Radiocarbon Ages of Mammoths in Northern Eurasia: Implications for Population Development and Late Quaternary Environment

Yuji Vasil'chuk,1 Jaan-Mati Punning2 and Alla Vasil'chuk3

Abstract: Many mammoth remains have been radiocarbon-dated. We present here more than 360 14C dates on bones, tusks, molars and soft tissues of mammoths and discuss some issues connected with the evolution of mammoths and their environment: the problem of the last mammoth; mammoth taphonomy; the plant remains and stable isotope records accompanying mammoth fossils; paleoclimate during the time of the mammoths and dating of host sediments. The temporal distribution of the 14C dates of fossils from the northern Eurasian territory is even for the entire period from 40 to 10 ka BP.

Introduction

Mammoth remains are very valuable objects for the study of Late Quaternary geochronology and paleoecology. The first finds of mammoth remains on northern islands in the Arctic and valleys of the great Siberian rivers drew the attention of scientists to the northern territories more than two centuries ago. The development of the mammoth population is one of the most interesting problems in reconstructing the dynamics of the environment during the Quaternary. The wide use of radiocarbon and paleoecological methods has provided valuable information on these dynamics. Today it is widely accepted that various fossil species of the genus Mammutthus characterize Late Quaternary periglacial environments.

Since the 14C method was first applied to the age determination of mammoth remains, the main problem has been reliability of the data. Geochemically, the most desirable materials for 14C analysis are well-preserved organic residues, i.e., bones rich in collagen, frozen carcasses, cud, dung or stomach contents from frozen ground or dry caves. In Russia, there are numerous sites from which whole carcasses of fossil mammoths have been dated by 14C (Fig. 1, Appendix): Yuribey River (Gydan Peninsula), Gydan (Gyda River), Pyasina River (Taimyr Peninsula), Mochoyava River (Taimyr Peninsula), Mammoth Shrenk (Taimyr Peninsula), Chekurova Settlement (Lower Lena River), Bukovskiy (Lena River), Beryosovka River, Shandrin River, Kirgilyakh River (baby mammoth “Dima”), Lyakhovskiy Bol'shoi Island, Tirekhnyakh River, Emynveem (Chukotka Peninsula).

It has been established that woolly mammoths spread over a vast area in northern Eurasia in the Late Pleistocene and even into the Holocene. The first 14C measurement of the fossil remains of mammoths was carried out by Heintz and Garutt (1965). Sulerzhitskij (1995) published more than 180 dates of Late Quaternary mammoths, most of which he had collected and dated himself. Stuart (1991) summarized the majority of 14C dates of mammoths of various species from northern Eurasia and North America.

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Fig. 1. Location of sites with dated mammoth remains. Site numbers refer to the number in the Appendix. = the southern limit of the ice wedge formation in the Late Pleistocene cryochron (40–10 ka BP) (in Asia after Vasil’chuk (1992), in Eastern Europe after Velichko (1984), in Western Europe after Maarleveld (1976).
METHODS

We sampled (Vasil’chuk 1992) mammoth bones from many reference sites in northern Yakutia: in the depression near Kular settlement (37.7 ka BP), near Zelyonyj Mys settlement (43.7 and >50 ka BP), Duvannyi Yar natural exposure (28.6, 33.8, 34.7 and >50 and 53 ka BP), and in Chukotka in the Mayn River valley and Ledovyi Obryv natural exposure (15.1 ka BP). We found re-deposited bones (drifted fossils) in the Holocene alas sediments, in the Kolyma River valley near the Omolon River mouth (15 ka BP).

Earlier we summarized a number of 14C dates on mammoth remains from northern Asia in order to reconstruct permafrost evolution during the last 40 ka (Vasil’chuk 1992). In addition to that list, we here summarize (Appendix) all the known 14C dates (>360) of mammoth remnants from northern Eurasia, mainly from permafrost areas (Appendix and Fig. 1).

One serious concern in using data obtained by dating of mammoth remains is its reliability. The systematic checking of bone data is underway at the Radiocarbon Laboratory of the Geological Institute in Moscow (L. Sulerzhitskij, personal communication). It is possible to draw some conclusions using the data obtained by multiple analysis of material from the same layer. There are many samples in the Appendix dated by bone material with different degrees of weathering (samples 12, 127, 139, 156, 246). The differences in the data are <1000 yr, in most cases within the statistical uncertainty of the dates. In some cases, different materials from the same layers were dated (Appendix, samples 85, 86, 87; 170, 171; 210, 211; 265, 266; 268, 269; 271, 272). The differences in data are modest and also within the limit of statistical uncertainty. This demonstrates that, in principle, fossils of mammoth fauna can be considered reliable as material for 14C dating.

The dates in the interval from 10 to 40 ka BP are distributed rather evenly; furthermore, there is no remarkable spatial grouping of mammoth finds in northern Eurasia. If 14C dates are an unbiased sample of mammoth populations, this indicates that mammoths lived constantly and continuously over northern Eurasia during the Middle/Late Wurm. Eastern Europe is characterized by a series of dates from 9.7 to >47.7 ka BP. The finds consist predominantly of molars, bones and tusks. In the northwestern part of European Russia, mammoth remains have been dated from 18.3 to >36 ka BP. In southern parts of western Siberia the dates range from 12.8 to 41.9 ka BP.

Whole carcasses have been found in the Yuribey and Gyda River valleys in northwestern Siberia; mammoth remains from this region have been dated from 9.6 to 35 ka BP. On the Taimyr Peninsula, Sulerzhitskij (1995) obtained several dates ranging from 9.6 to >53 ka BP without any significant time gaps. In central Siberia, fewer dates cover the interval from 20.7 to 49.7 ka BP (Appendix); this reduction may be explained by the topography and, consequently, biogeographical conditions of this mountainous region. The abundant 14C dates on mammoth remains in northern Yakutia range from 10.3 to >53 ka BP. From the Magadan region, data are available on the carcass of the Kirsilyakh baby mammoth and a few other finds, with ages from 21.6 to 41 ka BP. The Chukotka Peninsula is characterized by dates from 14.3 to 32 ka BP. In the Kamchatka Peninsula, 14C dates were obtained in the interval 12.6 to 40 ka BP (Sulerzhitskij 1995) (Appendix). Interesting dates are available from Arctic islands, especially Wrangel Island. Dates obtained from a dwarf form of mammoth are the youngest for mammoth finds in the world, falling into the interval 3.9 to 7.7 ka BP. The dates from 12.7 to 20 ka BP from these islands belong to mammoths of normal form (Vartanyan, Garutt and Sher 1993; Vartanyan et al. 1995). The oldest date on mammoth remains from the Arctic islands is 32 ka BP.

Mammoth bones also occur rather often in western Europe (Kurten 1968). Berglund et al. (1976) and Hakansson (1976) refer to some 14C dates on mammoth remains from South Sweden: 13, 19, 22.
and >30 ka BP. In Norway, some $^{14}$C dates on mammoth remains in the time interval from 19 to 32 ka BP have been obtained (Follestad and Olsson 1979). In Finland, Jungner and Sonninen (1983) and Donner, Jungner and Kurten (1979) obtained three $^{14}$C dates on samples collected by Donner: 15.5, 25.2 and >43 ka BP. Mammoth remains from Denmark have $^{14}$C ages from 13 to >39 ka BP (Aaris-Sorensen et al. 1990). In Germany, the dates vary from 15.8 to 30.3 ka BP; in Switzerland, from 12.2 to 34.6 ka BP; in Poland, from 20.2 to 23.0 ka BP; and in France, from 12 to 25.8 ka BP. Mammoth remains from Great Britain and Ireland have ages from 11.6 to >39.5 ka BP (Coope and Lister 1987; Stuart 1991).

The temporal distribution of mammoth remains (Fig. 2) displays no essential differences in the number of dated mammoths in the time interval from 15 to 45 ka BP. The spatial distribution of $^{14}$C-dated mammoth remains shows that mammoth fauna were connected mainly with Late Quaternary permafrost conditions (Fig. 1).

**DISCUSSION**

Several issues connected with mammoth evolution are of great scientific interest: the problem of the last mammoth; mammoth taphonomy; paleoclimate during the time of the mammoths and use of mammoth remains for the dating of host sediments.

**The Problem of the Last Mammoth**

The youngest $^{14}$C data for quasi-mammoth remains from the Western Hemisphere are those from North America on the *Mammut americanum*: 4470 ± 160 (M-2436) from Kuhl, Michigan; 8910 ± 150 (GSC-614) from Ferguson Farm, Ontario, and 9568 ± 1000 BP (M-282) from Lenawee, Michi-
Mammoth Taphonomy

Two aspects of the taphonomy of mammoth remains deserve attention. First, bones occurring in an unarticulated condition, almost without exception, indicate the redeposition of remains, typical of deposits of fluvial origin (such as alluvial, lacustrine, fluvioglacial). Therefore, as a rule the \(^{14}\text{C}\) dating of mammoth remains from these sediments gives the maximum age of sediment formation. Inclusion of younger bones in an older frozen deposit is not possible. As for syngenetic sediments of fluvial series, we can state with certainty that their ages are younger or equal to the ages of the enclosed bones. Second, the possible delivery of the bones by carnivores must be kept in mind.

The burial of whole mammoth carcasses is obviously an infrequent process, requiring the coincidence of several conditions. To remain intact, a carcass must be covered with sediments or be isolated from carnivores very quickly. Hence, the best conditions for preserving mammoth remains were offered by talus and alluvial sediments, high icy terraces and thermokarst depressions.

Plant remains in the stomach can be used to establish the season of a mammoth’s burial. All the mammoth carcasses found belonged to mammoths that perished in the summertime. Remains of mammoths that perished in the winter may have been destroyed by carnivores. This suggests that an important factor for the preservation of mammoth carcasses is the existence of permafrost conditions, during both fossilization and preservation.

Plant Remains and Pollen Accompanying Mammoth Fossils

The majority of the finds of subfossil mammoths and other large animals in northern Eurasia are connected with polygonal ice wedge complexes. Possibly mammoths’ pasturage depended directly on polygonal massifs. Palynological and plant macrofossil analyses have revealed an abundance of herbage in polygonal relief areas.
Pollen grains and plant remains in mammoths' guts (Table 1) indicate the feeding habits of the animals (Sukachev 1914; Solonevich, Tikhomirov and Ukraintseva 1977; Ukraintseva 1979; Sokolov 1982; Shilo et al. 1983; Guthrie 1990).

The host sediments that enclosed the Kirgilyakh baby mammoth are characterized by the predominance of pollen of herbs and shrubs (60–77%). Pollen of grass and sedges occur in equal quantities (10–25%), and other grasses are represented by 28 families such as Ranunculaceae (2–4%), Cruciferae (4–10%) and Artemisia (up to 4%). There are also pollen of hydrophilous taxa such as Potamogeton, Myriophyllum and Alismataceae. The content of Ericaceae (<2%), which is usually dominant in subfossil pollen spectra, is very small. The presence of larch pollen is evidence of larch forest at that time (Belaya and Kisterova 1978).

Pollen analyses of mammoths' digestive tracts and host sediments show a predominance of herb pollen or spores, presence of larch pollen (1–5%) and pollen of species that now live in southern areas (e.g., pollen of Ribes, Betula sect Albae), and the existence of typical tundra elements in the vegetation, e.g., Dryas punctata. The pollen and spores spectra showed some regional features, but these were evidence that mammoths lived in environments close to the modern larch forest and forest tundra.

Fossil flora found in the remains of the Yuribeyskiy mammoth (Gorlova 1982) consist of Cyperaceae (9 species), Poaceae (4 species), Salicaceae (3 species), Rosaceae (2 species), Betulaceae, Ericaceae and Pinaceae (1 species each). The present vegetation in the Arctic and the Subarctic is rather similar. However, the presence of macrofossils of Larix sibirica L. and Ribes spp. testifies to more favorable climatic conditions during the era of mammoths.

Naturally, to some extent, the content of the stomach reflects feeding preferences of mammoths. Plant remains belong to different life forms—shrubs, grasses, moss—and different habitats—dry meadows, steppe slopes, bottomland meadows, floodplain swamps, etc. This suggests the diversity of environmental conditions and biocoenoses in the areas where mammoths could live. Willow brushwood occurred in closed valleys, cereals and herbage occupied southern slopes of alluvial terraces, and sedges (particularly Carex strains) grew in meadows.

Analyses of both plant microfossils and pollen from dung and gut contents indicate a summer diet of grasses, sedges, mosses, and shoots of willow, draft birch and alder. A frozen forage mass from the stomach and gut of the Shandrin mammoth, found in Lower Indigirka, weighed ca. 250 kg. The
greater part of it consisted of stems and leaves of sedges, grasses and cotton-grass and the smaller part of sprouts of willow, birch and alder (Solonevich, Tikhomirov and Ukrainsteva 1977; Vereshchagin 1979). There were not any ripe seeds that might testify that the animal died in summer.

Well-preserved contents of mammoths’ digestive tracts have been studied from the Shandrin mammoth carcass (Ukrainsteva 1979). The remains of Cyperaceae, Eriophorum spp., Poaceae, Larix Daurica Turcz., Ericaceae, Vaccinium vitis-idaea L., some species of Polytrichum, Aulacomnium and Sphagnum have been identified. The main part of the pollen spectra from the enteron consists of spores of Bryales and Sphagnum (77%). Pollen of grasses makes up 19.4%, the majority of them pollen of grasses and sedges. Pollen of Dryas punctata, Valeriana capitata, Artemisia spp., Ledum spp. and Saxifraga spp. are also represented. All of these species presently grow in the same area. Pollen of larch, birch and alder bush were also found (ca. 4%). Nowadays analogous landscapes of larch light forests occur ca. 200 km to the south.

Sukachev (1914) identified grasses and sedges with ripe seeds in the stomach of Beryosovka mammoth, which evidently perished in late summer. Kupriyanova analyzed pollen and spores remains from the stomach of this mammoth: 8198 pollen grains and 7 spores were found (Tikhomirov and Kupriyanova 1954; Kupriyanova 1957). These are pollen of cereals (97%), forbs (2%), trees (1%) and spores. The pollen spectra are affected by the time of the mammoth’s death (second half of summer), showing a small amount of tree pollen, with predominance of the cereal pollen blooming during that period. The species list of the pollen from the mammoth’s stomach evidenced a varied flora corresponding to biocoenoses that exist at present ca. 1000 km to the south. Species of bunchgrass steppe with forbs and wormwood (Artemisia), upland meadow, inundation meadow, salt meadow and herb meadow have been determined.

Zaklinskaya studied the pollen content in the Taimyr Peninsula mammoth host sediments. All pollen spectra were characterized by the predominant herb pollen. The main part of the pollen consists of herbs of meadow plant communities of polygonal tundra, with cereals and sedges dominating (Zaklinskaya 1954). The paleobotanical and palynological data evidenced no sharp changes in the vegetation features, which therefore cannot be a cause of the mammoths’ extinction.

One of the details of paleobotanical characteristics was obtained from Selerican horse remains (Belorusova, Lovelius and Ukrainsteva 1977; Ukrainsteva 1979). Plant remains are represented by fossils of poplar, birch and mosses. Pollen spectra show a presence of hazel, juniper, spruce and elm in plant societies and Kobresia capilliformis as a dominant of dry meadows.

Lister and Sher (1995) pointed out that one problem of the climatic model of extinction is explaining how woolly mammoths survived an earlier interglacial. They proposed that the vegetation of the interglacial differed from that of the Holocene. In Siberia several interglacials have been recorded, but during these intervals, the vegetation differed from the vegetation of the modern larch-dominated taiga. Unfortunately, even now the climate-driven models do not show uniquely the reasons for the extinction of the mammoth population. Undoubtedly, in many cases, human involvement was important (Stuart 1991).

The pollen and plant fossils in the sediments accompanying the mammoth remains and the content of their stomachs show that the favorable season for mammoths’ fossilization in permafrost areas was late summer. More detailed paleoclimatic information about the time of mammoths’ existence can be provided by stable isotope data both from syngenetic sediments with ice wedges and directly from mammoth remains.
Isotope Records

Variations of the oxygen isotope composition are not substantial in the Late Pleistocene permafrost syngenetic deposits where mammoth remains have been found. The interval of $\delta^{18}O$ in the syngenetic ice wedge that formed 40–10 ka ago (Table 2) varies in the north of western Siberia from $-24$ to $-21\%o$, in northern Yakutia from $-34$ to $-29\%o$ and in northern Chukotka from $-32$ to $-29\%o$ (Vasil’chuk 1992). As snow meltwater was the main source of the moisture for ice wedges, the oxygen isotope records reflect mainly winter precipitation temperatures.

<table>
<thead>
<tr>
<th>Region of Siberia</th>
<th>$\delta^{18}O$ (‰)</th>
<th>$t_{mwD,1,F}$ ($^\circ$C)</th>
<th>$t_{mj}$ ($^\circ$C)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yamal and Gydan Peninsulas, north of western</td>
<td>$-21$ to $-24$</td>
<td>$-21$ to $-24$</td>
<td>$-32$ to $-36$</td>
</tr>
<tr>
<td>Siberia</td>
<td></td>
<td></td>
<td>($-22$ to $-28$)</td>
</tr>
<tr>
<td>Bykovsky Peninsula, mouth of Lena River,</td>
<td>$-30$ to $-34$</td>
<td>$-30$ to $-34$</td>
<td>$-45$ to $-49$</td>
</tr>
<tr>
<td>western Yakutia</td>
<td></td>
<td></td>
<td>($-32$ to $-34$)</td>
</tr>
<tr>
<td>Upper Kolyma River, northeastern Yakutia</td>
<td>$-29$ to $-33$</td>
<td>$-29$ to $-33$</td>
<td>$-43$ to $-49$</td>
</tr>
<tr>
<td>Vilyui and Aldan Rivers, central Yakutia</td>
<td>$-29$ to $-31$</td>
<td>$-29$ to $-31$</td>
<td>$-43$ to $-46$</td>
</tr>
<tr>
<td>Yamal an Gydan Peninsulas, north of western</td>
<td>$-29$ to $-32$</td>
<td>$-29$ to $-32$</td>
<td>$-44$ to $-46$</td>
</tr>
<tr>
<td>Siberia</td>
<td></td>
<td></td>
<td>($-27$ to $-29$)</td>
</tr>
<tr>
<td>Anadyr’ and mayn rivers, southern Chukotka</td>
<td>$-21$ to $-29$</td>
<td>$-21$ to $-29$</td>
<td>$-31$ to $-43$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>($-21$ to $-27$)</td>
</tr>
</tbody>
</table>

*Present mean January temperatures in parentheses for comparison

Using the relationship between the mean winter temperatures and oxygen isotope records obtained by Vasil’chuk (1992), it is possible to say that the winter climate was cold, stable and unchangeable in northern Eurasia from 40 to 10 ka ago.

Seasonal Climatic Conditions During the Time of the Mammoths

Mammoth remains are usually treated as indicators of very cold climatic conditions. The extinction of mammoths is one of the most often discussed problems in the paleogeography of the Late Quaternary. One of the most important causes of their extinction is connected with the change of climatic conditions and, therefore, the composition and production of biomass. The paleotemperature record obtained immediately from mammoth habitats, i.e., detailed records of syngenetic ice wedges, which have been dated as Late Pleistocene and Early Holocene, give valuable information about the mammoths’ environment. The oxygen isotope and pollen data from the same sections make it possible to reconstruct separately winter and summer temperatures. This approach is of great significance. Comparing the trends of winter and summer temperatures, we can see that winter temperatures changed especially abruptly at the Pleistocene/Holocene boundary.

An analysis of all information obtained indicates that mammoths were excellently adapted to Late Pleistocene long and cold winters without any thaws. They had long, shaggy coats and underwool, a thick layer of subcutaneous fat, tiny ears and short tails. Underwool is characterized by thick hair, which was four times thicker than that of present-day cold-adapted animals. Mammoths did not have adipose glands in their skin, so their wool would get wet when it was raining or foggy. Large
tusks came in handy for scraping snow and ice both for drinking purposes (like present-day elephants) and to expose buried forage. Their large size and spreading cushioned feet on which they distributed their weight may have enabled them to cope with snow better than most large herbivores in arctic and subarctic environments. The survival of such large animals in regions with a marked seasonal temperature range requires not only abundant summer herbage but also large quantities of winter feed, probably including dead grasses and bark from shrubs and trees.

At the Pleistocene/Holocene transition, winter temperatures changed sharply. Increasing Atlantic influences caused an increase in winter temperatures and the appearance of winter thaws. If thaws occurred in February or March, they could be fatal for mammoth herds, because the resulting multilayered ice crust made it impossible to find food and to move. The animals could not move because their legs were adapted to friable and relatively shallow snow cover but not to multilayered ice crust. Moreover, mammoth hair would have quickly become covered with ice, making the animals look like terrestrial icebergs.

We have reconstructed the environment in the mammoths’ time applying different methods. The oxygen isotope data in ice wedges enabled us to determine that during the interval from 40 to 10 ka BP, mean January temperatures in northern Siberia were ca. 8–12°C lower (in Chukotka up to 17–18°C) than the modern ones (Table 2). We have established that the interval from 40 to 10 ka BP was a single cryochron (Vasil’chuk 1992, 1993) with severe winters when the oscillations of temperatures were rather small, thawing was rare and the snow cover, as a rule, quite friable. Such winters permitted mammoths to dig out the grass easily from under the snow. Interpretation of pollen data enabled us to reconstruct the mean July temperatures for the period 40–10 ka BP. They were ca. 1–4°C lower than the contemporary ones (almost 7°C lower in the Chukotka Peninsula). During short periods of warming, the July temperatures could have been by 1–3°C higher than modern ones (Vasil’chuk and Vasil’chuk 1995).

Use of Mammoth Fossils for Dating the Host Sediments

Mammoth remains have been used widely in the dating of host sediments. The high degree of validity of 

14C of mammoth bones (Sulerzhitskij 1995), enables us to determine the lower limit of the host sediment age. In several sequences (Duvannyj Yar, Zelyonyj Mys and Kular in northern Yakutia) we have produced a series of 

14C dates on different kinds of organic matter—plant remains, peat, roots and wood, and bones. In many cases, the 

14C ages of plant remains were younger than the ages of bones from the same layers. For example, the ages of plant remains from Zelyonyj Mys sequences were in the interval from 27 to 37 ka BP and those of bones from the same depth from 43.7 to >50 ka BP (Vasil’chuk 1992). The same situation occurred in the Duvannyj Yar natural exposure, where the series of 

14C dates of plant remains lies in the interval from 40 to 20 ka BP, with three dates of mammoth bones in a normal sequence (28.6, 33.8, 34.7) and two inversion dates of >50 and 53 ka BP (Vasil’chuk 1992). We received non-inversion dates on tusk (15.1 ka BP) in the Ledovyj Obryv natural exposure in Chukotka, which were between the dates on plant remains of 34 and 14 ka BP (Vasil’chuk 1992). These data show that the dating of the host sediments by the use of mammoth bones is, in principle, possible; however, redeposition of separate bones is typical and must be taken into account in determining the host sediments’ age.

Because whole carcasses are, as a rule, not redeposited, their 

14C dates conform better with the age of the host formation. However, there are some exceptions. For example, the Kirgilyakh baby mammoth (which is 

14C-dated to 38–41 ka BP) had been redeposited together with frozen host sediments into the younger (14C-dated as Late Holocene) permafrost complex.
Mammoth Fossils and Reconstruction of Environmental Conditions

Some important regularities in the distribution of mammoth fossils appear within the Eurasian territory. First, the temporal distribution of the mammoth remains found in Eurasia is rather even for the whole period from 10 ka BP to the older limit of the \(^{14}C\) method (Fig. 2). Second, the spatial distribution of dated fossils shows that the southern boundary of the mammoths’ distribution is very close to the southern boundary of the ice wedge cast distribution, which is located ca. 45°N (Fig. 1). It may be assumed that the Late Pleistocene mammoth habitat corresponds to the severe permafrost area characterized by vast polygonal ice wedge landscapes. Third, as no breaks occur in the series of data from northern Asia, the European part of Russia and western Europe including Great Britain, it seems that the mammoths lived everywhere over this vast area. Therefore, the series of \(^{14}C\) dates from 40 to 10 ka BP on mammoth fossils from Scandinavia gives reason for critical evaluation of the scale and dynamics of the Late Pleistocene Glaciation in this region. Mammoth remains in South Sweden (from 13 to >30 ka BP), Norway (from 19 to 32 ka BP), Finland (from 15 to >43 ka BP) and Denmark (from 13 to 32 ka BP) suggest that large parts of Scandinavia were ice-free in Middle and Late Weichselian time (Donner, Jungner and Kurten (1979) reached similar conclusions).

So, for the period of the last glaciation, \(^{14}C\) dates on mammoth remains have been obtained from the entire territory of the supposed last glaciation area. \(^{14}C\) dates for the period of the last glaciation have been obtained in North America as well. Weber et al. (1981) received six \(^{14}C\) dates from bone fragments from Canyon Creek in interior Alaska—ca. 28, 32, 38, 39, 39 and 40 ka BP. In Canyon Creek, a portion of a tooth plate and bone fragments of \textit{Mammuthus primigenius} and many bones of \textit{Equus, Alces, Lepus, Canis, Ovis, Bison, etc.}, were sampled (Weber et al. 1981). Assuming that the \(^{14}C\) dates are trustworthy, the finds of mammoth remains show that our knowledge about the glaciation environment needs essential supplements.

CONCLUSION

Comprehensive analyses of \(^{14}C\), pollen, oxygen isotope and geological data enable us to draw some conclusions about the development of the mammoth fauna and their environment. In particular our data show that:

1. Mammoth remains from frozen ground are a very suitable material for \(^{14}C\) dating.
2. The temporal distribution of the \(^{14}C\) dates of fossils from the vast Eurasian territory is even for the whole period from 40 to 10 ka BP.
3. No time breaks appear in the series of dates in northern Asia, nor in eastern and western Europe.
4. The southern boundary of mammoths’ distribution is close to the southern boundary of the ice wedge cast distribution (and therefore close to the southern limit of severe permafrost). This demonstrates that the mammoth fauna is a typical component of Late Quaternary permafrost environments.

ACKNOWLEDGMENTS

We should like to thank L. D. Sulerzhitskij from the Geological Institute of the Russian Academy of Sciences for field assistance at the Kolyma River, for interesting discussions on \(^{14}C\) dating of mammoth remains, for \(^{14}C\) analyses and helpful comments on the manuscript. We acknowledge our debt to T. Kaare for the revision of the English text. Sincere thanks are due to A. Long, C. V. Haynes and an anonymous reviewer for critically reading and correcting the manuscript.
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**APPENDIX: RADIOCARBON DATES OF MAMMOTH REMAINS IN EURASIA**

<table>
<thead>
<tr>
<th>No.</th>
<th>14C date (yr BP), Lab code</th>
<th>Material dated</th>
<th>Site</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Eastern Europe</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>9780 ± 260 (TA-12)</td>
<td>Bone</td>
<td>Kunda Settlement</td>
</tr>
<tr>
<td>2</td>
<td>11,000 ± 200 (GIN-93)</td>
<td>Bone</td>
<td>Kostenki Settlement</td>
</tr>
<tr>
<td>3</td>
<td>12,200 ± 300 (IGAN-282)</td>
<td>Molar</td>
<td>Timonovka Settlement</td>
</tr>
<tr>
<td>4</td>
<td>12,630 ± 360 (GIN-4137)</td>
<td>Molar</td>
<td>Eliseevich Settlement</td>
</tr>
<tr>
<td>5</td>
<td>12,900 ± 200 (OxA-709)</td>
<td>Molar</td>
<td>Mezhirichi Settlement</td>
</tr>
<tr>
<td>6</td>
<td>12,970 ± 140 (LU-102)</td>
<td>Molar</td>
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**North of European Russia**

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**Western Siberia**

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**North of Western Siberia**

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**Taimyr Peninsula**

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### Ages of Mammoths in Northern Eurasia

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<td>275 7710 ± 40 (GIN-6995)</td>
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<tr>
<td>277 12,010 ± 110 (LU-2823)</td>
<td>Molar</td>
<td>Wrangel Island</td>
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<tr>
<td>278 12,750 ± 50 (GIN-6987)</td>
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<tr>
<td>279 12,900 ± 80 (LU-2792)</td>
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<tr>
<td>280 14,420 ± 100 (LU-1671)</td>
<td>Tusk</td>
<td>Kotel'niy Island</td>
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<tr>
<td>281 19,270 ± 300 (LU-654B)</td>
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<td>Severnaya Zemlya</td>
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<tr>
<td>282 19,970 ± 110 (LU-688)</td>
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<tr>
<td>283 19,990 ± 110 (LU-1790)</td>
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<td>Kotel'niy Island</td>
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<td>284 20,000 ± 110 (LU-2807)</td>
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<td>285 20,900 ± 100 (GIN-5760)</td>
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<td>286 25,030 ± 210 (LU-749B)</td>
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<td>287 25,800 ± 200 (GIN-4710B)</td>
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<td>Predeevskiy Island</td>
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<tr>
<td>289 29,020 ± 190 (K-3697)</td>
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<td>290 29,100 ± 400 (K-3805)</td>
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<td>Predeevskiy Island</td>
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<tr>
<td>291 29,100 ± 1000 (K-4710)</td>
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<td>292 32,100 ± 610 (K-4192)</td>
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<td>Rosmos 1</td>
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<td>293 34,600 +760/-690 (K-3697)</td>
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<td>294 21,530 ± 430 (K-3703)</td>
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<td>Myrup Banke</td>
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<td>295 24,190 ± 420 (K-3806)</td>
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<td>Munke Bjergby</td>
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<td>296 25,110 ± 440 (K-3699)</td>
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<td>Hadsund</td>
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<td>297 25,480 ±500 (K-3809)</td>
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<td>298 25,520 ±920 (K-3805)</td>
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<td>Ny Stengaard</td>
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<td>299 25,760 ±840 (K-3805)</td>
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<td>Ny Stengaard</td>
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<td>300 26,270 ±1400 (K-3805)</td>
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<td>301 27,810 ± 610 (K-4192)</td>
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<td>Stengardens Grusgrav 2</td>
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<td>303 29,570 ± 950 (K-3807)</td>
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<td>305 32,460 ±970 (K-4190)</td>
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<td>Lundehjerg 1</td>
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<td>306 39,900 ±790 (K-4191)</td>
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<td>307 39,500 ±790 (K-4188)</td>
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<td>308 39,600 ±790 (K-4587)</td>
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<td>309 15,810 ± 410 (HV-1961)</td>
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<tr>
<td>310 30,300 +2500/-1900 (Fra-5a)</td>
<td>Femur</td>
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<tr>
<td>311 12,270 ± 210 (Ly-877)</td>
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<td>Praz Rodet</td>
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<tr>
<td>312 34,600 ±2700/-1800 (Ly-751)</td>
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<td>Bioley-Orjulaz</td>
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<tr>
<td>313 20,200 ± 350 (OxA-635)</td>
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<td>Spadzia Street, Krakow</td>
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<td>314 20,600 ± 1050 (Ly-631)</td>
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<td>315 21,000 ± 900 (Ly-2542)</td>
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<td>316 23,040 ± 170 (GrN-6636)</td>
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<td>317 12,000 ± 220 (Ly-1351)</td>
<td>Scapula</td>
<td>Etiolles</td>
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<td>318 14,330 ± 260 (Ly-357)</td>
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<td>La Croze-sur-Suran 1</td>
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<tr>
<td>319 14,390 ± 300 (Ly-433)</td>
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<td>La Columbie rockshelter</td>
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<td>320 14,850 ± 350 (Ly-434)</td>
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<td>La Croze-sur-Suran 2</td>
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<td>321 12,900 ± 700 (Ly-1865)</td>
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<td>La Mère Clochette Grotto</td>
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<td>322 33,500 ± 1200 (D-122)</td>
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<td>323 11,650 ± 130 (OxA-2155)</td>
<td>Ivory rod</td>
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<td>324 12,080 ± 130 (OxA-1457)</td>
<td>Skull</td>
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<td>325 12,170 ± 130 (OxA-1890)</td>
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<td>Cough's Cave, Shropshire</td>
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<td>326 12,300 ± 180 (OxA-1316)</td>
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<td>327 12,320 ± 120 (OxA-1462)</td>
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<td>Robin Hood's cave</td>
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<td>328 12,330 ± 120 (OxA-1456)</td>
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<td>Species</td>
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<td>329</td>
<td>12,400 ± 160 (OxA-1455)</td>
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<td>12,460 ± 160 (OxA-1204)</td>
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<td>332</td>
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<td>18,000 ±1400/−1200 (Birm-146)</td>
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<td>335</td>
<td>26,700 ± 550 (OxA-1205)</td>
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<td>38,600 ±1720/−1420 (OxA-1566)</td>
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<td>39,500 ±3100/−2650 (Lu-746)</td>
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<td>&gt;39,500 (OxA-1566)</td>
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<td>28,100 ±3100/−2300 (U-746)</td>
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<td>19,150 ± 390 (Lu-887E)</td>
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<tr>
<td>361</td>
<td>36,100 ±2000/−1600 (Lu-880)</td>
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