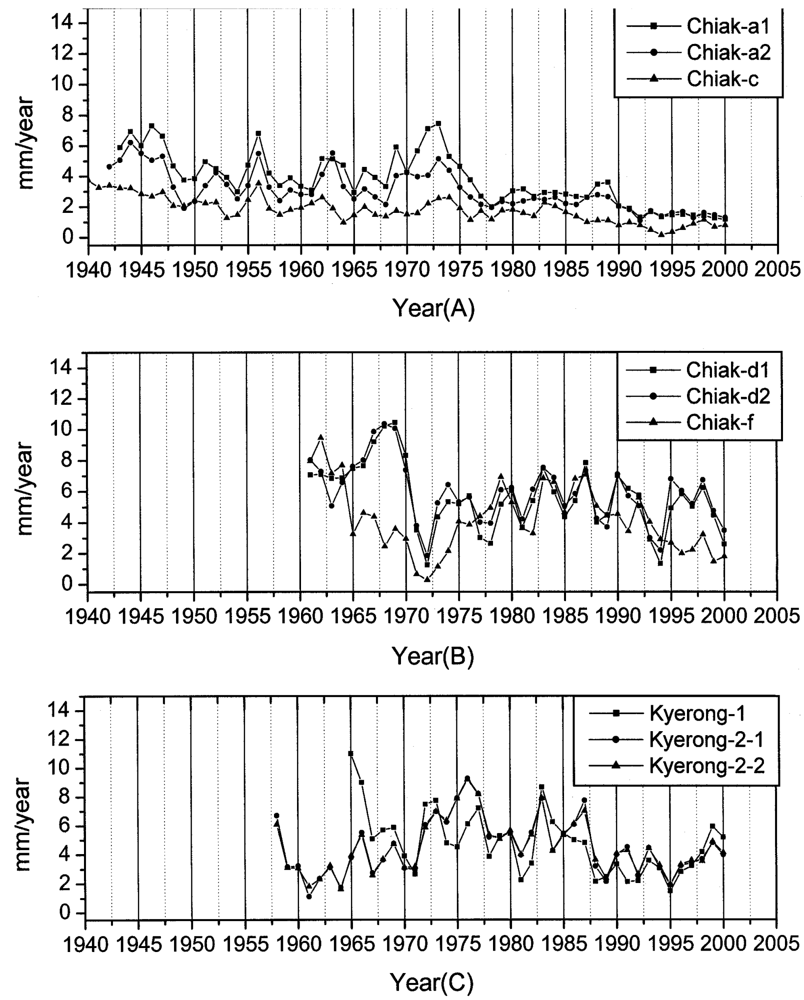


Figure 2 (A) tree-ring's width of Guryong temple area, Mt Chiak; (B) tree-ring's width of Bugok area, Mt Chiak; (C) tree-ring's width of Baekamdong area, Mt Kyeryong

1987, 1985, 1983, 1981, and 1972 (Figure 2[B]). Finally, Kyerong-1 from a different red pine tree at Baekamdong shows a strong correlation with Kyerong-2-1 and Kyerong-2-2 in 1999, 1995, 1992, 1983, 1981, 1973, 1971, 1969, and 1967 (Figure 2[C]). Therefore, our cross-dated tree-ring series show strong cross-correlations and are accurately identified in terms of their year.

For the study in this report, a 70-year-old red pine (Chiak-a2) from Mt Chiak was used for CH50, 55, 60, 62, 63, 64, 65, 66, 70, and 75 (Table 1), a 50-year-old red pine (Chiak-d1) from Mt Chiak for CH75-r, 79, 80, 81, 85, 90, 95, 99-r, and 00 (Table 1), a 50-year-old red pine (Chiak-d2) from Mt Chiak for CH00-r and a 50-year-old red pine (Kyeryong-2-1) from Mt Kyeryong for KR63 and 64 (Table 1), respectively.

Table 1 $\Delta^{14}C$ value from red pine in Mt Chiak and Mt Kyeryong

Ring formation (year)	Sample code	Site	$\delta^{13}C$ (‰ PDB)	$\Delta^{14}C$ (‰)
1950	CH50	Chiak (Guryong)	–19.5	–24.6 ± 10.5
1955	CH55	Chiak (Guryong)	–20.8	22.4 ± 11.3
1960	CH60	Chiak (Guryong)	–21.7	225.1 ± 11.7
1962	CH62	Chaik (Guryong)	–22.3	381.0 ± 12.7
1963	CH63	Chiak (Guryong)	–21.3	665.9 ± 21.0
1964	CH64	Chiak (Guryong)	–20.9	819.6 ± 14.7
1965	CH65	Chiak (Guryong)	–34.0	679.7 ± 29.1
1966	CH66	Chiak (Guryong)	–22.6	641.1 ± 13.9
1970	CH70	Chiak (Guryong)	–25.8	526.1 ± 14.5
1975	CH75	Chiak (Guryong)	–20.8	320.4 ± 13.4
1979	CH79	Chiak (Bugok)	–26.4	259.4 ± 13.3
1980	CH80	Chiak (Bugok)	–21.2	279.7 ± 14.9
1981	CH81	Chiak (Bugok)	–23.6	240.6 ± 14.8
1985	CH85	Chiak (Bugok)	–24.3	198.1 ± 10.6
1990	CH90	Chiak (Bugok)	–23.0	155.9 ± 10.5
1995	CH95	Chiak (Bugok)	–21.0	114.1 ± 13.9
2000	CH00	Chiak (Bugok)	–26.3	57.2 ± 9.9
1975(r)	CH75-r	Chiak (Bugok)	–23.5	393.0 ± 27.5
1999(r)	CH99-r	Chiak (Bugok)	–24.7	91.4 ± 19.9
2000(r)	CH00-r	Chiak (Bugok)	–28.5	50.0 ± 23.6
1963	KR63	Kyeryong (Baekamdong)	–24.0	751.7 ± 21.6
1964	KR64	Kyeryong (Baekamdong)	–25.4	841.9 ± 24.4

SAMPLE PREPARATION AND AMS ^{14}C ANALYSIS

Twenty-two tree rings were prepared for AMS analysis. Owing to the existence of very different levels of $\Delta^{14}C$ between consecutive tree rings, we removed the boundary region (~0.2 mm) of the tree ring. Each tree ring was carefully split and sliced to ~1 mm. Approximately 20 mg of each sample was used to extract cellulose. Cellulose was obtained for each sample by this process. The samples were heated to 80–85 °C in 0.5M HCl for 30 min and washed to neutral pH. The residues were heated again to 80–85 °C in 0.1M NaOH for 1 hr and washed to neutral pH. They were heated once more to 55–60 °C in a 4% solution of H_2O_2 at pH 11 for 1 hr and washed to neutral pH. Finally, they were heated to 80–85 °C in 0.5M HCl for 30 min (Sjören et al. 1981).

The obtained material was combusted to CO_2 using the element analyzer (EA). This CO_2 was reduced to graphite using H_2 and Fe catalyst (Lee et al. 2000; Vogel et al. 1987). The mass of the graphite was about 1 mg.

AMS $\Delta^{14}C$ measurements were performed using the AMS facility in Seoul National University (SNU) (Kim et al. 2000). The $^{14}C/^{12}C$ ratio of each sample was measured relative to the NIST standard of Oxalic Acid II. The $\Delta^{14}C$ of each sample was calculated after correcting for 1) the instrument's background, 2) isotopic fraction using $\delta^{13}C$, and 3) radioactive decay of both tree ring and standard sample (Hua et al. 1999).

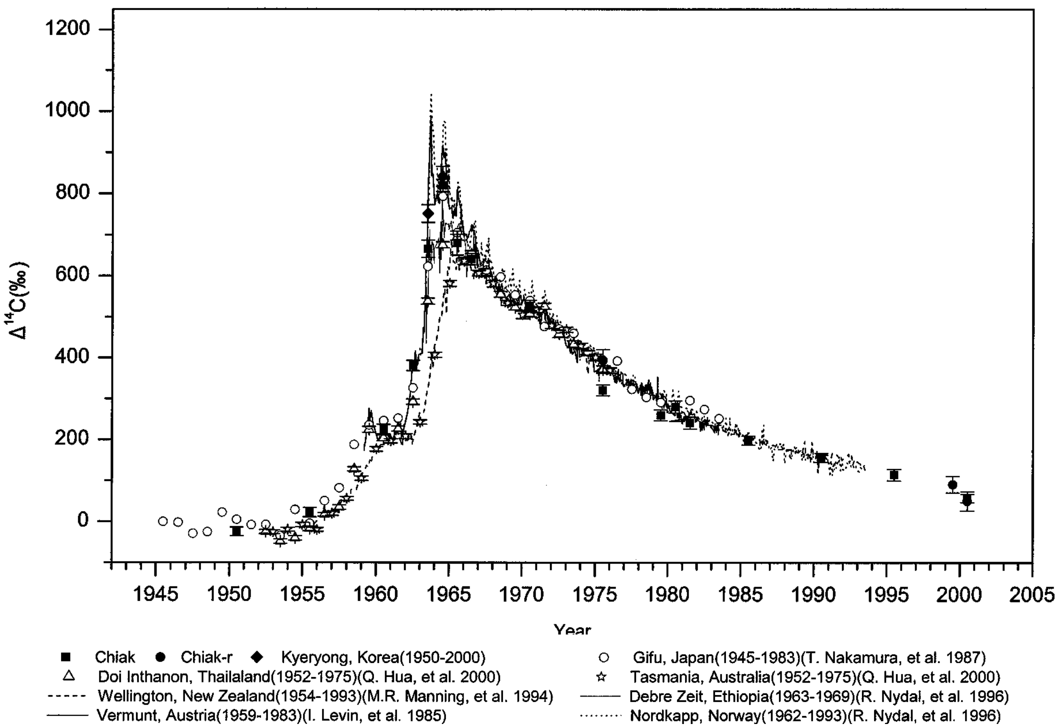


Figure 3 The observation of $\Delta^{14}C$ (‰) of atmospheric CO_2 and tree rings in the arctic zone, northern hemisphere temperate region, tropical zone

RESULTS AND DISCUSSION

The $\Delta^{14}C$ data for 1950–2000 AD are tabulated in Table 1 and illustrated in Figure 3. The growing season for red pine in Korea is from April to September, so the $\Delta^{14}C$ values for the tree rings are plotted as the points in the middle of the growing period.

For easy comparison, the atmospheric $\Delta^{14}C$ data from four regions—the arctic zone, northern hemisphere temperate region, tropical zone, and southern hemisphere temperate region—are plotted in Figure 3. They are the data for Nordkapp, Norway (71°06′N; 1962–1993 AD; Nydal et al. 1996a), Vermunt, Austria (47°N; 1959–1983 AD; Levin et al. 1985), Debre Zeit, Ethiopia (8°40′N; 1963–1969 AD; Nydal et al. 1996a), and Wellington, New Zealand (41°18′S; 1954–1993 AD; Manning et al. 1994).

Because the sample CH75 was taken in the vicinity of the Youngdong expressway, which was constructed in 1971 AD, the ^{14}C value appeared lower than the other regions, but there is general agreement between the ^{14}C tree-ring data in Korea and the atmospheric $\Delta^{14}C$ data in Vermunt and Nordkapp. The bomb peak in the $\Delta^{14}C$ tree-ring data in Korea appears in 1964 AD, whereas the atmospheric data in Vermunt and Nordkapp show the peak in 1963 AD. However, one should not regard this difference as a real delay between the ^{14}C tree-ring data in Korea and the atmospheric ^{14}C data in Vermunt and Nordkapp, as they are in good agreement on both the leading edge and the trailing edge sides of the bomb pulse. The apparent one-year difference is because although a dramatic increase in ^{14}C is peaked during 1963 for the atmosphere, the average over the growing season is lower in 1963 than in 1964. Thus, single whole growth ring for 1964 should (and does) have the higher ^{14}C value (Grootes et al. 1989).

Figure 3 also shows the data for Hinoki in Gifu, Japan (35.6°N; 1945–1983 AD; Nakamura et al. 1987), three-leaf pine in Doi Inthanon National Park, Thailand (18°33′N; 1952–1975 AD; Hua et al. 2000), and Huon pine in Tasmania, Australia (41°41′S; 1951–1975 AD; Hua et al. 2000).

The ^{14}C data from tree-ring samples in Mt Chiak and Gifu, which are in the northern hemisphere temperate region, show a similar tendency. The tree ring's bomb peaks in the northern hemisphere temperate region (Mt Chiak and Gifu) appear in the middle of 1964, while that in the tropical zone (Doi Inthanon National Park) is in the middle of 1965. There is a time delay of one year from the northern hemisphere temperate region to the tropical zone (Hua et al. 2000).

Figure 4 shows the exponential decay fitting of five data sets for $\Delta^{14}C$ data. They are respectively data for Mt Chiak, for Nordkapp (71°06′N; 1963–1993 AD; Nydal et al. 1996a), Vermunt (47°N; 1959–1983 AD; Levin et al. 1985), Gifu (35.6°N; 1945–1983 AD; Nakamura et al. 1987), and Doi Inthanon National Park (18°33′N; 1952–1975 AD; Hua et al. 2000). Because tree-ring sample CH75 is contaminated by dead carbon, the data of tree-ring sample CH75-r is used for fitting. The tree-ring sample CH00, CH00-r has similar ^{14}C value, so we chose CH00-r for fitting.

For comparison, the fitting interval for each data in Table 2 is chosen to start from 1965, and we used all available data points to calculate the decay lifetime. The plots are drawn from 1965 to last year by fitting, and from last year to 2000 by extrapolation. The fitting results are tabulated in Table 2.

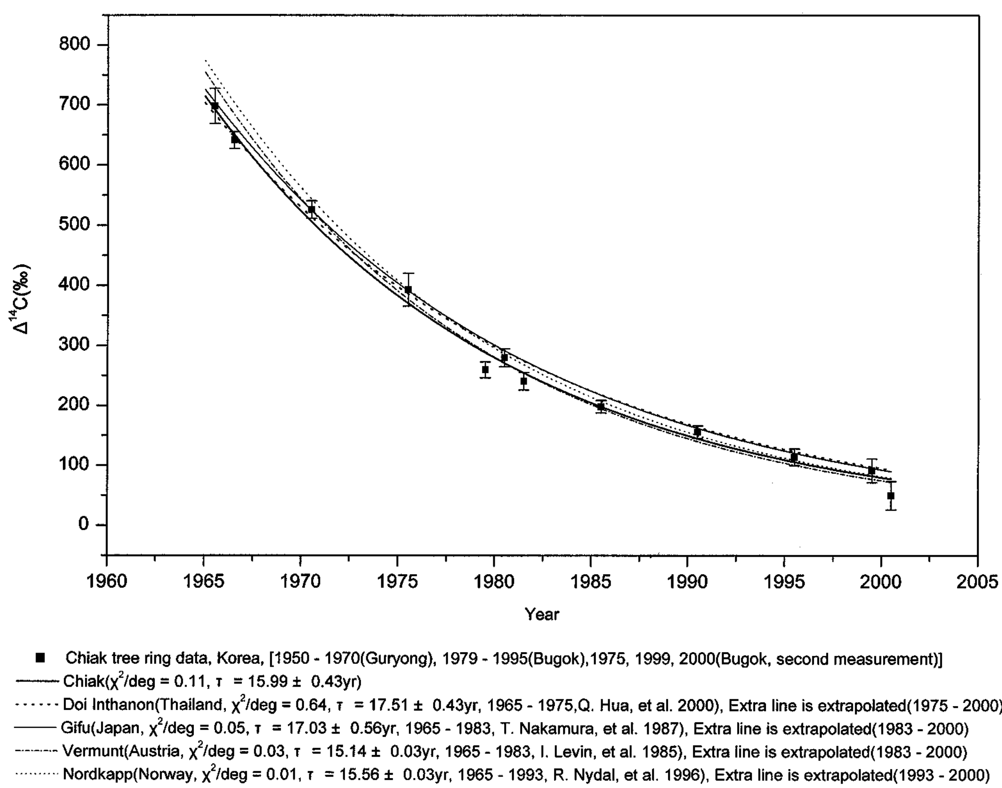


Figure 4 Chiak tree-ring data, Korea (1950–1970 [Guryong], 1979–1995 [Bugok], 1975, 1999, 2000 [Bugok, second measurement])

Table 2 The exponential decay fitting results for Mt Chiak and four other regions

Data set	Lifetime	Fitting interval	Location
Nordkapp, Norway	$\tau = 15.56 \pm 0.03$ yr	1965–1993	71°06′N
Vermunt, Austria	$\tau = 15.14 \pm 0.03$ yr	1965–1983	47°N
Mt Chiak, Korea	$\tau = 15.99 \pm 0.43$ yr	1965–2000	37°20´N, 37°23´N
Gifu, Japan	$\tau = 17.03 \pm 0.56$ yr	1965–1983	35.6°N
Doi Inthanon, Thailand	$\tau = 17.51 \pm 0.43$ yr	1965–1975	18°33'N

In fact, the decrease rate of the bomb peak is faster in the first years after 1965 than later on, since the ocean surface reservoir is gradually filled up with ^{14}C from the atmosphere. Our data and Nordkapp and Vermunt's data gives $\tau = \sim 13.5$ yr, which is a little faster than the value in Table 2, when fitted using data at the interval 1964–1970 AD. The lifetime ($\tau = 18.2$ yr) obtained by Nydal et al. (1996b) for Nordkapp's data at the interval 1973–1992 AD also conforms to this trend.

From the Table 2, we can say that the lifetime of low-latitude region (Doi Inthanon, Thailand) is long, while the lifetime of high-latitude regions (Nordkapp, Norway and Vermunt, Austria) are short. Although Mt Chiak, Korea and Gifu, Japan are located at the similar latitude, the lifetime of Mt Chiak, Korea is similar to that of high latitude region, while the lifetime of Gifu, Japan is similar to that of low latitude region. These trends of Mt Chiak, Korea and Gifu, Japan should be studied in more detail.

CONCLUSION

We have obtained bomb $\Delta^{14}C$ data for the northern hemisphere temperate region from red pines on Mt Chiak and Mt Kyeryong, Korea. These $\Delta^{14}C$ data show results consistent with other observations at the similar latitudes and, as a result, can be used for the study of the global carbon cycle, atmospheric transport and interaction between air and oceans. The lifetime of the $\Delta^{14}C$ data's exponential decay from 1965 to 2000 at Mt Chiak, Korea was obtained as 15.99 ± 0.43 yr.

ACKNOWLEDGMENTS

This work was supported by the Korea Engineering Science Foundation (KOSEF grant nr R01-2001-00022).

REFERENCES

Grootes PM, Farwell GW, Schmidt FH, Leach DD, Stuiver M. 1989. Importance of biosphere CO_2 in a subcanopy atmosphere deduced ^{14}C AMS measurements. *Radiocarbon* 31(3):475–80.

Hua Q, Barbetti M, Worbes M, Head J, Levchenko VA. 1999. Review of radiocarbon data from atmospheric and tree ring samples for the period 1945–1997 AD. *IAWA Journal* 20:261–83.

Hua Q, Barbetti M, Jacobsen GE, Zoppi U, Lawson EM. 2000. Bomb radiocarbon in annual tree rings from Thailand and Australia. *Nuclear Instruments and Methods in Physics Research* B172:359–65.

Kim JC, Lee CH, Kim IC, Park JH, Kang J, Cheoun MK, Kim YD, Moon CB. 2000. A new AMS facility in Korea. *Nuclear Instruments and Methods in Physics Research* B172:13–7.

Lee C, Kim JC, Park JH, Kim IC, Kang J, Cheoun MK, Choi SY, Kim YD, Moon CB. 2000. Progress in sample preparation system for the Seoul National University AMS facility. *Nuclear Instruments and Methods in Physics Research* B172:454–7.

Leung PL, Stokes MJ, Qiu SH, Cai LZ. 1995. A survey of environmental ^{14}C levels in Hong Kong. *Radiocarbon* 37(2):505–8.

Levin I, Kromer B, Schoch-Fischer H, Bruns M, Münnich M, Berdau D, Vogel JC, Münnich KO. 1985. 25 years of tropospheric ^{14}C observations in central Europe. *Radiocarbon* 27(1):1–19.

Manning MR, Melhuish WH. 1994. In: Boden TA, Kaiser DP, Sepanski RJ, Stoss FW, editors. *Trends 93 – a compendium of data on global change.* Oak Ridge National Laboratory: Carbon Dioxide Information Analysis Center. p 173.

Nakamura T, Nakkai N, Ohishi S. 1987. Applications of environmental ^{14}C measured by AMS as a carbon tracer, *Nuclear Instruments and Methods in Physics Research* B29:355–60.

Nydal R, Lovseth K. 1996a. Carbon-14 measurement in atmospheric CO_2 from Northern and Southern Hemisphere sites, 1962–1993. Oak Ridge National Laboratory: Carbon Dioxide Information Analysis Center.

Nydal R, Gislefoss J. 1996b. Further application of bomb ^{14}C as a tracer in the atmosphere and ocean. *Radiocarbon* 38(3):389–406.

Povinec P, Chudý M, Šivo A. 1986. Anthropogenic radiocarbon: past, present, and future. *Radiocarbon* 28(2A):668–72.

Sjoren B, Moldenius S. 1981. Effects of bleaching parameters on kinetics and stoichiometry of peroxide bleaching of mechanical pulp. *Chemistry and Biochemistry of Wood-based Processes and Products* 2: 125–31.

Vogel JS, Southon JR, Nelson DE. 1987. Catalyst and binder effects in the use of filamentous graphite for AMS. In: Gove HE, Litherland AE, Elmore D, editor. Proceedings of the 4th International Symposium on Accelerator Mass Spectrometry. *Nuclear Instruments and Methods in Physics Research* B29:50–6.

RADIOCARBON, Vol 44, Nr 2, 2002, p 567–580

RADIOCARBON DATING OF DEEP-SEA CORALS

Jess F Adkins[1] • Shelia Griffin[2] • Michaele Kashgarian[3] • Hai Cheng[4] • E R M Druffel[2] • E A Boyle[5] • R Lawrence Edwards[4] • Chuan-Chou Shen[4]

ABSTRACT. Deep-sea corals are a promising new archive of paleoclimate. Coupled radiocarbon and U-series dates allow ^{14}C to be used as a tracer of ocean circulation rate in the same manner as it is used in the modern ocean. Diagenetic alteration of coral skeletons on the seafloor requires a thorough cleaning of contaminating phases of carbon. In addition, 10% of the coral must be chemically leached prior to dissolution to remove adsorbed modern CO_2. A survey of modern samples from the full $\Delta^{14}C$ gradient in the deep ocean demonstrates that the coralline $CaCO_3$ records the radiocarbon value of the dissolved inorganic carbon.

INTRODUCTION

The radiocarbon content of dissolved inorganic carbon (DIC) in seawater is an important tool for constraining the rate of deep-water circulation. GEOSECS observations constrain the mean overturning time of the ocean to be about 800 years (Stuiver et al. 1983). At any one site in the ocean, considerations of both mixing and in-situ aging are important in determining the seawater $\Delta^{14}C$. In the modern western Atlantic for instance, there is a 100‰ range in $\Delta^{14}C$, but only about 150 years worth of aging (equivalent to about 20‰) since the water last was at the surface (Broecker and Peng 1982). In addition to mixing, $\Delta^{14}C$ ventilation age calculations from radiocarbon are complicated by the addition of nuclear bomb produced ^{14}C during the era of atmospheric testing. Some early measurements of surface waters help constrain the pre-bomb values (Bien et al. 1960; Broecker 1963; Fonselius and Ostlund 1959), but there are virtually no measurements from the deep where bomb radiocarbon can be seen today. A variety of tracer based methods have been used to "unmix" this bomb influence in newly formed deep waters (Broecker 1979; Broecker et al. 1985), but direct reconstructions are not available. Similar to the way surface corals and mollusks constrain pre-bomb surface water values to be uniformly –50‰ between 40°N and 40°S (Bard 1988; Druffel and Linick 1978), deep-sea corals could provide a map of natural radiocarbon before the bomb contamination.

Studies of fossil corals (Bard et al. 1993; Edwards et al. 1993) and varved sediments (Hughen et al. 1998) constrain the $\Delta^{14}C$ of the surface ocean and atmosphere for the past 30,000 years. Corals provide unique calibration points because they contain enough Uranium to make independent ^{230}Th dates on the exact same material used to generate ^{14}C ages. These combined measurements provide strong constraints on both changes in cosmogenic nuclide production rate and changes in the fluxes of carbon between active reservoirs. Rapid increases in past atmospheric $\Delta^{14}C$ are occasionally associated with a large-scale decrease in deep-water production rate (Stocker and Wright 1996), thus providing some of our best information about past ocean overturning rates.

More direct measurements of past deep-water circulation rate have been limited to comparisons between contemporaneous benthic and planktonic foraminifera (Broecker et al. 1990; Duplessy et al. 1989; Shackleton et al. 1988). Recently, deep-sea corals have been used as a new archive of past deep ocean $\Delta^{14}C$ itself (Adkins et al. 1998; Goldstein et al. 2001; Mangini et al. 1998). Similar to

[1]MIT/WHOI Joint Program in Oceanography. Now at California Institute of Technology, MS 100-23, 1200 E California Blvd., Pasadena, California 91125 USA. Email: jess@gps.caltech.edu.
[2]University of California at Irvine, Department of Earth System Science, Irvine, California 92697-3100 USA
[3]Center for Accelerator Mass Spectrometry L-397, Lawrence Livermore National Laboratory, PO Box 808, 7000 East Avenue, Livermore, California 94550 USA
[4]Dept. of Geology and Geophysics, University of Minnesota, 310 Pillsbury Drive SE, Minneapolis, Minnesota 55455 USA
[5]Dept. of Earth, Atmosphere and Planetary Sciences, MIT, E34-200, Cambridge, Massachusetts 02139 USA

surface corals, coupled ^{230}Th and ^{14}C dates in these samples provide a direct measurement of past seawater $\Delta^{14}C$ that is not model dependent. Calculation of past circulation rates from this data are constrained by the same problems of mixing and in-situ aging that modern measurements face (Adkins and Boyle 1999). With a large enough sample set in both space and time, one could potentially use deep-sea corals to create paleo $\Delta^{14}C$ maps similar to the modern GEOSECS data.

However, two important questions must be addressed before there is widespread use of deep corals as paleo $\Delta^{14}C$ archives. We need both an exhaustive study of the analytical techniques involved and a modern "core top" calibration. The latter point addresses the question "Do the corals record the radiocarbon value of the DIC in which they grow?" This is fundamentally about the coral's biomineralization itself. The first point addresses the question "Can we recover skeletal $\Delta^{14}C$ from past samples regardless of the radiocarbon's origin?" This is a question of cleaning techniques and analytical precision. Both points are examined in this paper.

METHODS

Physical and Chemical Cleaning

Cleaning methods are designed to remove contaminating carbon sources that accumulate both while the specimen is on the sea floor and while it is stored on land after collection. Black, organic carbon rich crusts that form in-situ on fossil corals after death have been described in our earlier work (Cheng et al. 2000). These crusts are diagenetic iron and manganese oxides that can trap significant amounts of detrital aluminosilicates. In addition, modern corals frequently have deposits of organic matter trapped between septa. Both of these phases can be removed with mechanical and chemical cleaning steps designed to attack an organic coating bound to the aragonite. The following procedure is based on one developed for trace metals in surface corals by Shen and Boyle (Shen and Boyle 1988).

Prior to chemical cleaning, all evidence of endolithic activity is drilled out to remove any possible reprecipitation of $CaCO_3$ by boring worms or sponges on the surface. Water rinses and scrubbing with a brush remove sediment from inside the coral and between the septa. Samples are then immersed in a 50/50 mixture of 30% H_2O_2 and 1N NaOH and ultrasonicated for 15 minutes. This oxidizing solution step is repeated several times. Occasionally, samples are again scrubbed with a brush to promote removal of the black crusts in small sheets. Oxidizing solution steps are repeated until there is very little black crust or polyp organic matter left on the sample. However, this process often leaves a brownish/orange organic stain on the $CaCO_3$. Quick dips (30 seconds to 2 minutes) in a 50/50 mixture of 30% H_2O_2 and 1% $HClO_4$ effectively remove this stain. The danger is that this perchloric acid step also dissolves about 5–10% of the sample. Small siphons for spent cleaning solutions and plastic racks to hold samples aid in the mechanics of the cleaning process. After the dilute perchloric step, samples are rinsed thoroughly with clean distilled water.

This cleaning process removes about 10% of the total coral weight. Immediately prior to dissolution, a second acid wash removes an additional 5–75% of the cleaned mass. This step is designed to reduce adsorbed modern CO_2 that accumulates during sample storage (Burr et al. 1992). For the second acid wash, pre-weighed samples are dipped into 6N HCl for 15–60 seconds followed by rinses in two separate beakers of deionized H_2O. After drying for several minutes in a 60 °C oven, the samples are cooled and reweighed to determine the percent of sample removed. Samples are then crushed in an agate mortar and pestle to facilitate dissolution in the reaction flasks. All equipment for handling coral samples is cleaned with 10% HCl prior to use.

Dissolution and Graphitization

Dissolution is carried out in specially designed finger flasks that contain a side arm for the phosphoric acid reservoir. Crushed samples are transferred to the acid cleaned flask with filter paper and care is taken not to spread fine $CaCO_3$ on the flask walls. Approximately 2 mL of 85% H_3PO_4 is added to the side arm with a cleaned Pasteur pipette. The flask is connected to a vacuum line using an 18/9 o-ring ball/socket joint and evacuated. Once the pressure has dropped, the sample reaction vessels are closed, removed from the line and tilted to allow the H_3PO_4 to spill out of the side arm and react with the coral sample. After reacting overnight, the samples are extracted on a vacuum line through two dry ice/isopropyl alcohol water traps. The purified sample is expanded into a known volume and measured with a MKS Baratron Type 122A absolute pressure gauge. Two milliliters of CO_2 gas are isolated for AMS analysis and about 4.6% (usually about 0.1–0.3 mL at STP) of the residual is saved for $\delta^{13}C$ determination. All excess is frozen into a glass tube. The tube is flame sealed and stored. $^{13}C/^{12}C$ ratios were determined at the Woods Hole Oceanographic Institution.

Graphitization of the 2 mL CO_2 sample for AMS analysis follows the method of Vogel (Vogel et al. 1987). Graphite samples are pressed into targets and measured for their $^{14}C/^{13}C$ ratio at the Lawrence Livermore National Lab Center for Accelerator Mass Spectrometry (CAMS). The corrected fraction modern (F) is reported as described by Donahue et al. (1990). The "old" oxalic acid standard is normalized to 1950 and a $\delta^{13}C$ value of −19‰ and the sample is normalized to a $\delta^{13}C$ of −25‰. With these adjustments the radiocarbon age is given by (Stuiver and Polach 1977; Donahue et al. 1990):

$$\text{Radiocarbon age} = \tau \ln F$$

where τ is the Libby mean life of 8033 years. The measured fraction modern, F_m, is converted to the true fraction modern (F) by accounting for the blank introduced during graphite formation:

$$F = F_m\,(1+f) - f$$

where f is the fraction modern of a ^{14}C-free calcite sample that is processed exactly the same way as the coral samples.

Leaching Experiments

There is considerable evidence that surface corals have a significant component of adsorbed modern CO_2 on their skeletons (Burr et al. 1992). But deep-sea corals are generally not porous; they have a smaller surface area to volume ratio and are less susceptible to modern contamination. We designed several leaching experiments to test for the presence of adsorbed CO_2. In each case we placed the unleached coral sample, with an excess of phosphoric acid, inside a reaction flask. Periodically the evolved CO_2 gas was removed and purified as described above. Smaller amounts of gas were collected at the beginning of the experiment and larger portions were collected at the end, sometimes after several days of sitting in the reaction vessels. Several different types of samples were used for these tests. JFA 20c is a *Desmophyllum cristagalli* with a U-series age of 65,455 ± 246 years (Cheng et al. 2000). This age corresponds to an F of 0.0003. Both cleaned and untreated pieces of this ^{14}C-dead sample were processed. We also dissolved successive fractions from calcite blanks that were acidified in HCl immediately prior to the experiment as described above. For this test some samples were crushed in a mortar and pestle prior to dissolution and some were not.

RESULTS

All calcite blanks from a 5-year period are listed in Table 1. The total standard deviation in F corresponds to an age detection limit of ~44,000 ^{14}C years. Rather than use this overall average, samples are blank corrected using the calcites from their same graphitization run. Only the data from August 1995 shows a small deviation from the routine CAMS backgrounds.

Table 1 Calcite blank data. The variance of the measured fraction modern over this five-year time period corresponds to a maximum radiocarbon age of >44,000 years.

Date	UCID #	CAMS #	Wt. (mg)	CO_2 Gas (ml) Total	AMS	F_m	error (1 σ)
March 1995	663	19384	52	10.36	1.35	0.0028	0.0002
	664	19385	42	9.76	1.30	0.0027	0.0003
August 1995	1006	22458	82	18.12	1.30	0.0066	0.0006
	1012	22459	61	10.77	1.37	0.0066	0.0004
August 1996	1535A	30195	47	11.35	1.98	0.0025	0.0002
	1535B	30196	47	11.35	2.06	0.0024	0.0002
March 1997	2059	36256	274	61.33	1.93	0.0025	0.0002
	2056	36259	65	13.63	1.93	0.0015	0.0002
May 1997	2205			2.45	1.99	Sample Lost	
	2206	39264		2.08	1.93	0.0040	0.0003
	2207	39265		3.56	1.96	0.0026	0.0001
	2208	39266	65.5	6.94	1.95	0.0024	0.0001
	2209	39267		2.41	1.97	0.0024	0.0003
	2210	39268		1.61	1.53	0.0040	0.0001
	2211	39269		5.59	1.96	0.0031	0.0002
	2212	39270	82.5	9.41	1.95	0.0024	0.0002
May 2000	3214	66007		6.5	1.5	0.0027	0.0001
	3250	66006		10.13	1.5	0.0033	0.0001
	3786	66010				0.0036	0.0001
	3978	66008		10.24	1.54	0.0025	0.0001
July 2000	3224	66955		10.36	1.51	0.0009	0.0001

Average	0.0031
Std Deviation	0.0014

Results from leaching experiments are presented in Table 2 and Figure 1 (figures begin on page 574). Neither crushed nor uncrushed calcite shows a trend in the fraction modern of the successive fraction removed (higher fraction number), and all data fall within the long-term range for all blanks (Figure 1A). The pre-dissolution HCl wash clearly removes any adsorbed modern CO_2 from these types of samples. Similar results for ^{14}C-dead *D. Cristagalli* are shown in Figure 1b. There is some evidence for adsorbed CO_2 in samples that have been dissolved less than 5%. All other cleaned samples, not affected by leaks in the finger flasks (see Discussion), have the same fraction modern within experimental error.

The modern calibration data set is listed in Table 3. Uranium series ages for these corals are reported in Table 4. Data were collected and ages calculated as described in Cheng et al. (2000). Corrected ages and age errors are given relative to 1950 (years BP) and include a correction for unsupported ^{230}Th using the ^{232}Th data. ^{14}C replicates of the same CO_2 gas graphitized separately always agree within 2 σ. A modern coral standard of *Porites sp*. run many times over the course of this study gives a value of 0.9461 ± 0.0025, well within the long-term average from the UCI lab.

Table 2 Radiocarbon data from all leaching experiments. Errors are 1 σ.

Fraction Number	UCID #	CAMS #	Start wt. (mg)	CO_2 Gas (ml) Total	AMS	Fraction Modern	error
JFA 20c Top							
1	2039	36240	301.1	2.77	1.87	0.0119	0.0008
2	2040	36241		5.58	1.95	0.0084	0.0008
3	2041	36242		7.70	1.92	0.0077	0.0008
4	2042	36243		9.56	1.93	0.0066	0.0008
5	2043	36244		4.85	1.92	0.0097	0.0008
JFA 20c Bottom I							
1	2044	36245	231.8	2.78	1.62	0.0178	0.0009
2	2045	36246		4.09	1.90	0.0120	0.0009
3	2046	36247		7.28	1.93	0.0109	0.0009
4	2047	36248		9.13	1.93	0.0110	0.0008
5	2048	36249		30.55	1.94	0.0218	0.0009
JFA 20c Bottom II							
1	2049	36250	226.6	2.48	1.68	0.0174	0.0010
2	2050	36251		4.36	1.94	0.0118	0.0008
3	2051	36252		10.59	1.92	0.0132	0.0009
4	2052	36253		11.26	1.93	0.0160	0.0008
5	2053A	36254		22.75	1.91	0.0248	0.0008
5	2053B	36255			1.93	0.0240	0.0008
Calcite Uncrushed							
1	2205		65.5	2.45	1.99	Lost during graphitizaton	
2	2206	39264		2.08	1.93	0.0040	0.0003
3	2207	39265		3.56	1.96	0.0026	0.0001
4	2208	39266		6.94	1.95	0.0024	0.0001
Calcite Crushed							
1	2209	39267	82.5	2.41	1.97	0.0024	0.0003
2	2210	39268		1.61	1.53	0.0040	0.0001
3	2211	39269		5.59	1.96	0.0031	0.0002
4	2212	39270		9.41	1.95	0.0024	0.0002
JFA 62.1 Top							
1	2197	39255	87.8	1.95	1.87	0.6852	0.0030
2	2198	39256		4.56	1.98	0.6837	0.0027
3	2199	39257		4.65	1.97	0.6840	0.0032
4	2200	39258		9.26	1.95	0.6799	0.0029
JFA 62.1 Bottom							
1	2201	39259	48.5	1.66	1.57	0.6777	0.0029
2	2202	39260		2.8	1.88	0.6757	0.0030
3	2203	39261		3.44	1.96	0.6776	0.0030
4	2204	39262		3.02	1.95	0.6790	0.0032

Table 3 Modern "core top" calibration data set

ID	UCID	CAMS #	Depth (meters)	Lat	Long	Species	Cal Age (years)	err	^{14}C Age	err	$\Delta^{14}C$	error	DIC $\Delta^{14}C$	err
85080	655	19373	990-1150	43.47S	150.29E	D. cristagali	34	10	1000	50	-113	6	-115	20
47413	654	19372	421	50.38S	167.38E	D. cristagalli	37	4	590	40	-67	5	-62	8
48740.1	1020	22462	1420-1470	48°41'N	10°54'W	D. cristagalli	139	9	720	50	-70	6	-70	10
86873.1	1018	22460	1112	25°53'S	5°44'E	St. campaniformis	331	115	1400	60	-126	14	-120	8
91545.2	1003	22446	1510-1600	21°18'S	36°18'E	St. nobilis	407	35	1550	50	-134	7	-125	10
BI-103-3	1013	22454	1355	18°N	157°W	E. rostrata	688	14	2710	50	-224	5	-230	12
JFA 47.1	1021	22463	1790-1803	48°10'S	148°16'E		850	24	2190	50	-156	6	-150	20
94069.1	3222	66899	710	30°31'S	178°39'W	D. cristagalli	986	10	1530	30	-69	4	-70	8
Samples without U-series Ages														
48518	1023	22465	1420-1470	48°41'N	10°54'W	S. variabilis			640	50	-77	6	-70	10
47373	1022	22464	2010-2100	49°51'S	178°35'E	F. impensum			1420	50	-162	5	-164	8
93177.3	999	22442	4100	34°43'N	123°4'W	F. marenzelleri			2020	50	-222	5	-230	10
83522	1004	22447	1760	21°31'S	81°31'W	Caryophyllia sp.			2210	50	-241	5	-210	10

Table 4 Uranium series data. Only the data for new corals are shown. Errors are 2 σ and ages are at the time of measurement. Age uncertainties are calculated from the ^{232}Th concentration and the error on the ^{230}Th/^{238}U activity as described in Cheng et al. (2000a). Half-lives for ^{230}Th and ^{234}U are the most recent as reported in Cheng et al. (2000b).

ID	^{238}U (ppb)	^{232}Th (ppt)	δ^{234}U (measured)	^{230}Th/^{238}U (activity)	Age (years BP)	δ^{234}U (initial)
86873.1	4191 ±11	1039 ±27	146.5 ±5.2	0.00473 ±0.00013	284 ±115	146.6 ±5.2
91545.2	4952 ± 4	371 ±44	146.5 ±1.4	0.00464 ±0.00008	356 ±35	146.6 ±1.4
BI-103-3	5553 ± 4	154 ±27	145.1 ±1.1	0.00733 ±0.00007	641 ±14	145.4 ±1.1
JFA 47.1	4706 ± 3	227 ±48	145.9 ±1.2	0.00912 ±0.00010	802 ±24	146.2 ±1.2
94069.1	4070 ± 5	65 ±3	145.6 ±1.3	0.01038 ±0.00008	936 ±10	146.0 ±1.3

DISCUSSION

Leaching Experiments

The ^{14}C-dead deep-sea coral, sample JFA 20c, shows some effect of modern CO_2 contamination in the initial fraction of CO_2 leached. Carbon from the first 5–10% of the coral sample is slightly elevated in its fraction modern (Figure 1B). This effect occurs in both the cleaned and untreated samples. *D. cristagalli* samples must be washed in acid prior to dissolution to avoid this problem. The effect is not as large as that for surface corals where acid treatments of up to 50% mass loss did not remove all of the modern contamination (Burr et al. 1992). This large difference between porous surface corals and relatively dense deep-sea specimens is not surprising and is probably due to their different surface area to volume ratios.

There is also a clear effect of the cleaning procedure on the radiocarbon age. Untreated samples with intact black crusts (gray points in Figure 1b) are always elevated in their fraction modern relative to the cleaned piece from the same sample (black points in Figure 1b). As we used phosphoric acid to acidify our samples, it is unlikely that the contaminating carbon phase is something other than $CaCO_3$. Removing the black crusts eliminates reduced organic carbon, but this is not easily hydrolyzed in the H_3PO_4. Contaminating $CaCO_3$ probably comes from secondary precipitates that are somehow protected or promoted by the formation of black crusts. The difference between gray and black points in Figure 1b is not due to adsorbed modern CO_2 as its effect is removed in the first fraction leached. Cleaning fossil samples prior to radiocarbon age determination is crucial to determining the correct Δ^{14}C of past water masses.

In both the calcite and coral leaching experiments there is evidence for a small modern CO_2 blank in the preparation lines, and a larger contamination from leaks in the o-ring seals (Figure 1). The leak source, however, is only apparent in samples that sat for several days while they reacted. These samples are marked with dashed circles around the data points. The rate of sample dissolution slowed considerably during the leaching experiments and stopped altogether for the cleaned sample of JFA 20c. These last fractions sat in the reaction vessel for several days and are clearly contaminated. Actual samples for measuring past Δ^{14}C are never exposed to this long delay and are unaffected by leaks in the reaction flask.

There is clear evidence for a small contamination from modern CO_2 in the gas handling lines themselves, but only for the smallest samples. This effect is evident by plotting a sample's fraction modern versus its size (Figure 2). ^{14}C-dead samples should show no trend in their measured fraction modern as a function of amount of $CaCO_3$ reacted, but the individual fractions from our leaching

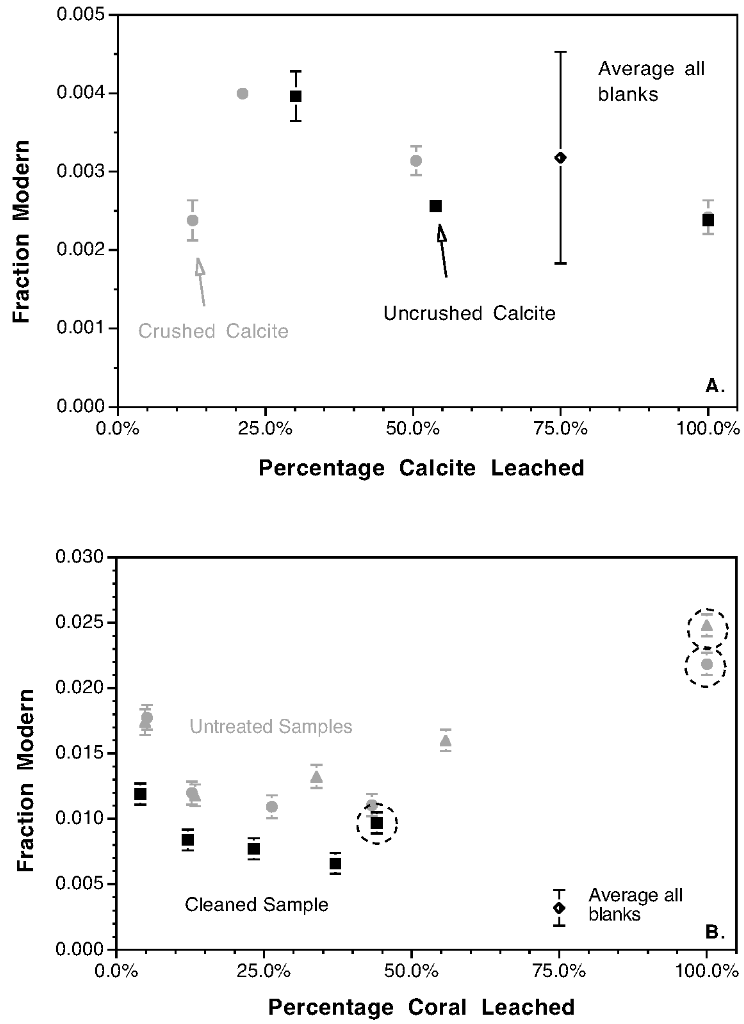


Figure 1 ^{14}C-dead $CaCO_3$ leaching experiment results. A. Calcite results for samples both crushed (gray circles) and not crushed (black squares) prior to dissolution. B. *D. cristagalli* sample JFA 20c results for both cleaned (black squares) and untreated (gray circles and triangles) samples. Dotted circles around the last point in each series indicate contamination from a leak in the reaction flasks (see Discussion). In both figures the half-filled diamond is the average and 1 σ standard deviation of all blanks in Table 1.

experiments do show larger ^{14}C values for samples below about 2–3 mL of CO_2. The effect is larger for coral samples than for calcites, but our paleo $\Delta^{14}C$ sample sizes are always larger than the 2–3 mL threshold.

We also successively dissolved the top and bottom pieces of a Holocene aged coral to test the top/bottom age reversals found in deglacial corals by Adkins et al. (1998). Sample JFA 62.1 was dredged from 1420 m on the Pluto Seamount in the eastern basin of the North Atlantic. This sample has black crusts like the deglacial samples, but grew during a time when we do not expect rapid changes in the deep $\Delta^{14}C$ of DIC. As such, the top to bottom age difference should only reflect the

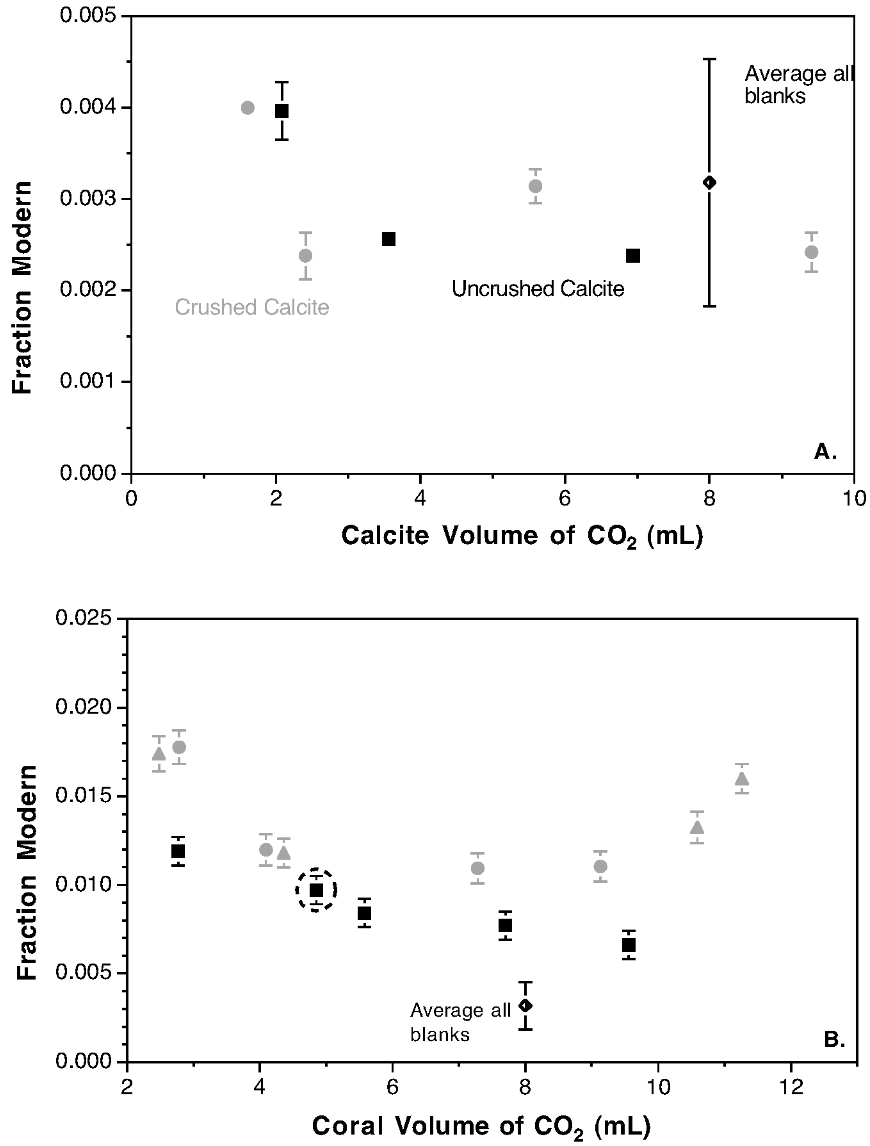


Figure 2 The same data as in Figure 1 but plotted against sample size instead of percentage removed. Symbols are as described in Figure 1. Higher fraction modern values for the smallest samples indicate a contribution from modern carbon in the preparation lines (see text).

coral's mean extension rate. Figure 3 illustrates that there is a clear difference in the ages of the top and bottom pieces (70 ± 28 yr) and that there is no difference between successive acid treatments of the same piece. Unlike the deglacial corals in Adkins et al. (1998) this sample is younger at the top than at the bottom. Age "reversals" between the top and bottom of a single coral are therefore representative of a change in the seawater DIC at that site during the coral's lifetime. The 70 ± 28-yr age difference implies a mean growth rate of ~0.7 mm/yr, in good agreement with the U-series derived mean growth rates of several modern *D. cristagalli* (Cheng et al. 2000).

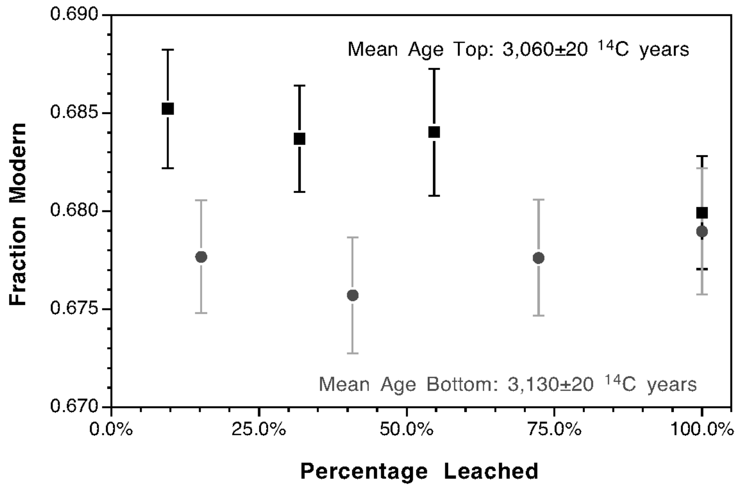


Figure 3 Stepwise dissolution experiment results for sample JFA 62.1, a *D. cristagalli* from 1400 m deep in the northeast Atlantic Ocean. The top of the coral is younger than the bottom by 70 ± 28 yr. This difference corresponds to a mean extension rate of ~0.7 mm/yr.

Calibration Data Set

Our modern coral calibration is shown in Figure 4. Samples were initially determined to be "modern" by inspection of the quality of the septa and the lack of endolithic activity. Water $\Delta^{14}C$ values for all coral samples are estimated from nearby GEOSECS stations. Coral ^{14}C data for these samples fall on or below the 1:1 line in Figure 4. Falling below this line indicates that a coral is older than the water in which it grew. By measuring the U-series age of these "too old" samples, we can correct for the time between the date the coral stopped growing and the day we measured its age. In all cases where we made both ^{230}Th and ^{14}C dates (black squares), the samples came back onto the 1:1 line. An example of how we determine the water $\Delta^{14}C$ is shown in Figure 5. This sample from the South Pacific is nearly 1000 years old and lies at the modern (mid 1970s) depth of bomb ^{14}C penetration, as indicated by the tritium data. The fact that our old coral point lies on the mid-'70s $\Delta^{14}C$ trend supports the ^3H conclusion that the bomb ^{14}C influence is small below 550 m (Broecker et al. 1985).

The data in Figure 4 are a clear demonstration that within analytical error deep-sea corals, from a variety of genera, are excellent recorders of the $\Delta^{14}C$ of the dissolved inorganic carbon (DIC) in which they grow. Modern looking samples may have spent considerable time dead on the sea floor and/or in sample drawers before being measured, but this effect can be accurately and precisely determined. As several of our samples in this set are hundreds of years old (Table 3) and were clean enough to be called "modern", the black crusts, at least in the modern ocean, do not seem to form immediately after the coral's death.

The 1:1 correspondence between coral $\Delta^{14}C$ and seawater DIC $\Delta^{14}C$ is strong evidence that inorganic carbon is the sole source of skeletal $CaCO_3$. However, we can more quantitatively use the data in Figure 4 to test what fraction of a coral's skeleton can come from metabolic CO_2. These organisms are essentially filter feeders, eating the available detritus that washes over them. Several of the specimens in Figure 4 grew when this food source was contaminated by bomb ^{14}C. The elevated level of $\Delta^{14}C$ in this organic matter relative to the surrounding DIC (Griffin and Druffel 1989) pro-

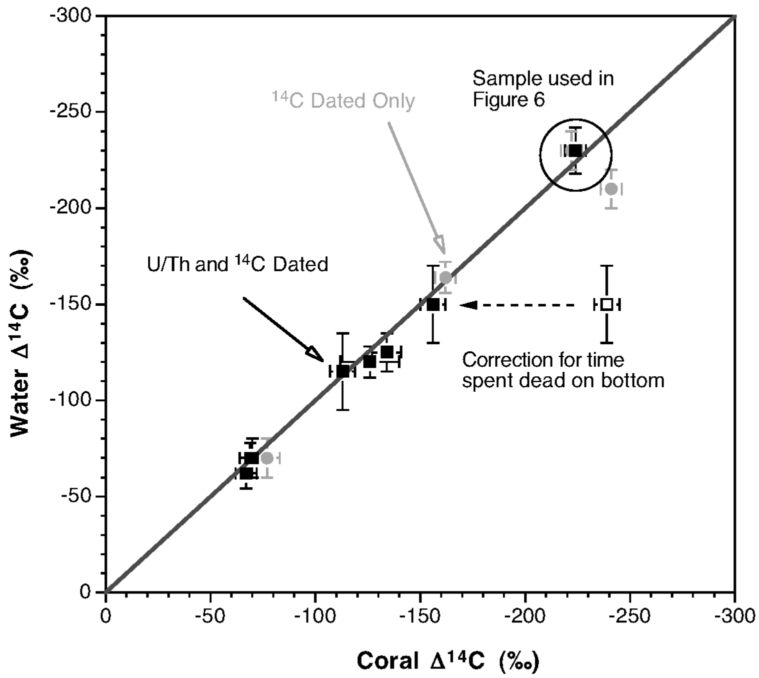


Figure 4 Modern calibration of ^{14}C in deep-sea corals. Water data are estimated from nearby GEOSECS stations. Corals are measured as described in the text. Gray circles are samples with only ^{14}C dates. Black squares are samples with both ^{14}C and ^{230}Th dates. The open black square shows how a ^{14}C date is transformed into the Δ^{14}C at the time of death by correction with a ^{230}Th age. All samples fall on a 1:1 line, indicating that corals are an excellent archive of seawater Δ^{14}C. The circled sample is the coral used in the percent metabolic CO_2 calculation (see Figure 6 and text).

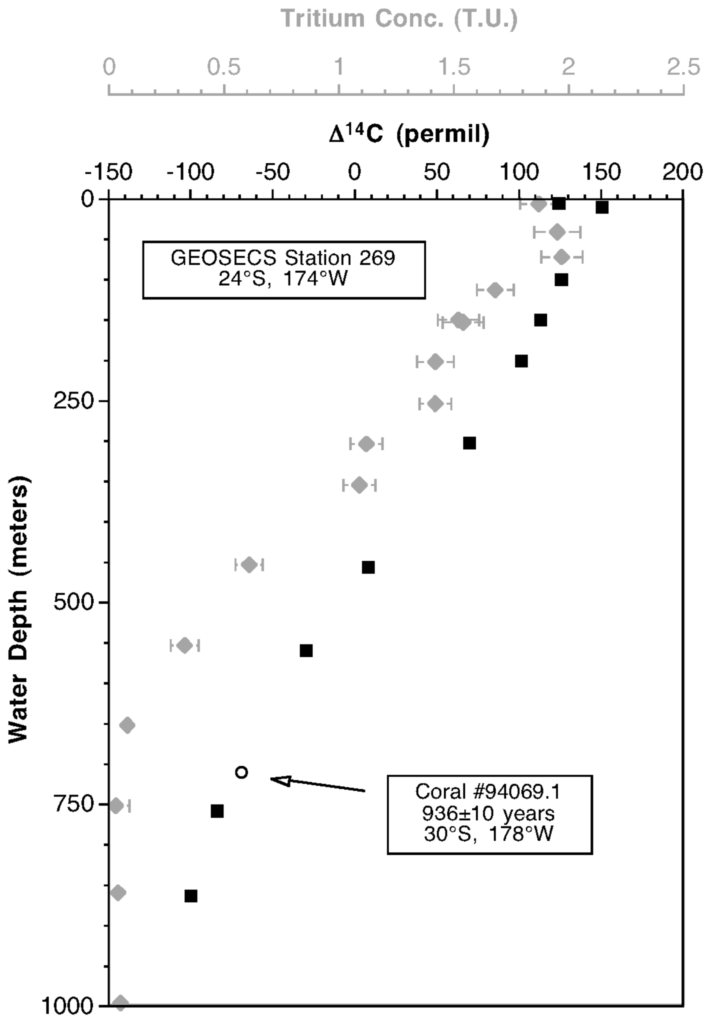
vides a test of how much organically derived CO_2 is fixed into the skeletal aragonite. We can write the radiocarbon mass balance equation for a coral's skeleton as follows:

$$(\text{Fraction Respired } CO_2)(\Delta^{14}C \text{ of Food}) + (1-\text{Fraction Respired } CO_2)(\Delta^{14}C \text{ of DIC}) = \text{Skeleton } \Delta^{14}C$$

While within the error bars all of our data falls on a 1:1 line between DIC Δ^{14}C and coral Δ^{14}C, the circled data point in Figure 4 falls about 8‰ above the line. Sample number 93177.3 is a *Fungiacyathus marenzelleri* that was picked alive from 4100 m in the sub-tropical north-east Pacific (very close to Station M, 34°50'N, 123°00'W) on 20 October 1992. By adopting a water to coral difference of 10‰ and using a water Δ^{14}C value of −230‰, we can rewrite the above equation:

$$\Delta^{14}C \text{ of Food} = 10/(\text{Fraction Respired } CO_2 - 230)$$

This function is plotted in Figure 6 for a range of fractions of respired CO_2 in the skeleton. Using data on the Δ^{14}C of suspended and sinking particulate organic carbon (POC) from almost exactly the same location as the coral (Druffel et al. 1996), we can constrain the maximum respired CO_2 our data allows in the skeleton. The oldest food source, suspended POC, gives a maximum value of about 8%. Within the errors of our AMS measurements and the estimates of bottom water Δ^{14}C of DIC, the skeletons of deep-sea corals are drawn entirely from ambient inorganic carbon. There is room in the data for a maximum of 8% of the skeleton to be of a respired origin. This result has



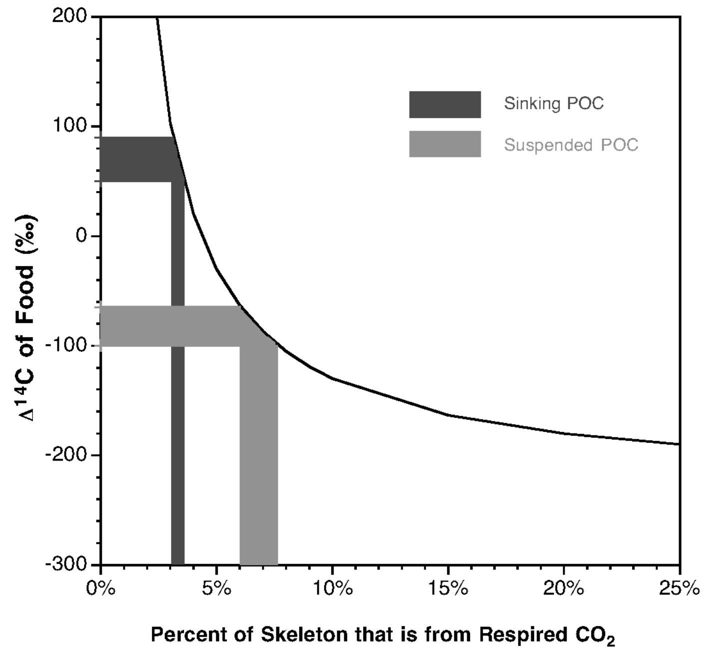


Figure 6 (above) Results of the metabolic carbon calculation described in the text. The black line describes all possible combinations of the fraction of skeletal carbon that is from the coral's food source and the $\Delta^{14}C$ of that source. Particulate data from a nearby hydrographic station shows that at most 8% of the skeleton could be from suspended particulate organic carbon (POC). Within error the sample used to make the black line lies on the 1:1 modern calibration line, so that 0% respired carbon in the skeleton is also a possibility.

Figure 5 (left) Example of water $\Delta^{14}C$ estimation for use in Figure 4. Sample 94069.1 lies on the trend in the modern $\Delta^{14}C$ profile. At this depth in the mid-1970s the influence of bomb ^{3}H was negligible.

important implications for the mechanism of coral calcification when there are not photosymbionts to feed dissolved organic carbon to the polyp.

CONCLUSION

Before reliable ^{14}C ages can be collected, fossil deep-sea corals must be cleaned of their black crusts and endolithic activity. Immediately prior to graphitization, these samples must have at least 10% of their mass acid leached to remove the effect of adsorbed modern CO_2. Once these precautions are taken, it is clear that deep-sea corals record the $\Delta^{14}C$ of the DIC in which they grow. At most, 8% of the skeleton can come from respired CO_2. Coupled with U-series ages this makes deep-sea corals a promising new archive of paleo-ventilation rates. When there is no change in bottom water $\Delta^{14}C$ during a coral's lifetime, the ^{14}C age difference between the top and the bottom reflects the mean skeletal extension rate.

REFERENCES

Adkins JF, Boyle EA. 1999. Age screening of deep-sea corals and the record of deep North Atlantic circulation change at 15.4 ka. In: Abrantes F, Mix A, editors. *Proceedings of the Sixth International Conference on Paleoceanography.* Elsiever. Forthcoming.

Adkins JF, Cheng H, Boyle EA, Druffel ERM, Edwards L. 1998. Deep-sea coral evidence for rapid change in ventilation of the deep North Atlantic 15,400 years ago. *Science* 280:725–8.

Bard E. 1988. Correction of accelerator mass spectrometry ^{14}C ages measured in planktonic foraminifera: paleoceanographic implications. *Paleoceanography* 3: 635–45.

Bard E, Arnold M, Fairbanks R, Hamelin B. 1993. ^{230}Th-^{234}U and ^{14}C ages obtained by mass spectrometry on corals. *Radiocarbon* 35(1):191–9.

Bien GS, Rakestraw NW, Suess HE. 1960. Radiocarbon concentration in Pacific Ocean water. *Tellus* 12:436–43.

Broecker WS. 1963. $^{14}C/^{12}C$ ratios in surface ocean water. *Nuclear Geophysics* 1963:138–49.

Broecker WS. 1979. A revised estimate for the radiocarbon age of North Atlantic Deep Water. *Journal of Geophysical Research* 84:3218–26.

Broecker WS, Klas M, Clark E, Trumbore S, Bonani G, Wolfli W, Ivy S. 1990. Accelerator mass spectrometric measurements on foraminifera shells from deep sea cores. *Radiocarbon* 32(2):119–33.

Broecker WS, Peng T-H. 1982. *Tracers in the sea*. Eldigio Press.

Broecker WS, Peng T-H, Ostlund G, Stuiver M. 1985. The distribution of bomb radiocarbon in the ocean. *Journal of Geophysical Research* 90:6953–70.

Burr GS, Edwards RL, Donahue DJ, Druffel ERM, Taylor FW. 1992. Mass spectrometric ^{14}C and U-Th measurements in coral. *Radiocarbon* 34(3):611–8.

Cheng H, Adkins JF, Edwards RL, Boyle EA. 2000. U-Th dating of deep-sea corals. *Geochemica et Cosmochemica Acta* 64:2401–16.

Donahue DJ, Linick TW, Jull AJT. 1990. Isotope ratio and background corrections for accelerator mass spectrometry radio carbon measurements. *Radiocarbon* 32(2):135–42.

Druffel EM, Linick TW. 1978. Radiocarbon in annual coral rings of Florida. *Geophysical Research Letters* 5(11):913–6.

Druffel ERM, Bauer JE, Williams PM, Griffin S, Wolgast D. 1996. Seasonal variabiltiy of particulate organic radiocarbon in the northeast Pacific Ocean. *Journal of Geophysical Reseach* 101: 20,543–52.

Duplessy J-C, Arnold M, Bard E, Juillet-Leclerc A, Kallel N, Labeyrie L. 1989. AMS ^{14}C study of transient events and of the ventilation rate of the Pacific intermediate water during the last deglaciation. *Radiocarbon* 31(3):493–502.

Edwards LR, Beck WJ, Burr GS, Donahue DJ, Chappell JMA, Bloom AL, Druffel ERM, Taylor FW. 1993. A large drop in atmospheric $^{14}C/^{12}C$ and reduced melting in the Younger Dryas, documented with ^{230}Th ages of corals. *Science* 260:962–7.

Fonselius S, Ostlund G. 1959. Natural radiocarbon measurements on surface water from the North Atlantic and the Arctic Sea. *Tellus* 11:77–82.

Goldstein SJ, Lea DW, Chakraborty S, Kashgarian M, Murrell MT. 2001. Uranium-series and radiocarbon geochronology of deep-sea corals: implications for Southern Ocean ventilation rates and the oceanic carbon cycle. *Earth and Planetary Science Letters* 193: 167–82.

Griffin S, Druffel ERM. 1989. Sources of carbon to deep-sea corals. *Radiocarbon* 31(3): 533–43.

Hughen KA, Overpeck JT, Lehman SJ, Kashgarian M, Southon J, Peterson LC, Alley R, Sigman DM. 1998. Deglacial changes in ocean circulation from an extended radiocarbon calibration. *Nature* 391:65–8.

Mangini A, Lomitschka M, Eichstadter R, Frank N, Vogler S, Bonani G, Hajdas I, Patzold J. 1998. Coral provides way to age deep water. *Nature* 392:347–8.

Shackleton NJ, Duplessy J-C, Arnold M, Maurice P, Hall MA, Cartlidge J. 1988. Radiocarbon age of the last glacial Pacific deep water. *Nature* 335:708–11.

Shen GT, Boyle EA. 1988. Determination of lead, cadmium and other trace metals in anually-banded corals. *Chemical Geology* 67:47–62.

Stocker TF, Wright DG. 1996. Rapid changes in ocean circulation and atmospheric radiocarbon. *Paleoceanography* 11:773–96.

Stuiver M, Polach HA. 1977. Reporting of ^{14}C data. *Radiocarbon* 19(3):355–63.

Stuiver M, Quay PM, Ostlund HG. 1983. Abyssal water carbon-14 distribution and the age of the world oceans. *Science* 219:849–51.

Vogel JS, Nelson DE, Southon JR. 1987. ^{14}C background levels in an accelerator mass spectrometry system. *Radiocarbon* 29:323–33

RADIOCARBON, Vol 44, Nr 2, 2002, p 581–590

PRE-BOMB RADIOCARBON VARIABILITY INFERRED FROM A KENYAN CORAL RECORD

Nancy S Grumet[1] • Thomas P Guilderson[2] • Robert B Dunbar[3]

ABSTRACT. We report results from AMS radiocarbon measurements ($\Delta^{14}C$) in corals recovered off the coast of Kenya. Bimonthly samples which span the pre-bomb era average –51‰ (±3.7; n=43), when age and Suess effect are corrected, and over the time of interest (1946–1954) do not exhibit any discernible seasonality. Relative to regional pre-bomb $\Delta^{14}C$ values in the western Indian Ocean, our results indicate ^{14}C enrichment off the coast of Kenya. Furthermore, the absence of a distinct subannual $\Delta^{14}C$ signal suggests that open and coastal upwelling is negligible off the coast of Kenya. Unlike pre-bomb values south of the equator near Seychelles and Madagascar, our pre-bomb value are enriched by more than 10‰. The enrichment of pre-bomb Kenyan $\Delta^{14}C$ values relative to sites around Mauritius, northern Madagascar and Seychelles, suggest that the influence of depleted $\Delta^{14}C$ water transported in the SEC is limited to regions south of 3 to 4°S.

INTRODUCTION

The intimate relationship between the Indian Ocean and the atmosphere is revealed in the seasonal reversal of the Indian-Asian monsoons. The monsoons develop primarily as a response to the large thermal gradients between the Asian continent and the Indian Ocean. During the Northern-Hemisphere winter, a high-pressure cell develops over the Asian land mass and contributes to the creation of the Northeast (NE) monsoon; the extremely cold and dry air masses over land force air from the northeast to the southwest and drive surface ocean circulation counter-clockwise in the northern Indian Ocean. In contrast, during the Northern-Hemisphere summer, the Asian land mass becomes very warm and a low-pressure cell develops and forms the Southwest (SW) monsoon. Strong southwesterly flow in the lower troposphere brings substantial amount of moisture to India and releases it as precipitation from June to September.

The influence of the monsoons on the Indian Ocean is seen in the reversals of the surface circulation and in the hydrological conditions of the surface waters to 10–20°S. The northern and equatorial Indian Ocean circulation is especially complex with large seasonal variations and reversals in major current systems. For example, as a response to prevailing southwesterly flow in the lower troposphere during the SW monsoon, a northward flowing Somali Current (SC) is strongly developed as a continuation of the South Equatorial Current (SEC) and East African Coast Current (EACC) (Figure 1a). Recognized as the western boundary current that causes structural readjustment in the baroclinicity down to 1000 m, the SC is responsible for strong upwelling along the northern coasts of Somali and Oman and the development of the Southern Gyre (SG) and Great Whirl (GW) during the SW monsoon (Luther 1999). Surface water flow is predominantly in an eastward direction. In contrast, during the NE monsoon, northeasterly winds develop causing surface waters north of the equator to flow to the west or southwest comprising the North Equatorial Current (NEC) north of the equator and at the equator, south-flowing water off the coast of Somalia together with the northflowing EACC feed the Equatorial Counter Current (ECC), which moves eastward across the Indian Ocean between 0° and 8°S (Figure 1b) (Schott and McCreary 2001).

The complex oceanography in the northern and equatorial Indian Ocean, briefly described above, is responsible for regional differences in the strength and amount of upwelling of subsurface water. As

[1]Department of Geological and Environmental Sciences, Stanford University, Stanford, California 94305 USA.
Email: ngrumet@leland.stanford.edu.
[2]Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory, Livermore, California 94551.
Also at the Institute of Marine Sciences, University of California at Santa Cruz, Santa Cruz, California 65064 USA.
[3]Department of Geological and Environmental Sciences, Stanford University, Stanford, California 94305 USA

a result, there is considerable spatial radiocarbon ($\Delta^{14}C$) variability in surface waters of the western Indian Ocean. This is illustrated in the regional deviations in the ^{14}C offset from atmospheric $^{14}CO_2$, referred to as the reservoir effect, of marine calcareous shells from the northern and equatorial Indian Ocean (Dutta et al. 2001; Southon et al. 2002). For example, Southon et al. (2002) illustrate that Arabian Sea upwelling significantly influences the western Indian Ocean pre-bomb $\Delta^{14}C$ signal. The regional mean using Suess-corrected $\Delta^{14}C$ values for the western Arabian Sea (n=8) is −73 ± 2.8‰, while waters farther from the upwelling region, such as those in the tropical Indian Ocean (n=11) yield a regional mean of –66 ± 2.6‰ (Southon et al. 2002). The distribution of $\Delta^{14}C$ inferred from carbonates can highlight regional differences in oceanographic processes (e.g., Moore et al. 1997).

Oceanographic measurements of $\Delta^{14}C$, such as those conducted by Geochemical Ocean Section Study (GEOSECS), Indian Gaz Ocean (INDIGO), and World Ocean Circulation Experiment (WOCE) programs have been used to construct vertical profiles of $\Delta^{14}C$ and have increased our understanding of intense monsoon driven upwelling that occurs off the coast of Somalia and the Arabian Coast (e.g. Ostlund and Stuiver 1980; Broecker et al. 1985; Bard et al. 1989; Key et al. 1996). While results from these programs have been extremely valuable, the profiles are subject to

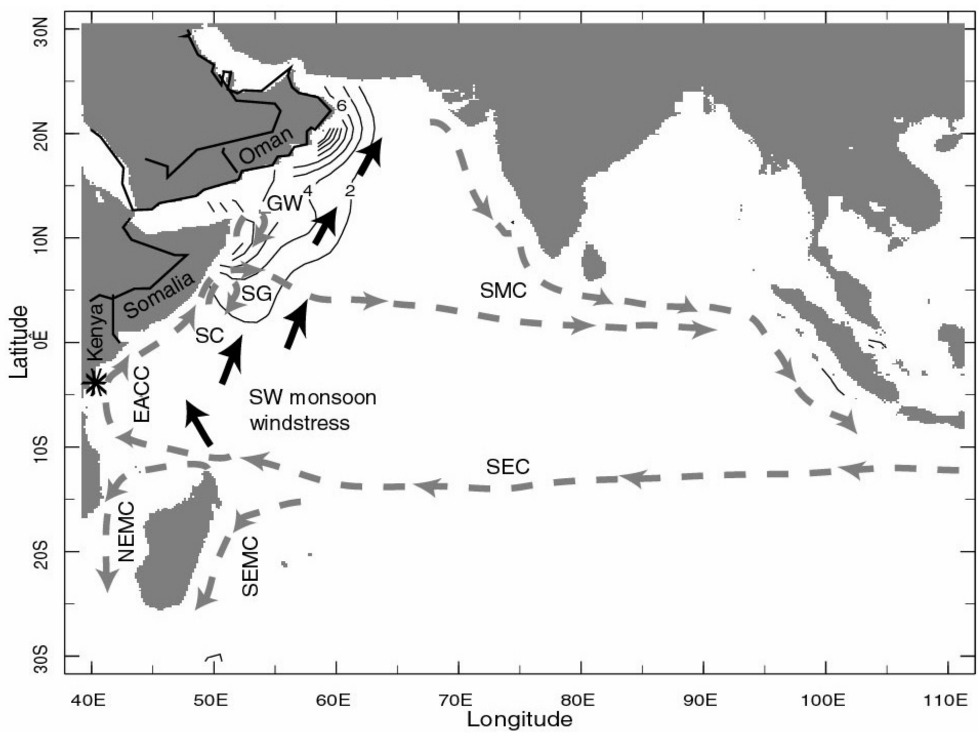


Figure 1a Coral cores were collected by drilling massive colonies of *Porites lutea* off the coast of Kenya, designated by a star, at Malindi (3°14′S, 40°8′E), and Watamu (3°23′S, 39°52′E). Summer (July-Aug.-Sept.) surface (<10 m) nitrate concentrations are shown by contours intervals in µmol/L (Conkright et al. 1998). Surface currents in the Indian Ocean during the SW monsoon: Somali Current (SC), East African Coast Current (EACC), Southwest Monsoon Current (SMC), South Equatorial Current (SEC), and Northeast and Southeast Madagascar Currents (NEMC and SEMC). Upwelling regions are associated with the Southern Gyre (SG) and Great Whirl (GW) (after Schott and McCreary 2001). Thick black arrows indicate predominant SW monsoon wind stress from the US National Centers for Environmental Prediction (NCEP) climatology for July.

temporal aliasing since the measurements represent a "snapshot" of conditions. Such snapshots may be augmented with time series developed from $\Delta^{14}C$ record from tropical corals.

^{14}C measurements from banded corals have been shown to represent $\Delta^{14}C$ levels of dissolved inorganic carbon (DIC) from the surrounding surface water (Druffel and Linick 1978; Druffel 1982). The accreted aragonite thus provides an unaltered record of $^{14}C/^{12}C$ ratios present in seawater (e.g. Druffel 1989; Brown et al. 1993; Guilderson et al. 1998; Guilderson et al. 2000). In this study we present the first continuous, bimonthly resolved time series of pre-bomb $\Delta^{14}C$ measured in a coral from the western Indian Ocean. These results expand our knowledge of spatial resolution of ^{14}C reservoir corrections in the western Indian Ocean and add a time domain component to this valuable data set. Furthermore, the bimonthly sample resolution allows us to address questions regarding $\Delta^{14}C$ variability attributed to the seasonally reversing monsoons. Ultimately, these combined efforts will aid in our understanding of regional oceanography as well as air-sea exchange rates in the Indian Ocean.

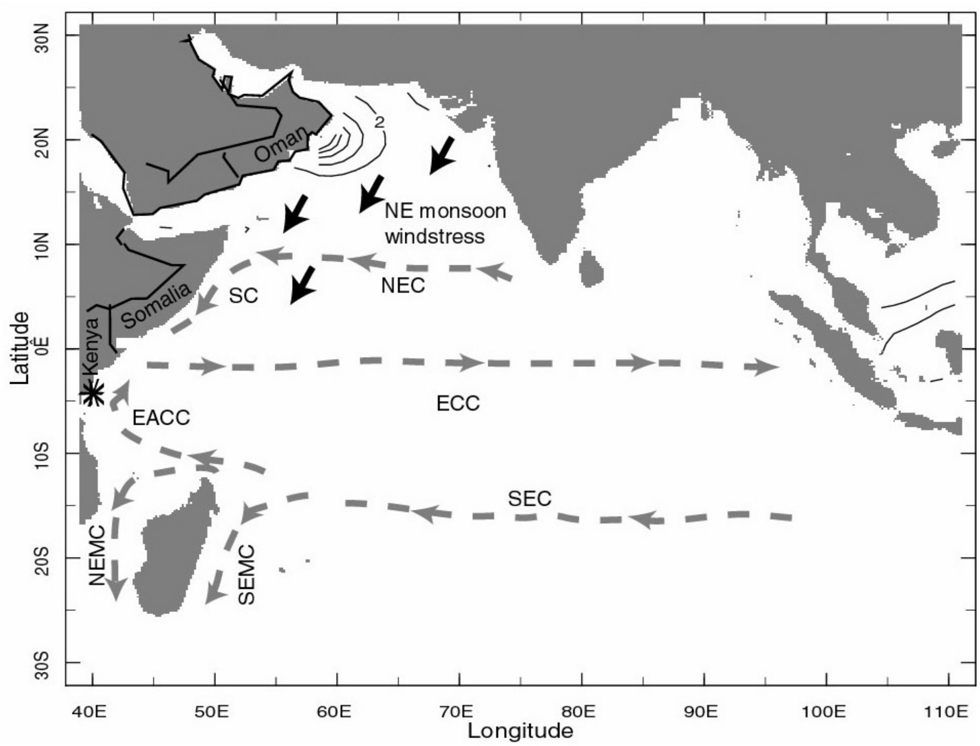


Figure 1b Coral cores were collected by drilling massive colonies of *Porites lutea* off the coast of Kenya, designated by a star, at Malindi (3°14′S, 40°8′E), and Watamu (3°23′S, 39°52′E). Winter (Jan.-Feb.-March) surface (<10 m) nitrate concentrations are shown by contours intervals in μmol/L (Conkright et al. 1998). Surface currents in the Indian Ocean during the NE monsoon: Somali Current (SC), East African Coast Current (EACC), North Equatorial Current (NEC), Equatorial Counter Current (ECC), South Equatorial Current (SEC), and Northeast and Southeast Madagascar Currents (NEMC and SEMC) (after Schott and McCreary, 2001). Thick black arrows indicate predominant NE monsoon wind stress from the US National Centers for Environmental Prediction (NCEP) climatology for January.

METHODS

Cores collected from massive hermatypic corals *Porites lutea* off the coast of Kenya were sampled to assess the seasonal and spatial variability in the coral oxygen isotope ($\delta^{18}O$) and $\Delta^{14}C$ signal (Figure 1a). Coral cores presented here were collected in 1996 from Kenya at Malindi (3°14′S, 40°8′E), and Watamu (3°23′S, 39°52′E). The Malindi coral site is approximately 1 km offshore and at a depth of about 5 m at mean tide. It is an open coast patch reef site on a point. The Watamu coral is approximately 600 m offshore and 200 m landward of an intermittent barrier system. Water depth is about 7 m at the Watamu site. X-radiography of the cores reveals pronounced annual variations in skeletal density and growth rates range from 11 to 15 mm/yr. A transect was mapped along a prominent growth axis of the cores and sampled continuously from the top of the coral slab to approximately 626 mm in the Watamu core and between 325–375 mm in the Malindi core. Samples were collected using a low speed drill to extract aragonite powder every 2 mm for $\Delta^{14}C$ analysis (~6 samples per year) and 1 mm for $\delta^{18}O$ analysis (~12 samples per year).

Oxygen and carbon isotope measurements were analyzed at the Stanford University Stable Isotope Laboratory. Aliquots of coralline aragonite weighing 55 to 95 µg were acidified with orthophosphoric acid at 70 °C and analyzed using a Kiel III carbonate device coupled to a Finnigan MAT 252 mass spectrometer. Approximately 15% of the samples were replicated, yielding an average standard deviation of less than 0.05‰ for $\delta^{18}O$ and 0.12‰ for $\delta^{13}C$. Unknowns were calibrated against a known standard NBS-19 (NIST SRM 8544) and with a Stanford in-house standard (SLS-#1). All results are reported relative to the international V-PDB (Vienna Pee Dee Belemite) standard (Grumet et al. 2001).

Aragonite splits ~10 mg were hydrolyzed to CO_2 in individual reaction chambers, evacuated, heated and acidified with orthophosphoric acid at 90 °C. The resultant CO_2 was converted to graphite in the presence of iron catalyst (Vogel et al. 1987). Graphite targets were measured at the Center for Accelerator Mass Spectrometry (CAMS) facility at Lawrence Livermore National Laboratory (LLNL) (Davis et al. 1990). ^{14}C results are reported as $\Delta^{14}C$ ‰ as defined by Stuiver and Polach (1977). These results include a minor background correction using a calcite standard and are $\delta^{13}C$ and age corrected (Table 1). Concurrent analysis of an in-house standard yielded an external error of ±3.7‰ (1σ, normalized to Fmodern=1.0; n=23).

Well-developed annual density bands and minimum and maximum $\delta^{18}O$ values, as well as a calibration period from 1990–1996, were used to define the chronology parallel to instrumental sea-surface temperature (SST) measurements (Grumet et al. 2001). Instrumental SST records indicate that the maximum (minimum) temperature off the coast of Kenya occurs in March/April (July/August). Accordingly, the minimum and maximum coral $\delta^{18}O$ values were assigned the corresponding calendar date. Samples in between these points were linearly interpolated to make an age model. The assigned calendar months also show a strong correspondence to changes in density. The minimum $\delta^{18}O$ values in April occur within the high-density bands, where calcification exceeds extension when the temperature is the warmest.

RESULTS

In our record, we sample the pre-bomb interval between 1947–1954 (n=43). The pre-bomb record suggests that a fossil fuel correction, known as the Suess Effect, of 14‰ be applied to the age corrected data. This correction is based on back-casting the slope (–0.23‰ yr^{-1}) of the pre-bomb age-corrected data to 1890. However, work by Stuiver and Quay (1981) suggests that the slope of the fossil fuel effect is not constant between 1860–1950, primarily as a result of cosmic ray flux changes.

Table 1 AMS $\Delta^{14}C$ measurements of ~bimonthly Kenyan samples

Coral ID and depth (mm)	Year	CAMS#	$\Delta^{14}C$ [‰] age corrected	±	$\Delta^{14}C$ [‰] Suess corrected[a]
Watamu 96-534	1955	73533	–625	26	–511
Watamu 96-536	1954	73534	–617	26	–508
Watamu 96-538	1954	73535	–581	27	–472
Watamu 96-540	1954	73673	–550	27	–442
Watamu 96-544	1954	73674	–597	28	–490
Watamu 96-546	1954	73675	–630	27	–523
Watamu 96-550	1953	73676	–629	28	–522
Watamu 96-552	1953	73677	–605	27	–498
Watamu 96-554	1953	73678	–624	27	–518
Watamu 96-556	1953	73679	–644	24	–538
Watamu 96-560	1952	73680	–624	29	–519
Watamu 96-562	1952	67915	–658	27	–553
Watamu 96-564	1952	67916	–642	27	–537
Watamu 96-566	1952	67917	–634	27	–530
Watamu 96-568	1952	67918	–617	33	–513
Watamu 96-570	1952	67919	–674	27	–570
Watamu 96-572	1952	67920	–588	27	–484
Watamu 96-574	1951	67921	–567	27	–464
Watamu 96-576	1951	67922	–590	27	–487
Watamu 96-578	1951	67923	–557	27	–454
Watamu 96-582	1951	67924	–644	26	–542
Watamu 96-584	1951	67925	–659	27	–557
Watamu 96-586	1950	67926	–670	27	–569
Watamu 96-588	1950	67927	–633	27	–532
Watamu 96-590	1950	67928	–612	30	–510
Watamu 96-592	1950	67929	–634	25	–533
Watamu 96-594	1950	67930	–605	28	–505
Watamu 96-596	1950	67931	–644	28	–544
Watamu 96-598	1950	67932	–647	35	–547
Watamu 96-600	1949	67933	–676	27	–576
Watamu 96-602	1949	67934	–573	30	–474
Watamu 96-604	1949	67935	–630	28	–531
Watamu 96-606	1949	67936	–620	31	–521
Watamu 96-608	1949	67937	–570	28	–471
Watamu 96-610	1949	67938	–597	28	–499
Watamu 96-612	1948	67939	–559	29	–461
Watamu 96-614	1948	67940	–580	24	–482
Watamu 96-616	1948	67941	–551	28	–453
Watamu 96-618	1948	67942	–471	28	–374
Watamu 96-620	1948	67943	–543	28	–447
Watamu 96-622	1947	67944	–631	28	–535
Watamu 96-624	1947	74050	–681	29	–585
Watamu 96-626	1947	74051	–664	31	–568
Mal96 D2-325	1953	77066	–585	22	–474

Table 1 AMS Δ14C measurements of ~bimonthly Kenyan samples (*Continued*)

Coral ID and depth (mm)	Year	CAMS#	$\Delta^{14}C$ [‰] age corrected	±	$\Delta^{14}C$ [‰] Suess corrected[a]
Mal96 D2-327	1953	77067	–627	27	–516
Mal96 D2-330	1952	77068	–612	27	–502
Mal96 D2-333	1952	77069	–654	27	–544
Mal96 D2-335	1952	77070	–602	27	–492
Mal96 D2-3375	1952	77071	–653	32	–544
Mal96 D2-340	1952	77072	–596	27	–486
Mal96 D2-341	1952	77073	–671	26	–562
Mal96 D2-3435	1952	77074	–572	24	–463
Mal96 D2-347	1952	77075	–621	34	–513
Mal96 D2-349	1952	77076	–644	26	–535
Mal96 D2-351	1951	77077	–688	25	–580
Mal96 D2-354	1951	77078	–672	32	–564
Mal96 D2-3565	1951	77079	–719	26	–612
Mal96 D2-3595	1951	77080	–647	30	–539
Mal96 D2-3625	1951	77081	–696	26	–589
Mal96 D2-365	1951	77082	–682	31	–575
Mal96 D2-3675	1951	77083	–712	26	–605
Mal96 D2-370	1950	77084	–720	26	–614
Mal96 D2-3725	1950	77085	–681	20	–574
Mal96 D2-375	1950	77086	–664	31	–558

[a]Estimated marine fossil fuel (Suess) effect, 10‰ (1890–1950)

For example, a change in atmospheric ^{14}C trend occurs around 1937 when the gradient changed from –2.8‰ to –6.8‰. Given our limited data set, our back-casted slope most likely overestimates the Suess Effect. Furthermore, the short data set (7 years) can not capture changes associated with dynamic processes operating on an interannual to decadal time scale that are unrelated to the Suess effect. Therefore, we must look to model results and existing pre-bomb coral $\Delta^{14}C$ time series from other sites in order to make an appropriate Suess correction.

The Suess Effect for the central gyres is 7–12‰ according to box diffusion models of Stuiver et al. (1986) and Oeschger et al. (1975). Druffel et al. (2001) measured a value of 7‰ at Hawaii and a range between 10–12‰ for the Florida Keys (Druffel, 1997). Southon et al. (2002) made a fossil fuel correction in the Indian Ocean of 10‰ (1910–1952) by combining model results from Stuiver et al. (1986) and pre-bomb coral samples (Druffel and Suess 1986). We believe a Suess correction of 10‰ is appropriate for the Watamu site given that waters reaching Watamu are relatively shallow (J Southon, personal communication; ERM Druffel, personal communication). All results reported below are age corrected as well as fossil fuel corrected.

Pre-bomb $\Delta^{14}C$ levels measured in the Watamu coral have a range between –58‰ in boreal summer of 1947 to a maximum value of –37‰ in boreal winter of 1948 (Figure 2a). Within the eight-year record, $\Delta^{14}C$ levels average –51‰ with a standard deviation of ±4‰. The average annual range is 6‰, calculated as the difference between the minimum and maximum $\Delta^{14}C$ value within a given year. In order to substantiate our findings from Watamu, we sampled a coral recovered nearby from Malindi. Between 1950 and 1953, Malindi $\Delta^{14}C$ levels have a range between –61‰ in the fall of 1950 to –46‰ in the winter of 1952 (Figure 2b). The average Malindi $\Delta^{14}C$ value is −54‰ with a standard deviation of ±4‰. The average annual range is 7‰.

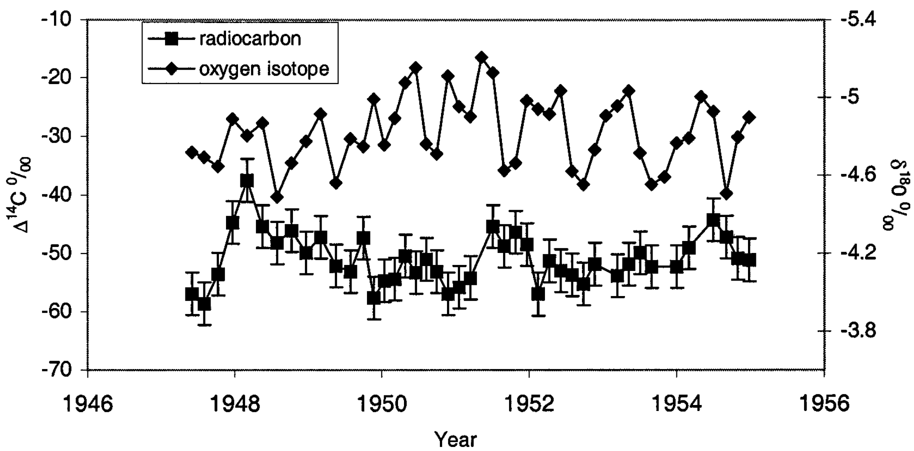


Figure 2a Radiocarbon and oxygen isotope time series from Watamu between 1947 and 1955. Pre-bomb $\Delta^{14}C$ levels measured in the Watamu coral have an annual range between –58‰ in boreal summer of 1947 to a maximum value of –37‰ in boreal winter of 1948. Radiocarbon levels average –51‰ with an average subannual range of 6‰.

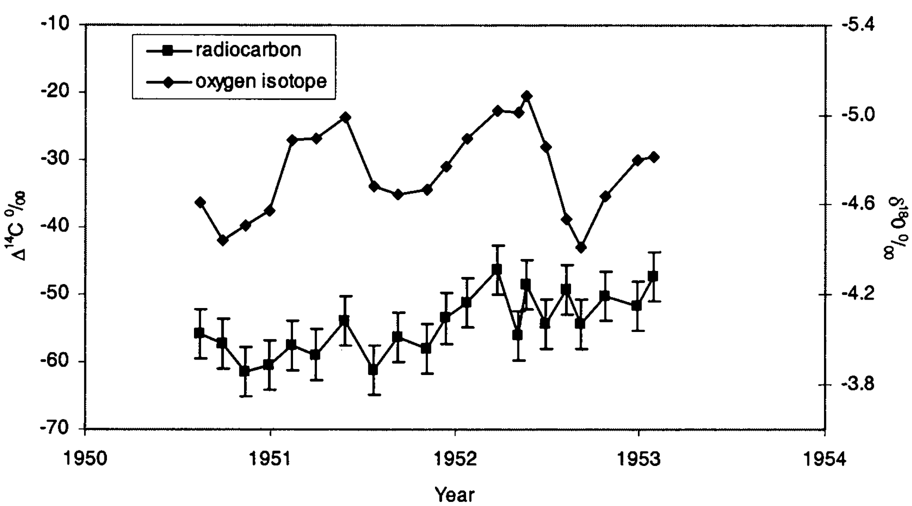


Figure 2b Radiocarbon time series from Malindi between 1950 and 1953. Between 1950 and 1953, Malindi $\Delta^{14}C$ levels have an annual range between –61‰ in the fall of 1950 to –46‰ in the winter of 1952. The average Malindi $\Delta^{14}C$ value is 54 ‰ with an average subannual range of 7‰.

DISCUSSION

The lack of a pronounced seasonal signal distinguishable from the analytical error in the Watamu and Malindi pre-bomb $\Delta^{14}C$ records is consistent with the absence of local upwelling, either due to Ekman pumping driven by strong positive windstress curl or offshore deflection of surface waters by Ekman transport. These results are consistent by nutrient profiles. Profiles from GEOSECS (Spencer et al. 1982) in 1978 and WOCE (R Key, personal communication) in 1995 illustrate a relatively shallow thermocline but nutrient poor surface waters. Average phosphate concentrations in the surface waters (<10 m) off the coast of Kenya from annual LEVITUS94 data (Levitus et al. 1994) are

0.18 µmol/kg and nitrate concentrations are 0.15 µmol/kg. In the upwelling regions of the Arabian Sea nutrient concentrations in the inshore coastal zone are elevated (nitrate is 18 µmol/kg, phosphate is 1.48 µmol/kg) (Woodward et al. 1999). Off the coast of Somalia, in the Great Whirl, nitrate concentration varies between 3 and 8 µmol/kg (Veldhuis et al. 1997). The effect of upwelling is to deliver nutrients and relatively depleted $\Delta^{14}C$ to the upper water column, as observed off the coasts of Somalia and Oman. In contrast, reduced nutrient surface concentrations off the coast of Kenya and concurrent enrichment of $\Delta^{14}C$ characterize the lack of coastal and nearby open-ocean upwelling in this region.

The lack of upwelling off the coast of Kenya is in stark contrast to the productive, vigorous upwelling regions north of the equator. As discussed earlier, the northward flowing Somali Current is responsible for upwelling along the northern coasts of Somali and Oman during the SW monsoon (Luther 1999). As a result, nutrient rich, depleted $\Delta^{14}C$ water strongly influences this region. Southon et al. (2002) estimate a regional $\Delta^{14}C$ mean of –73 ± 2.8‰ in the western Arabian Sea. In contrast, they calculated a mean of –66 ± 2.6‰ in the tropical southwestern Indian Ocean. Combining our results with previous work (Dutta et al. 2001; Southon et al. 2002), there is considerable spatial variability in pre-bomb $\Delta^{14}C$ values in calcareous shells and corals from the western and northern Indian Ocean In many cases, the variability is due to differences in regional ocean circulation patterns discussed above.

Southon et al. (2002) suggest that the influence of monsoon-driven upwelling is propagated throughout the western Indian Ocean by the major current systems, especially the SEC. Relatively depleted $\Delta^{14}C$ values from Sri Lanka (Ceylon) are consistent with this southeast transport of ^{14}C-depleted Arabian Sea water (Southon et al. 2002). Eventually acting as a westward return flow, areas situated in the SEC pathway, such as Mauritius, northern Madagascar and Seychelles exhibit depleted pre-bomb $\Delta^{14}C$ values. Southon et al. (2002) suggest that these values represent advection of ^{14}C-depleted water into the SEC via southeasterly flow from the Arabian Sea. In contrast, our results from the western, equatorial Indian Ocean average –51‰. These samples are enriched by more than 10‰ compared to average southwestern Indian Ocean values reported by Southon et al. (2002). The influence of freshwater could raise the seawater $\Delta^{14}C$ by either equilibrating with atmospheric CO_2 or by increasing the stratification and reducing the amount of vertical mixing. However, the influence of freshwater at Watamu is negligible since the Mida Creek, which is near the coral site, is an ancient creek (McClanahan, personal communication). Furthermore, salinity values range between 33.5 and 36.6 ppt (Obura 1995). These observations suggest that the Watamu site is fairly protected from riverine influence. If the SEC is a source of depleted $\Delta^{14}C$, as Southon et al. (2002) propose, the northern limit of the SEC, and hence the influence of subsurface Indian Ocean water, is apparently south of our sites (3–4°S). This enrichment therefore, suggests that westward return flow of water transported southeast from the Arabian Sea does not reach the surface waters surrounding the Kenyan coral sites, or alternatively there exist spatial-temporal biases in the discrete $\Delta^{14}C$ measurements available.

CONCLUSION

Bimonthly Watamu coral $\Delta^{14}C$ values between 1947 and 1955 averages –51‰. In comparison, surface water pre-bomb $\Delta^{14}C$ levels in the northern Indian Ocean are closer to –73‰ (Southon et al. 2002). Our results demonstrate that there is no immediate source of subsurface, $\Delta^{14}C$ depleted water to the surface water off the coast of Kenya. Surface water nutrient concentrations are consistent with the lack of deeper water replenishment by upwelling in this region. The absence of a distinct subannual $\Delta^{14}C$ signal suggests that coastal and nearby open-ocean upwelling are negligible. Furthermore, the enrichment of pre-bomb Kenyan $\Delta^{14}C$ values relative to sites around Mauritius, northern Madagascar and Seychelles, suggest that the influence of depleted $\Delta^{14}C$ water transported in the SEC is limited to regions south of 3 to 4°S.

ACKNOWLEDGMENTS

We thank P Zermenko and D Mucciarone for analytical support and the Kenya Wildlife Service and Fithe Kenya Marine and Fisheries Research Institute for logistical and field support. This work was supported by a US DOE Global Change Education Program Fellowship to N S Grumet and a grant to R B Dunbar by NSF Climate Dynamics and Earth System History program grants OCE-9896157. $\Delta^{14}C$ analyses were performed at the CAMS under the auspices of the US DOE by the UC, LLNL under Contract No. W-7405-Eng-48. $\Delta^{14}C$ analyses were funded by the University of California's and LLNL's Exploratory Research in the Institutes (98-ERI-002 and 01-ERI-009). $\Delta^{14}C$ data will be archived at the WDC-A paleoclimate archive in Boulder, Colorado. We thank an anonymous reviewer for constructive criticism and suggestions that helped to improve the manuscript.

REFERENCES

Bard E, Arnold M, Ostlund HG, Maurice P, Monfray P, Duplessy J-C. 1989. Penetration of bomb radiocarbon in the tropical Indian Ocean measured by means of accelerator mass spectrometry. *Earth and Planetary Science Letters* 87:379–89.

Broecker, WS, Peng T-S, Ostlund HG, Stuiver M. 1985. The distribution of bomb radiocarbon in the ocean. *Journal of Geophysical Research* 90:6953–70.

Brown TA, Farwell GW, Grootes PW, Schmidt FH, Stuiver M. 1993. Intra-annual variability of the radiocarbon content of corals from the Galapagos Islands. *Radiocarbon* 35(2):245–51.

Conkright M, Levitus S, O'Brien T, Boyer T, Antonov J, Stephens C. 1998. *World Ocean Atlas 1998 CD-ROM Data Set Documentation.* Technical Report 15. NODC Internal Report, Silver Springs, Maryland. 16 p.

Davis JC, Proctor ID, Southon JR, Caffee MW, Heikkinen DW, Roberts ML, Moore TL, Turteltaub KW, Nelson DE, Loyd DH, Vogel JS. 1990. LLNL/UC AMS facility and research program Nuclear. *Instruments and Methods in Physics Research B* 52:269–72.

Druffel EM, Linick TW. 1978. Radiocarbon in annual coral rings of Florida. *Geophysical Research Letters* 5:913–6.

Druffel EM, Suess HE. 1983. On the radiocarbon record in banded corals: exchange parameters and net transport of the $^{14}CO_2$ between atmosphere and surface ocean. *Journal of Geophysical Research* 88:1271–80.

Druffel EM. 1982. Banded corals: changes in oceanic ^{14}C during the Little Ice Age. *Science* 218:13-9.

Druffel ERM. 1989. Decade time scale variability of ventilation in the North Atlantic: high precision measurements of bomb in banded corals. *Journal of Geophysical Research* 94:3271–85.

Druffel ERM. 1997. Geochemistry of corals: Proxies of past ocean chemistry, ocean circulation, and climate. *Proceedings of National Academy of Science* 94: 8354–61.

Druffel ERM, Griffin S, Guilderson TP, Kashgarian M, Southon J, Schrag DP. 2001. Changes in subtropical North Pacific radiocarbon and correlation with climate variability. *Radiocarbon* 43(1):15–25.

Dutta K, Bhushan R, Somayajulu BLK. 2001. ΔR correction values for the northern Indian Ocean. *Radiocarbon* 43(2A):483–8.

Grumet NS, Dunbar RB, Cole JE. 2001. Multisite record of climate change from Indian Ocean corals. *9th International Coral Reef Symposium*, Bali, Indonesia. Forthcoming.

Guilderson TP, Schrag DP, Kashgarian M, Southon J. 1998. Radiocarbon variability in the western equatorial Pacific inferred from a high-resolution coral record from Nauru Island. *Journal of Geophysical Research* 103:24,641–50.

Guilderson TP, Schrag DP, Goddard E, Kashgarian M, Wellington GM, Linsley BK. 2000. Southwest subtropical Pacific surface water in a high-resolution coral record. *Radiocarbon* 42(2):249–56.

Key RM, Quay PD, Jones GA, McNichol AP, von Reden KF, Schneider R. 1996. WOCE AMS radiocarbon 1 Pacific Ocean results P6, P16 and P17. *Radiocarbon* 38(3):425–518.

Levitus S, Burgett R, Boyer T. 1994. *World ocean atlas 1994. Volume 3: nutrients.* Washington DC: NOAA Atlas NESDIS 3, US Department of Commerce.

Luther ME. 1999. Interannual variability in the Somali Current 1954-1976. *Nonlinear Analysis* 35:59–83.

Moore MD, Schrag DP, Kashgarian M. 1997. Coral constraints on the source of the Indonesian throughflow. *Journal of Geophysical Research* 102:12,359–65.

Obura D. 1995. Environmental stress and life history strategies, a case study of corals and river sediment from Malindi, Kenya. PhD dissertation. University of Miami.

Oeschger H, Siegenthaler U, Schotterer U, Gugelmann A. 1975. Box diffusion-model to study carbon-dioxide exchange in nature. *Tellus* 27:168–92.

Ostuland HG, Stuiver M. 1980. GEOSECS Pacific radiocarbon. *Radiocarbon* 22(1):25–53.

Schott FA, McCreary JP. 2001. The monsoon circulation of the Indian Ocean. *Progress in Ocean.* 51:1–123.

Southon J, Kashgarian M, Fontugne M, Metivier B, Yim WWS. 2002. Marine reservoir corrections for the Indian Ocean and Southeast Asia. *Radiocarbon* 44(1): 167–80.

Spencer D, Broecker WS, Craig H, Weiss RF. 1982. *Geosecs Indian Ocean Expedition. Volume 6, Sections and Profiles IDOE.* National Science Foundation. 140 p.

Stuiver M, Polach HA. 1977. Discussion reporting of ^{14}C data. *Radiocarbon* 19(3):355–63.

Stuiver M, Quay PD. 1981. Atmospheric ^{14}C changes resulting from fossil fuel CO_2 release and cosmic ray flux variability. *Earth and Planetary Science Letters* 53:349–362.

Stuiver M, Pearson GW, Braziunas TF.1986. Radiocarbon age calibration of marine samples back to 9000 cal BP. *Radiocarbon* 28(2B):980–1021.

Swallow JC. 1984. Some aspects of the physical oceanography of the Indian Ocean. *Deep-Sea Research* 31: 639–50.

Tomczak M, Godfrey, JS. 1994. *Regional oceanography: an introduction*. Oxford: Pergamon Press. 422 p.

Veldhuis MJW, Kraay GW, Van Bleijswijk GD, Baars MA. 1997. Seasonal and spatial variability in phytoplankton biomass, productivity and growth in the northwestern Indian Ocean: the southwest and northeast monsoon, 1992–1993. *Deep-Sea Research I* 44: 425–49.

Vogel JS, Southon JR, Nelson DE. 1987. Catalyst and binder effects in the use of filamentous graphite for AMS. *Nuclear Instruments and Methods in Physics Research B* 29:50–6.

Woodward EMS, Rees AP, Stephens JA. 1999. The influence of the southwest monsoon upon the nutrient biogeochemistry of the Arabian Sea. *Deep-Sea Research II* 46:571–91.

RADIOCARBON, Vol 44, Nr 2, 2002, p 591–595

CORRECTING FOR CONTAMINATION IN AMS ^{14}C DATING

Ken Mueller • Paul Muzikar[1]

Prime Lab, Department of Physics, Purdue University, West Lafayette, Indiana 47907 USA

ABSTRACT. When using accelerator mass spectrometry (AMS) for radiocarbon dating, it is important to correct for carbon contamination that is added to the sample and the standard during chemical processing. We derive an equation for making this correction that generalizes previous work in several ways. We treat the case in which contaminating carbon is added during both the combustion step and graphitization step. Taking this two-stage contamination process into account is particularly important when only a fraction of the CO_2 produced in the combustion is graphitized. We also allow for the fact that the ^{13}C fractions of the sample, the standard, and the contaminants may be different.

INTRODUCTION

The chemical processing of samples for accelerator mass spectrometry radiocarbon (AMS ^{14}C) dating inevitably introduces contamination by extraneous carbon. Correcting for this effect is important in obtaining accurate dates, especially for small samples (Vogel et al. 1987; Kirner et al. 1995). Donahue and coworkers (Donahue et al. 1990) derived a widely used formula for making this correction. More recently, Brown and Southon (Brown 1994; Brown and Southon 1997) derived a rather complex correction formula, which takes into account the fact that the contaminating carbon will in general not be modern, and that the standard will also be contaminated. (See also Currie et al. 1994, which presents a correction formula which allows for nonmodern extraneous carbon.)

In this paper we derive and discuss a correction formula that generalizes previous work in two ways. First, we allow for the fact that contamination may enter the sample at two different stages in the preparation process, and that these contaminants will in general have different properties. For specificity, we imagine that one contaminant enters during the combustion stage, and another enters during the graphitization stage; for carbonate samples, the first stage would be the hydrolysis which produces the CO_2. If, as is often the case, only a fraction of the CO_2 resulting from the combustion is graphitized, the two contaminants must be treated separately. Second, we allow for the fact that the sample, the standard, and the contaminants may have different ^{13}C contents.

DERIVATION

For our derivation, we will adopt the "constant contaminant mass" model, a model that has received justification from various experiments. We assume that, regardless of sample size, fixed masses of foreign carbon m_{c1} and m_{c2} are introduced into the sample during the chemical processing. We assume that m_{c1} enters during the combustion stage which produces CO_2, while m_{c2} enters during the graphitization stage. Finally, we assume that a fraction x of the CO_2 is graphitized. There are two reasons why x is often less than one: 1) an aliquot of CO_2 may be drawn off for a $\delta^{13}C$ determination, or 2) the amount of CO_2 may be too large for the graphitization tube.

In AMS dating, the $^{14}C/^{13}C$ ratio of the unknown sample is measured relative to that of a standard. This standard will also be chemically processed and have contamination introduced. In general this contamination of the standard must be taken into account. For simplicity we will assume that the all the CO_2 produced by the standard is graphitized.

To derive our formula, we first establish our notation. We let M denote the mass of carbon of the unknown sample (without the contaminants), x the fraction which is graphitized, m_{c1} the carbon

[1]Corresponding author. Email: paul@physics.purdue.edu.

mass of the first contaminant, m_{c2} the carbon mass of the second contaminant, and M_{ox} the carbon mass of the standard; a commonly used standard is oxalic acid II. Let w denote the number of ^{14}C atoms per unit mass of the sample, and let w_{c1}, w_{c2}, and w_{ox} be the corresponding quantities for the contaminants and the standard. Finally, let v be the number of ^{13}C atoms per unit mass of the sample, with v_{c1}, v_{c2}, and v_{ox} the corresponding quantities for the contaminants and the standard. (Throughout this paper, the term "mass" can be taken to mean either grams or moles, with the corresponding interpretation of the w's and v's.)

Then, the actually measured ratio is given by

$$F_m = \frac{(^{14}\mathrm{C}/^{13}\mathrm{C})_{sample,\ measured}}{(^{14}\mathrm{C}/^{13}\mathrm{C})_{ox,\ measured}} \tag{1}$$

or

$$F_m = \frac{\dfrac{x(Mw + m_{c1}w_{c1}) + m_{c2}w_{c2}}{x(Mv + m_{c1}v_{c1}) + m_{c2}v_{c2}}}{\dfrac{M_{ox}w_{ox} + m_{c1}w_{c1} + m_{c2}w_{c2}}{M_{ox}v_{ox} + m_{c1}v_{c1} + m_{c2}v_{c2}}} \tag{2}$$

The true value of F is given by

$$F = \frac{w/v}{w_{ox}/v_{ox}} \tag{3}$$

The goal is to obtain the value of F from the measured value F_m, assuming that by previous experiments we have determined the properties of the contaminating carbon; this point will be discussed later in this paper. We may rearrange the previous equations to obtain the following

$$F = \frac{\left(1 + \dfrac{m_{c1}w_{c1}}{M_{ox}w_{ox}} + \dfrac{m_{c2}w_{c2}}{M_{ox}w_{ox}}\right)\left(1 + \dfrac{m_{c1}v_{c1}}{Mv} + \dfrac{m_{c2}v_{c2}}{xMv}\right)}{\left(1 + \dfrac{m_{c1}v_{c1}}{M_{ox}v_{ox}} + \dfrac{m_{c2}v_{c2}}{M_{ox}v_{ox}}\right)} F_m - \frac{m_{c1}w_{c1}v_{ox}}{Mw_{ox}v} - \frac{m_{c2}w_{c2}v_{ox}}{xMw_{ox}v} \tag{4}$$

Equation (4) is the central result of this paper; it contains the two stage contamination effects, and the effects due to the different ^{13}C contents of the sample, contaminants, and standard. As it stands it is perhaps unusably complicated, and so in the following sections we discuss various physically motivated simplifications which are justified in appropriate circumstances.

ONE-STAGE CONTAMINATION MODEL

In this section show how our result simplifies if we set $x = 1$ and $m_{c2} = 0$, and thus adopt the more usual one-stage contamination model. Setting $m_{c2} = 0$ and $x = 1$ in the previous equation gives

$$F = \frac{\left(1+\frac{m_{c1}w_{c1}}{M_{ox}w_{ox}}\right)\left(1+\frac{m_{c1}v_{c1}}{Mv}\right)}{\left(1+\frac{m_{c1}v_{c1}}{M_{ox}v_{ox}}\right)} F_m - \frac{m_{c1}w_{c1}v_{ox}}{Mw_{ox}v} \tag{5}$$

Note that in three places, ^{13}C ratios appear (v_{c1}/v, v_{ox}/v, and v_{c1}/v_{ox}). This equation generalizes previous work on the one stage model, in that it incorporates the effects of these ^{13}C ratios. However, these three ratios will usually be very close to unity; in addition they always multiply m_{c1}, which presumably will always have an uncertainty in its precise value due to experimental error. Thus, in most cases it will be sufficiently accurate to set these three ratios equal to one, and so obtain the formula:

$$F = \frac{\left(1+\frac{m_{c1}w_{c1}}{M_{ox}w_{ox}}\right)\left(1+\frac{m_{c1}}{M}\right)}{\left(1+\frac{m_{c1}}{M_{ox}}\right)} F_m - \frac{m_{c1}w_{c1}}{Mw_{ox}} \tag{6}$$

Note that if the contaminant carbon had, for some reason, an unusual ^{13}C content, so that v_{c1}/v was not close to one, then the more accurate equation (5) would have to be used. Another situation in which equation (5) might have to be used would be in the case of a very old sample, for which F_m was much less than one. If F_m were small, then the last term in (5) could be a substantial correction effect, and the fact that v_{ox}/v differed from one could make a difference.

Several aspects of equation (6) deserve comment. First, note that structurally it is very similar to the formula derived by Donahue et al. (1990). In the special case that $w_{c1} = w_{ox}$, it reduces to

$$F \rightarrow \left(1+\frac{m_{c1}}{M}\right)F_m - \frac{m_{c1}}{M} \tag{7}$$

which parallels the Donahue et al. (1990) formula.

If the mass of the standard is very large so that $\frac{m_{c1}}{M_{ox}} \rightarrow 0$, equation (6) reduces to a slightly different formula

$$F \rightarrow F_m + \frac{m_{c1}}{M}\left(F_m - \frac{w_{c1}}{w_{ox}}\right) \tag{8}$$

In this limit, whether F is greater than or less than F_m depends in a simple way on the ^{14}C content of the contaminating carbon. Note that (8) is equivalent to the Currie et al. (1994) formula.

Finally, we can see that equation (6) is equivalent to the Brown Southon (1997) result by making the following identifications

$$\frac{R_s^A}{R_{ox1}^A} = F \qquad \frac{R_s}{R_{ox1}} = F_m \tag{9}$$

$$C_{ox1}h_{box1} = \frac{m_{c1}}{M_{ox} + m_{c1}} \qquad C_s h_{bs} = \frac{m_{c1}}{M + m_{c1}} \tag{10}$$

$$h_{bs} = \frac{w_{c1}}{w_{ox}} \frac{m_{c1}}{M + m_{c1}} \qquad h_{box1} = \frac{w_{c1}}{w_{ox}} \frac{m_{c1}}{M_{ox} + m_{c1}} \tag{11}$$

In order to use equation (6) in analyzing data, it is necessary to determine both m_{c1} and w_{c1}/w_{ox}; this is not a trivial task, since many experiments yield only the product $m_{c1}w_{c1}/w_{ox}$. However, Brown and Southon (1997) were able to determine the needed quantites by a well-designed series of measurements.

Note that if $x = 1$ and all the ^{13}C ratios in (4) are set equal to one, we also arrive at version of the one stage model, even without setting m_{c2} equal to zero. In a sense this point is obvious, since if all the CO_2 is graphitized, the two contaminants may be combined into one effective contaminant. To see this, start with (4) and set $x = 1$, along with all the ^{13}C ratios. This gives

$$F = \frac{\left(1 + \frac{m_c w_c}{M_{ox} w_{ox}}\right)\left(1 + \frac{m_c}{M}\right)}{\left(1 + \frac{m_c}{M_{ox}}\right)} F_m - \frac{m_c w_c}{M w_{ox}} \tag{12}$$

where we have defined the properties of an average contaminant (m_c, w_c) as follows:

$$m_c = m_{c1} + m_{c2} \qquad m_c w_c = m_{c1} w_{c1} + m_{c2} w_{c2} \tag{13}$$

TWO-STAGE CONTAMINATION MODEL

When x is not equal to one, we must resort to the two-stage model. As argued in the previous section, it will usually be sufficiently accurate to set all the ^{13}C ratios in (4) equal to one. Doing this produces the following equation

$$F = \frac{\left(1 + \frac{m_{c1} w_{c1}}{M_{ox} w_{ox}} + \frac{m_{c2} w_{c2}}{M_{ox} w_{ox}}\right)\left(1 + \frac{m_{c1}}{M} + \frac{m_{c2}}{xM}\right)}{\left(1 + \frac{m_{c1}}{M_{ox}} + \frac{m_{c2}}{M_{ox}}\right)} F_m - \frac{m_{c1} w_{c1}}{M w_{ox}} - \frac{m_{c2} w_{c2}}{x M w_{ox}} \tag{14}$$

So we can see that when $x < 1$, the correction formula is more complicated, and cannot be reduced to an effective single contaminant model; we need to know the values of m_{c1}, m_{c2}, $m_{c1}w_{c1}/w_{ox}$, and $m_{c2}w_{c2}/w_{ox}$.

We note that the paper by Vogel et al. (1987) does address this issue. They were able to separately determine the contamination added during combustion and during graphitization. In our notation, they were able to measure $m_{c1}w_{c1}$ and $m_{c2}w_{c2}$. In a more recent paper Schleicher et al. (1998) were able to determine the contamination introduced during different steps in their procedure.

ACKNOWLEDGMENTS

We thank Tom Brown for important discussions, and for providing us with a copy of his thesis. We also thank Pankaj Sharma and Matt Coon for useful discussions.

REFERENCES

Brown TA. 1994. PhD dissertation. University of Washington.

Brown TA, Southon JR. 1997. Corrections for contamination background in AMS C14 measurements. *Nuclear Instruments and Methods in Physics Research* B123:208–13.

Currie LA, Klouda GA, Klinedinst DB, Sheffield AE, Jull AJT, Donahue DJ, Connolly MV. 1994. Fossil and biomass combustion: C14 for source identification, chemical tracer development, and model validation. *Nuclear Instruments and Methods in Physics Research* B92:404–9.

Donahue DJ, Linick TW, Jull AJT. 1990. Isotope ratio and background corrections for accelerator mass spectrometry radiocarbon measurements. *Radiocarbon* 32(2):135–42.

Kirner DL, Taylor RE, Southon JR. 1995. Reduction in background for microsamples for AMS dating. *Radiocarbon* 37(2):697–704.

Schleicher M, Grootes PM, Nadeau M-J, Schoon A. 1998. The carbonate ^{14}C background and its components at the Leibniz AMS facility. *Radiocarbon* 40(1): 85–93.

Vogel JS, Nelson DE, Southon JR. 1987. ^{14}C background levels in an accelerator mass spectrometry system. *Radiocarbon* 29(3):323–33.

RADIOCARBON, Vol 44, Nr 2, 2002, p 597–598

COMMENT ON 'DETERMINATION OF THE RADIOCARBON AGE OF PARCHMENT OF THE VINLAND MAP'

K R Ludwig

Berkeley Geochronology Center, 2455 Ridge Road, Berkeley, California, 94709, USA. Email: kludwig@bgc.org.

I wish to point out some statistical errors in the uncertainty calculations for the radiocarbon age of the Vinland Map (Donahue et al. 2002). First, the authors state that the 14C measurements of samples with chemical treatments B, C, D, and E "… result in consistent radiocarbon ages", and that "… two (of these analyses) are 1.5 sigma, and the others are one sigma or less, from the weighted average." In fact, the overall scatter of the data show that it is improbable that these data are statistically coherent, largely because analysis J21C lies 2.1 sigma from the weighted mean.

The usual parameter for examining the coherence of data with known, Gaussian errors is the "reduced χ^2", or in the usual geochronological terminology, *MSWD* (= Mean Square of Weighted Deviates; McIntyre et al. 1966; Wendt and Carl 1991), and defined as

$$\frac{\sum (x_i - \bar{x}) / \sigma^2{}_{x_i}}{\sum (1/\sigma^2_{x_i})}$$

where $\bar{x}$ is the weighted average of the individual data points, x_i .

The *MSWD* for the five Vinland Map samples considered coherent by Donahue et al. (2002) is 2.58, indicating that the observed amount of scatter from the weighted mean is a factor of $\sqrt{2.58}$ greater than expected from the assigned errors. The product of the *MSWD* and the 4 degrees of freedom has a χ^2 distribution about the degrees of freedom, from which the probability of the assigned errors yielding as much as the observed amount of scatter can be calculated. This probability is only 0.035—significantly less that the usual cutoff of 0.05. Thus, according to usual statistical practice, the five analyses selected by Donahue et al. (2002) do not agree within their assigned errors.

Second, though the standard deviation of the weighted average is indeed ±0.0033 as given in the paper, the value should not be taken as equivalent to a Gaussian, 68.2% confidence error, since it was calculated from only 4 degrees of freedom. Expansion of this value by the appropriate Student's-*t* factor is required to obtain the correct error at a given confidence limit, which would result in a much larger 95%-confidence age-error than stated by Donahue et al. (2002). The essential point, however, is that because the 5 analyses are not in statistical agreement, the relevance of their average value (weighted or otherwise) to the true age of the Vinland Map is unclear, and calculation of confidence limits of the resulting age from any of the standard algorithms is not straightforward.

The three samples that were treated with chemical processes C, D, and E, however, *are* statistically indistinguishable (MSWD = 0.96, probability = 0.38), with a weightedaverage ^{14}C modem-carbon fraction of 0.9391 ± 0.0025 (68.2% conf.), where the error is calculated in the statistically appropriate way for a weighted mean of coherent measurements (Bevington 1969),

$$\sigma^2_{\bar{x}} = \frac{1}{\sum (1/\sigma^2_{x_i})}.$$

The resulting age range (from OxCal 3.5; Bronk Ramsey 1995) is 1404–1440 AD (95.4% conf.)—not much different than the 1411–1468 AD calculated by Donahue et al. (2002), but in this case statistically justified.

REFERENCES

Bevington PR. 1969. *Data reduction and error analysis-for the physical sciences.* New York: McGraw-Hill. p 73.

Donahue DJ, Olin JS, Harbottle G. 2002. Radiocarbon dating of parchment of the Vinland map. *Radiocarbon* 44(l):45–52.

McIntyre GA, Brooks C, Compston W, Turek A. 1966. The statistical assessment of Rb-Sr isochrons. *Journal of Geophysical Research* 71:5459–68.

Bronk Ramsey C. 1995. Radiocarbon calibration and analysis of stratigraphy: the OxCal Program. *Radiocarbon* 37(2):425–430.

Wendt I, Carl C. 1991. The statistical distribution of the mean squared weighted deviation. *Chemical Geology (Isotope Geoscience Section)* 86:275–85.

LETTER TO THE EDITOR

Dear Sirs,

We read with interest the recent paper of Donahue et al. (2002) on the radiocarbon dating of the Vinland map, and concur entirely with its conclusion that the parchment is of 15th century date. However, we have to question what relevance this has for the date of the production of the map itself. The authors themselves note the presence in or on the parchment of a carbon containing substance, apparently constituting some 20–30% of the dry weight of the samples treated, the carbon of which is clearly post-bomb in activity, and which is dated by them to around the time of the first appearance and examination of the object. This material could be removed from the parchment by a solvent based pre-treatment.

The production of forgeries using authentic materials of the correct age for the purported object is well documented and the presence of such a large quantity of modern carbon in this case must set alarm bells ringing. It is therefore necessary to look at possible routes by which this material may have become attached to the parchment. One such route would involve deliberate deception. If it was the intention of a forger to produce a document on old parchment, it would first be necessary to remove any existing markings, probably by abrasion. Regardless of whether any cleaning of the surface was required, it would also be necessary to prepare a smooth surface which could then be drawn on. There are a number of materials which would be suitable for such a task. Parchment and leather are frequently repaired and resurfaced by the application of organic materials such as starch and parchment size (a gelatin based material produced by heating small shavings of parchment in water), or by the application of fats such as lanolin (for examples see KB 1997; Hassel 1999). At the time of the discovery of the map, another material, cellulose nitrate, was also frequently used on such materials. In this respect it is worth noting that in the recent paper of Brown and Clark (2002) on the Raman spectroscopic analysis of the black and yellow lines on the map, a high fluorescence background was found in the pigmented regions. Such a background is explicable by the presence of organic materials on the surface of the parchment. It could, of course, be equally argued that the presence of a large quantity of modern material might be the result of rather clumsy conservation treatment applied at the time of the first discovery of the piece, rather than as part of the process of production, but without clear evidence of this, doubts must remain.

As the authors themselves point out, dating of the parchment itself does not necessarily have any direct relevance to the question of the authenticity of the map drawn on it. The paper has, however, brought something additional to the debate: there is a large amount of modern material on, or in, the parchment. The identification of this material would be of great interest, but would not necessarily resolve the debate over the authenticity of the map. The doubt would remain as to whether there had been a deliberate attempt to deceive or significant interventive conservation.

Janet Ambers and Sheridan Bowman

Dept of Scientific Research, The British Museum, Gt Russell St, London, WC1B 3DG, United Kingdom

REFERENCES

Brown KL, Clark RJH. 2002. Analysis of pigmentary material on the Vinland map and Tartar Relation by Raman microprobe spectroscopy. *Analytical Chemistry* 74:3658–3661.

Donahue DJ, Olin JS, Harbottle G. 2002. Determination of the radiocarbon age of parchment of the Vinland map. *Radiocarbon* 44(1):45–52.

KB and the Central Research Laboratory for Objects of Art and Science, Netherlands. 1997. Guidelines for the conservation of leather and parchment bookbindings http://www.kb.nl/kb/resources/frameset_kb.html?/kb/cons/leather/ .

Hassel B. 1999. Conservation treatment of medieval parchment documents damaged by heat and water. Preprint from the 9th International Congress of IADA, Copenhagen, 15–21 August 1999. http://palimpsest.stanford.edu/iada/ta99_253.pdf

RADIOCARBON, Vol 44, Nr 2, 2002, p 601–630

RUDJER BOŠKOVIĆ INSTITUTE RADIOCARBON MEASUREMENTS XV

Bogomil Obelić[1] • Ines Krajcar Bronić • Nada Horvatinčić

Rudjer Bošković Institute, P.O.Box 180, 10002 Zagreb, Croatia

INTRODUCTION

In this report we present dating of archaeological samples performed since 1995 in the Radiocarbon Laboratory of the Rudjer Bošković Institute. Several samples from the period before 1995, which were not included in our previous data lists, are given as well. Sample preparation, proportional counter technique, and processing of data are essentially the same as reported earlier (Srdoč et al. 1971, 1979; Obelić 1989). The quality assurance and quality control system according to ISO 17025 has been improved within the IAEA TC Regional Project on Quality Control and Quality Assurance for Nuclear Analytical Techniques. The laboratory participated in ^{14}C intercomparison studies (Horvatinčić et al. 1990; Krajcar Bronić et al. 1995; Bryant et al. 2001; Radiocarbon 2001). We use Oxalic Acid I as modern standard, and anthracite and marble as background standards.

Age calculations follow the conventional protocol (Mook and van der Plicht 1999) based on Libby half-life of 5570 ± 30 yr and using AD 1950 as the reference year. Ages and standard deviations (1 σ error) of samples are adjusted for stable isotope fractionation to normalized concentration ratio ($\delta^{13}C = -25‰$) according to recommendations in Stuiver and Polach (1977) and using the default $\delta^{13}C$ values. Calibrated ages are calculated from non-rounded ^{14}C conventional ages by using the program OxCal v.3.0 (Bronk Ramsey 1995, 1998) with 1 σ error (confidence level 68.2%). When several calendar age ranges are obtained, probability for each interval is given. Probabilities less then 5% are omitted. In reports both the conventional ^{14}C ages and the calibrated range intervals are rounded.

ARCHAEOLOGICAL SAMPLES

CROATIA

Andautonia Series

Wood collected from Roman settlement Andautonia (Figure 1), village Ščitarjevo (45°46′N, 16°07′E), 101 m asl, near Zagreb, NW Croatia. Submitted 1995 by D Nemeth–Ehrlich (Z-2594 and Z-3005) and 2000 by D Doračić (Z-2979), Archaeological Museum, Zagreb. Previous measurements: Z-146 (Srdoč et al. 1971) and Z-283 (Srdoč et al. 1975).

Z-2594 Andautonia 1 **pMC: 101.1 ± 1.1**
Wood from thermal well between objects B and C. Expected age: 1st century

Comment: (DNE) Result does not confirm the presumption.

Z-2979 Andautonia 2 **1900 ± 90**
Wood from well B-20, 3.5 m depth (cal AD 20–220, 68.2%).

Z-3005 Andautonia 3 **2000 ± 75**
Wood, B-15, from planking of burned grave (cal 100 BC–AD 90, 68.2%).

[1]Corresponding author. Email: Bogomil.Obelic@irb.hr.

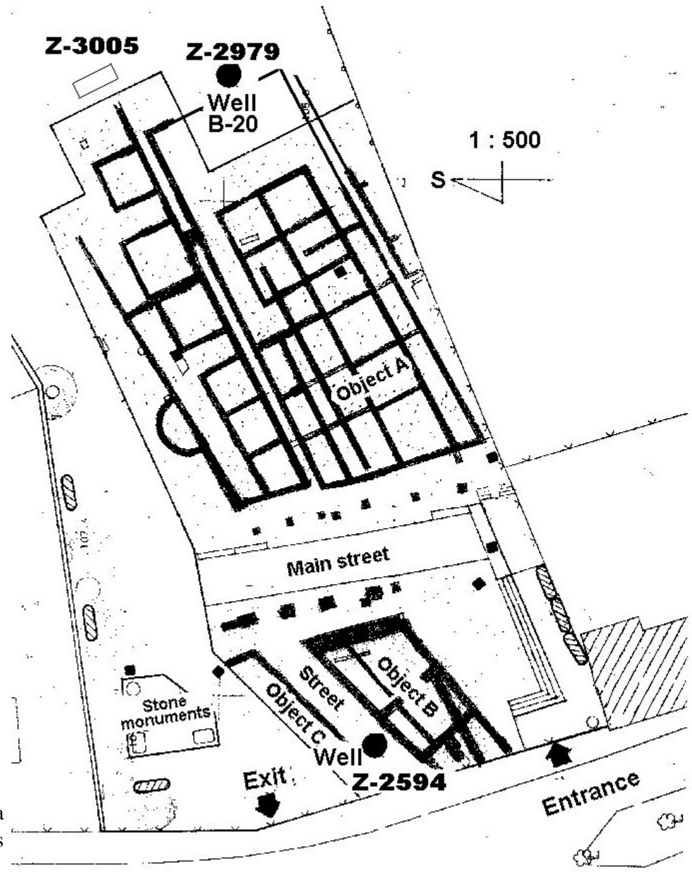


Figure 1 Archaeological site Andautonia near Zagreb with locations where samples were taken for ^{14}C analyses

Z-2809 Bošnjaci–Vjerovi **80 ± 70**

Inner part of oak monoxyle below water, Bošnjaci–Vjerovi (45°03′01″N, 18°45′20″E), 76 m asl, near Županja, Slavonia, E Croatia. Collected 1997 by K Bušić-Jelić and submitted 1998 by B Marijan, Županja Regional Museum (cal AD 1680–1730, 17.4%; AD 1810–1930, 49.3%).

Comment: (BM) treatment of samples for permanent exhibition in Regional Museum.

Z-2716 Bršljanka **460 ± 70**

Human bones belonging to one or two persons found in Bršljanka Cave near Lupoglav (45°21′09″N, 14°06′22″E) in Istria, W Croatia. Submitted 1997 by F Boras, State Commission for War and Post-war Victims, Zagreb (cal AD 1390–1530, 48.8%; AD 1570–1630, 14.9%).

Z-2823 Čačinci **370 ± 90**

Human bones found in catacombs of the church in Slatinski Drenovac near Čačinci (45°33′13″N, 17°42′28″E), 222 m asl, Slavonia, E Croatia. Suspected victims of WWII buried in this church. Collected 1998 by T Tomić and submitted by L Skavić, Commune of Čačinci (cal AD 1470–1660, 68.2%).

Comment: (TT) Expected Middle Ages.

Čakovec Old Town Series

Wood from base construction of entrance fortress of Old Town Čakovec (46°23′26″N, 16°26′28″E), Međimurje, NW Croatia (Figure 2). Determination of time of construction of various phases of the Old Town. Collected and submitted 1993 by S Petr-Marčec, Regional Museum of Međimurje, Čakovec. Previous measurements: Z-2436, Z-2437 (Obelić et al. 1994).

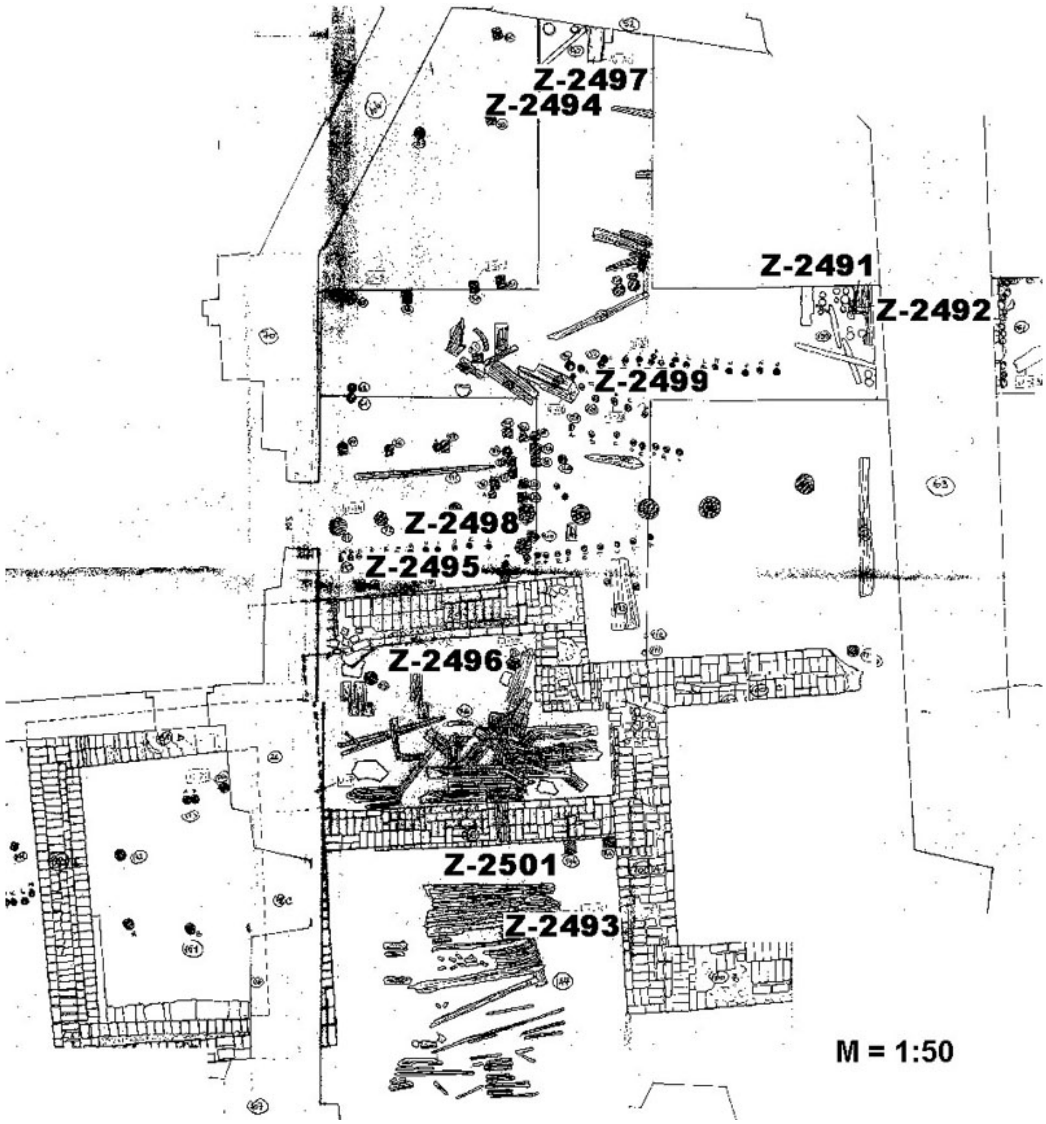


Figure 2 Old Town Čakovec, entrance fortress, with locations of samples taken for ^{14}C analyses

Z-2501 Čakovec Old Town 1 **825 ± 95**
Buried wooden post from construction, U-36, No. 144. Oak (*Quercus petrea* or *Quercus robur*), 163.18 m asl (cal AD 1060–1090, 8.0%; AD 1120–1140, 5.1%; AD 1150–1290, 55.1%).

Comment: (SP) Expected age: 14th–15th century.

Z-2491 Čakovec Old Town 2 **355 ± 80**
Wood found in soil, grilled shape pylon of the base construction of ramparts, U-37, No.158/8. Alder (*Alnus glutinosa Geartn*.), 161.80 m asl (cal AD 1460–1640, 68.2%).

Comment: (SP) Expected age: 15th–16th century.

Z-2492 Čakovec Old Town 3 **400 ± 80**
Wood found in soil, grilled shape pylon of the base construction of ramparts, U-38, No.161. Alder (*Alnus glutinosa Geartn*.), 161.70 m asl (cal AD 1430–1530, 41.6%; AD 1560–1630, 26.6%).

Comment: (SP) Expected age: 15th–16th century.

Z-2493 Čakovec Old Town 4 **635 ± 60**
Wooden board from construction found in soil, U-39, No.147/6. Oak (*Quercus petrea* or *Quercus robur*), 163.85 m asl (cal AD 1295–1330, 26.7%; AD 1340–1395, 41.5%).

Comment: (SP) Expected age: 14th–15th century.

Z-2494 Čakovec Old Town 5 **350 ± 55**
Wooden post found in soil, pier of the bridge, U-40, No.59. Oak (*Quercus petrea* or *Quercus robur*), 163.49 m asl (cal AD 1480–1530, 25.5%; AD 1550–1640, 42.7%).

Comment: (SP) Expected age: 14th–15th century.

Z-2495 Čakovec Old Town 6 **360 ± 80**
Small wooden post from construction supporting earthen dam, U-41, No. 80/d. Oak (*Quercus petrea* or *Quercus robur*), 163.40 m asl (cal AD 1450–1530, 29.3%; AD 1540–1640, 28.9%).

Comment: (SP) Expected age: 14th–15th century.

Z-2496 Čakovec Old Town 7 **515 ± 65**
Wooden board from construction found in soil, U-42, No. 146/10. Juniper (*Picea excelsa*), 163.23 m asl (cal AD 1320–1360, 18.0%; AD 1380–1450, 50.2%).

Comment: (SP) Expected age: 14th–16th century.

Z-2497 Čakovec Old Town 8 **375 ± 80**
Wooden board from base construction of ramparts, U-43, No. 143. Oak (*Quercus petrea* or *Quercus robur*), 162.00 m asl (cal AD 1440–1530, 36.2%; AD 1550–1640, 32.0%)

Comment: (SP) Expected age: 14th–15th century.

Z-2498 Čakovec Old Town 9 **415 ± 80**
Wooden post from construction found in soil, U-44, No. 55. Oak (*Quercus petrea* or *Quercus robur*), 163.76 m asl (cal AD 1420–1530, 48.2%; AD 1570–1630, 20.0%).

Comment (SP): Expected age: 14th–15th century.

Z-2499 Čakovec Old Town 10 **460 ± 80**

Small wooden post from construction supporting earthen dam, found in soil, U-45, No. 132b. Oak (*Quercus petrea* or *Quercus robur*), 162.87 m asl (cal AD 1390–1520, 59.2%; AD 1590–1620, 5.5%).

Comment (SP): Expected age: 14th–16th century.

Z-2560 Ćilipi **1570 ± 95**

Human bones found below basement of a house, Ćilipi (42°33′01″N, 18°17′04″E), 126 m asl near Dubrovnik. Collected 1993 by N Grbić, Dubrovnik, and submitted by Đ Miljanić, Rudjer Bošković Institute, Zagreb (cal AD 400–610, 68.2%).

Z-2503 Donji Miholjac–Šašnato Polje **30,200 +1900/–1550**

Metatharsal bone of giant deer (*Megaceros giganteus*) found 4 m deep in Holocene and Upper Pleistocene alluvium at site Šašnato Polje near Donji Miholjac (45°45′39″N, 18°10′02″E), E Slavonia. Collected 1987 by M Malez, and submitted 1994 by M Paunović, Croatian Academy of Sciences and Arts, Zagreb. The site was unearthed 1987 by a floating dredger during exploitation of gravel from Drava River alluvium. Among other faunal remains a fossil human mandible was found, showing the traits, which resemble in many aspects to that of the late and more progressive Neanderthals in SE Europe (Winkler and Paunović 1992).

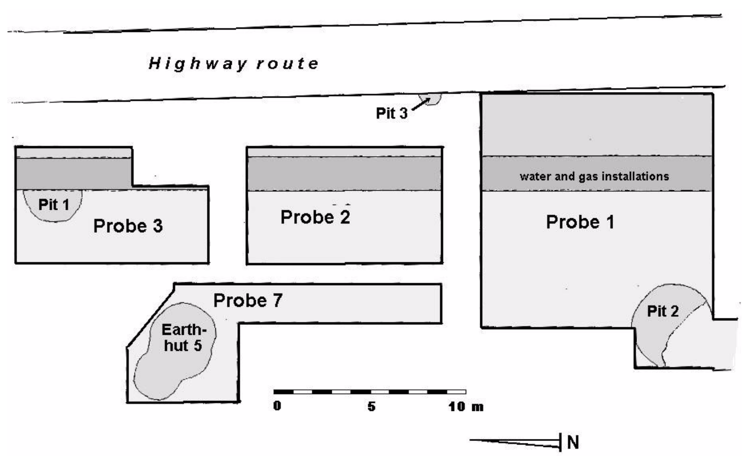


Figure 3 Excavations at Đakovo loop highway (site Grabrovac) with locations of pits where ^{14}C samples were taken

Đakovo–Grabrovac Series

Wood and charcoal samples from archaeological excavations on the Đakovo loop highway route at site Grabrovac near Đakovo (45°18′30″N, 18°24′38″E), 108 m asl, Slavonia, E Croatia (Figure 3). Collected 1997 and submitted 1998 by A Durman, Faculty of Philosophy, Zagreb.

Comment: (AD) Unlike most prehistoric settlements found in Slavonia, which were condensed on tells, this one was scattered at the edge of Jošava Lake. Therefore objects of particular cultures scarcely overlap and each culture could occupy its own zone. Previous archaeological investigations at this site established three culture layers: Sopot (4500–4000 BC), Baden (3350–3000 BC) and Litzen (2000–1800 BC).

Z-2735 Grabrovac 1 **3550 ± 100**
Wood, probe 1, pit 2 (bottom) (cal 2030–1740 BC, 68.2%).

Comment: (AD) Late Vučedol culture (Eneolithic, 2500–2200 BC).

Z-2736 Grabrovac 2 **3750 ± 100**
Wood, probe 1, pit 2 (cal 2310–2010 BC, 65.1%).

Comment: (AD) Late Vučedol culture (Eneolithic, 2500–2200 BC).

Z-2740 Grabrovac 3 **3620 ± 100**
Charcoal, probe 3, pit 1 (cal 2140–1870 BC, 62.8%).

Comment: (AD) Late Vučedol culture (Eneolithic, 2500–2200 BC).

Z-2741 Grabrovac 4 **3220 ± 90**
Charcoal, probe 7, earth–hut 5 (cal 1610–1400 BC, 68.2%).

Comment: (AD) Litzen culture (late phase of Early Bronze age, 2000–1800 BC).

Z-2757 Grabrovac 5 **3330 ± 100**
Charcoal, probe 7, earth–hut 5 (cal 1740–1500 BC, 68.2%).

Comment: (AD) Litzen culture (late phase of Early Bronze age, 2000–1800 BC).

Z-2758 Grabrovac 6 **3250 ± 80**
Charcoal probe 7, earth–hut 5 (2) (cal 1620–1430 BC, 68.2%).

Comment: (AD) Litzen culture (late phase of Early Bronze age, 2000–1800 BC).

Z-2847 Đurđic **200 ± 85**
Human bones (femur or tibia) found 102 cm depth in grave X near St George church, village Đurđic (45°47′31″N, 16°50′33″E), 155 m asl, near Bjelovar, C Croatia. Mixed with parts of constructive material, buried in soil without coffin. Collected and submitted 1998 by G Jakovljević, Municipal Museum Bjelovar (cal AD 1630–1700, 17.8%; AD 1720–1820, 21.4%; AD 1830–1890, 10.9%; AD 1910–1950, 10.1%)

Comment: (GJ) Expected Late Middle Ages.

Gabajeva Greda Series

Wood from 14 m long monoxyle boat found in gravel-pit Prosenica I at Gabajeva Greda, Hlebine near Koprivnica (46°09′35″N, 16°57′49″E), 117 m asl, N Croatia. Below water level. Submitted 1999 by H Malinar, Zagreb.

Comment: (HM) Establishing of age for valorization of the monoxyle to be presented in Koprivnica Regional Museum.

Z-2903 Gabajeva Greda 1 **125 ± 85**
Wood, top of the bow, 30 cm below surface (cal AD 1670–1770, 27.7%; AD 1800–1950, 40.5%).

Z-2904 Gabajeva Greda 2 **240 ± 70**
Wood, left side after first frame (rib) of the boat, patch on the hole (cal AD 1520–1590, 16.5%; AD 1620–1690, 21.7%; AD 1730–1810, 29.3%; AD 1920–1950, 5.7%).

Z-2905 Gabajeva Greda 3 **pMC: 102.7 ± 1.2**
Wood from core, lower part of the bow.

Comment: (HM) Expected the oldest sample within the series. Result does not confirm the presumption.

Z-2906 Gabajeva Greda 4 **95 ± 80**
Wood, left side of the boat (cal AD 1680–1740, 19.0%; AD 1800–1930, 47.6%).

Comment: (HM) The outermost part, tree rings expected to be the youngest.

Z-2907 Gabajeva Greda 5 **310 ± 80**
Oakum, most probably served to choke up the boat, right side of the boat (cal AD 1680–1740, 19.0%; AD 1800–1930, 47.6%).

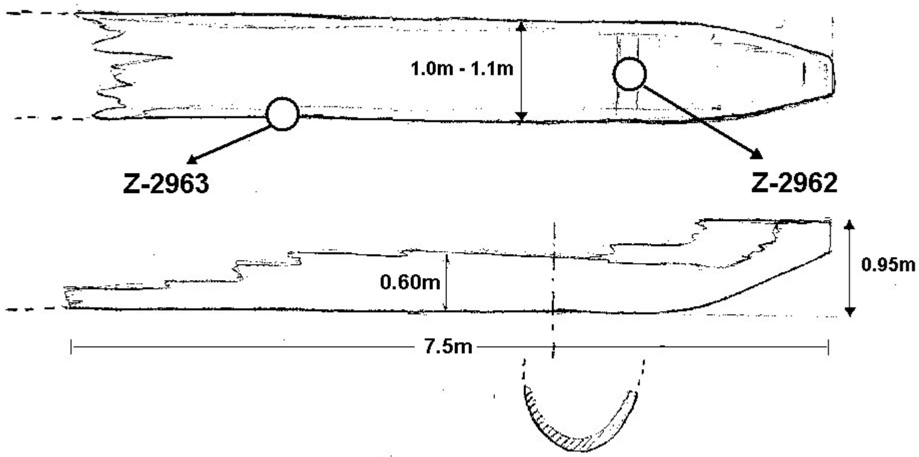


Figure 4 Monoxyle found near Ivanja Reka

Ivanja Reka Series

Oak (*Quercus* sp.) monoxyle (Figure 4) found in gravel pit Svibovski Otok close to Sava River, Ivanja Reka village (45°48′N, 16°07′E), 120 m asl near Zagreb, 6 m deep in wet sand below 3 m layer of soil and humus. Water level varies depending on season. Collected and submitted in 2000 by D Habuš-Skendžić, Sesvete Regional Museum.

Z-2962 Ivanja Reka 1 **435 ± 65**
Wood, central part of monoxyle corresponding to the core of trunk (cal AD 1410–1520, 59.9%; AD 1590–1620, 8.3%).

Z-2963 Ivanja Reka 2 **325 ± 70**
Wood, outer part of monoxyle (cal AD 1490–1650, 68.2%).

Jalžabet–Bistričak Series

Charcoal samples from the grave (Tumulus II) (Figure 5) found below humus in sand soil, village Jalžabet, location Bistričak, near Varaždin (46°15′39″N, 16°28′30″E), 168 m asl, NW Croatia. Collected 1989 and submitted 2001 by M Šimek, Municipal Museum Varaždin.

Comment: (MŠ) Expected age: 7th–6th century BC, Hallstatt culture (Šimek 1998).

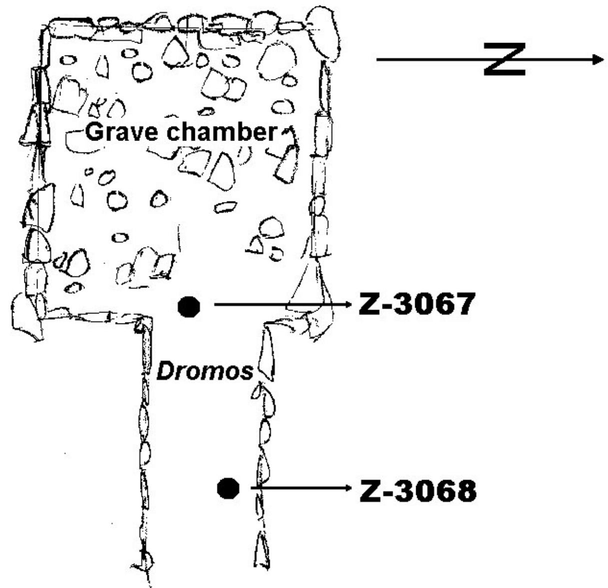


Figure 5 Jalžabet–Bistričak, Tumulus II, excavations 1989

Z-3067 Jalžabet–Bistričak 1 **2350 ± 100**

Charcoal, U1K, cover of grave, segment II, 30 cm depth (cal 800–650 BC, 13.8%; 550–350 BC, 45.0%; 300–200 BC, 9.4%).

Z-3068 Jalžabet–Bistričak 2 **2440 ± 100**

Charcoal, U2D, entrance to grave ("*dromos*") 55–70 cm depth (cal 760–680 BC, 19.4%; 670–630 BC, 7.3%; 560–400 BC, 38.6%).

Z-2645 Kašljevac **3350 ± 100**

Human bones from mass graveyard in forest Lipov Breg at village Kašljevac near Bjelovar (45°53′N, 17°00′E), 172 m asl. Submitted 1996 by F Boras, State Commission for War and Post-war Victims, Zagreb (cal 1770–1510 BC, 68.2%).

Z-2852 Klana–Gomance **17,100 ± 400**

Fossil animal bone (shoulder-blade of *Bos* sp.) found in a profile of the alluvial strata in the valley Gomance at Klana village (45°26′56″N, 14°22′43″E) near Rijeka, W Croatia, during the geological mapping of Quaternary sediments in the Kvarner region. Collected 1988 and submitted 1999 by Lj Marjanac, Croatian Academy of Sciences and Arts, Zagreb.

Comment: (LjM) Investigation of sediment genesis and reconstruction of paleoenvironment in Pleistocene.

Z-2520 Motovun **415 ± 65**

Wood sample from tree stump found 4.5 m depth at the edge of Mirna riverbed sediment, 500 m upstream from Motovun bridge (45°20′10″N, 13°49′41″E), 9 m asl, in Istria. Collected and submitted 1994 by J Rubinić, Istrian Water Authorities, Labin (cal AD 1420–1530, 54.4%; AD 1590–1630, 13.8%).

Comment: (JR) Dating to establish dynamics of filling up of Mirna River valley by eroded sediments. Some stumps were found 30 years ago, during works on river melioration.

Figure 6 Phallic stalagmite, the focus of ritual in Nakovana Cave sanctuary

Nakovana Cave Series

Illyrian sanctuary from Hellenistic times in Nakovana Cave above village Nakovana (43°00′N, 17°05′E), 318 m asl, near Orebić on Pelješac peninsula, S Dalmatia. In the middle chamber a central phallic stalagmite (Figure 6) surrounded by a remarkable quantity of imported artifacts, including thousands of high quality Hellenistic pottery fragments was found. The stalagmite clearly served as the focus of ritual. Dating of the base of the stalagmite (Z-3024) and charcoal below carbonate crust overlying the Hellenistic layer near the stalagmite (Z-3025). Samples were collected and submitted in year 2000 by S Forenbaher, Institute of Anthropological Research, Zagreb.

Comment: (SF) Sample Z-3024, taken from the base of the phallic stalagmite, dates the beginning of its growth. It was submitted in order to test the hypothesis that the stalagmite must have been transferred from its original position and placed on a prehistoric layer of Neolithic age. Estimated age of the Neolithic layer, based upon diagnostic potsherds contained within it, is ≥5500 BP. Date of the base of the stalagmite post-dates the Neolithic layer for at least 500 years. The two dates follow normal stratigraphic sequence, the lower being the older. Consequently, the hypothesis that the stalagmite must have been transferred from elsewhere and placed on the Neolithic layer is rejected. The dates by themselves do not solve the question whether the stalagmite has grown in situ, or has been transferred from a different position. Charcoal sample Z-3025 was taken from carbonate crust precipitated over Hellenistic layer, dated by ceramics to between the 4th and 1st centuries BC, and was expected to be younger than 1st century BC. It dates precipitation of the crust after abandonment of the sanctuary (Royal Ontario Museum 2000; Forenbaher and Kaiser 2001).

Z-3024 Nakovana Cave 1 **4940 ± 90**
Stalagmite, middle part of bottom (the oldest part). Conventional ^{14}C age corrected for initial activity $A_0 = 85\%$ gives 3630 ± 85.

Z-3025 Nakovana Cave 2 **1520 ± 75**
Charcoal below carbonate crust precipitated over Hellenistic layer dated by ceramics to 4th–1st century BC (cal AD 430–620, 68.2%).

Nova Bukovica Series

Charcoal samples found during systematic excavations of late Bronze and early Iron Age necropolis with cremation tombs in tumulus No. 4 on the site Sjenjak at Nova Bukovica, 7 km SW from Slatina (45°40′N, 17°46′E), 117 m asl, Slavonia. Collected 1997 and 1998 and submitted 1999 by K Minichreiter, Institute of Archaeology, Zagreb.

Comment: (KM) Bronze needle for man's clothes found in one of tumuli dates 700–500 BC, before arrival of Celts. The pottery found in tombs was manufactured in Baierdorf-Velatice style and is similar to Dalj, Donja Dolina, and Marijanec-Kaptol cultures (Minichreiter 1998).

Z-2926 Nova Bukovica 1 **2810 ± 75**
Charcoal, lower beam, burning site 11, probe C/1 (cal 1050–890 BC, 56.9%; 880–830 BC, 11.3%).

Z-2927 Nova Bukovica 2 **2115 ± 100**
Charcoal, southern beam, grave 20, probe E/6 (cal 360–290 BC, 12.6%; 240 BC–1 AD, 55.6%).

Z-2929 Nova Bukovica 3 **2970 ± 90**
Charcoal, grave 30, probe A/7 (cal 1320–1040 BC, 67.3%).

Z-2930 Nova Bukovica 4 **2630 ± 90**
Charcoal, grave 47, probe A/5–A/6, 1.17–1.3 m depth (cal 910–750 BC, 51.7%; 640–590 BC, 8.6%).

Z-2931 Nova Bukovica 5 **2670 ± 110**
Charcoal from urn, grave 47, probe A/5–A/6, 1.41–1.60 m depth, north (cal 1000–760 BC, 63.9%).

Z-2932 Nova Bukovica 6 **2630 ± 90**
Charcoal, grave 47, probe A/5–A/6, 1.75 m depth, center of pit, bottom (cal 980–780 BC, 68.2%).

Osijek–Herrmann's Wineyard Series

Charcoal and bone from Neolithic site (Sopot culture) found during the construction of collector for municipal sewerage at location Herrmann's Wineyard in town Osijek (45°33′04″N, 18°41′38″E), 98 m asl, E Slavonia. Cultural layer reaches up to 2 m and in some parts, in pits and trenches, even more. Collected 1998 by J Šimić, Osijek Regional Museum, and submitted by N Radić, Rudjer Bošković Institute, Zagreb.

Z-2830 Herrmann's Wineyard 1 **5210 ± 120**
Charcoal from fireplace, 1.80–2.00 m depth. Bottom of cultural layer (cal 4230–4180 BC, 7.7%; 4170–3930 BC, 53.2%; 3860–3810 BC, 7.3%).

Z-2831 Herrmann's Wineyard 2 **5600 ± 100**
Human bone found 1.9 m depth below cultural layer. Partly in clay and partly at the border of a pit (cal 4540–4340 BC, 68.2%).

Comment: (JŠ) Expected age 6000 yr.

Otok Series

Samples from archaeological site Otok near Vinkovci (45°08′48″N, 18°53′02″E), 85 m asl, E Slavonia. Collected 1970 by N Dimitrijević, Faculty of Philosophy, Zagreb. Submitted 1998 by A Durman (Z-2761 and Z-2762) and 1999 by I Jurić, Faculty of Agronomy (Z-2913), Zagreb. Samples Z-2761 and Z-2913 from the same finding.

Comment: (AD) Sopot culture (Neolithic).

Z-2761 Otok 1 **5650 ± 125**
Grain from a ceramic pot surrounded by charcoal found below floor of a house, depth 0.70–0.80 m, quadrant 10/ij (cal 4620–4350 BC, 67.2%).

Z-2913 Otok 2 **5555 ± 125**
Charred grain (*Triticum aestivum* L.), same as Z-2761, identified as *Thell sp. vulgare* (J McKey, Institute of Genetics, Uppsala, Sweden) (cal 4540–4310 BC, 59.3%; 4300–4250 BC, 8.9%) (Jurić et al. 2001).

Comment: (IJ) Expected age 5000 yr

Z-2762 Otok 3 **5330 ± 120**
Charcoal, quadrant 10/ij, depth 0.77 m (cal 4330–4290 BC, 7.1%; 4260–4040 BC, 57.6%).

Z-2642 Pakrac **355 ± 90**
Human bones from mass graveyard in Pakrac (45°26′53″N, 17°11′42″E), 203 m asl, W Slavonia. Collected 1996 by B Vukušić, Pakrac, and submitted 1996 by F Boras and V Jukić, State Commission for War and Post-war Victims, Zagreb (cal AD 1450–1640, 68.2%).

Comment: (FB) Possible remains of WWII prisoners from neighboring prison Šeovica or victims executed in 1946. According to indications of archaeologist V Herc from Čazma (personal communication), the remains from Pre-Turkish period (late Middle Ages).

Pećinovac Series

Charcoal in clay layers from Pećinovac Cave near Kanfanar (45°07′N, 13°50′E), 150 m asl, Istria. Excavations performed to preserve the cultural heritage in Croatia during the construction of the highway "Istrian Y" on the route Rovinj-Žminj. Collected 1998 by D Brajković and submitted by M Paunović, Croatian Academy of Sciences and Arts, Zagreb.

Z-2790 Pećinovac 1 **2000 ± 100**
Charcoal from hearth, 45–50 cm depth (cal 120 BC–AD 90, 59.5%; AD 100–130, 5.3%).

Comment: (MP) Expected Middle Ages.

Z-2791 Pećinovac 2 **3890 ± 110**
Charcoal from hearth, 70–100 cm depth (cal 2500–2190 BC, 65.8%).

Comment: (MP) Expected Bronze Age.

Premantura Series

Charcoal from Pećina na Gradini Cave (code PRM 99), Premantura (44°48′47″N, 13°54′40″E), 60 m asl, Istria. Collected and submitted 1999 by D Brajković, Institute of Palaeontology, Croatian Academy of Sciences and Arts, Zagreb.

Comment: (DB) Expected Roman period.

Z-2854 Premantura 1 **1645 ± 130**
Charcoal from fireplace, mixed with clay, probe I, layer 2 (cal AD 240–550, 68.2%).

Z-2855 Premantura 2 **1580 ± 90**
Charcoal from fireplace, mixed with clay, probe II, layer 4/5 (cal AD 400–600, 68.2%).

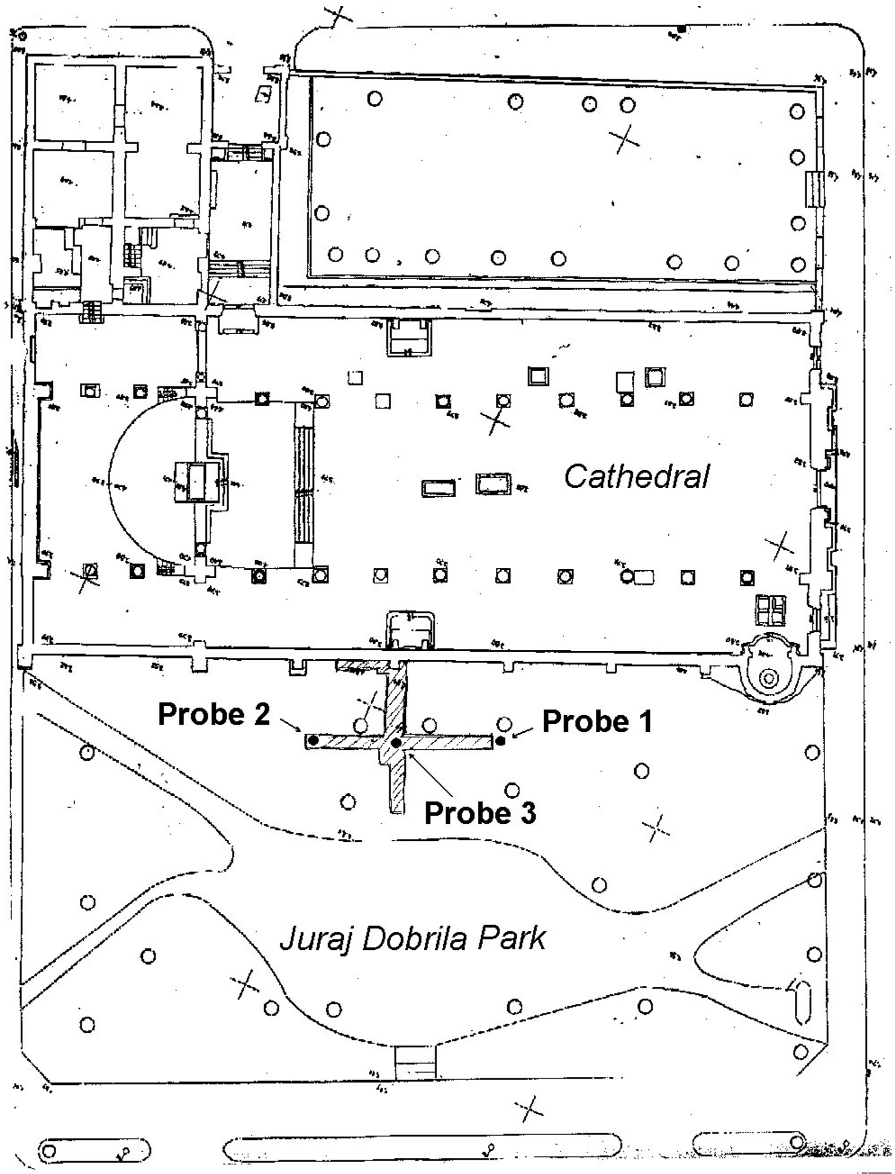


Figure 7 Ground plan of Juraj Dobrila Park and the Cathedral in Pula showing positions of three drilling probes from which samples were taken

Pula Series

Wood and bone samples collected during geological drilling in Juraj Dobrila Park at the line of antique wall uncovered NW of and parallel to the wall of the Cathedral in Pula (44°52′06″N, 13°50′53″E), Istria. Groundwater level at 3.20 m depth. Three drilling probes were taken (Figure 7): Probe 1: 0–4.30 m limestone slabs and traces of mortar, 4.30–5.20 m crushed small lime material, darker sand and sea sediment, 5.20–10 m wooden pilots and muddy material, 10–13.50 m clayey mud and fragments of rocks. Probe 2: 0–5.20 m stone material, 5.20–7.40 m wooden pilots, 7.40–8.20 m mud, wood, ceramics and shells, 8.20 m bedrock. Probe 3: 0–5.60 m stone and sand, 5.70–6.10 m wood, 6.10–6.50 m mud, half-crushed pebbles, 6.50–8 m rinsed mud and crushed stone, 8–9.70 m bedrock. Collected and submitted 1995 by K Mihovilić, Archaeological Museum of Istria, Pula.

Z-2587 Pula 1 **205 ± 90**
Bones, probe 1, 1.15–1.60 m depth, separated from the surrounding charcoal (cf. Z-2590) (cal AD 1630–1710, 18.5%; AD 1720–1890, 39.9%; AD 1910–1950, 9.9%).

Z-2590 Pula 2 **200 ± 90**
Charcoal separated from bones, probe 1, 1.15–1.60 m depth (cf. Z-2587) (cal AD 1630–1700, 17.8%; AD 1720–1820, 29.2%; AD 1830–1890, 11.1%; AD 1910–1950, 10.1%).

Z-2588 Pula 3 **pMC: 99.7 ± 1.6**
Bones, probe 1, 1.30 m depth.

Z-2589 Pula 4 **2060 ± 100**
Wood, probe 1, 5.3–6.9 m depth (cal 210 BC–AD 60, 68.2%).

Z-2580 Pula 5 **2080 ± 100**
Wood, probe 1, 6.25–6.85 m depth. Visible 30–35 tree-rings (cal 210 BC–AD 30, 66.2%).

Z-2581 Pula 6 **2200 ± 100**
Wood, probe 2, 6.40–7.40 m depth (cal 390–160 BC, 66.0%).

Z-2582 Pula 7 **1980 ± 100**
Wood, probe 3, 5.70–6.10 m depth (cal 120 BC–AD 140, 68.2%).

Pupićina Cave Series

Charcoal samples from Pupićina Cave near village Vranje (45°19′N, 14°10′E), 250 m asl in Istria. Collected and submitted 1995 and 1996 by P Miracle, Cambridge University, England, and S Forenbaher, Institute of Anthropological Research, Zagreb (Miracle and Forenbaher 1998; Miracle 2002). Charcoal associated with hearths, trash and living floors left by human occupants of the cave. Charcoal removed in the field from natural sedimentological units.

Comment: (PM) Samples from specific quadrants are from individual chunks of charcoal. Aim of the study: dating of stratigraphy: transition Neolithic to Bronze Age; dating of Pleistocene–Holocene transition; environmental changes in Istria.

Z-2577 Pupićina Cave 1 **3200 ± 150**
Charcoal, quadrant M13 CD, level 13 (cal 1690–1290 BC, 67.0%).

Comment: (PM) Expected Bronze Age.

Z-2573 Pupićina Cave 2 **3340 ± 110**
Charcoal, quadrant M13 CD, level 14 (cal 1750–1490 BC, 68.2%).

Comment: (PM) Expected Bronze Age.

Z-2629 Pupićina Cave 3 **4750 ± 160**
Charcoal, quadrant N17, level 110 (cal 3750–3300 BC, 66.5%).

Z-2630 Pupićina Cave 4 **4740 ± 250**
Charcoal, quadrant N16, level 117 (cal 3800–3100 BC, 68.2%).

Z-2575 Pupićina Cave 5 **6590 ± 240**
Charcoal, quadrant M13 CD, levels 20 and 21 (cal 5750–5290 BC, 68.2%).

Comment: (PM) Expected Neolithic.

Z-2634 Pupićina Cave 6 **9480 ± 180**
Charcoal, quadrant N14C, level 202 (cal 9150–8600 BC, 68.2%).

Comment: (PM) Upper midden. Expected Mesolithic.

Z-2635 Pupićina Cave 7 **8700 ± 170**
Charcoal, quadrant N14C, level 203 (cal 8000–7550 BC, 63.7%).

Comment: (PM) Upper midden. Expected Mesolithic.

Z-2572 Pupićina Cave 8 **9580 ± 180**
Charcoal, quadrant O14 B + ABCD, level 25 (cal 9220–8740 BC, 68.2%).

Comment: (PM) Lower midden. Expected Mesolithic.

Z-2578 Pupićina Cave 9 **8330 ± 210**
Charcoal, quadrant O13 B, level 27 (cal 7580–7080 BC, 68.2%).

Comment: (PM) Lower midden. Expected Mesolithic.

Z-2576 Pupićina Cave 10 **10,000 ± 270**
Charcoal, quadrant O14 ABCD and O13 ABCD, levels 29-30 (cal 10,200–9200 BC, 68.2%).

Comment: (PM) Expected Early Mesolithic.

Z-2636 Pupićina Cave 11 **11,100 ± 300**
Charcoal, quadrants N15A and N15B, level 207 (cal 11,550–10,900 BC, 68.2%).

Comment: (PM) Expected Early Mesolithic.

Z-2574 Pupićina Cave 12 **10,600 ± 200**
Charcoal, quadrants O14 D and O13 ABCD, levels 31–34 (cal 11,000–10,350 BC, 67.0%).

Comment: (PM) Expected Late Upper Paleolithic.

Z-2631 Pupićina Cave 13 **10,000 ± 180**
Charcoal, quadrants O14D, O14B and O14C, level 35 (cal 10,000–8600 BC, 68.2%).

Comment: (PM) Expected Late Upper Paleolithic.

Račinovci Series

Monoxyle boat found in Sava riverbed at Račinovci near Županja (44°51′59″N, 18°57′13″E), E Slavonia, 79 m asl. Collected 2000 and submitted 2001 by B Marijan, Županja Regional Museum.

Z-3026 Račinovci 1 **330 ± 65**
Wood, outer part (cal AD 1490–1640, 68.2%).

Z-3027 Račinovci 2 **465 ± 70**
Wood, inner part (cal AD 1390–1500, 62.0%).

Z-3072 Senj **1340 ± 105**

Charred grains found at foundations of a burned Roman house at Mala Placa square in town Senj (44°59′22″N, 14°54′21″E), 0 m asl, SW Croatia. Collected 1956 by B Ljubović, Municipal Museum Senj, and submitted 2001 by S Lulić, Rudjer Bošković Institute, Zagreb (cal AD 600–810, 66.4%).

Z-2462 Sinj **1160 ± 135**

Wooden part of a Frankish spear, well preserved, found in Cetina riverbed in Sinj valley (43°42′4″N, 16°40′20″E), 293 m asl, Dalmatia. Submitted 1993 by A Milošević, Sinj Regional Museum. Wood species: ash-tree (*Fraxinus* sp. L.) determined at the Faculty of Forestry, Zagreb (cal AD 710–750, 5.6%; AD 760–1000, 62.6%).

Comment: (AM) Expected age: end of 8th and beginning of 9th century, times of Charlemagne and formation of the first Croatian state.

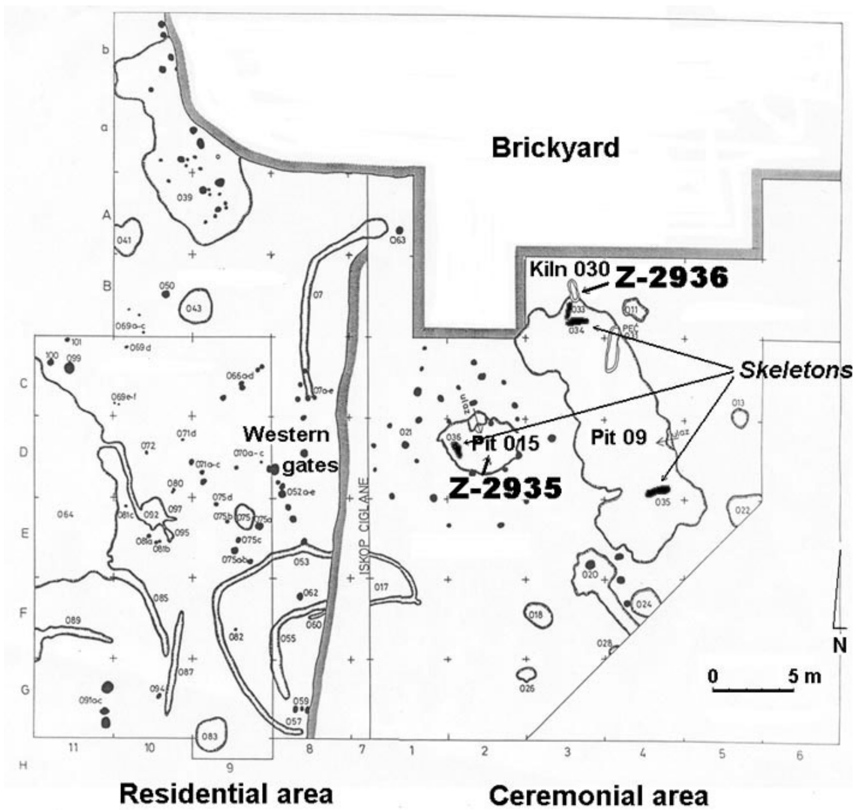


Figure 8 Map of the site Slavonski Brod–Galovo. Sampling locations for ^{14}C dating are shown, as well as positions of human skeletons.

Slavonski Brod–Galovo Series

Charcoal from archaeological site Galovo (Figure 8) at the eastern part of Slavonski Brod city limits (45°09′31″N, 17°59′12″E), 78 m asl, Slavonia. Ceremonial and burial area site of the early phase (Linear A phase) of the Starčevo culture. The ceremonial area is separated from the residential area of the settlement by wooden fences among which there are several passages ("Western Gate",

Figure 8). One-layered location with no mixture of different cultures. Collected 1997 and submitted 1999 by K Minichreiter, Institute of Archaeology, Zagreb.

Comment: (KM) The same phase of Starčevo culture as Zadubravlje (cf. Z-2921 to Z-2925, this article), but difference up to 2000 years possible. Expected age: 8000–6000 yr (Minichreiter 1996–1997; Krajcar Bronić et al. 2002).

Z-2935 Slavonski Brod–Galovo 1 **6185 ± 130**
Charcoal from SE and E part of pit 015, probe D/2, 1.56 m depth. A male skeleton is found in the west part of the pit (cal 5300–4960 BC, 68.2%).

Z-2936 Slavonski Brod–Galovo 2 **6830 ± 110**
Charcoal, SE from pit 09, kiln 030, quadrant C/3, 1.60–1.80 m depth. A cattle horn, ritually buried, is found below pieces of pottery with animal bones and stone tools in the pit centre. Two skeletons of grown-up persons were found close to the kiln 030 in the northern part of the pit, and a skeleton without skull in the southern part (cal 5810–5620 BC, 64.9%).

Z-3083 Sotin **570 ± 115**
Human bones, partly charred, from mass grave near the church in Sotin (45°17′40″N, 19°05′40″E), 122 m asl, E Slavonia. Submitted 2001 by M Šlaus, Croatian Academy of Sciences and Arts, Department of Archaeology, Zagreb (cal AD 1290–1450, 68.2%).

Comment: (MŠ) Suspected remains of victims of war 1991–1995 in Croatia.

Z-2966 Sućidar **1760 ± 80**
Human bone from grave found at foundation of a family house, Sućidar in Split (43°32′25″N, 16°17′58″E), Dalmatia. Collected and submitted 2000 by Š Anđelinović, Split (cal AD 210–390, 59.6%).

Stenjevec Series

Samples from Old-Croatian graveyard found in yard near the church in Stenjevec (45°49′N, 15°53′E), 129 m asl, near Zagreb. Submitted 1995 by K Simoni, Archaeological Museum, Zagreb.

Z-2545 Stenjevec 1 **220 ± 90**
Charcoal from ceramic fire-place or kiln dug from soil (cal AD 1520–1570, 7.9%; AD 1620–1700, 18.7%; AD 1720–1820, 25.9%, AD 1830–1880, 7.3%; AD 1910–1950, 8.5%).

Z-2546 Stenjevec 2 **2720 ± 80**
Wood from a tomb below skeleton (cal 940–800 BC, 63.9%).

Comment: (KS) Expected age of skeleton: 10th–13th century AD.

Z-2547 Stenjevec 3 **2640 ± 150**
Wooden beam or monoxyle, partly destroyed, near mediaeval necropolis (cal 980–520 BC, 68.2%).

Z-2824 Varaždin–Herczer Palace **590 ± 90**
Animal bones found in layer of gravel and dark soil below cellar No.2 of Herczer palace, Varaždin (46°18′35″N, 16°20′11″E), 153 m asl, N Croatia. Collected and submitted 1998 by M Šimek, Municipal Museum Varaždin (cal AD 1300–1420, 68.2%).

Comment: (MŠ) Probably basements of an older building. Expected Middle Ages.

Vinkovci Series

Archaeological rescue excavations at several sites in town Vinkovci (45°17′31″N, 18°48′05″E), 87 m asl, E Slavonia. Collected 1996 and 1998, and submitted 1997, 1998, and 1999 by M Krznarić-Škrivanko, Vinkovci Municipal Museum.

Comment: (MK) Investigation of continuity and way of life of Sopot culture (Dimitrijević 1968, 1979).

A) Site Ervenica

Charcoal from Neolithic layers excavated from pit III, Matije Gupca street No. 137. Open type settlement of the oldest (I-B) phase of Sopot culture at the left bank of Bosut River (Krznarić-Škrivanko 1997, 1999).

Comment: (MKŠ) Expected age: before 4500 BC. Both dates do not confirm expectation. Possibility of flooding from Bosut River.

Z-2755 Ervenica 1 **880 ± 65**
Charcoal found in soil, pit III, quadrant C-4, V/MG-137, 1.55 m depth (cal AD 1040–1100, 24.8%; AD 1110–1220, 43.4%).

Z-2829 Ervenica 2 **765 ± 70**
Charcoal from fireplace, pit III, quadrant C-4, V/MG-137, 1.55 m depth (cal AD 1180–1300, 68.2%).

B) Tell Sopot

Charcoal from eponymic Neolithic tell Sopot, 3 km SW from Vinkovci. Samples Z-2909 and Z-2911 belong to house basements denoted as stratigraphic unit (s.u. further on) 20 from Phase II of Sopot culture. Samples Z-2752, Z-2753, Z-2754, Z-2826 and Z-2827 belong to burned-down wooden construction of a 4 × 6 m house s.u. 11 from Phase III. Both settlements Ervenica and Sopot belong to Sopot culture, although with no direct connection (Iskra-Janošić and Krznarić-Škrivanko 1997, Krznarić-Škrivanko 1998a, 1998b, 1999, 2000).

Z-2752 Tell Sopot 1 **5675 ± 120**
Charcoal from wooden subconstruction below the floor of a house, quadrant E-6, 1.05-1.25 m depth (cal 4680–4630 BC, 5.8%; 4620–4360 BC, 62.4%).

Comment: (MK) Expected age: 3700–3600 BC.

Z-2753 Tell Sopot 2 **5790 ± 125**
Charcoal from wooden subconstruction below the floor of a house, quadrant C/D-4, 1.05–1.25 m depth (cal 4780–4490 BC, 68.2%).

Comment: (MKŠ) Expected age: 3700–3600 BC.

Z-2754 Tell Sopot 3 **5360 ± 130**
Charcoal, part of wooden construction of prehistoric house s.u. 11, quadrant G-9, s.u. 2 (cal 4320–4270 BC, 14.4%; 4260–4040 BC, 53.8%).

Comment: (MKŠ) Expected age: 3450–3350 BC.

Z-2826 Tell Sopot 4 **6340 ± 100**
Charcoal, part of wooden construction supporting wall of house s.u. 11, probe Sopot III, block 5, quadrant I6, 2.11 m depth (cal 5470–5210 BC, 65.7%).

Comment: (MKŠ) Expected age: 4300 BC.

Z-2827 Tell Sopot 5 **5380 ± 100**
Charcoal from house s.u. 11, probe Sopot III, block 5, quadrant I6, 2.11 m depth (cal 4340–4210 BC, 36.8%; 4200–4140 BC, 13.5%; 4130–4040 BC, 17.9%).

Z-2909 Tell Sopot 6 **5220 ± 100**
Charcoal from wooden wall construction of burned house s.u. 20, quadrant I-6, block 5, 2.11 m depth, (cal 4230–4180 BC, 8.9%; 4170–3940 BC, 59.3%).

Comment: (MKŠ) Expected age: 4300 BC.

Z-2911 Tell Sopot 7 **5330 ± 90**
Charcoal from fallen wooden wall construction of house s.u. 20, quadrant J-6, block 5, 3.54–3.67 m depth (cal 4250–4040 BC, 66.1%).

Comment: (MKŠ) Expected age: 4600 BC.

C) Tell Market

Z-2912 Tell Market **1680 ± 150**
Charcoal from overthrown floor board taken during rescue excavations at Vinkovci Market in Duga Ulica street No. 40, 1.92 depth, within the W ramparts of Roman town *Colonia Aurelia Cibalae*. Foundation with rests of Starčevo ceramics was found 2 m deep (Dizdar and Krznarić-Škrivanko 1999/2000, Iskra-Janošić 2000, 2001) (cal AD 210–550, 68.2%).

Comment: (MKŠ) Expected Starčevo culture (ca. 5000 BC). Dated material may not have originated in levels from which it was recovered.

D) Dirov Brijeg

Z-2828 Dirov Brijeg **2190 ± 80**
Charcoal found at hill Dirov Brijeg in Josipa Kozarca street, Vinkovci, pit I, 1.60 m depth, from a fortificated La Téne settlement inhabited by Celtic tribe Scordians from 2nd and 1st century BC until the Roman conquest (Dizdar 2001) (cal 380–160 BC, 66.3%).

Zadubravlje–Dužine Series

Charcoal samples from Starčevo culture settlement (Linear A phase) Dužine at village Zadubravlje (45°09′48″N, 18°09′10″E), 88 m asl near Sava River. Rescue archaeological excavations at the area of 6200 m^2 on highway route E-70 Zagreb-Belgrade, 17 km E from Slavonski Brod, Slavonia. The architecture of the Early Neolithic "craft" settlement shows a high level of practical organization of the settlement (Figure 9). The settlement consists of several units with distinct purposes (residential area, food storage and preparation, stone-tool workshop, pottery workshop and cloth manufacture) with accompanying structures (well, ceremonial area) necessary for the existence of a tribal community. The same phase of Starčevo culture as Slavonski Brod–Galovo (cf. Z-2935 and Z-2936, this article) (Minichreiter 1993, Krajcar Bronić et al. 2002). Collected 1989 and 1990 and submitted 2000 by K Minichreiter, Institute of Archaeology, Zagreb.

Comment: (KM) Expected age: 8000–6000 yr.

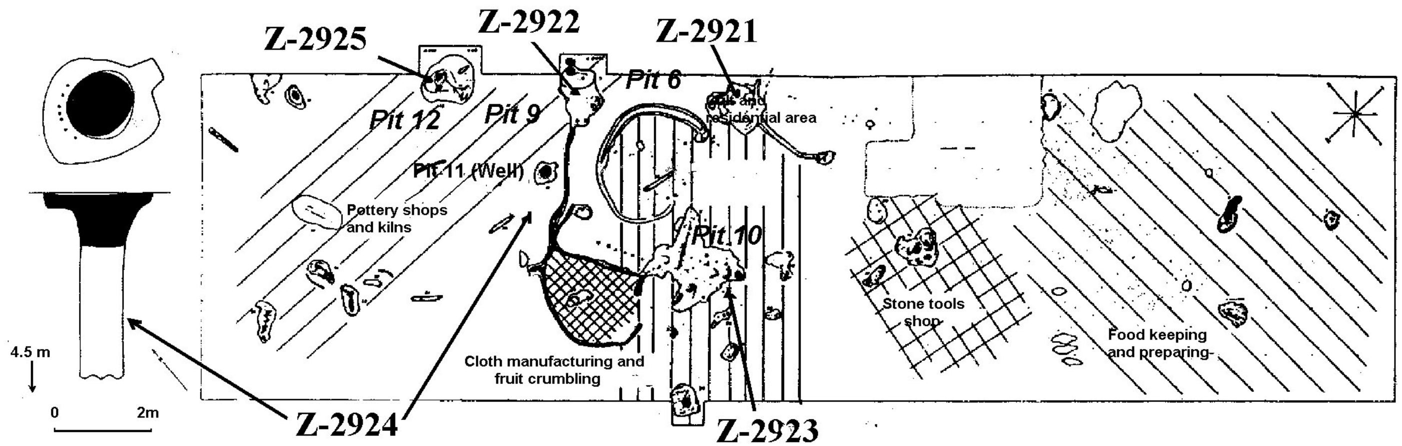


Figure 9 Map of the site Zadubravlje–Dužine with marked most important pits and locations where charcoal samples for ^{14}C analyses were taken from. On the left-hand side the plan of the well is shown.

Z-2921 Zadubravlje–Dužine 1 **6710 ± 110**
Charcoal from residential pit No. 6, quadrant A/14-A/15, 1.3–1.5 m depth (cal 5720–5530 BC, 68.2%).

Z-2922 Zadubravlje–Dužine 2 **6700 ± 100**
Charcoal from SW part of working pit No. 9 containing two ovens with hemispheral domes, probably used for baking of bread and two cylindrical kilns for firing of pottery vessels. Quadrant A/18, 1.56–1.79 m depth (cal 5720–5530 BC, 68.2%).

Z-2923 Zadubravlje–Dužine 3 **6990 ± 120**
Charcoal from SE part of large housing pit No.10, quadrant D-E/15, 1.71 m depth. In the west area of pit 10 fragments of pottery and animal bones are found, and below them a ritually buried cattle horn (cal 5990–5940 BC, 12.2%; 5930–5740 BC, 56.0%).

Z-2924 Zadubravlje–Dužine 4 **7610 ± 140**
Charcoal from well No. 11 from the center of the settlement, quadrant C/19, depth 3.90-4.1 m (cal 6600–6340 BC, 57.8%; 6320–6250 BC, 9.1%).

Comment: (KM) The oldest known Neolithic well in Europe. Constructed at the early phase of the settlement (Minichreiter 1993, 1997).

Z-2925 Zadubravlje–Dužine 5 **6260 ± 130**
Charcoal, working pit No.12 with a cigar-shaped kiln and a domed kiln for firing of pottery. Quadrant A/20-21, 1.7–1.9 m depth (cal 5370–5040 BC, 68.2%).

Županja–Dubovo-Košno Series

Charcoal taken during rescue archaeological excavations on the highway route E-70 Zagreb-Belgrade near Županja, (45°04′35″N, 18°41′52″E) 83 m asl, Slavonia, E Croatia. Collected and submitted 2000 by B Marijan, Županja Regional Museum.

Comment: (BM) According to the artifacts, the site belongs to Sopot culture. Expected age: 6500 years (Marijan 2000).

Z-2969 Županja–Dubovo-Košno 1 **6220 ± 140**
Charcoal, No. 152 mixed with soil exposed to groundwater, pit, quadrant H-8, s.u.160 (cal 5320–4990 BC, 68.2%).

Z-2973 Županja–Dubovo-Košno 2 **6530 ± 100**
Charcoal, No. 214 from earth–hut, quadrant F-38, s.u. 148, western part (cal 5620–5580 BC, 7.4%; 5560–5460 BC, 38.0%; 5450–5370 BC, 22.9%).

Z-2998 Županja–Dubovo-Košno 3 **6220 ± 100**
Charcoal from earth hut exposed to groundwater, quadrant R-38/39, s.u. 1144 (cal 5300–5050 BC, 68.2%).

Z-3045 Županja–Dubovo-Košno 4 **6320 ± 100**
Charcoal, quadrant Z-43d, PU 339, s.u. 1804 (cal 5390–5200 BC, 51.2%; 5170–5140 BC, 5.1%).

Z-3046 Županja–Dubovo-Košno 5 **6380 ± 100**
Charcoal, quadrant H-49d, PU 228, s.u. 308 (cal 5480–5290 BC, 67.0%).

Z-3047 Županja–Dubovo-Košno 6 **4680 ± 90**
Charcoal, quadrant M-42/43, PU 682, s.u. 281 (cal 3630–3580 BC, 12.4%; 3540–3360 BC, 55.8%).

Z-3048 Županja–Dubovo **2920 ± 90**

Charcoal, quadrant E-23b, s.u. 2, found in destroyed archaeological layer at site Dubovo, 350 m east from Dubovo-Košno on the highway route. Collected and submitted 2000 by B Marijan (cal 1310–970 BC, 65.9%).

Comment: (BM) Expected age: 3300 yr; probably Bronze Age culture group "Barice-Gređani" (Marijan 2000).

SLOVENIA

Z-2836 Bohova near Maribor **1780 ± 90**

Charcoal from the archaeological site Bohova (46°30′50″N, 15°39′30″E), 262 m asl, near Maribor (quadrants 296, 297/S II, s.u. 120) on the highway route, N Slovenia. Submitted 1999 by M Culiberg, Institute of Biology, Scientific Research Center of the Slovenian Academy of Sciences and Arts, Ljubljana (cal AD 130–350, 66.2%).

Comment (MC): Expected Roman age.

Cerknica Lake Series

Peat sediment from the borehole in the eastern part of the Cerknica Lake (45°44′10″N, 14°24′50″E), 550 m asl, SW Slovenia. Collected and submitted 2000 by M Culiberg.

Z-2977 Cerknica Lake 1 **2630 ± 70**

Peat, 122–130 cm depth (cal 900–760 BC, 67.1%).

Z-2978 Cerknica Lake 2 **9170 ± 100**

Peat, 268–275 cm depth (cal 8530–8490 BC, 7.9%; 8480–8270 BC, 60.3%).

Čatež Series

Charcoal from archaeological site Šentvid above Čatež (45°53′22″N, 15°36′09″E), 370 m asl, E Slovenia. Collected 1997 and submitted 1998 by A Jovanovič, Brežice Regional Museum, Slovenia.

Z-2750 Čatež 1 **1860 ± 90**

Charcoal in soil from the interior of a house, s.u. 011, quadrant C/8, 0.5 m depth (cal AD 50–260, 64.3%).

Comment: (AJ) Expected period: beginning of Romanization.

Z-2751 Čatež 2 **1950 ± 90**

Charcoal in soil, s.u. 010, quadrant D/13, 1 m depth (cal AD 50–140, 59.2%).

Comment: (AJ) Expected age: 10th–8th century BC.

Z-2541 Črniče **>37,000**

Wood sample, *Pinus* trunk (40 cm in diameter) was found in the clay sediment during the construction of the highway route near Črniče in Vipava Valley (45°53′30″N, 13°46′30″E), 120 m asl, W Slovenia. Collected and submitted 1995 by A Šercelj and M Culiberg, Institute of Biology, Scientific Research Center of the Slovenian Academy of Sciences and Arts, Ljubljana.

Črnomelj Series

Charcoal mixed with soil from the route of local sewerage in town Črnomelj (45°34′36″N, 15°11′24″E), 140 asl, SE Slovenia. Digging on the fluvial plane of Lahinja River below the town.

All layers under groundwater influence. Collected and submitted 1997 by P Mason, Institute for Protection of Cultural Heritage, Novo Mesto.

Z-2780 Črnomelj 1 **2560 ± 140**
Charcoal, probe 12, Hallstatt layer of waste material, quadrant 32, s.u. 275 (cal 830–510 BC, 62.9%).
Comment: (PM) Expected Iron Age, 4th century BC.

Z-2781 Črnomelj 2 **2155 ± 80**
Charcoal, probe 12, layer of charred material in Hallstatt culture, quadrant 32, s.u. 317 (cal 360–280 BC, 20.9%; 260–90 BC, 46.6%).

Comment: (PM) Expected age: 4th century BC.

Z-2782 Črnomelj 3 **2055 ± 260**
Charcoal, probe 4, foundation from Hallstatt culture layer, quadrant 20, s.u. 145 (cal 400 BC–AD 250, 68.2%).

Comment: (PM) Expected age: 4th century BC.

Z-2783 Črnomelj 4 **1530 ± 115**
Charcoal, probe 5, burned board from the grave, s.u. 125 (cal AD 420–640, 68.2%).

Comment: (PM) Expected age: 6th–7th century AD.

Z-2784 Črnomelj 5 **1985 ± 95**
Charcoal, probe 5, La Téne layer of charred and waste material, quadrant 59, s.u. 154 (cal 110 BC–AD 130, 68.2%).

Comment: (PM) Expected age: 2nd to 1st century BC.

Z-2785 Črnomelj 6 **2020 ± 96**
Charcoal, probe 5, La Téne layer of charred and waste material, quadrant 64, s.u. 154 (cal 170 BC–AD 80, 68.2%).

Comment: (PM) Expected age: 2nd to 1st century BC.

Z-2786 Črnomelj 7 **2030 ± 100**
Charcoal, probe 6, La Téne layer of charred and waste material, quadrant 66, s.u. 154 (cal 170 BC–AD 80, 68.2%).

Comment: (PM) Expected age: 2nd to 1st century BC.

Z-2787 Črnomelj 8 **2050 ± 100**
Charcoal, probe 6, La Téne layer of charred and waste material, quadrant 67, s.u. 154 (cal 200 BC–AD 60, 68.2%).

Comment: (PM) Expected age: 2nd to 1st century BC.

Z-2788 Črnomelj 9 **2050 ± 100**
Charcoal, probe 6, La Téne layer of charred and waste material, quadrant 72, s.u. 154 (cal 180 BC–AD 70, 68.2%).

Comment: (PM) Expected age: 2nd to 1st century BC.

Z-2789 Črnomelj 10 **1810 ± 95**
Charcoal, probe 6, La Téne layer of charred and waste material, quadrant 75, s.u. 154 (cal AD 120–350, 64.5%).

Comment: (PM) Expected age: 2nd to 1st century BC.

Dolga Vas Series

Archaeological excavations on the Lendava loop highway route at village Dolga Vas (46°35′16′N, 16°26′30″E), 190 m asl, site Gornje Njive, near Murska Sobota, NE Slovenia. At the area of 4400 m^2, clearly recognizable settlement phases from Copper Age, Bronze Age, Roman period and Middle Ages are uncovered. Collected 1997 by B Kerman and submitted 2000 by I Šavelj, Murska Sobota Regional Museum.

Comment: (BK) Samples taken from sectors I, II and XIII belong to Roman period, from sector IV to Middle Ages and prehistory, and from sectors V and XVIII to Middle Ages.

Z-2939 Dolga Vas 1 **2030 ± 75**
Charcoal from pit with wooden well, sector I, quadrant 14-15, s.u. 019 (cal 160–130 BC, 6.9%; 120 BC–AD 60, 61.3%).

Z-2941 Dolga Vas 2 **2010 ± 100**
Charcoal from ruin, sector I, quadrant 19, s.u. 020 (cal 170–130 BC, 6.2%; 120 BC–AD 90, 58.3%).

Z-2942 Dolga Vas 3 **1890 ± 100**
Charcoal from ruin, sector I, quadrant 19, s.u. 020 (cal AD 1–250, 68.2%).

Z-2943 Dolga Vas 4 **2090 ± 160**
Charcoal from ruin, sector I, quadrant 19, s.u. 020 (cal 360–280 BC, 11.3%; 260 BC–AD 70, 56.9%).

Z-2945 Dolga Vas 5 **1860 ± 70**
Charcoal from entrenchment, 20–40 cm depth, sector I, quadrant 26, s.u. 023 (cal AD 70–250, 68.2%).

Z-2946 Dolga Vas 6 **1615 ± 60**
Charcoal from pit or entrenchment, sector II, quadrant 34–35, s.u. 121 (cal AD 380–540, 68.2%).

Z-2947 Dolga Vas 7 **1990 ± 120**
Charcoal from ruin, 40–60 cm depth, sector II, quadrant 23, s.u. 020 (cal 170 BC–AD 130, 68.2%).

Z-2948 Dolga Vas 8 **1800 ± 75**
Charcoal from ruin, 20–40 cm depth, sector II, quadrant 34, s.u. 020 (cal AD 120–340, 68.2%).

Z-2949 Dolga Vas 9 **1680 ± 85**
Charcoal from melting furnace, 40–60 cm depth, sector II, quadrant 23, s.u. 122 (cal AD 240–440, 65.6%).

Z-2950 Dolga Vas 10 **1555 ± 60**
Charcoal from melting furnace, 60 cm depth, sector II, quadrant 23, s.u. 122 (cal AD 430–570, 68.2%).

Z-2951 Dolga Vas 11 **1075 ± 70**
Charcoal from oven, NE half, sector II, quadrant 6, s.u. 007 (*cf.* Z-2952 and Z-2960) (cal AD 890–1030, 68.2%)

Z-2952 Dolga Vas 12 **1575 ± 60**
Charcoal from oven, 20-40 cm depth, sector II, quadrant 6, s.u. 007 (cf. Z-2951 and Z-2960) (cal AD 420–560, 68.2%).

Z-2960 Dolga Vas 13 **1880 ± 70**
Charcoal from oven, NE half, 20–40 cm depth, sector II, quadrant 6, s.u. 007 (cf. Z-2951 and Z-2952) (cal AD 60–240, 68.2%).

Z-2953 Dolga Vas 14 **1670 ± 100**
Charcoal from mediaeval pit, sector IV, quadrant 69, s.u. 045 (cal AD 240–470, 59.5%; AD 480–540, 8.7%).

Z-2954 Dolga Vas 15 **3140 ± 110**
Charcoal from prehistoric pit, sector IV, quadrant 42, s.u. 032 (cal 1530–1250 BC, 67.2%).

Z-2955 Dolga Vas 16 **740 ± 65**
Charcoal from mediaeval pit, sector V, quadrant 73, s.u. 072 (cal AD 1210–1310, 63.8%).

Z-2956 Dolga Vas 17 **1785 ± 70**
Charcoal from hearth, sector XIII, quadrant 180, s.u. 172 (cf. Z-2957) (cal AD 130–340, 68.2%).

Z-2957 Dolga Vas 18 **1820 ± 75**
Charcoal from hearth, 20–40 cm depth, sector XIII, quadrant 180, s.u. 172 (cf. Z-2956) (cal AD 120–260, 54.9%; AD 280–330, 9.2%).

Z-2958 Dolga Vas 19 **1755 ± 70**
Charcoal, vertical post, 40–60 cm depth, sector XVI, quadrant 231, s.u. 266 (cal AD 210–390, 65.9%).

Z-2959 Dolga Vas 20 **840 ± 70**
Charcoal from mediaeval entrenchment from sector XVIII, quadrant 251, s.u. 282 (cal AD 1150–1280, 60.9%).

Dolnji Lakoš Series

Samples of vegetable detritus from the borehole at Dolnji Lakoš near Lendava (46°33′30″N, 16°26′00″), 160 m asl. Bronze age site at the vicinity. Collected and submitted 1996 by M Culiberg. Previous ^{14}C measurements: Z-1467, Z-1468, Z-1469 (Srdoč et al. 1987).

Z-2668 Dolnji Lakoš 1 **4285 ± 115**
Detritus, 175–185 cm depth (cal 3040–2840 BC, 40.0%; 2820–2660 BC, 24.5%).

Z-2669 Dolnji Lakoš 2 **5855 ± 160**
Detritus, 185-195 cm depth (4860–4520 cal BC, 62.3%).

Z-2934 Gradišče nad Bašljem **960 ± 85**
Charred *Avena* grain, Gradišče nad Bašljem, near Preddvor (46°19′40″N, 14°24′10″E), 873 m asl, N Slovenia. Quadrant 3/44, layer 2/2. Collected by T Knific, National Museum of Slovenia, and submitted 1999 by M Culiberg (cal AD 990–1190, 68.2%).

Comment: (MC) Expected Early Slavic time.

Izola Series

Wood found in layers with organic material during archaeological investigation in old part of town Izola (Isola) (45°32′08″N, 13°40′07″E), Slovenian Littoral. Collected 1995 by F Bonin and submitted by S Karinja, Maritime Museum in Piran, Slovenia.

Z-2600 Izola 1 **845 ± 75**
Wood (cal AD 1060–1090, 6.9%; AD 1120–1140, 5.3%; AD 1150–1280, 56.0%).

Z-2601 Izola 2 **1535 ± 105**
Wood (cal AD 420–620, 68.2%).

Z-2508 Koper Road **1290 ± 80**
Wood sample (*Quercus,* sp.), 120 cm depth, rest of building material, basement of a road at Prešern square in Koper (Capodistria) (45°32′48″N, 13°43′45″E), Slovenian Littoral. Rescue excavations during reconstruction of the road. Collected and submitted 1994 by M Erič, Archaeological Department, Faculty of Philosophy, Ljubljana (cal AD 650–810, 64.9%).

Comment: (ME) Expected age: AD 600 to 1000.

Z-2965 Lendava **2070 ± 75**
Subfossil wood (*Quercus sp.*), sample MS-S2, tree rings 188–198, archaeological excavations of Roman well, 0.5 to 3.0 m depth, Lendava (46°34′23″N, 16°27′01″E) near Murska Sobota, NE Slovenia. Collected and submitted 2000 by T Levanič, Biotechnical Faculty, Department of Wood Science and Technology, Univ of Ljubljana (cal 180 BC–AD 20, 68.2%).

Comment: (TL) Expected age: AD 200–300.

Z-2518 Ljubljansko Barje Boat **3600 ± 110**
Wood from a boat found at Ljubljansko Barje peat bog, Ljubljana (46°03′21″N, 14°30′30″E), 272 m asl. Collected 1994 by pupils of School in Nature within the framework of the movement "Science to Young People" and submitted by J Pezdič, Jožef Stefan Institute, Ljubljana (cal 2140–2070 BC, 10.7%; 2060–1860 BC, 45.7%; 1850–1770 BC, 11.8%).

Ormož–Hajndl Series

Wood from rescue excavations on highway route at archaeological site Klanče–Hajndl, west part of town Ormož (46°24′39″N, 16°09′05″E), 202 m asl. Collected 1999 by I Žižek, and submitted 2000 by S Olić, Municipal Museum Ptuj.

Z-2975 Ormož–Hajndl 1 **2480 ± 75**
Wood, prehistoric well, Hajndl 2, sector 34, quadrant 742. s.u. 649B (cal 770–510 BC, 65.9%).

Comment: (SO) Expected Hallstatt period.

Z-3004 Ormož–Hajndl 2 **2880 ± 80**
Wood, No. 30, Hajndl 2, sector 34, s.u. 653, 74/A (cal 1130–920 BC, 60.2%).

Comment: (SO) Expected Bronze Age to early Halstatt period.

Ormož–Hardek Series

Charcoal from location Hardek, east part of Ormož (46°24′39″N, 16°09′05″E), 202 m asl, NE Slovenia during rescue excavation on Ormož loop highway. Collected by I Žižek, Ptuj Regional Museum, and submitted 1997 by S Forenbacher, Institute for Anthropological Research, Zagreb (samples Z-2721, Z-2729 and Z-2742) and 1999 by M Culiberg (Z-2933).

Z-2721 Ormož–Hardek 1 **24,100 ± 1100**
Wood, quadrant 184/XI.

Z-2729 Ormož–Hardek 2 **4130 ± 160**
Charcoal, quadrant 124/VIII (cal 2890–2470 BC, 68.2%).

Z-2742 Ormož–Hardek 3 **5200 ± 120**
Charcoal, mixed sample from quadrants 258/XIV and 259/XIV (cal 4230–4190 BC, 6.2%; 4170–3930 BC, 49.9%; 3880–3800 BC, 12.2%).

Z-2933 Ormož–Hardek 4 **5290 ± 110**
Charcoal from oak, probe 1, quadrant 5A, pit 2 (cal 4250–3980 BC, 68.2%).

Comment: (MC) Expected: Neolithic.

Z-2556 Piran **2100 ± 100**
Wood found 115 cm below sea level in harbor of Piran (45°32′N, 13°34′E), Slovenian Littoral. Found together with 23 fragments of different kinds of wood during archaeological investigations of old Roman harbor. Collected and submitted 1994 by S Karinja, Maritime Museum Piran (cal 250–320 BC, 6.2%; 210 BC–AD 20, 60.6%).

Ptuj Series

Charcoal from rescue excavations in Ptuj (46°25′17″N, 15°52′11″E), 220 m asl, NW Slovenia. Collected and submitted 2000 by M Lubšina-Tušek, Regional Institute for Protection of Cultural Heritage Maribor, branch office Ptuj.

A) School Parking Place–Volkmerjeva Ulica Street

Z-3013 Ptuj–Parking Place 1 **1650 ± 70**
Charcoal, oven No. 2, lime-kiln, quadrants 24, 25, 26 and 27 (cal AD 330–470, 48.5%; AD 480–540, 14.9%).

Z-3015 Ptuj–Parking Place 2 **5870 ± 130**
Charcoal, pit 10, the oldest phase of Eneolithic object 2, quadrants 28, 29 (cal 4860–4550 BC, 64.8%).

Z-3019 Ptuj–Parking Place 3 **1760 ± 95**
Charcoal, oven No. 3 from Roman period (cal AD 130–160, 6.4%; AD 170–390, 61.8%).

Z-3020 Ptuj–Parking Place 4 **2160 ± 70**
Charcoal, oven No.1, quadrant 28 (cal 360–280 BC, 21.8%; 260–90 BC, 46.4%).

Comment: (MLT) Expected Bronze age. Date does not confirm expectation. Possible mixing with younger material.

B) Koresova Ulica Street

Comment: (MLT) Expected Roman period.

Z-3021 Ptuj–Koresova Ulica 1 **2955 ± 110**
Wood, lower part of barrel hope, well 1, sample IV, parcel 1119/51 (cal 1320–1010 BC, 67.5%).

Z-3022 Ptuj–Koresova Ulica 2 **1950 ± 60**
Wood from the construction of well 2, sample VI, parcel 1119/51 (cal AD 1–130, 63.7%).

C) Other samples from Ptuj

Z-2988 Ptuj–Viktorina Ptujskega **2960 ± 60**
Charcoal from Grave 2 found during reconstruction of street Viktorina Ptujskega. Collected M Lubšina-Tušek and submitted 1999 by S Olić (cal 1300–1050 BC, 68.2%).

Comment: (SO) Expected Iron age.

Z-2989 Ptuj–Mali Grad **1840 ± 70**
Charcoal from grave construction (Grave 2) found in a yard at location Mali Grad. Collected M Lubšina-Tušek and submitted 1999 by S Olić (cal AD 80–260, 65.4%).

Comment: (SO) Expected Roman period.

Slavnik Series

Samples of dark grey clay, sediment of a former lake in the karst basin Zajezeri near Podgorje (45°31′10″N, 13°56′30″E), 480 m asl, at the foothills of Slavnik Mt., SW Slovenia. Collected and submitted 1994 by A Šercelj.

Z-2542 Slavnik 1 **525 ± 135**
Clay, 150–160 cm depth (cal AD 1290–1520, 65.5%).

Z-2543 Slavnik 2 **2490 ± 110**
Clay, 190–200 cm depth (cal 790–510 BC, 65.5%).

Z-2544 Slavnik 3 **2500 ± 100**
Clay, 255–256 cm depth (cal 790–510 BC, 67.4%)

Z-3052 Šentpavel **1840 ± 70**
Charcoal (No.34) from the archaeological site Šentpavel (46°06'40"N, 14°36'10"E), 285 m asl near Domžale (quadrant A3/B3, s.u. 022) on the highway route. Collected 1999 by M Novšak, company Arhej, Sevnica and submitted 2001 by M Culiberg (cal AD 80–260, 66.0%).

Comment: (MC) Expected Roman times.

Šiman Series

Charcoal from archaeological site Šiman, northern from Žalec, village Gotovlje near Celje (46°14'54"N, 15°13'52"E), uncovered during rescue archaeological excavations on the highway route Ljubljana-Maribor. Collected and submitted 1995 and 1996 by S Olić.

Z-2819 Šiman 1 **1660 ± 90**
Charcoal, quadrant L-38, s.u. 008, 281.70 m asl (cal AD 320–470, 54.6%; AD 480–540, 12.1%).

Z-2820 Šiman 2 **1810 ± 115**
Charcoal from pit in sterile clay, 50 cm below humus, quadrant J-36, s.u. 009, 282.40 m asl (cal AD 80–350, 67.2%).

Z-2821 Šiman 3 **3700 ± 150**
Charcoal from Bronze Age pit with pottery and flintstone artifacts, quadrant K-39/4 (cal 790–510 BC, 67.4%).

Z-2621 Škocjan na Krasu **2100 ± 80**

Charcoal from prehistoric site Škocjan na Krasu (45°31'48"N, 13°47'30"E), 135 m asl, SW Slovenia. Rescue excavations uncovered remains from late Bronze Age, Iron Age and Antique period. Sample PN 6 from s.u. 12 was taken from one of six beams found at the basement of a burned house. Collected 1996 by P Turk, University of Ljubljana, Slovenia (cal 210 BC–AD 10, 68.2%).

Comment: (PT) Stratigraphically between late Bronze Age (13th to 12th century BC) and Antique layers (1st century AD).

Škocjanski Zatok Series

Marine sediment. Borehole in Rižana riverbed, Škocjanski Zatok near Koper (45°32′20″N, 13°44′40″E), Slovenian Littoral. Carbonate admixtures of detritus, chalk lime-stone, alluvial deposits and mollusks. Only organic part measured. Collected 1994 by A Šercelj and submitted by M Culiberg.

Z-2522 Škocjanski Zatok 1 **4730 ± 120**

Organic sediment, 4.25 m depth (cal 3640–3370 BC, 68.2%).

Z-2524 Škocjanski Zatok 2 **3480 ± 140**

Organic sediment, 3.50 m depth (cal 1980–1610 BC, 66.8%).

Z-2525 Škocjanski Zatok 3 **985 ± 90**

Organic sediment, 1.9 m depth (cal AD 970–1180, 68.2%).

Z-2846 Vrtičnik **2330± 100**

Charcoal from an urn (barrow No.5, KK 1/97, layer 2), Vrtičnik near Tupaliče (46°14′50″N, 14°26′40″E), 533 m asl. Collected 1997 by M Ogrin, Museum of Gorenjska and submitted 1999 by M Culiberg (cal 400–170 BC, 68.2%).

Comment: (MO) Hallstatt–Urnfield culture.

BOSNIA AND HERCEGOVINA

Z-2165 Laminci Jaružani **pMC: 98.9 ± 1.0**

Cow bone found in location Čakljeva Humka, Laminci Jaružani near Bosanska Gradiška (45°06'N, 17°22'E), 95 m asl, NW Bosnia. Submitted 1989 by B Čović, State Museum in Sarajevo.

Z-3097 Lištani **1695 ± 95**

Charcoal, square C2 b/d, 0.40–0.60 m depth, found near the base of a building, Lištani near Livno (43°49′35″N, 17°00′28″E), SW Bosnia. Submitted 2001 by M Marić, Franciscan Monastery in Livno (cal AD 230–440, 64.4%).

Comment: (MM) Expected 1st to 6th century AD.

Livno Series

Charcoal from St John cemetery at Livno (43°49′35″N, 17°00′28″E), 789 m asl, SW Bosnia. Collected 1994 by B Marijan and submitted by B Vrdoljak, Franciscan Monastery in Livno.

Z-2533 Livno 1 **1705 ± 95**

Charcoal (Kr.32) from pit at the cemetery together with Roman amphorae (cal AD 210–440, 67.2%).

Comment: (BM) Expected Roman period.

Z-2534 Livno 2 **940 ± 225**

Charcoal (Kr.14A) from St John cemetery (church), together with many other findings, including Old-Croatian ones (cal AD 890–1280).

ACKNOWLEDGMENTS

We thank B Mustač for sample preparation. Work prepared under the Project Grant P00980207 from Ministry of Science and Technology of the Republic of Croatia.

REFERENCES

Bronk Ramsey C. 1995. Radiocarbon calibration and analysis of stratigraphy: the OxCal Program. *Radiocarbon* 37(2):425–30.

Bronk Ramsey C. 1998. The OxCal Program Manual, v.3.0 [WWW document]. The Oxford Radiocarbon Accelerator Unit, University of Oxford. URL: <http://www.rlaha.ox.ac.uk/oxcal/oxcal.htm>. Accessed 2002 July 2.

Bryant C, Carmi I, Cook GT, Gulliksen S, Harkness DD, Heinemeier J, McGee E, Naysmith P, Possnert G, Scott EM, van der Plicht J, van Strydonck M. 2001. Is comparability of ^{14}C dates an issue?: A status report on the Fourth International Radiocarbon Intercomparison. *Radiocarbon* 43(2A): 321–4.

Dimitrijević S. 1968. Sopotsko-lengyelska kultura (in Croatian). In*: Arheološke monografije I.* Zagreb: Archaeological Institute of Faculty of Philosophy.

Dimitrijević S. 1979. Sopotska kultura (in Croatian). In*: Preistorija jugoslovenskih zemalja II*. Sarajevo.

Dizdar M. 2001. Latenska naselja na vinkovačkom području (Summary*:* La Téne settlements in Vinkovci region). *Disertacije i monografije 3.* Zagreb.

Dizdar M, Krznarić-Škrivanko M. 1999/2000. Prilog poznavanju arhitekture starčevačke kulture u Vinkovcima (Summary*:* Contribution to the knowledge of architecture of Starčevo culture in Vinkovci). *Vjesnik Arheološkog muzeja u Zagrebu*, 3s, XXXII-XXXIII: 7–22.

Forenbaher S, Kaiser T. 2001. Nakovana Cave: an Illyrian ritual site. *Antiquity* 75:677–8.

Horvatinčić N, Srdoč D, Obelić B, Krajcar Bronić I. 1990. Radiocarbon dating of intercomparison samples at the Zagreb Radiocarbon Laboratory. *Radiocarbon* 32(3):295–300.

Iskra-Janošić I. 2000. Zaštitno iskopavanje u Vinkovcima–Duga ulica 20 (Summary: Rescue excavation in Vinkovci–Duga Ulica street 20). *Obavijesti Hrvatskog arheološkog društva* No. 2: 60–3.

Iskra-Janošić I. 2001. Urbanizacija Cibala i razvoj keramičarskih središta (Summary: Urbanization of Cibalae and development of ceramic center). *Croatian Academy of Sciences and Arts, Center for Scientific Work in Vinkovci and Municipal Museum Vinkovci.* Zagreb-Vinkovci.

Iskra-Janošić I, Krznarić-Škrivanko M. 1997. Sustavno istraživanje neolitičkog naselja Sopot pokraj Vinkovaca (in Croatian). *Obavijesti Hrvatskog arheološkog društva*, year XXIX, No. 1. Zagreb. p 20–4.

Jurić I, Bogunović M, Dikić M, Balen J. 2001. Značajke poljoprivredne proizvodnje u naseljima Starčevačke culture na prostoru između Vinkovaca i Slavonskog Broda (Summary: Characteristics of agricultural production in settlements of the Starčevo culture in the area between Vinkovci and Slavonski Brod in Croatia). *Društvena istraživanja* 10. Zagreb. p 1131–58.

Krajcar Bronić I, Horvatinčić N, Obelić B, Bistrović R. 1995. Radiocarbon Intercomparison Studies at the Rudjer Bošković Institute. *Radiocarbon* 37(2):805–11.

Krajcar Bronić I, Minichreiter K, Obelić B, Horvatinčić N. 2002. Zadubravlje–the oldest early Neolithic (Starčevo culture) settlement in Croatia. *Proceedings of the 4th International Conference "^{14}C and Archaeology".* Oxford, England, UK, 9–14 April 2002. Submitted for publication.

Krznarić-Škrivanko M. 1997. Prapovijesno naselje na Ervenici (Summary: Prehistoric settlement at Ervenica). *Opvscvla Archaeologica* Vol. 21. Zagreb. p 205–15.

Krznarić-Škrivanko M. 1998. Druga etapa sustavnog arheološkog iskopavanja gradine Sopot (Summary: Second stage of systematic archaeological excavations on gradina Sopot). *Obavijesti Hrvatskog arheološkog društva*, year XXX, No. 1. Zagreb. p 30–4.

Krznarić-Škrivanko M. 1998. Treća sezona iskopavanja na gradini Sopot (Summary: Third stage of excavations on gradina Sopot). *Obavijesti Hrvatskog arheološkog društva*, year XXX, No. 3. Zagreb. p 71–4.

Krznarić-Škrivanko M. 1999. Mlađe kameno doba (Summary: Neolithic in Vinkovci). Catalogue *Vinkovci u svijetu arheologije.* Vinkovci, 1999. p 11–21.

Krznarić-Škrivanko M. 2000. Četvrta sezona sustavnog istraživanja gradine Sopot (*Summary:* Fourth season of systematic investigations of gradina Sopot). *Obavijesti Hrvatskog arheološkog društva*, year XXXIII, No. 2. Zagreb. p 49–52.

Marijan B. 2000. Zaštitna istraživanja arheoloških lokaliteta uz južni trak autoceste Zagreb-Lipovac, dionica Velika Kopanica–Županja, poddionica Babina Greda–Županja (Summary: Archaeological rescue excavations at the site along the southern carriageway of the motorway Zagreb–Lipovac, section Velika Kopanica–Županja, subsection Babina Greda–Županja). *Obavijesti Hrvatskog arheološkog društva*, year XXXII, No. 2:35–45.

Minichreiter K. 1993. Arhitektura Starčevačkog naselja kod Zadubravlja (Summary: The architecture of the Starčevo settlement at Zadubravlje). *Izdanje Hrvatskog arheološkog društva.* Zagreb. p 97–112.

Minichreiter K. 1996-1997. Zoomorphic idols of the Starčevo ceremonial and burial area site at Galovo, Slavonski Brod. *Prilozi Instituta za arheologiju.* Zagreb. 13/14:7–22.

Minichreiter K. 1997. Otkriće najstarijeg bunara na tlu Hrvatske u arheološkim istraživanjima kod Slavonskog Broda (Summary: Discovery of the oldest well on the territory of Croatia during archaeological investigations in the area of Slavonski Brod). *Hrvatske vode* 5/20:215–21.

Minichreiter K. 1998. Arheološka istraživanja brončano i željeznodobne nekropole u tumulima u Novoj Bukovici kod Slatine (Summary: Archaeological investigation of Bronze and Iron-Age necropolis in tumuli of Nova Bukovica near Slatina). *Glasnik slavonskih muzeja*, No. 2 (57):58–60.

Miracle P. 2000. *Pupićina Cave project*. IstriaNet.org, USA. <http://www.istrianet.org/istria/archeology/pupicina.htm>. WWW document, accessed 2 July 2002.

Miracle P. 2002. Mesolithic meals from Mesolithic middens. In: Miracle P, Milner N, editors. *Consuming passions and patterns of consumption*. Cambridge: McDonald Institute for Archeaological Research (ISBN 0-9519420-8-5).

Miracle P, Forenbaher S. 1998. Pupićina Cave project: Brief summary of the 1998 season. *Histria Archaeologica* 29:27–48.

Mook WG, van der Plicht J. 1999. Reporting ^{14}C activities and concentrations. *Radiocarbon* 41(3): 227–39.

Obelić B. 1989. The Radiocarbon Data Base at Rudjer Bošković Institute Radiocarbon Laboratory. *Radiocarbon* 31(3):1057–62.

Obelić B, Horvatinčić N, Srdoč D, Krajcar Bronić I, Sliepčević A, Grgić S. 1994. Rudjer Bošković Institute radiocarbon measurements XIII. *Radiocarbon* 36(2):303–24.

Radiocarbon. 2001. *Report on the FIRI Workshop, Edinburgh March 2001*. Arizona Board of Regents, Tucson. URL: <http://www.radiocarbon.org/Announcements/FIRI-results.html>. Website document accessed 2 July 2002.

Royal Ontario Museum. 2000. *The Secrets of Nakovana Cave*. Royal Ontario Museum. URL: <http://www.rom.on.ca/nakovana/>. Website document accessed 2 July 2002.

Srdoč D, Breyer B, Sliepčević A. 1971. Rudjer Bošković Institute radiocarbon measurements I. *Radiocarbon* 13(1):135–40.

Srdoč D, Sliepčević A, Planinić J. 1975. Rudjer Bošković Institute radiocarbon measurements III. *Radiocarbon* 17(1):149–55.

Srdoč D, Obelić B, Horvatinčić N, Sliepčević A. 1979. Measurement of the ^{14}C activity of the ANU sucrose secondary standard by means of the proportional counter technique. *Radiocarbon* 21(3):321–8.

Srdoč D, Obelić B, Sliepčević S, Krajcar Bronić I, Horvatinčić N. 1987. Rudjer Bošković Institute radiocarbon measurements X. *Radiocarbon* 29(1):135–47.

Stuiver M, Polach HA. 1977. Discussion: reporting of ^{14}C data. *Radiocarbon* 19(3):355–363.

Šimek M. 1998. Ein Grabhgel mit Pferdebestattung bei Jalžabet, Kroatien; Das Karpatenbecken und die Osteuropäische Steppe (in German). *Südosteuropa Schriften* Band 2. München-Rahden. p 493–510.

Winkler EM, Paunović M. 1992. Ein menschlicher Unterkiefer aus den jungpleistozänen Ablagerungen der Drau bei Šašnato Polje, Kroatien. *Mitteilungen der Anthropologischen Gesellschaft in Wien* 122:109–53. In German.

RADIOCARBON UPDATES

Passing

We regret to announce that geologist and *Radiocarbon* contributor Glenn Goodfriend passed away in October 2002 after an extended illness. Dr Goodfriend's specialties included amino-acid racemization and shell dating. Goodfriend used gas chromatography and high-performance liquid chromatography equipment to analyze climate change and date archaeological sites related to human evolution. He was based at George Washington University in Washington DC. *Radiocarbon* will publish an obituary in an upcoming issue.

Radiocarbon Conference

The 18th International Radiocarbon Conference will be held 1–5 September 2003 in Wellington, New Zealand. The conference is hosted by the Rafter Radiocarbon Laboratory of the Institute of Geological and Nuclear Sciences. Abstracts must be submitted by 15 May 2003. Abstract acceptance is conditional upon registration of the presenting author. Visit www.14Conference2003.co.nz for full details, or contact Dr Nancy Beavan Athfield at the address below.

Radiocarbon Conference 2003
Rafter Radiocarbon Laboratory
Institute of Geological and Nuclear Sciences
P O Box 31-312
Lower Hutt, New Zealand
Fax +64 4 570 4657
Email: 14Conf-info@gns.cri.nz

Laboratory News

Malaysia

The Malaysian Institute of Nuclear Technology Research (MINT) opened a new liquid scintillation spectrometry laboratory for counting benzene. The lab's code is RCMINT. For more information, contact Dr Abdul Nassir Ibrahim, MINT Radiocarbon Laboratory, Industrial Technology Division, Malaysian Institute of Nuclear Technology Research, Bangi, 43000 Kajang, Selangor, Malaysia. Their telephone number is 603-89250510, fax 603-89250907, and email nassir@mint.gov.my.

Reserve for b/w
GEOCHRON ad

Files in Quark,
sent to JCI June 2002

RADIOCARBON

$5 Back Issues Clearance Sale

YEAR	VOL.	Write in the number of copies desired for each issue					
		NR 1	NR 2	NR 2A	NR 2B	NR 3	NR 4
1980	22						
1981	23						
1982	24						
1983	25						
1984	26						
1985	27						
1986	28						
1987	29						
1988	30						
1989	31						
1990	32						
1991	33						
1992	34						

Calculate Payment

____ copies × $5 ea. = $________

Subtotal: $________

Shipping via surface mail:
(Contact us for other shipping methods)
Add $2 ea. book for US
Add $3 ea. book outside US

___ copies × $____ea. = $________

Shipping total: $________

Total due: $________

Payment & Shipping Address

❑ MasterCard ❑ Visa
❑ Check enclosed ❑ Please bill me

Name:

Address:

Fax: E-mail:

For Credit-Card Orders

Card number: Expiration date:

Signature: Phone:

For online Contents see: `http://www.radiocarbon.org/Pubs/contents.html`

Prices good while supplies last. Mail or fax this form to:

RADIOCARBON, 4717 East Fort Lowell Road, Room 104, Tucson, Arizona 85712-1201 USA
Phone: +1 520 881-0857; Fax: +1 520 881-0554; orders@radiocarbon.org

14C RADIOCARBON

An International Journal of
Cosmogenic Isotope Research

The University of Arizona
Department of Geosciences
4717 E. Fort Lowell Rd, Rm. 104
Tucson, AZ 85712-1201 USA

E-mail: orders@radiocarbon.org
http://www.radiocarbon.org/

2003 PRICE LIST

Proceedings of the 17th International Radiocarbon Conference (Vol 43, Nrs 2A, 2B and 3, 2001)	$75.00*
Proceedings of the 16th International Radiocarbon Conference (Vol 40, Nrs 1 and 2, 1998)	50.00
INTCAL98 (1998 Calibration issue; Vol 40, Nr 3, 1998)	40.00
Calibration 1993 (Vol 35, Nr 1, 1993)	40.00
Proceedings of the 15th International Radiocarbon Conference (Vol 37, Nr 2, 1995)	50.00
Liquid Scintillation Spectrometry 1994 (ISBN: 0-9638314-3-7; 1996)	20.00
Liquid Scintillation Spectrometry 1992 (ISBN: 0-9638314-0-2; 1993) (ISBN: 0-9638314-0-2; 1993)	10.00
Special offer—**LSC 92** and **LSC 94** package—save $5.00	25.00
Tree Rings, Environment and Humanity (ISBN 0-9638314-2-9; 1996) (Proceedings of the International Tree-Ring Conference, Tucson, Arizona, 1994)	20.00

SUBSCRIPTION RATES VOLUME 44, Nrs 1–3, 2003 (subscriptions include free online access)

Institution	**175.00**
Individual	**80.00**
Lifetime Subscription—Institutional	2500.00
Lifetime Subscription—Individual	1000.00

BACK ISSUES (except conference proceedings and special issues)

	Single issue	40.00
VOLUMES 1–9	each volume	40.00
VOLUMES 10–21	each volume	65.00
VOLUMES 22–43	each volume	100.00
Radiocarbon Conference Proceedings		50.00

SPECIAL FULL-SET OFFER—Volumes 1–43 (1959–2002) 1200.00

Big savings. Includes bound copies of 35 out-of-print issues. Take $50.00 off for each additional set.

2002–03 POSTAGE & HANDLING

	U.S.	Foreign
Subscription	--	$10.00
Single back issue	$2.00	$7.00
Book or Proceedings	$4.00	$13.00
Full set	$65.00	$200.00

Surface mail rates are listed here. Please contact us for airmail or express delivery rates.

Orders must be prepaid. We accept payments by Visa and MasterCard, or by check or money order payable in US$ to *Radiocarbon*. Bank funds transfers are also accepted. Please contact us for instructions.

Federal tax ID 86-6004791

*Postage will be added; see above chart. Subscription rates and book prices are subject to change.