

Life and extinction of megafauna in the ice-age Arctic

Daniel H. Mann^{a,1}, Pamela Groves^b, Richard E. Reanier^c, Benjamin V. Gaglioti^d, Michael L. Kunz^e, and Beth Shapiro^{f,1}

^aGeosciences Department, University of Alaska, Fairbanks, AK 99775; ^bInstitute of Arctic Biology, University of Alaska, Fairbanks, AK 99775; ^cReanier & Associates, Inc., Seattle, WA 98166; ^dWater and Environmental Research Center, University of Alaska, Fairbanks, AK 99775; ^eCooperative Extension and Resources, University of Alaska, Fairbanks, AK 99775; and ^fDepartment of Ecology and Evolutionary Biology and University of California, Santa Cruz Genomics Institute, University of California, Santa Cruz, CA 95064

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Understanding the population dynamics of megafauna that inhabited the mammoth steppe provides insights into the causes of extinctions during both the terminal Pleistocene and today. Our study area is Alaska's North Slope, a place where humans were rare when these extinctions occurred. After developing a statistical approach to remove the age artifacts caused by radiocarbon calibration from a large series of dated megafaunal bones, we compare the temporal patterns of bone abundance with climate records. Megafaunal abundance tracked ice age climate, peaking during transitions from cold to warm periods. These results suggest that a defining characteristic of the mammoth steppe was its temporal instability and imply that regional extinctions followed by population reestablishment from distant refugia were characteristic features of ice-age biogeography at high latitudes. It follows that long-distance dispersal was crucial for the long-term persistence of megafaunal species living in the Arctic. Such dispersal was only possible when their rapidly shifting range lands were geographically interconnected. The end of the last ice age was fatally unique because the geographic ranges of arctic megafauna became permanently fragmented after stable, interglacial climate engendered the spread of peatlands at the same time that rising sea level severed former dispersal routes.

ice age | megafauna | extinction | paleoecology | mammoth steppe

One of the most intriguing examples of mass extinction and the most accessible in terms of its geological record occurred around the end of the Wisconsin ice age ca. 10–45 calendar ka B.P. (10,000–45,000 calendar y ago) when some 65% of terrestrial megafauna genera (animals weighing >45 kg) became globally extinct (1). Based on what we know about recent species extinctions, the causes of extinction are usually synergistic, often species-specific, and therefore, complex, which implies that there is no universal explanation for end-Pleistocene extinctions (2, 3). Globally and specifically in the Arctic (3–10), megafaunal extinctions have been variously blamed on overhunting, rapid climate change, habitat loss, and introduced diseases (3–10). Further complicating a clear understanding of the causes of ice-age extinctions is that the magnitude and tempo of environmental change during the last 100,000 y of the Pleistocene were fundamentally different than during the Holocene (11), and these differences had far-reaching implications for community structure, evolution, and extinction causes (12).

A recent survey comparing the extinction dates of circum-boreal megafauna with ice-age climate suggests that extinctions and genetic turnover were most frequent during warm, interstadial events (13). However, the mechanisms for these extinctions remain unclear, partly because this previous study considered multiple taxa living in many different ecosystems. Here, we focus on five megafaunal species that cohabited a region of the Arctic with an ecological setting that is relatively well-understood. To avoid the methodological problems involved in pinpointing extinction dates (13), we infer population dynamics from changes in the relative abundance of megafauna over time. Using a uniquely large dataset of dated megafaunal bones from one particular area, we test a specific paleoecological hypothesis relating rapid climate change to population dynamics—namely, that transitions from cold to warm intervals were briefly optimal for grazing megafauna.

The study area is Alaska's North Slope, the tundra region bordered to the south by the Brooks Range and to the north by the Arctic Ocean (Fig. 1). The North Slope is a particularly interesting place to study end-Pleistocene extinctions for several reasons. First, its ice-age megafauna included iconic species like woolly mammoth (*Mammuthus primigenius*), steppe bison (*Bison priscus*), and cave lion (*Panthera spelaea*) (14). Second, the local extinctions of megafauna on Alaska's North Slope occurred at a time when archaeological remains are rare, suggesting that people seldom ventured there (15, 16). Third, bone preservation in arctic environments tends to be excellent because of the presence of permafrost (perennially frozen ground), which makes it possible to ¹⁴C date large numbers of bones from many different species (SI Appendix, Table S1). Our record of dated bones provides key insights into the temporal dynamics and biogeographical characteristics of the mammoth steppe, a biome that was unique to the ice ages and the exact nature of which has been long debated (17).

Background

Mammoth Steppe. Episodically during the late Pleistocene, the mammoth steppe extended from Europe to northwestern Canada (18). Its soils were relatively dry, warm, and fertile compared with those of the present day (19, 20) (SI Appendix, SI Text), and its vegetation supported large herds of grazing mammals in species-rich communities (14, 17, 18). The biomasses and diversities of these ice-age communities contrast starkly with the impoverished megafaunal communities living in the same regions today (10, 21). The climate supporting the mammoth steppe was more continental than today (18) and, as detailed below, it was much more changeable at millennial and centennial timescales.

The nature and, for some authors, even the veracity of the mammoth steppe remain controversial (14, 17). Some paleobotanists

Significance

Understanding species extinction is a major concern today, and past extinctions provide valuable lessons. Numerous mammal species became extinct in the Arctic at the end of the ice age, but it is unclear why. By comparing numbers of dated bones with climate records, we find that megafaunal species, like mammoth, horse, and bison, experienced boom and bust cycles during the ice age as they tracked rapid climate changes. For these species to persist, long-distance dispersal was necessary. Their extinction on the North Slope occurred as the ice age ended, because rising sea level severed dispersal routes and spreading peat simultaneously degraded range quality. This finding suggests that arctic mammals can be resilient to environmental changes but only if their habitats remain widely interconnected.

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¹To whom correspondence may be addressed. Email: bashapir@ucsc.edu or dhmann@alaska.edu.

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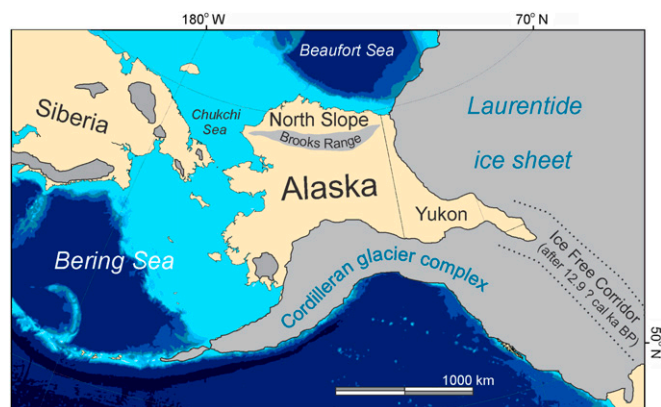


Fig. 1. The North Slope is the tundra region between the Brooks Range and the Arctic Ocean. The light blue area shows the extent of the Bering Land Bridge during the last glacial maximum (LGM) ca. 19,000 calendar y B.P. Glacier extent (gray) during the LGM is based on the works by Dyke (64) and Brigham-Grette et al. (71). The timing of the opening of the ice-free corridor is still uncertain.

argue that the palynological evidence is inconsistent with the productive grasslands that paleozoologists infer based on the nature of the megafauna (22). Compromise solutions to this debate have suggested a spatial mosaic of habitats: some polar desert-like in character and others more steppe-like (23–27).

Timing of Regional Extinctions on Alaska's North Slope. Based on current evidence, the regional extinction of the ice-age megafauna was complete in arctic Alaska before 12 calendar ka B.P. (10), leaving caribou (*Rangifer tarandus*), tundra muskox (*Ovibos moschatus*), and brown bear (*Ursus arctos*) as the only surviving megafaunal species. Of the Pleistocene species, horse (*Equus* cf. *ferus*) and steppe bison survived the longest. The most recent horse lived between 12.4 and 12.7 calendar ka B.P. (Beta-339279) (SI Appendix, Table S1), and the most recent bison lived between 12.2 and 12.6 calendar ka B.P. (CAMS-53767). The most recent lion lived between 13.0 and 13.3 calendar ka B.P. (CAMS-53909), and the most recent mammoth lived between 13.5 and 14.1 calendar ka B.P. (AA-26006). Moose (*Alces alces*) is a postglacial newcomer, arriving north of the Brooks Range ca. 14 calendar ka B.P. (CAMS-91810). There is no direct paleontological evidence in the form of dated bones in mainland Alaska supporting claims based on ancient DNA (aDNA) that mammoth and horse survived as late as 7,500 calendar y B.P. (28). The DNA in question was extracted from wind-blown sediment that may have incorporated biological material previously stored in permafrost.

Climate Change, Paludification, and the Demise of the Mammoth Steppe. Guthrie (14, 18) cited climate change, specifically the loss of climatic continentality, as the ultimate cause of the disappearance of the mammoth steppe at the end of the Pleistocene. As sea level rose across Alaska's continental shelves and storm tracks shifted poleward, maritime air masses invaded more frequently, transforming the North Slope's summer climate from sunny, dry, and relatively warm to its present state of cloudy, damp, and relatively cool (29, 30). Guthrie (14, 18) identified paludification, the spread of peat and organic soil horizons across previously well-drained landscapes, as the proximate cause of the demise of the mammoth steppe (31).

Peat flourishes during cool, moist summers, and its presence has transformative effects on ecosystems. Peat stabilizes hillslopes and dune fields and restricts loess deposition, which allows soil acidification to proceed unhindered by inputs of unweathered mineral material (20). As organic matter accumulates and soils acidify, nutrient cations, including Ca, K, NH_4 , and Na, are leached away, whereas other nutrients, like phosphorous compounds, are increasingly bound to organic matter and made unavailable to plants (32, 33). In response, vegetation shifts toward plant taxa that

are heavily defended with antiherbivory compounds (SI Appendix, SI Text).

Peat also cools the underlying ground (34), which allows permafrost to rise nearer the surface and it perches the water table there. The resulting combination of increased moisture and colder temperature retards decomposition, reduces nutrient availability, and encourages more peat to form (35). Many regions in northern Eurasia and northwestern North America that supported mammoth steppe during the ice age are today blanketed by peat-rich plant communities (36) incapable of supporting large biomasses of grazing mammals.

Warm Transitions Were Briefly Optimal Hypothesis. Guthrie (37) identified the Pleistocene–Holocene transition (12–16 calendar ka B.P.) as a highly favorable time for megafauna (Fig. 2). Guthrie (37) speculated that this was the case because the Pleistocene–Holocene transition was a period of ecological disequilibrium, during which the climate had become warmer and wetter but the vegetation cover had not yet had time to equilibrate with these changes. During this lag period, the edible graminoids and forbs that had dominated the mammoth steppe became more productive and could support more animals. Today, grasses and forbs flourish at tundra sites where soils and vegetation have been disturbed (38, 39) but only until paludification recurs. On the North Slope, 500–700 y are required for peat to accumulate to a steady-state thickness on a previously bare surface of a mineral soil (35). During the ice age, short-lived pulses of high-quality range occurring before either paludification became widespread or full glacial climate resumed may have created transitory bonanzas for megafaunal grazers, which resulted in short-lived peaks in the relative abundance of these animals on the landscape.

Approach

Predictions from the Warm Transitions Were Briefly Optimal Hypothesis. The hypothesis by Guthrie (37) makes a number of predictions that can be addressed using our data and analyses.

- Megafaunal abundance peaked during warm interstadial periods, particularly during their initial stages.
- In the course of the most recent of these interstadials, the Bølling–Allerød [Greenland Interstadial-1 (GI-1)], megafaunal abundance declined as paludification progressed.

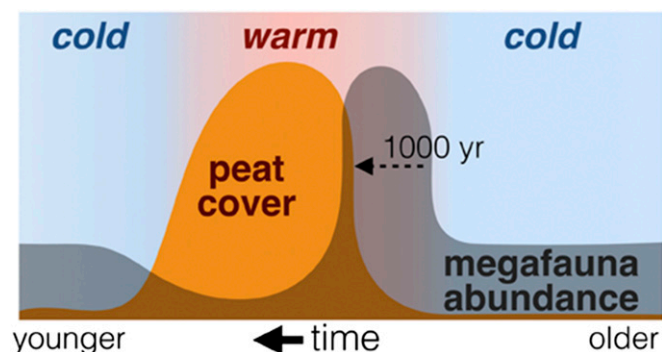
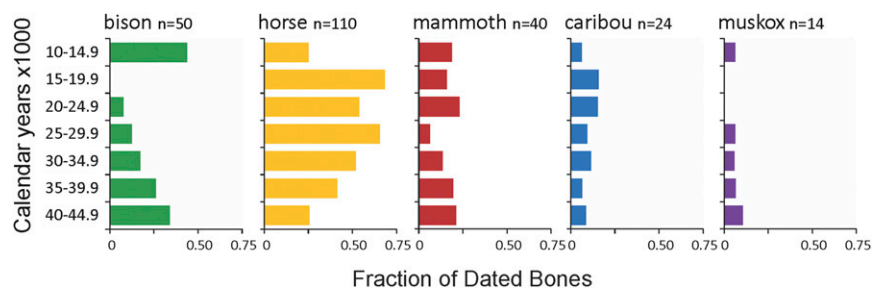


Fig. 2. Death by peat? The warm transitions were briefly optimal hypothesis asserts that highest range quality and hence, the largest numbers of megafauna occurred during the initial stages of interstadial (warm) periods before widespread paludification could occur and before climate reverted to full glacial conditions. A short-lived bloom of ruderal plant species provided a grazing bonanza during this transition period, when both soils and climate were relatively warm and moist. Megafauna populations crashed after widespread paludification occurred and moist acidic tundra vegetation became widespread, a process requiring ~1,000 y after an interstadial began (35). Mammoth steppe consisting of sparse grass and forb vegetation was widespread during the colder, drier stadials, when megafauna existed at some intermediate level of abundance. Between 11,700 and 50,000 calendar y B.P., the duration of interstadials varied between 100 and 2,600 y, whereas the intervening cold stadials lasted 500–8,000 y (47).



- iii) Widespread paludification took place during lengthy interstadials.
- iv) Megafaunal diets shifted in response to widespread paludification during these long-lasting interstadials.
- v) Population declines caused by the spread of organic soils during lengthy interstadials caused population bottlenecks among arctic megafauna that are recorded by changes in gene frequencies.

Distinguishing Calibration Noise in Cumulative Probability Distributions of ^{14}C Dates. To test the warm transitions were briefly optimal hypothesis, we need to compare temporal trends in megafaunal abundance with climate records. Cumulative probability distributions (CPDs) of ^{14}C dates can be informative proxies for changes in abundance through time, and they have been widely used in paleontology, archaeology, and geomorphology (6, 40–42). Unfortunately, the interpretation of CPDs is complicated by artifacts introduced during the calibration of ^{14}C dates to calendar ages by variations in slope of the curve relating ^{14}C age to calendar age (42–44) (*SI Appendix, SI Text*). Here, we use a Monte Carlo-based approach to separate data-derived peaks in CPDs from calibration-induced noise. This method compares the CPD of a set of real calibrated dates with the CPDs of multiple simulated sets of calibrated dates to identify peaks in bone abundance that are unlikely to result from calibration artifacts. If the warm transitions were briefly optimal hypothesis is correct, peaks in megafaunal abundance should coincide with the warm interstadials, specifically the initial stages of interstadial warming.

Results

The relative abundances of herbivorous megafaunal species living on the North Slope of Alaska shifted markedly through time (Fig. 3). Horses increased in relative abundance after 40 calendar ka B.P., whereas muskoxen were apparently absent between 15 and 25 calendar ka B.P. along with steppe bison between 15 and 20 calendar ka B.P. The combined CPD of 263 megafaunal bones

dating to between 10 and 45 calendar ka B.P. has numerous peaks (Fig. 4). The curve loses some of this spiky character before 30 calendar ka B.P., because the range of possible calibrated ages increases as error terms of individual dates increase.

The Monte Carlo procedure allows us to identify peaks in the bone-abundance curve that are not caused by calibration effects. Eight of the peaks in the CPD rise above the calibration noise at the $P \leq 0.05$ level, suggesting that these eight peaks were times of unusually abundant megafauna (Fig. 4). In general, peaks in megafaunal abundance coincide with warm, mid-Wisconsin interstadials between 30 and 50 calendar ka B.P. The most recent peak in abundance occurred during GI-1e, which in northwest Europe, was manifested as the Bølling-Allerød warm period.

The $\delta^{15}\text{N}$ N values of horse bone collagen reflect dietary changes over time (45). On the North Slope, starting ca. 47 calendar ka B.P. and ending at 10 calendar ka B.P., *Equus* bone collagen $\delta^{15}\text{N}$ values became increasingly less positive, with values changing from +8‰ to +10‰ between 30 and 47 calendar ka B.P. to from +1‰ to +2‰ at the time of extirpation ca. 12.6 calendar ka B.P. (Fig. 5).

Discussion

Comparing Bone Abundance to Climate. Although peaks in bone abundance generally coincide with warm interstadials, correlations differ slightly according to which proxy record is compared (Fig. 6). Some of these differences are caused by the dating uncertainties present in all of the records, and others probably reflect real differences in how global climate trends were expressed in different regions. Of the three proxy records, methane (CH₄) is the most globally applicable because of its rapid mixing in the atmosphere. Compared with the CH₄ record, megafauna populations peaked on the North Slope during GI-12, -11, -8, -6-7, -5, -4, and -1. Another bone peak occurred at the outset of GI-2 at ca. 24 calendar ka B.P. (Fig. 6).

Comparison of bone abundances with $\delta^{18}\text{O}$ records from speleothems in southeast China suggests similar correlations (Fig. 6, *Middle*), with peaks in megafaunal abundance early in GI-1 and -2.

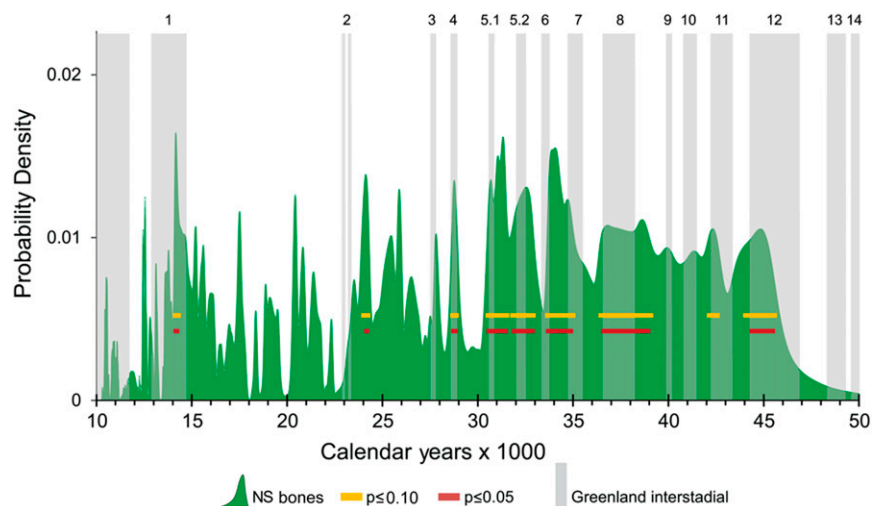


Fig. 4. The CPD of 263 calibrated ages of North Slope (NS) megafaunal bones (solid green). Yellow bars mark times when there is a $P \leq 0.10$ of the peaks in bone abundance being explicable as artifacts of the ^{14}C calibration process. Red bars mark peaks where $P \leq 0.05$. Vertical gray bars depict the Greenland Interstadials (GIs) after Rasmussen et al. (47).

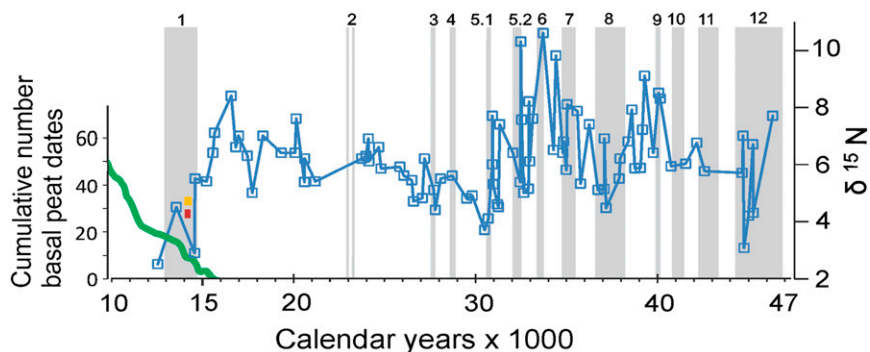


Fig. 5. The $\delta^{15}\text{N}$ of 90 bones of caballine horses of differing ages from Alaska's North Slope. The numbered columns show the GIs. The green line shows the cumulative number of basal peat dates from Alaska (72). Red and yellow bars show the timing of the bone abundance peak in the early stages of GI-1. Horse diet changed radically as peat spread during GI-1. Similar shifts in diet occurred during some of the earlier interstadials. Bone ages are plotted by their median calibrated ages.

A bone peak ca. 28.5–29 calendar ka B.P. may correlate to the beginning of GI-3, although this particular interstadial is not recorded clearly in the Chinese record. There are suggestions that bone peaks also occurred during the initial stages of GI-11, -8, and -6. Comparisons to the Greenland Ice Core Project (GRIP) $\delta^{18}\text{O}$ record suggest that bone peaks occurred during GI-1, -4, -5.1, -5.2, -8, and -12 (Fig. 6, *Bottom*). A bone peak occurred at the onset of GI-2.2, and a similar timing is suggested for GI-5.1 and possibly, GI-10.

Testing the Warm Transitions Were Briefly Optimal Hypothesis.

Prediction 1: Megafaunal abundance peaked during warm interstadial periods, particularly during their initial stages. The youngest interstadials, GI-2.2 and -1, are of particular interest because the precision of age control in both the ice-core records and the ^{14}C dating technique decline with age (46, 47) (*SI Appendix, SI Text*). The warming trend culminating in GI-2.2 began ca. 24 calendar ka B.P. (Fig. 6). The peak in bone abundance at 23.9–24.3 calendar ka B.P. occurred, therefore, during its earliest stages. In the CH_4 and Chinese $\delta^{18}\text{O}$ records, peak megafaunal abundance occurred in the initial stages of GI-1. In the GRIP $\delta^{18}\text{O}$ record, this same bone peak falls during the warmest part of GI-1 but is still within the first millennium of this lengthy interstadial. These correlations tend to confirm predictions made by the hypothesis by Guthrie (37).

Prediction 2: In the course of the most recent interstadial, the Bolling-Allerød (GI-1), megafaunal abundance declined as paludification progressed. Consistent with this prediction, the bone peak occurring ca. 14 calendar ka B.P. ended ~1,100 y before GI-1 terminated (Fig. 6). Furthermore, it coincided with the initial rapid spread of peat across the North Slope and preceded the widespread paludification occurring later (Fig. 5) (31).

Prediction 3: Widespread paludification took place during lengthy interstadials. Peat layers dating to mid-Wisconsin interstadials are widespread in both Siberia and Alaska (48). In northwest Alaska, peat layers and elevated percentages of spruce pollen suggest that paludification accompanied the intermittent presence of forests there between 40 and 60 calendar ka B.P. (49). On Siberia's Lena River Delta, buried peat layers date to 32–52 calendar ka B.P. (45). Along the Kolyma River, peat-rich buried soils date to 44–46, 40–43, 36, and 32 calendar ka B.P. (50), and on the New Siberian Islands, buried soils suggest that paludification occurred at 73° N during some mid-Wisconsin interstadials (51). These reports confirm that paludification was widespread in the Arctic during at least some interstadials, suggesting that a short-lived grazing bonanza followed by the spread of peat may have occurred during lengthy (>1,000 y) interstadials.

Prediction 4: Megafaunal diets shifted in response to widespread paludification during lengthy interstadials. At the outset of GI-1, the shift from mammoth steppe to the moist tundra vegetation accompanying widespread paludification coincided with a striking change in the diet of horses (Fig. 5). Similar shifts in $\delta^{15}\text{N}$ occurred earlier during several of the longest interstadials, including GI-8, which lasted 1,640 y, and GI-12, which lasted 2,580 y (47). Declining $\delta^{15}\text{N}$ during interstadials is consistent with paludification's impact on vegetation composition, soil temperature, soil moisture, and rooting depths of plants (10, 52).

Prediction 5: Population declines caused by the spread of organic soils during lengthy interstadials caused population bottlenecks among arctic megafauna that are recorded by changes in gene frequencies. Consistent with this prediction, paleontological records and aDNA indicate that population bottlenecks affected a number of megafaunal species at high latitudes between 36 and 48 calendar ka B.P., the interval that saw some of the longest interstadials. Noncaballine

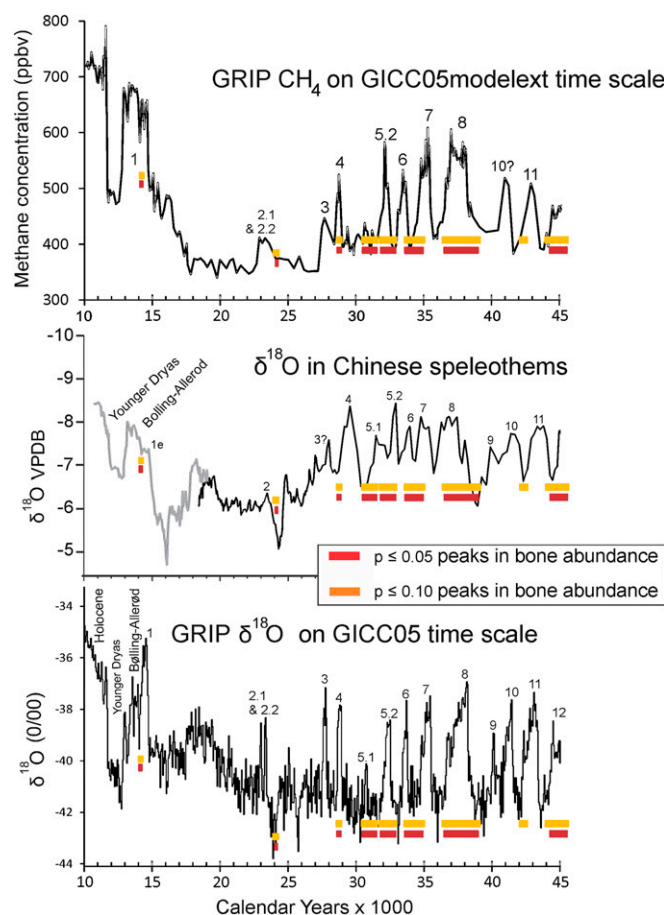


Fig. 6. Comparisons between peaks in megafaunal bone abundance and climate proxy records. The terminology and timing of the GIs are from Rasmussen et al. (47). (*Top*) Methane concentrations in the GRIP core (47). (*Middle*) The $\delta^{18}\text{O}$ record from Chinese speleothems (73). The dynamics of $\delta^{18}\text{O}$ in southeast China are dominated by changing evaporative source areas and transport distances of precipitation. (*Bottom*) $\delta^{18}\text{O}$ in the GRIP core (47). The close correlation between the CH_4 record and the $\delta^{18}\text{O}$ record attests to the global extent of the climatic events recorded in Greenland. ppbv, Parts per billion by volume; VPDB, Vienna Pee Dee Belemnite.

horses became extinct in Alaska ca. 36 calendar ka B.P. (53). Based on aDNA, Alaskan brown bears experienced a significant population decline around that same time (54). Ancient DNA further suggests the numbers of steppe bison, horses, and mammoths living at high latitudes decreased markedly 35–45 calendar ka B.P. (3, 55, 56). Also based on aDNA, population bottlenecks affected cave lions sometime after 50 calendar ka B.P. (57) and muskoxen after 48 calendar ka B.P. (3, 58). Although the precise timing of these population bottlenecks remain obscure (13), their occurrence during the mid-Wisconsin interstadials is consistent with the hypothesis by Guthrie (37). We interpret these bottlenecks as side effects of widespread paludification during lengthy interstadials, such as GI-14, -12, and -8.

Synthesis

Accepting the warm transitions were briefly optimal hypothesis (Fig. 2) leads to new inferences concerning the nature of the mammoth steppe, the biogeography of its megafaunal inhabitants, and the probable causes of their end-Pleistocene extinctions.

Mammoth Steppe: A Biome Defined by Its Instability. Concurrence between peaks in numbers of bones and periods of climatic transitions implies the occurrence of boom and bust cycles in ice-age megafaunal populations in arctic Alaska (Fig. 6). Changes in the abundance of taxa through time—for instance, the absence of bison between 15 and 20 calendar ka B.P. (Fig. 3)—suggest the occurrence of regional-scale extinctions followed by recolonization. Megafaunal populations were fluctuating because the ecosystems supporting them were changing. Together with the global climate records (Fig. 6), our data suggest that short-term (10^1 – 10^3 y) ecological instability was a characteristic feature of the mammoth steppe in arctic Alaska during the last ice age.

Like an azonal soil that never equilibrates with regional climate and has properties that are, instead, determined by the nature and timing of the last geomorphic or ecological disturbance, the mammoth steppe may have been an azonal biome that never fully equilibrated to any single climate state. If true, this implies that, in addition to being a spatial mosaic of ecosystems (26), the mammoth steppe was also a temporal mosaic with soils, vegetation, and fauna that were chronically engaged in ecological successions triggered by repeated, short-lived, and radical shifts in climate. One reason that no clear analogs of the mammoth steppe exist today may be simply that the degree of climatic instability experienced at high latitudes during the late Pleistocene is absent today.

Ice-Age Dispersability Imperative. Survival in an azonal biome requires coping with incessant environmental change, and arctic megafauna may have been forced to play a game of musical chairs across continental distances. Survival would have been especially challenging for populations dependent on either long-distance migration, like some caribou herds are today in northern Alaska, or episodic long-distance dispersal between shifting locations of suitable habitat. In Africa today, the regional persistence of elephant populations depends on episodic dispersals of subpopulations between patches of favorable habitat, often across hundreds of kilometers (59). During some Pleistocene stadials (14), mammoth steppe covered a region three times that of sub-Saharan Africa, and the very un-Holocene tempo of ice-age climate change meant that patches of suitable forage were flickering in and out of existence every few centuries. The imperative may have been to disperse or be extirpated.

Fatal Intersection of Events. With this dispersability imperative in mind, the intersection of two events made GI-1 (the Bølling–Allerød) uniquely fatal for megafauna in arctic Alaska. First, paludification had ample time to transform soils and vegetation over this interstadial’s 1,800-y span (Fig. 5). Second, relative sea level was rising rapidly, reducing the land area of northern Alaska, weakening the continentality of the climate, and blocking dispersal routes to Siberia.

The degree of isolation between Alaska and Siberia established after 14 calendar ka B.P. was extreme compared with most of the late Pleistocene. The Bering Land Bridge was finally

submerged between 12 and 13 calendar ka B.P. (60, 61) when sea level surpassed the -50-m level, a height not reached for the previous 40,000 y. By the early Holocene, relative sea level stood higher along the coast of northern Alaska than it had at any time in the previous 100,000 y (62, 63).

As the Bering Land Bridge was closing, the ice-free corridor between the Cordilleran and Laurentide Ice Sheets was slowly opening. The corridor may have first appeared 13.5–14 calendar ka B.P. (64), but it probably remained ecologically impassable to megafauna until after GI-1 ended ca. 12.9 calendar ka B.P. (55, 65, 66). The end of the last ice age was probably uniquely fatal for arctic megafauna because of the unusual intersection of two events: widespread paludification that drastically reduced range quality for megafaunal grazers and simultaneously hindered their ability to disperse across the resulting soggy landscape and flooding of dispersal routes to Asia before the ice-free corridor leading to lower-latitude North America fully opened.

Materials and Methods

¹⁴C Dating of Bones and Analysis of Bone δ¹⁵N. We dated 496 bones from disarticulated skeletons on Alaska's North Slope (10) (*SI Appendix, SI Text and Table S1*). These bones were in good condition and were identified by their definitive morphological characteristics. In certain instances, temporal and ecological assumptions were used in our identifications (*SI Appendix, Table S1*). Bone collagen was dated by accelerator MS techniques without ultrafiltration (*SI Appendix, SI Text*). We excluded bones with nonfinite ages, bones of extant taxa that were <10 calendar ka B.P. in age, and bones with finite ages >43,500 ¹⁴C y B.P., and included 41 previously published bone dates from the North Slope that met these criteria (10). We therefore use 263 megafaunal bones to make CPDs for comparison with proxy records of climate change. The species composition of these 263 bones is 113 caballine horses, 52 steppe bison, 40 woolly mammoths, 26 caribou, 16 tundra muskoxen, 7 cave lions, 3 moose, 2 wolves (*Canis lupus*), 2 saiga antelope (*Saiga tatarica*), 1 short-faced bear (*Arctodus simus*), and 1 brown bear. We described the changing species composition of the megafauna through time by calculating the percentage of the total number of bones of each taxon where median-calibrated ages fall within 5,000-y age bins between 10 and 45 calendar ka B.P. Smaller bin sizes tended to distort abundance trends because of the spiky nature of the dated bone record. We measured δ¹⁵N in bone collagen of ¹⁴C-dated horse bones using an Elemental Analyzer Isotope Mass Spectrometer.

Distinguishing Calibration Noise in CPDs of ^{14}C Dates. Some peaks and valleys in the CPDs of calibrated ^{14}C dates are artifacts resulting from the calibration process (*SI Appendix, SI Text*). We use a Monte Carlo approach to distinguish which peaks in a CPD of ^{14}C dates are not caused by calibration noise. We calibrated the ^{14}C dates using the OxCal program [version 4.2.4 (67)] and the IntCal13 calibration curve (68) to produce a summed CPD. For the simulated datasets, we cannot simply produce sets of randomly chosen ^{14}C dates; unlike randomly chosen calendar ages, every ^{14}C age is not equally likely, because randomly chosen ^{14}C ages are not uniformly distributed in calendar time (*SI Appendix, SI Text*). Instead, we generate 999 sets of 263 random calendar ages using OxCal from the time interval corresponding to 9,310–43,100 ^{14}C y B.P. Error estimates for each of these simulated dates come from a regression equation relating SD to calendar age in the real bone dataset. We next use the R_Simulate procedure in OxCal to assign a ^{14}C date and an error term to each of the randomly chosen calendar ages. These simulated ^{14}C dates are calibrated using R_Simulate to create 999 CPDs containing 263 calibrated dates each in 5-y bins, which then become the Monte Carlo trials against which the CPD of the real $n = 263$ calendar ages is compared. Finally, we estimate how extreme the upper-tail probability of the actual bone CPD is with respect to the CPDs of the randomly generated dates. We calculate empirical P values by tallying the number of times 999 simulated probability values in each bin equalled or exceeded the bone data values using the relation $P = (r + 1)/(n + 1)$, where r is the number of random values greater than or equal to the observed bone value, and n is the number of randomly generated datasets (69, 70). The timespans where $P \leq 0.05$, for example, define time periods when the bone CPD peaks are different from what would be expected by chance at the $\alpha = 0.05$ level. This procedure allows us to identify peaks in the CPD that warrant comparison with climate proxy data.

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Supporting information for

**LIFE AND EXTINCTION OF MEGAFUNA IN THE
ICE-AGE ARCTIC**

Authors: Daniel H. Mann¹, Pamela Groves², Richard E. Reanier³, Benjamin V. Gaglioti⁴,
Michael L. Kunz⁵, Beth Shapiro⁶

Authors affiliations:

¹*Geosciences Department, University of Alaska, Fairbanks, AK 99775*

²*Institute of Arctic Biology, University of Alaska, Fairbanks, AK 99775*

³*Reanier & Associates, Inc., 1215 SW 170th Street, Seattle, WA 98166*

⁴*Water and Environmental Research Center, University of Alaska, Fairbanks, AK 99775*

⁵*Cooperative Extension and Resources, University of Alaska, Fairbanks, AK 99775*

⁶*Department of Ecology and Evolutionary Biology and UCSC Genomics Institute, University of
California Santa Cruz, Santa Cruz, CA 9506*

1: ¹⁴C AGES OF ALASKAN NORTH SLOPE MEGAFAUNA USED IN THIS STUDY

Genus	species	field ID	depository ^a	catalog number	skeletal element	¹⁴ CLab [#] and number	¹⁴ C date reported (yrs BP)		$\delta^{13}\text{C}$ ‰ (VPDB)	$\delta^{15}\text{N}$ ‰ (AIR)	$\delta^{13}\text{C}$ -normalized date used for calibration		95.4% calibrated range (cal yr BP) ^f		used in Monte Carlo (x)	source
							¹⁴ C date	std dev ^e			¹⁴ C date	std dev ^e				
<i>Alces</i>	<i>alces</i>	KIG05-4.1	UAMES	30186	antler	Beta-339266	modern	-	-23.40	0.50	-	-	-	-		(1)
<i>Alces</i>	<i>alces</i>	MAY12-64	UAMES	30187	antler	Beta-339275	modern	-	-21.30	0.60	-	-	-	-		(1)
<i>Alces</i>	<i>alces</i>	IK08-129	UAMES	30181	antler	Beta-339280	210	30	-20.80	0.70	210	30	...	305		(1)
<i>Alces</i>	<i>alces</i>	TIT10-58	UAMES	30188	antler	Beta-339271	290	30	-20.70	0.90	290	30	288	458		(1)
<i>Alces</i>	<i>alces</i>	IK12-094	UAMES	30184	antler	Beta-339281	310	30	-21.10	-0.40	310	30	301	465		(1)
<i>Alces</i>	<i>alces</i>	IK02-210	UAMES	10355	mandible	CAMS-91966	320	35	-20.30	0.26	320	35	304	474		(1)
<i>Alces</i>	<i>alces</i>	IK01-404	UAMES	11844	mandible	CAMS-92094	665	35	-20.87	-0.59	665	35	556	678		(1)
<i>Alces</i>	<i>alces</i>	IK12-077	UAMES	30183	cranium	Beta-339274	950	30	-20.70	1.00	950	30	795	926		(1)
<i>Alces</i>	<i>alces</i>	IK99-229	UAMES	10691	mandible	CAMS-64459	980	40	-20.00	8.56	980	40	795	959		(1)
<i>Alces</i>	<i>alces</i>	IK08-016	UAMES	30180	mandible	Beta-339268	1,180	30	-21.30	1.80	1,180	30	999	1,221		(1)
<i>Alces</i>	<i>alces</i>	IK99-393	n/a	n/a	metatarsal	Beta-134225	1,280	40	-19.50	n/a	1,280	40	1,086	1,294		(1)
<i>Alces</i>	<i>alces</i>	IK99-776	UAMES	11066	mandible	CAMS-64474	1,370	40	-20.40	1.33	1,370	40	1,186	1,351		(1)
<i>Alces</i>	<i>alces</i>	IK99-556	UAMES	10996	mandible	CAMS-64467	1,760	40	-19.85	0.68	1,760	40	1,566	1,810		(1)
<i>Alces</i>	<i>alces</i>	IK01-023	UAMES	12022	mandible	CAMS-92076	2,450	35	-20.77	0.99	2,450	35	2,360	2,705		(1)
<i>Alces</i>	<i>alces</i>	GAAR-7846	n/a	n/a	n.r. ^b	CAMS-58096	2,460	40	-21.00	n/a	2,460	40	2,364	2,710		(1)
<i>Alces</i>	<i>alces</i>	IK98-0888	UAMES	3288	mandible	CAMS-64418	2,540	50	-20.26	n/a	2,540	50	2,464	2,756		(1)
<i>Alces</i>	<i>alces</i>	IK12-096	UAMES	30185	antler	Beta-339282	2,790	30	-21.30	-0.60	2,790	30	2,795	2,960		(1)
<i>Alces</i>	<i>alces</i>	KIG09-2	n/a	n/a	cranium	Beta-263035	2,900	40	-21.10	n/a	2,900	40	2,925	3,165		(1)
<i>Alces</i>	<i>alces</i>	TIT12-35	UAMES	30191	antler	Beta-339283	9,310	40	-20.30	-1.20	9,310	40	10,303	10,654	x	(1)
<i>Alces</i>	<i>alces</i>	IK09-70	UAMES	30182	antler	Beta-339270	9,610	40	-21.00	0.90	9,610	40	10,775	11,161	x	(1)
<i>Alces</i>	<i>alces</i>	IK99-472	UAMES	10922	tooth	CAMS-91810	12,245	40	-20.30	-0.13	12,245	40	14,000	14,314	x	(1)
<i>Arctodus</i>	<i>simus</i>	ROM:VP 43646	n/a	n/a	n.r. ^b	TO-2539	27,190	280	n/a	n/a	27,190	280	30,805	31,530	x	(2)
<i>Arctodus</i>	<i>simus</i>	T99-033	UAMES	8685	metapodial	CAMS-58092 ^c	42,600	2,200	-19.00	n/a	42,600	2,200	43,570	...		(1)
<i>Arctodus</i>	<i>simus</i>	T99-033	UAMES	8685	metapodial	CAMS-58095 ^c	46,500	3,600	-18.60	n/a	46,500	3,600	41,365	64,621		(1)
<i>Bison</i>	<i>priscus</i>	IK98-0343	UAMES	9079	humerus	CAMS-53767	10,510	50	-20.61	2.84	10,510	50	12,173	12,644	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-1114	UAMES	9896	astragalus	CAMS-53891	10,990	50	-20.10	2.65	10,990	50	12,729	12,996	x	(1)

Genus	species	field ID	depository ^a	catalog number	skeletal element	¹⁴ CLab# and number	¹⁴ C date reported (yrs BP)		$\delta^{13}\text{C}$ ‰ (VPDB)	$\delta^{15}\text{N}$ ‰ (AIR)	$\delta^{13}\text{C}$ -normalized date used for calibration		95.4% calibrated range		used in Monte Carlo (x)	source
							¹⁴ C date	std dev ^e			¹⁴ C date	std dev ^e				
<i>Bison</i>	<i>priscus</i>	IK98-0027	UAMES	8847	astragalus	CAMS-53756	11,810	50	-20.71	2.63	11,810	50	13,485	13,756	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0528	UAMES	9577	humerus	CAMS-53774	12,270	50	-20.21	4.10	12,270	50	14,011	14,487	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0303	n/a	n/a	vertebra	CAMS-58091	12,320	60	-20.24	3.69	12,320	60	14,070	14,686	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0142	UAMES	8801	metatarsal	CAMS-53760	12,410	50	-19.98	2.66	12,410	50	14,168	14,846	x	(1)
<i>Bison</i>	<i>priscus</i>	IK01-428	UAMES	11664	astragalus	AA-48281	12,560	130	-20.00	2.66	12,560	130	14,218	15,247	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0661	UAMES	9464	metapodial	CAMS-53777	17,160	80	-20.18	2.82	17,160	80	20,476	20,946	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0504	UAMES	9238	femur	CAMS-53772	19,420	100	-19.97	3.84	19,420	100	23,046	23,682	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-1090	UAMES	9804	astragalus	CAMS-53890	21,040	120	-20.04	6.45	21,040	120	25,093	25,679	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0401	UAMES	8842	metatarsal	CAMS-53770	21,530	130	-20.37	4.35	21,530	130	25,591	26,051	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-1254	UAMES	9967	humerus	CAMS-53901	23,680	170	-19.85	5.50	23,680	170	27,495	28,111	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0302	UAMES	8998	metatarsal	CAMS-53764	24,500	180	-20.22	4.31	24,500	180	28,092	28,920	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-1184	UAMES	10031	horn core	CAMS-53899	25,980	230	-19.70	4.16	25,980	230	29,604	30,779	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-1043	UAMES	10043	astragalus	CAMS-53888	26,550	230	-19.46	5.66	26,550	230	30,363	31,129	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0095	UAMES	9206	tibia	CAMS-53758	27,400	260	-20.56	4.57	27,400	260	30,924	31,706	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0374	n/a	n/a	metatarsal	CAMS-53768	27,590	280	-20.48	2.65	27,590	280	30,998	32,142	x	(1)
<i>Bison</i>	<i>priscus</i>	IK05-18.1	UAMES	29449	cranium	Beta-308262	27,600	140	-20.10	n/a	27,600	140	31,126	31,620	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-1115	UAMES	9897	astragalus	CAMS-53892	28,120	290	-19.32	4.82	28,120	290	31,329	32,843	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0616	UAMES	9648	metacarpal	CAMS-53775	29,040	340	-20.20	5.17	29,040	340	32,228	33,926	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-1164	UAMES	10073	metacarpal	CAMS-53897	29,570	340	-20.02	5.00	29,570	340	32,999	34,362	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0430	UAMES	9038	metacarpal	CAMS-53771	30,000	540	-20.00	n/a	30,000	540	33,059	35,128	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0256	UAMES	9156	metatarsal	CAMS-53763	31,410	420	-20.35	4.23	31,410	420	34,578	36,209	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0096	UAMES	9207	tibia	CAMS-53759	31,630	440	-19.85	4.89	31,630	440	34,684	36,430	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-1035	UAMES	9988	humerus	CAMS-53885	32,270	470	-19.64	5.34	32,270	470	35,151	37,726	x	(1)
<i>Bison</i>	<i>priscus</i>	IK01-215	UAMES	11742	metatarsal	AA-48772	32,300	1,500	-20.20	4.43	32,300	1,500	33,894	40,602	x	(1)
<i>Bison</i>	<i>priscus</i>	IK09-15	UAMES	29454	cranium	Beta-308267	32,870	200	-19.90	n/a	32,870	200	36,302	37,701	x	(1)
<i>Bison</i>	<i>priscus</i>	IK01-433	UAMES	11669	radius	AA-48282	33,000	1,500	-19.90	3.45	33,000	1,500	34,550	41,204	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0012	UAMES	9172	femur	CAMS-53755	33,280	530	-19.43	3.50	33,280	530	36,231	38,781	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-1323	UAMES	9877	femur	CAMS-53903	33,320	540	-20.19	4.40	33,320	540	36,241	38,847	x	(1)
<i>Bison</i>	<i>priscus</i>	IK01-460	UAMES	11934	astragalus	AA-48775	33,520	940	-19.90	5.13	33,520	940	35,750	40,210	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-1121	UAMES	11159	metacarpal	CAMS-53894	33,580	550	-19.63	3.84	33,580	550	36,409	39,200	x	(1)
<i>Bison</i>	<i>priscus</i>	IK01-234	UAMES	11947	astragalus	AA-48773	34,100	1,000	-20.00	5.92	34,100	1,000	36,273	40,970	x	(1)

Genus	species	field ID	depository ^a	catalog number	skeletal element	¹⁴ Clab# and number	¹⁴ C date reported (yrs BP)		$\delta^{13}\text{C}$ ‰ (VPDB)	$\delta^{15}\text{N}$ ‰ (AIR)	$\delta^{13}\text{C}$ -normalized date used for calibration		95.4% calibrated range		used in Monte Carlo (x)	source
							¹⁴ C date	std dev ^e			¹⁴ C date	std dev ^e				
<i>Bison</i>	<i>priscus</i>	TIT11-88	UAMES	29460	cranium	Beta-308271	34,440	240	-20.10	n/a	34,440	240	38,455	39,553	x	(1)
<i>Bison</i>	<i>priscus</i>	IK05-18.2	UAMES	29450	cranium	Beta-308263	35,060	250	-20.50	n/a	35,060	250	38,952	40,228	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0659	UAMES	9462	mandible	CAMS-53776	35,580	720	-19.98	4.56	35,580	720	38,762	41,626	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0916	UAMES	9348	astragalus	CAMS-53782	35,710	730	-20.29	4.19	35,710	730	38,863	41,740	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-1222	UAMES	9899	metatarsal	CAMS-53900	36,320	780	-20.77	5.70	36,320	780	39,422	42,270	x	(1)
<i>Bison</i>	<i>priscus</i>	IK01-373	UAMES	11981	astragalus	AA-48278	36,500	2,300	-20.00	6.37	36,500	2,300	36,515	47,157	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0863	UAMES	9327	astragalus	CAMS-53914	36,520	800	-20.60	4.51	36,520	800	39,603	42,435	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-1120	UAMES	9906	metatarsal	CAMS-53893	37,460	890	-20.70	6.66	37,460	890	40,314	43,280	x	(1)
<i>Bison</i>	<i>priscus</i>	IK11-37	UAMES	29457	cranium	Beta-306117	38,010	370	-19.40	n/a	38,010	370	41,739	42,765	x	(1)
<i>Bison</i>	<i>priscus</i>	IK08-31	UAMES	29452	cranium	Beta-308265	38,150	330	-20.20	n/a	38,150	330	41,877	42,800	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0377	UAMES	8811	radius	CAMS-53769	38,700	1,000	-19.89	4.46	38,700	1,000	41,431	44,679	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0889	UAMES	9343	astragalus	CAMS-53779	38,800	1,100	-20.31	3.66	38,800	1,100	41,382	45,006	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0890	UAMES	9532	astragalus	CAMS-53780	38,800	1,100	-20.42	5.26	38,800	1,100	41,382	45,006	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0915	UAMES	9347	astragalus	CAMS-53781	39,800	1,200	-20.34	4.51	39,800	1,200	41,976	46,005	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-0174	UAMES	8931	astragalus	CAMS-53761	39,850	1,200	-20.42	4.50	39,850	1,200	42,006	46,046	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-1122	UAMES	9919	metacarpal	CAMS-53895	40,700	1,300	-20.03	4.30	40,700	1,300	42,415	47,266	x	(1)
<i>Bison</i>	<i>priscus</i>	IK09-16	UAMES	29455	cranium	Beta-308268	42,000	490	-19.60	n/a	42,000	490	44,505	46,280	x	(1)
<i>Bison</i>	<i>priscus</i>	TIT10-09	UAMES	29459	cranium	Beta-308270	42,400	520	-20.10	n/a	42,400	520	44,781	46,761	x	(1)
<i>Bison</i>	<i>priscus</i>	IK98-1045	UAMES	10045	mandible	CAMS-53889	43,000	1,800	-20.21	4.15	43,000	1,800	44,215	49,997	x	(1)
<i>Bison</i>	<i>priscus</i>	IK10-12	UAMES	29456	cranium	Beta-308269	44,520	650	-20.00	n/a	44,520	650	46,411	49,481		(1)
<i>Bison</i>	<i>priscus</i>	IK98-1042	n/a	n/a	radius	CAMS-53887	44,800	2,200	-19.59	3.48	44,800	2,200	45,320	...		(1)
<i>Bison</i>	<i>priscus</i>	IK98-1125	UAMES	9923	astragalus	CAMS-53896	45,300	2,400	-20.01	4.53	45,300	2,400	45,489	...		(1)
<i>Bison</i>	<i>priscus</i>	IK06-22	UAMES	29451	cranium	Beta-308264	45,610	740	-20.10	n/a	45,610	740	47,591	...		(1)
<i>Bison</i>	<i>priscus</i>	IK98-0032	UAMES	9090	metacarpal	CAMS-53757	46,100	2,200	-20.61	3.26	46,100	2,200	46,180	...		(1)
<i>Bison</i>	<i>priscus</i>	IK98-0305	UAMES	8917	radius	CAMS-53766	46,100	2,600	-20.10	5.65	46,100	2,600	45,831	...		(1)
<i>Bison</i>	<i>priscus</i>	IK09-14	UAMES	29453	cranium	Beta-308266	46,280	810	-19.00	n/a	46,280	810	48,108	...		(1)
<i>Bison</i>	<i>priscus</i>	IK98-0671	UAMES	9303	metatarsal	CAMS-53778	47,000	2,900	-20.46	6.15	47,000	2,900	42,341	59,391		(1)
<i>Bison</i>	<i>priscus</i>	IK98-0928	UAMES	9506	astragalus	CAMS-53783	49,600	4,000	-20.25	-3.27	49,600	4,000	44,325	70,774		(1)
<i>Bison</i>	<i>priscus</i>	IK01-216	UAMES	11743	metatarsal	OxA-11136	49,700	1,400	-19.80	n/a	49,700	1,400	47,230	53,285		(3)
<i>Bison</i>	<i>priscus</i>	IK98-0527	UAMES	9567	vertebra	CAMS-53773	50,000	4,200	-20.70	2.66	50,000	4,200	44,676	72,630		(1)
<i>Bison</i>	<i>priscus</i>	IK01-074	UAMES	11863	metatarsal	AA-48770	>38,000		-20.00	5.78	>38,000		n/a	n/a		(1)

Genus	species	field ID	depository ^a	catalog number	skeletal element	¹⁴ CLab [#] and number	¹⁴ C date reported (yrs BP)		$\delta^{13}\text{C}$ ‰ (VPDB)	$\delta^{15}\text{N}$ ‰ (AIR)	$\delta^{13}\text{C}$ -normalized date used for calibration		95.4% calibrated range (cal yr BP) ^f		used in Monte Carlo (x)	source
							¹⁴ C date	std dev ^e			¹⁴ C date	std dev ^e				
<i>Bison</i>	<i>priscus</i>	IK99-501	UAMES	10881	metatarsal	AA-48766	>39,000		-20.40	3.98	>39,000		n/a	n/a		(1)
<i>Bison</i>	<i>priscus</i>	IK99-145	UAMES	10738	cranium	AA-48262	>39,400		-19.10	3.95	>39,400		n/a	n/a		(1)
<i>Bison</i>	<i>priscus</i>	IK01-315	UAMES	11687	metacarpal	AA-48774	>40,000		-19.50	7.64	>40,000		n/a	n/a		(1)
<i>Bison</i>	<i>priscus</i>	IK99-717	UAMES	11226	astragalus	AA-48247	>40,300		-19.70	n/a	>40,300		n/a	n/a		(1)
<i>Bison</i>	<i>priscus</i>	IK01-098	UAMES	11770	metatarsal	AA-48270	>40,700		-19.70	5.87	>40,700		n/a	n/a		(1)
<i>Bison</i>	<i>priscus</i>	IK01-143	UAMES	11943	metatarsal	AA-48248	>40,900		-19.99	6.56	>40,900		n/a	n/a		(1)
<i>Bison</i>	<i>priscus</i>	IK01-095	UAMES	11701	metacarpal	AA-48269	>41,000		-19.20	4.91	>41,000		n/a	n/a		(1)
<i>Bison</i>	<i>priscus</i>	IK01-260	UAMES	12012	radius	AA-48274	>41,000		-19.80	6.50	>41,000		n/a	n/a		(1)
<i>Bison</i>	<i>priscus</i>	IK99-141	UAMES	11142	astragalus	AA-48243	>41,100		-19.16	2.80	>41,100		n/a	n/a		(1)
<i>Bison</i>	<i>priscus</i>	IK01-065	UAMES	11855	astragalus	AA-48266	>41,100		-20.40	4.26	>41,100		n/a	n/a		(1)
<i>Bison</i>	<i>priscus</i>	IK01-088	UAMES	11676	metatarsal	AA-48268	>41,100		-20.20	6.47	>41,100		n/a	n/a		(1)
<i>Bison</i>	<i>priscus</i>	IK99-530	UAMES	10858	metacarpal	AA-48767	>41,100		-19.80	6.89	>41,100		n/a	n/a		(1)
<i>Bison</i>	<i>priscus</i>	IK99-567	UAMES	11233	astragalus	AA-48246	>41,500		-20.30	6.23	>41,500		n/a	n/a		(1)
<i>Bison</i>	<i>priscus</i>	TIT11-92	UAMES	29461	cranium	Beta-306118	>43,500		-18.10	n/a	>43,500		n/a	n/a		(1)
<i>Bison</i>	<i>priscus</i>	IK12-001	UAMES	29458	skeleton	Beta-324600	>43,500		-20.00	4.20	>43,500		n/a	n/a		(1)
<i>Bison</i>	<i>priscus</i>	IK98-0218	UAMES	8851	astragalus	CAMS-53762	>46,600		-20.40	2.69	>46,600		n/a	n/a		(1)
<i>Bison</i>	<i>priscus</i>	IK98-1041	UAMES	10041	radius	CAMS-53886	>48,500		-19.52	4.04	>48,500		n/a	n/a		(1)
<i>Bison</i>	<i>priscus</i>	IK98-1299	UAMES	9819	ulna	CAMS-53902	>49,500		-20.05	3.30	>49,500		n/a	n/a		(1)
<i>Bison</i>	<i>priscus</i>	IK98-1015	UAMES	9912	horn core	CAMS-53784	>49,900		-20.36	2.03	>49,900		n/a	n/a		(1)
<i>Bison</i>	<i>priscus</i>	IK98-1167	UAMES	10090	astragalus	CAMS-53898	>49,900		-20.20	4.86	>49,900		n/a	n/a		(1)
<i>Canis</i>	<i>lupus</i>	TIT10-60	UAMES	30193	mandible	Beta-339272	13,000	50	-18.10	7.10	13,000	50	15,316	15,766	x	(1)
<i>Canis</i>	<i>lupus</i>	IK99-702	UAMES	11055	mandible	CAMS-58094	37,200	1,100	-21.20	n/a	37,200	1,100	39,661	43,604	x	(1)
<i>Canis</i>	<i>lupus</i>	IK08-096	UAMES	30192	femur	Beta-339269	>43,500		-20.00	8.90	>43,500		n/a	n/a		(1)
<i>Equus</i>	<i>ferus</i>	Tes57-02	UAMES	30196	phalange	Beta-339279	10,570	40	-21.20	2.50	10,570	40	12,422	12,660	x	(1)
<i>Equus</i>	<i>ferus</i>	JDL12-1	UAMES	29462	cranium	Beta-331878 ^c	11,710	50	-20.70	4.50	11,710	50	13,715	14,016	x	(1)
<i>Equus</i>	<i>ferus</i>	JDL12-1	UAMES	29462	cranium	Beta-339258 ^c	12,240	50	-20.50	n/a	12,240	50	13,973	14,368	x	this study
<i>Equus</i>	<i>ferus</i>	IK01-353	UAMES	11953	mandible	CAMS-92091	12,465	40	-20.59	2.89	12,465	40	14,273	14,970	x	(1)
<i>Equus</i>	<i>ferus</i>	IK02-109	UAMES	3294	metacarpal	CAMS-120651 ^c	12,480	35	-20.41	5.50	12,480	35	14,309	14,997	x	(1)
<i>Equus</i>	<i>ferus</i>	IK02-109	UAMES	3294	metacarpal	CAMS-121738 ^c	12,490	45	-20.40	5.50	12,490	45	14,314	15,036	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-033	UAMES	3300	tooth	CAMS-120673	12,780	35	-20.67	5.40	12,780	35	15,089	15,364	x	(1)
<i>Equus</i>	<i>ferus</i>	IK07-08	UAMES	29463	metacarpal	Beta-331866 ^c	12,980	50	-20.80	6.40	12,980	50	15,298	15,740	x	(1)

Genus	species	field ID	depository ^a	catalog number	skeletal element	¹⁴ Clab [#] and number	¹⁴ C date reported (yrs BP)		$\delta^{13}\text{C}$ ‰ (VPDB)	$\delta^{15}\text{N}$ ‰ (AIR)	$\delta^{13}\text{C}$ -normalized date used for calibration		95.4% calibrated range (cal yr BP) ^f		used in Monte Carlo (x)	source
							¹⁴ C date	std dev ^e			¹⁴ C date	std dev ^e				
<i>Equus</i>	<i>ferus</i>	IK07-08	UAMES	29463	metacarpal	Beta-345282 ^c	13,010	50	-20.50	n/a	13,010	50	15,324	15,779	x	this study
<i>Equus</i>	<i>ferus</i>	TIT05-07.1	UAMES	29464	metacarpal	Beta-331882	13,010	60	-20.70	7.10	13,010	60	15,308	15,796	x	(1)
<i>Equus</i>	<i>ferus</i>	TIT10-35	UAMES	29465	metacarpal	Beta-331883	13,400	50	-20.90	8.40	13,400	50	15,924	16,299	x	(1)
<i>Equus</i>	<i>ferus</i>	IK98-0537	UAMES	3283	metatarsal	CAMS-91792	13,685	40	-20.77	6.60	13,685	40	16,300	16,747	x	(1)
<i>Equus</i>	<i>ferus</i>	IK98-0111	UAMES	3284	metatarsal	CAMS-120655	13,925	40	-20.59	7.00	13,925	40	16,631	17,071	x	(1)
<i>Equus</i>	<i>ferus</i>	TIT09-02	UAMES	29466	cranium	Beta-263037	14,290	70	-20.90	n/a	14,290	70	17,158	17,620	x	(1)
<i>Equus</i>	<i>ferus</i>	TIT11-069	UAMES	29467	mandible	Beta-331887	14,360	60	-20.40	6.30	14,360	60	17,263	17,703	x	(1)
<i>Equus</i>	<i>ferus</i>	T04-001	UAMES	3289	tibia	CAMS-120711	14,540	45	-20.98	5.00	14,540	45	17,550	17,910	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-335	UAMES	3295	metatarsal	CAMS-120676	15,095	40	-21.48	7.00	15,095	40	18,162	18,505	x	(1)
<i>Equus</i>	<i>ferus</i>	MAY08-02	UAMES	29468	cranium	Beta-258461	15,630	70	-20.20	n/a	15,630	70	18,723	19,036	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-065	UAMES	10693	metacarpal	Beta 369776 ^c	15,790	60	-20.80	n/a	15,790	60	18,882	19,217	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-065	UAMES	10693	metacarpal	Beta 369785 ^c	15,890	60	-20.60	6.30	15,890	60	18,960	19,380	x	(1)
<i>Equus</i>	<i>ferus</i>	WC11-09	UAMES	29469	phalange	Beta-331891	16,170	60	-20.40	6.40	16,170	60	19,290	19,716	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-461	UAMES	3299	metatarsal	CAMS-120683	16,885	45	-20.83	6.40	16,885	45	20,166	20,545	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-514	UAMES	3290	metacarpal	CAMS-120685	16,925	45	-20.97	7.60	16,925	45	20,221	20,586	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-774	UAMES	3297	metacarpal	CAMS-92073	17,290	60	-20.74	5.38	17,290	60	20,640	21,065	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-562	UAMES	3286	metatarsal	CAMS-120700	17,300	60	-21.29	6.20	17,300	60	20,650	21,080	x	(1)
<i>Equus</i>	<i>ferus</i>	TIT10-03	UAMES	29470	cranium	Beta-283250	17,670	70	-20.80	n/a	17,670	70	21,080	21,651	x	(1)
<i>Equus</i>	<i>ferus</i>	BR12-01	UAMES	29471	astragulus	Beta-331862 ^c	17,720	70	-20.80	5.40	17,720	70	21,171	21,736	x	(1)
<i>Equus</i>	<i>ferus</i>	BR12-01	UAMES	29471	astragulus	Beta-339251 ^c	17,760	70	-20.60	n/a	17,760	70	21,244	21,785	x	this study
<i>Equus</i>	<i>ferus</i>	n/a	n/a	n/a	n.r. ^b	I-9371	19,250 ^d	360	-21.10*	n/a	19,314	360	22,477	24,096	x	(4)
<i>Equus</i>	<i>ferus</i>	n/a	n/a	n/a	n.r. ^b	CAMS-145093	19,830	100	n/a	n/a	19,830	100	23,575	24,148	x	(5)
<i>Equus</i>	<i>ferus</i>	IK98-0246	UAMES	3280	metatarsal	CAMS-120656 ^c	19,880	70	-20.71	6.20	19,880	70	23,679	24,158	x	(1)
<i>Equus</i>	<i>ferus</i>	IK98-0246	UAMES	3280	metatarsal	CAMS-121741 ^c	19,900	60	-20.70	6.20	19,900	60	23,720	24,170	x	(1)
<i>Equus</i>	<i>ferus</i>	IK02-191	UAMES	3298	metacarpal	CAMS-91964	20,050	70	-20.51	6.29	20,050	70	23,890	24,340	x	(1)
<i>Equus</i>	<i>ferus</i>	IK13-23	UAMES	32964	radius	Beta-362038	20,070	80	-20.70	6.10	20,070	80	23,896	24,374	x	this study
<i>Equus</i>	<i>ferus</i>	T02-016	UAMES	3292	metatarsal	CAMS-120703	20,190	70	-20.51	6.90	20,190	70	24,030	24,483	x	(1)
<i>Equus</i>	<i>ferus</i>	IK01-342	UAMES	3285	metacarpal	CAMS-120647 ^c	20,640	80	-20.37	6.60	20,640	80	24,518	25,189	x	(1)
<i>Equus</i>	<i>ferus</i>	IK01-342	UAMES	3285	metacarpal	CAMS-121734 ^c	20,720	90	-20.40	6.60	20,720	90	24,575	25,286	x	(1)
<i>Equus</i>	<i>ferus</i>	n/a	UAMES	n/a	n.r. ^b	CAMS-145113	20,720	110	n/a	n/a	20,720	110	24,545	25,311	x	(5)

Genus	species	field ID	depository ^a	catalog number	skeletal element	¹⁴ CLab [#] and number	¹⁴ C date reported (yrs BP)		$\delta^{13}\text{C}$ ‰ (VPDB)	$\delta^{15}\text{N}$ ‰ (AIR)	$\delta^{13}\text{C}$ -normalized date used for calibration		95.4% calibrated range		used in Monte Carlo (x)	source
							¹⁴ C date	std dev ^e			¹⁴ C date	std dev ^e				
<i>Equus</i>	<i>ferus</i>	IK99-207	UAMES	3293	metacarpal	CAMS-91802	20,850	80	-20.48	5.85	20,850	80	24,872	25,481	x	(1)
<i>Equus</i>	<i>ferus</i>	n/a	n/a	n/a	n.r. ^b	I-9274	20,810 ^d	410	-21.10*	n/a	20,874	410	24,179	25,950	x	(4)
<i>Equus</i>	<i>ferus</i>	IK10-01	UAMES	29472	cranium	Beta-283242	21,210	90	-20.80	n/a	21,210	90	25,291	25,779	x	(1)
<i>Equus</i>	<i>ferus</i>	AK-109-V-1	UAMES	23920	mandible	GX-13939	21,220	800	n/a	n/a	21,220	800	23,850	27,316	x	(4)
<i>Equus</i>	<i>ferus</i>	AK-109-V-2	UAMES	23919	radius	GX-13941	21,420	440	n/a	n/a	21,420	440	24,583	26,687	x	(4)
<i>Equus</i>	<i>ferus</i>	IK99-442	UAMES	3282	metacarpal	CAMS-91809	21,560	80	-20.85	5.91	21,560	80	25,685	26,016	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-789	UAMES	3291	cranium	CAMS-120702	21,750	80	-20.95	5.60	21,750	80	25,825	26,144	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-577	UAMES	10890	metacarpal	CAMS-91983	22,110	90	-20.76	5.44	22,110	90	26,059	26,595	x	(1)
<i>Equus</i>	<i>ferus</i>	IK10-073	UAMES	29473	metacarpal	Beta-331872 ^c	22,170	90	-20.90	4.70	22,170	90	26,100	26,672	x	(1)
<i>Equus</i>	<i>ferus</i>	IK10-073	UAMES	29473	metacarpal	Beta-339244 ^c	22,300	100	-20.30	n/a	22,300	100	26,204	26,968	x	this study
<i>Equus</i>	<i>ferus</i>	IK02-200	UAMES	10354	mandible	CAMS-91965	22,330	90	-19.97	4.81	22,330	90	26,256	26,997	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-430	UAMES	10715	metatarsal	CAMS-120682 ^c	22,410	80	-20.84	n/a	22,410	80	26,406	27,072	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-711	UAMES	10885	metatarsal	CAMS-120701	22,450	90	-20.72	6.20	22,450	90	26,445	27,110	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-430	UAMES	10715	metatarsal	CAMS-121755 ^c	22,600	90	-20.80	n/a	22,600	90	26,581	27,235	x	(1)
<i>Equus</i>	<i>ferus</i>	IK07-02	UAMES	29474	metacarpal	Beta-331864	22,860	90	-20.30	5.10	22,860	90	26,998	27,450	x	(1)
<i>Equus</i>	<i>ferus</i>	IK06-23	UAMES	30194	cranium	Beta-339267	23,230	90	-19.70	5.50	23,230	90	27,310	27,685	x	(1)
<i>Equus</i>	<i>ferus</i>	IK01-320	UAMES	11735	metatarsal	CAMS-120646 ^c	23,790	110	-20.88	5.60	23,790	110	27,639	28,090	x	(1)
<i>Equus</i>	<i>ferus</i>	n/a	n/a	n/a	n.r. ^b	I-9318	23,910 ^d	470	-21.10*	n/a	23,974	470	27,360	29,039	x	(4)
<i>Equus</i>	<i>ferus</i>	IK01-320	UAMES	11735	metatarsal	CAMS-121733 ^c	24,070	100	-20.90	5.60	24,070	100	27,820	28,414	x	(1)
<i>Equus</i>	<i>ferus</i>	IK08-080	UAMES	29484	metacarpal	Beta-331870	24,690	110	-21.10	4.80	24,690	110	28,446	28,987	x	(1)
<i>Equus</i>	<i>ferus</i>	IK08-082	UAMES	29483	metacarpal	Beta-346834 ^c	24,880	120	-20.80	n/a	24,880	120	28,613	29,267		this study
<i>Equus</i>	<i>ferus</i>	IK99-129	UAMES	10814	mandible	CAMS-91801	24,900	100	-20.28	4.90	24,900	100	28,650	29,245	x	(1)
<i>Equus</i>	<i>ferus</i>	n/a	n/a	n/a	n.r. ^b	AAR-11185	25,460	230	n/a	n/a	25,460	230	28,980	30,299	x	(5)
<i>Equus</i>	<i>ferus</i>	T02-001	UAMES	8607	mandible	CAMS-91958	25,680	140	-20.83	3.70	25,680	140	29,425	30,350	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-367	UAMES	10548	metatarsal	CAMS-120679 ^c	26,020	120	-20.58	5.30	26,020	120	29,832	30,713	x	(1)
<i>Equus</i>	<i>ferus</i>	IK01-218	UAMES	11745	metatarsal	CAMS-121731 ^c	26,130	120	-20.90	6.00	26,130	120	29,986	30,808	x	(1)
<i>Equus</i>	<i>ferus</i>	IK12-063	UAMES	30195	mandible	Beta-339273	26,190	120	-20.50	7.70	26,190	120	30,145	30,875	x	(1)
<i>Equus</i>	<i>ferus</i>	IK01-218	UAMES	11745	metatarsal	CAMS-120717 ^c	26,210	130	-20.91	6.00	26,210	130	30,151	30,896	x	(1)
<i>Equus</i>	<i>ferus</i>	IK13-36	UAMES	32959	metacarpal	Beta-362040	26,380	120	-20.00	4.10	26,380	120	30,409	30,960	x	this study
<i>Equus</i>	<i>ferus</i>	IK99-367	UAMES	10548	metatarsal	CAMS-121752 ^c	26,460	130	-20.60	5.30	26,460	130	30,485	31,007	x	(1)

Genus	species	field ID	depository ^a	catalog number	skeletal element	¹⁴ Clab [#] and number	¹⁴ C date reported (yrs BP)		$\delta^{13}\text{C}$ ‰ (VPDB)	$\delta^{15}\text{N}$ ‰ (AIR)	$\delta^{13}\text{C}$ -normalized date used for calibration		95.4% calibrated range		used in Monte Carlo (x)	source
							¹⁴ C date	std dev ^e			¹⁴ C date	std dev ^e				
<i>Equus</i>	<i>ferus</i>	KIK08-01	UAMES	29475	metacarpal	Beta-331879	26,770	140	-21.60	4.60	26,770	140	30,720	31,146	x	(1)
<i>Equus</i>	<i>ferus</i>	IK11-001	UAMES	29476	metacarpal	Beta-331874	26,890	150	-20.80	4.50	26,890	150	30,777	31,209	x	(1)
<i>Equus</i>	<i>ferus</i>	TIT11-070	UAMES	29477	mandible	Beta-331888	27,060	140	-20.60	7.40	27,060	140	30,870	31,283	x	(1)
<i>Equus</i>	<i>ferus</i>	IK01-080	UAMES	11647	mandible	CAMS-92078 ^c	27,810	210	-21.06	5.37	27,810	210	31,165	32,232	x	(1)
<i>Equus</i>	<i>ferus</i>	IK12-015	UAMES	29478	metacarpal	Beta-331877	27,930	150	-20.70	6.40	27,930	150	31,284	32,209	x	(1)
<i>Equus</i>	<i>ferus</i>	IK97-102	UAMES	8622	metacarpal	Beta-117138	28,120	250	-24.50	n/a	28,120	250	31,368	32,754	x	(1)
<i>Equus</i>	<i>ferus</i>	IK01-459	UAMES	11933	metapodial	CAMS-91957	28,260	210	-20.92	7.56	28,260	210	31,511	32,818	x	(1)
<i>Equus</i>	<i>ferus</i>	IK10-074	UAMES	29479	metacarpal	Beta-331873	28,330	150	-20.60	5.00	28,330	150	31,648	32,788	x	(1)
<i>Equus</i>	<i>ferus</i>	IK13-35	UAMES	32961	metatarsal	Beta-362039	28,500	150	-20.80	10.30	28,500	150	31,818	33,018	x	this study
<i>Equus</i>	<i>ferus</i>	IK99-244	UAMES	10834	metacarpal	CAMS-120675	28,500	160	-20.58	8.20	28,500	160	31,796	33,041	x	(1)
<i>Equus</i>	<i>ferus</i>	IK98-1176	UAMES	10009	metacarpal	CAMS-91797	28,500	200	-20.87	5.14	28,500	200	31,722	33,143	x	(1)
<i>Equus</i>	<i>ferus</i>	T04-004	UAMES	11353	radius	CAMS-120712	28,540	170	-21.29	6.10	28,540	170	31,826	33,142	x	(1)
<i>Equus</i>	<i>ferus</i>	IK01-080	UAMES	11647	mandible	CAMS-91781 ^c	28,600	200	-21.06	5.37	28,600	200	31,860	33,315	x	(1)
<i>Equus</i>	<i>ferus</i>	IK01-368	UAMES	12011	metatarsal	CAMS-121736	28,690	160	-21.20	7.60	28,690	160	32,146	33,389	x	(1)
<i>Equus</i>	<i>ferus</i>	n/a	n/a	n/a	n.r. ^b	USGS-804	28,700	460	n/a	n/a	28,700	460	31,572	33,745	x	(2)
<i>Equus</i>	<i>ferus</i>	IK06-17	UAMES	29480	metacarpal	Beta-331863	29,560	150	-20.90	6.50	29,560	150	33,474	34,030	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-254	UAMES	10644	metacarpal	CAMS-91806	29,700	200	-21.23	9.81	29,700	200	33,515	34,201	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-383	UAMES	11205	metatarsal	CAMS-120680 ^c	29,830	190	-21.26	6.40	29,830	190	33,620	34,294	x	(1)
<i>Equus</i>	<i>ferus</i>	TIT11-071	UAMES	29481	mandible	Beta-343824 ^c	29,880	180	-20.90	n/a	29,880	180	33,664	34,324	x	this study
<i>Equus</i>	<i>ferus</i>	IK07-06	UAMES	29495	metacarpal	Beta-339236 ^c	30,030	180	-21.40	n/a	30,030	180	33,769	34,471	x	this study
<i>Equus</i>	<i>ferus</i>	TIT11-071	UAMES	29481	mandible	Beta-331889 ^c	30,260	190	-20.90	6.80	30,260	190	33,921	34,660	x	(1)
<i>Equus</i>	<i>ferus</i>	IK07-06	UAMES	29495	metacarpal	Beta-331865 ^c	30,560	160	-21.10	5.80	30,560	160	34,159	34,843	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-383	UAMES	11205	metatarsal	CAMS-121753 ^c	30,560	200	-21.30	6.40	30,560	200	34,110	34,892	x	(1)
<i>Equus</i>	<i>ferus</i>	TIT11-072	UAMES	29482	mandible	Beta-331890 ^c	30,610	200	-21.70	8.10	30,610	200	34,144	34,936	x	(1)
<i>Equus</i>	<i>ferus</i>	TIT11-072	UAMES	29482	mandible	Beta-339257 ^c	30,790	190	-21.10	n/a	30,790	190	34,300	35,101	x	this study
<i>Equus</i>	<i>ferus</i>	IK98-0539	UAMES	9548	mandible	CAMS-91793	30,900	300	-21.16	7.87	30,900	300	34,238	35,479	x	(1)
<i>Equus</i>	<i>ferus</i>	IK01-183	UAMES	11878	metatarsal	CAMS-92083	31,230	270	-21.70	5.32	31,230	270	34,613	35,732	x	(1)
<i>Equus</i>	<i>ferus</i>	IK08-082	UAMES	29483	metacarpal	Beta-331869 ^c	31,680	190	-21.00	7.40	31,680	190	35,094	36,055	x	(1)
<i>Equus</i>	<i>ferus</i>	TIT10-38	UAMES	29485	metacarpal	Beta-331886 ^c	32,250	220	-21.30	5.10	32,250	220	35,628	36,641	x	(1)
<i>Equus</i>	<i>ferus</i>	IK08-081	UAMES	33201	metacarpal	Beta 369779 ^c	32,270	280	-20.90	n/a	32,270	280	35,518	36,877	x	this study

Genus	species	field ID	depository ^a	catalog number	skeletal element	¹⁴ Clab [#] and number	¹⁴ C date reported (yrs BP)		$\delta^{13}\text{C}$ ‰ (VPDB)	$\delta^{15}\text{N}$ ‰ (AIR)	$\delta^{13}\text{C}$ -normalized date used for calibration		95.4% calibrated range		used in Monte Carlo (x)	source
							¹⁴ C date	std dev ^e			¹⁴ C date	std dev ^e				
<i>Equus</i>	<i>ferus</i>	n/a	n/a	n/a	n.r. ^b	I-9275	32,270 ^d	1,500	-21.10*	n/a	32,334	1,500	33,921	40,629	x	(4)
<i>Equus</i>	<i>ferus</i>	IK98-1142	UAMES	9972	mandible	CAMS-91796	32,600	300	-21.13	5.13	32,600	300	35,853	37,654	x	(1)
<i>Equus</i>	<i>ferus</i>	IK01-282	UAMES	11794	metacarpal	CAMS-92089	32,700	300	-20.87	4.47	32,700	300	35,994	37,816	x	(1)
<i>Equus</i>	<i>ferus</i>	TIT10-38	UAMES	29485	metacarpal	Beta-339248c	32,980	260	-21.30	n/a	32,980	260	36,340	38,056	x	this study
<i>Equus</i>	<i>ferus</i>	IK09-51	UAMES	29486	metacarpal	Beta-339242 ^c	33,090	240	-23.00	n/a	33,090	240	36,477	38,154		this study
<i>Equus</i>	<i>ferus</i>	IK09-51	UAMES	29486	metacarpal	Beta-331871 ^c	33,150	200	-21.60	5.50	33,150	200	36,602	38,157	x	(1)
<i>Equus</i>	<i>ferus</i>	TIT10-36	UAMES	29487	metacarpal	Beta-331884 ^c	33,200	240	-21.40	6.20	33,200	240	36,615	38,277	x	(1)
<i>Equus</i>	<i>ferus</i>	TIT10-36	UAMES	29487	metacarpal	Beta-339255 ^c	33,250	240	-21.40	n/a	33,250	240	36,678	38,325	x	(1)
<i>Equus</i>	<i>ferus</i>	IK98-0288	UAMES	8859	metatarsal	CAMS-120721 ^c	33,420	340	-21.45	6.80	33,420	340	36,670	38,575	x	(1)
<i>Equus</i>	<i>ferus</i>	IK08-081	UAMES	33201	metacarpal	Beta 369782 ^c	33,700	300	-22.00	7.40	33,700	300	37,049	38,800		this study
<i>Equus</i>	<i>ferus</i>	IK98-0112	UAMES	9021	metacarpal	CAMS-91790	33,800	400	-21.09	7.91	33,800	400	36,900	39,162	x	(1)
<i>Equus</i>	<i>ferus</i>	IK98-0288	UAMES	8859	metatarsal	CAMS-121742 ^c	33,820	290	-21.50	6.80	33,820	290	37,272	38,959	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-790	UAMES	10910	mandible	CAMS-92074	33,870	350	-20.72	5.86	33,870	350	37,126	39,162	x	(1)
<i>Equus</i>	<i>ferus</i>	IK01-369	UAMES	11973	metacarpal	CAMS-92093 ^c	33,900	400	-21.16	5.87	33,900	400	37,037	39,336	x	(1)
<i>Equus</i>	<i>ferus</i>	KIG05-2.2	UAMES	32769	metacarpal	Beta 369781 ^c	34,000	270	-21.10	8.50	34,000	270	37,729	39,161	x	(1)
<i>Equus</i>	<i>ferus</i>	IK01-369	UAMES	11973	metacarpal	CAMS-91782 ^c	34,200	400	-21.16	5.87	34,200	400	37,694	39,760	x	(1)
<i>Equus</i>	<i>ferus</i>	IK01-150	UAMES	12014	mandible	CAMS-92081	34,210	370	-21.20	7.21	34,210	370	37,825	39,690	x	(1)
<i>Equus</i>	<i>ferus</i>	TIT10-37	UAMES	29488	metacarpal	Beta-331885 ^c	34,320	270	-20.90	9.10	34,320	270	38,321	39,522	x	(1)
<i>Equus</i>	<i>ferus</i>	KIG05-2.2	UAMES	32769	metacarpal	Beta 369780 ^c	34,360	290	-20.90	n/a	34,360	290	38,330	39,605	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-404	UAMES	11122	metacarpal	CAMS-120681 ^c	34,690	340	-22.11	8.30	34,690	340	38,524	39,999	x	(1)
<i>Equus</i>	<i>ferus</i>	TIT10-37	UAMES	29488	metacarpal	Beta-339247 ^c	34,780	290	-22.30	n/a	34,780	290	38,652	39,990	x	this study
<i>Equus</i>	<i>ferus</i>	IK13-57	UAMES	32952	cranium	Beta-362042	35,200	290	-20.40	6.40	35,200	290	39,021	40,481	x	this study
<i>Equus</i>	<i>ferus</i>	IK99-404	UAMES	11122	metacarpal	CAMS-121754 ^c	35,380	360	-22.10	8.30	35,380	360	39,105	40,866	x	(1)
<i>Equus</i>	<i>ferus</i>	IK13-56	UAMES	32958	metacarpal	Beta-362041	35,460	300	-21.00	8.50	35,460	300	39,339	40,836	x	this study
<i>Equus</i>	<i>ferus</i>	n/a	n/a	n/a	n.r. ^b	CAMS-91789	35,500	400	n/a	n/a	35,500	400	39,183	41,077	x	(5)
<i>Equus</i>	<i>ferus</i>	IK98-0009	UAMES	9169	mandible	CAMS-91889	35,600	400	-21.00	5.93	35,600	400	39,320	41,177	x	(1)
<i>Equus</i>	<i>ferus</i>	T99-025	UAMES	8728	metacarpal	Beta 369777 ^c	35,850	390	-20.40	n/a	35,850	390	39,650	41,356	x	(1)
<i>Equus</i>	<i>ferus</i>	IK98-0394	UAMES	8814	metacarpal	CAMS-91791	36,500	500	-21.40	6.02	36,500	500	40,137	41,980	x	(1)
<i>Equus</i>	<i>ferus</i>	IK01-121	UAMES	11782	metacarpal	CAMS-92079	37,400	540	-21.15	6.75	37,400	540	40,995	42,645	x	(1)
<i>Equus</i>	<i>ferus</i>	T99-025	UAMES	8728	metacarpal	Beta 369784 ^c	37,490	390	-21.00	4.40	37,490	390	41,330	42,478	x	(1)

Genus	species	field ID	depository ^a	catalog number	skeletal element	¹⁴ Clab [#] and number	¹⁴ C date reported (yrs BP)		$\delta^{13}\text{C}$ ‰ (VPDB)	$\delta^{15}\text{N}$ ‰ (AIR)	$\delta^{13}\text{C}$ -normalized date used for calibration		95.4% calibrated range		used in Monte Carlo (x)	source
							¹⁴ C date	std dev ^e			¹⁴ C date	std dev ^e				
<i>Equus</i>	<i>ferus</i>	IK99-806	UAMES	11068	metacarpal	CAMS-92075	38,090	590	-20.84	5.76	38,090	590	41,503	43,151	x	(1)
<i>Equus</i>	<i>ferus</i>	IK12-010	UAMES	29492	metacarpal	Beta-343825 ^c	38,790	440	-20.90	n/a	38,790	440	42,129	43,405	x	this study
<i>Equus</i>	<i>ferus</i>	IK01-165	UAMES	11622	metacarpal	Beta 369783 ^c	38,850	450	-20.90	3.70	38,850	450	42,150	43,484	x	(1)
<i>Equus</i>	<i>ferus</i>	IK08-078	UAMES	29490	metacarpal	Beta-339239 ^c	40,480	580	-20.80	n/a	40,480	580	43,085	45,135	x	(1)
<i>Equus</i>	<i>ferus</i>	IK08-079	UAMES	29489	metacarpal	Beta-331868 ^c	40,880	400	-21.20	5.70	40,880	400	43,602	45,195	x	(1)
<i>Equus</i>	<i>ferus</i>	IK01-165	UAMES	11622	metacarpal	Beta 369778 ^c	40,930	560	-20.90	n/a	40,930	560	43,415	45,480	x	(1)
<i>Equus</i>	<i>ferus</i>	IK08-078	UAMES	29490	metacarpal	Beta-331867 ^c	40,960	370	-20.60	7.00	40,960	370	43,731	45,222	x	(1)
<i>Equus</i>	<i>ferus</i>	IK99-111	UAMES	10544	metacarpal	CAMS-91799	41,000	800	-20.79	3.07	41,000	800	43,160	45,991	x	(1)
<i>Equus</i>	<i>ferus</i>	IK12-011	UAMES	29491	metacarpal	Beta-339253 ^c	41,090	560	-20.90	n/a	41,090	560	43,546	45,622	x	this study
<i>Equus</i>	<i>ferus</i>	IK12-011	UAMES	29491	metacarpal	Beta-331876 ^c	41,410	570	-20.90	4.20	41,410	570	43,835	45,930	x	(1)
<i>Equus</i>	<i>ferus</i>	IK13-58	UAMES	32951	cranium	Beta-362043	41,830	630	-21.40	6.70	41,830	630	44,140	46,459	x	this study
<i>Equus</i>	<i>ferus</i>	IK12-010	UAMES	29492	metacarpal	Beta-331875 ^c	41,840	410	-20.40	4.30	41,840	410	44,495	45,985	x	(1)
<i>Equus</i>	<i>ferus</i>	IK02-072	UAMES	10534	metatarsal	CAMS-120650 ^c	42,500	1,000	-21.27	7.70	42,500	1,000	44,189	48,357	x	(1)
<i>Equus</i>	<i>ferus</i>	IK08-079	UAMES	29489	metacarpal	Beta-339240 ^c	42,540	660	-21.10	n/a	42,540	660	44,690	47,311	x	this study
<i>Equus</i>	<i>ferus</i>	IK02-072	UAMES	10534	metatarsal	CAMS-121737 ^c	43,700	1,000	-21.30	7.70	43,700	1,000	45,330	49,411	x	(1)
<i>Equus</i>	<i>ferus</i>	IK02-026	UAMES	10434	mandible	CAMS-91959	46,770	1,710	-20.70	1.65	46,770	1,710	43,796	51,544		(1)
<i>Equus</i>	<i>ferus</i>	n/a	n/a	n/a	n.r. ^b	I-9319	>40,000 ^d		-21.10*	n/a	>40,064		n/a	n/a		(4)
<i>Equus</i>	<i>ferus</i>	n/a	n/a	n/a	n.r. ^b	I-9320	>40,000 ^d		-21.10*	n/a	>40,064		n/a	n/a		(4)
<i>Equus</i>	<i>ferus</i>	IK10-02	UAMES	29493	cranium	Beta-283243	>42,800		-20.90	n/a	>42,800		n/a	n/a		(1)
<i>Equus</i>	<i>ferus</i>	KIK12-02	UAMES	29494	phalange	Beta-331880	>43,500		-21.00	5.70	>43,500		n/a	n/a		(1)
<i>Mammut</i> ^g	<i>americanum</i>	MAY12-45	UAMES	30200	molar	UCIAMS-117241	47,000	2,300	-20.94	3.46	47,000	2,300	43,099	54,886		(6)
<i>Mammut</i>	<i>americanum</i>	IK01-277	UAMES	12060	molar	UCIAMS-117236	49,800	3,300	-20.88	3.05	49,800	3,300	44,822	65,508		(6)
<i>Mammut</i>	<i>americanum</i>	MAY12-70	n/a	n/a	molar	UCIAMS-117237	>46,100		-21.13	3.50	>46,100		n/a	n/a		(6)
<i>Mammut</i>	<i>americanum</i>	KIG12-15	UAMES	30199	molar	UCIAMS-117235	>46,400		-20.88	3.16	>46,400		n/a	n/a		(6)
<i>Mammut</i>	<i>americanum</i>	IK10-106	UAMES	30201	molar	UCIAMS-117232	>47,500		-20.81	3.01	>47,500		n/a	n/a		(6)
<i>Mammut</i>	<i>americanum</i>	IK99-237	UAMES	2414	molar	UCIAMS-117234	>48,100		-20.76	4.08	>48,100		n/a	n/a		(6)
<i>Mammut</i>	<i>americanum</i>	IK01-321	UAMES	12047	molar	UCIAMS-117240	>48,800		-20.67	3.54	>48,800		n/a	n/a		(6)
<i>Mammut</i>	<i>americanum</i>	IK08-127	UAMES	30198	molar	UCIAMS-117243	>51,200		-20.73	2.98	>51,200		n/a	n/a		(6)
<i>Mammut</i>	<i>americanum</i>	IK99-328	UAMES	11095	molar	UCIAMS-117233	>51,200		-21.19	3.08	>51,200		n/a	n/a		(6)
<i>Mammut</i>	<i>americanum</i>	IK05-3.5	UAMES	30197	molar	UCIAMS-117242	>51,700		-21.19	2.80	>51,700		n/a	n/a		(6)

Genus	species	field ID	depository ^a	catalog number	skeletal element	¹⁴ Clab [#] and number	¹⁴ C date reported (yrs BP)		$\delta^{13}\text{C}$ ‰ (VPDB)	$\delta^{15}\text{N}$ ‰ (AIR)	$\delta^{13}\text{C}$ -normalized date used for calibration		95.4% calibrated range		used in Monte Carlo (x)	source
							¹⁴ C date	std dev ^e			¹⁴ C date	std dev ^e				
<i>Mammut</i>	<i>americanum</i>	IK98-963	UAMES	9705	molar	UCIAMS-117239	>51,700		-20.96	2.77	>51,700		n/a	n/a		(6)
<i>Mammut</i>	<i>americanum</i>	IK98-967	n/a	n/a	molar	CAMS-91794	>54,000		-20.99	n/a	>54,000		n/a	n/a		(1)
<i>Mammuthus</i> ^g	<i>primigenius</i>	UNM6648	UAMES	30202	n.r. ^b	AA-26006	11,910	130	-21.20	n/a	11,910	130	13,470	14,062	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	IK24	n/a	n/a	n.r. ^b	AA-17614	12,190	130	-21.84	n/a	12,190	130	13,750	14,707	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	AK204-V-1	UAMES	28809	n.r. ^b	AA-14954	12,490	170	-21.10	n/a	12,490	170	14,080	15,250	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	UNM11997	n/a	n/a	n.r. ^b	AA-26028	13,290	140	-21.30	n/a	13,290	140	15,534	16,400	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	KIK10- SK	UAMES	29496	cranium	Beta-283246	14,070	60	-19.60	n/a	14,070	60	16,864	17,380	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	UMN6068c	n/a	n/a	n.r. ^b	AA-26015	15,740	230	-22.80	n/a	15,740	230	18,560	19,584	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	49MIS117	n/a	n/a	n.r. ^b	Shell-6713A	17,300 ^d	800	-21.50*	n/a	17,357	800	19,161	23,040	x	(8)
<i>Mammuthus</i>	<i>primigenius</i>	IK02-181	UAMES	10522	fibula	CAMS-120653 ^c	17,870	60	-20.90	7.60	17,870	60	21,435	21,865	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK02-181	UAMES	10522	fibula	CAMS-121739 ^c	17,965	50	-20.90	7.60	17,965	50	21,563	21,945	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-257	UAMES	12016	molar	CAMS-92087	19,530	80	-21.34	10.11	19,530	80	23,210	23,818	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK13	n/a	n/a	n.r. ^b	AA-17620	19,560	330	-21.17	n/a	19,560	330	22,774	24,352	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	IK3	n/a	n/a	n.r. ^b	AA-17623	19,970	350	-21.25	n/a	19,970	350	23,191	25,040	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	HAR-057-1	n/a	n/a	femur	Beta-192036	20,150	110	-21.50	n/a	20,150	110	23,934	24,500	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	UNM6068a	n/a	n/a	n.r. ^b	AA-26013	24,193	510	-21.40	n/a	24,193	510	27,476	29,389	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-0339	UAMES	9053	scapula	CAMS-120677 ^c	24,460	130	-21.49	7.60	24,460	130	28,166	28,797	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-0339	UAMES	9053	scapula	CAMS-121751 ^c	24,850	110	-21.50	7.60	24,850	110	28,594	29,202	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	T02-110	n/a	n/a	n.r. ^b	CAMS-91967	26,410	150	-20.49	8.03	26,410	150	30,382	30,995	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK8	n/a	n/a	n.r. ^b	AA-17616 ^x	28,020	810	-21.61	n/a	28,020	810	30,858	33,854	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	IK99-120b	UAMES	10688	mandible	CAMS-91800	28,200	200	-21.20	7.86	28,200	200	31,475	32,730	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-040	UAMES	11998	radius	CAMS-92077 ^c	28,220	210	-21.20	7.56	28,220	210	31,481	32,775	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-040	UAMES	11998	radius	CAMS-91783 ^c	29,100	200	-21.20	7.56	29,100	200	32,810	33,762	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-0063	UAMES	9096	tibia	CAMS-120654 ^c	29,250	200	-21.08	8.30	29,250	200	32,966	33,866	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK99-495	UAMES	10851	mandible	CAMS-120684	29,740	190	-21.20	7.97	29,740	190	33,559	34,214	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-0063	UAMES	9096	tibia	CAMS-121740 ^c	30,730	200	-21.10	8.30	30,730	200	34,232	35,055	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK99-745	UAMES	10905	molar	CAMS-92072	30,990	250	-20.58	9.03	30,990	250	34,422	35,482	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	AK323-V-1	UAMES	29130	n.r. ^b	AA-22574	31,100	1,200	-21.80	n/a	31,100	1,200	33,069	38,628	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	IK35	n/a	n/a	n.r. ^b	AA-17602	31,300	1,200	-21.04	n/a	31,300	1,200	33,365	38,815	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	UMN6068b	n/a	n/a	n.r. ^b	AA-26014	31,600	1,200	-21.40	n/a	31,600	1,200	33,663	39,014	x	(7)

Genus	species	field ID	depository ^a	catalog number	skeletal element	¹⁴ Clab [#] and number	¹⁴ C date reported (yrs BP)		$\delta^{13}\text{C}$ ‰ (VPDB)	$\delta^{15}\text{N}$ ‰ (AIR)	$\delta^{13}\text{C}$ -normalized date used for calibration		95.4% calibrated range		used in Monte Carlo (x)	source
							¹⁴ C date	std dev ^e			¹⁴ C date	std dev ^e				
<i>Mammuthus</i>	<i>primigenius</i>	IK99-5001	UAMES	8632	tusk	CAMS-91779 ^c	33,000	300	-20.77	7.16	33,000	300	36,329	38,172	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	AK268-V-1	UAMES	28766	n.r. ^b	AA-22575	33,300	1,600	n/a	n/a	33,300	1,600	34,672	41,645	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	T02-032	UAMES	8635	femur	CAMS-121756 ^c	33,340	280	-20.90	n/a	33,340	280	36,709	38,439	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	T02-032	UAMES	8635	femur	CAMS-120705 ^c	33,370	290	-20.90	n/a	33,370	290	36,722	38,473	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK99-575	UAMES	11028	molar	CAMS-91812 ^c	33,400	300	-20.75	9.12	33,400	300	36,732	38,509	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK14	n/a	n/a	n.r. ^b	AA-17619	33,400	1,600	-26.60	n/a	33,400	1,600	34,745	41,705	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	IK99-5001	UAMES	8632	tusk	CAMS-91968 ^c	33,530	340	-20.77	7.16	33,530	340	36,777	38,680	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK99-575	UAMES	11028	molar	CAMS-91780 ^c	33,600	400	-20.75	9.12	33,600	400	36,701	38,866	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	T02-033	n/a	n/a	n.r. ^b	CAMS-120706 ^c	33,880	300	-21.40	7.00	33,880	300	37,344	39,070	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	T02-033	n/a	n/a	n.r. ^b	CAMS-121757 ^c	33,920	310	-21.40	7.00	33,920	310	37,384	39,162	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	49IKR-VP	n/a	n/a	n.r. ^b	USGS-807	36,400	560	-21.80	n/a	36,400	560	39,928	41,994	x	(2)
<i>Mammuthus</i>	<i>primigenius</i>	IK4	n/a	n/a	n.r. ^b	AA-17627	36,700	2,300	-21.98	n/a	36,700	2,300	36,771	47,391	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	IK17	n/a	n/a	n.r. ^b	AA-17616 ^x	36,800	2,500	-22.98	n/a	36,800	2,500	36,759	48,085	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	AK1014	n/a	n/a	n.r. ^b	AA-22615	37,400	2,600	-18.80	n/a	37,400	2,600	37,905	49,029	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	IK10	n/a	n/a	n.r. ^b	AA-17622	37,800	2,700	-22.51	n/a	37,800	2,700	38,434	49,274	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	IK33	n/a	n/a	n.r. ^b	AA-17605	38,000	2,700	-21.72	n/a	38,000	2,700	38,609	49,237	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	IK6	n/a	n/a	n.r. ^b	AA-17628	39,700	3,400	-23.05	n/a	39,700	3,400	40,291	...	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	IK25	n/a	n/a	n.r. ^b	AA-17615	39,800	3,400	-21.05	n/a	39,800	3,400	40,397	...	x	(7)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-1275	UAMES	10080	humerus	CAMS-120670	40,760	830	-21.80	7.09	40,760	830	42,980	45,840	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK99-235	UAMES	10752	molar	CAMS-91803	40,870	820	-21.53	8.44	40,870	820	43,057	45,917	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-1102	UAMES	9823	vertebra	CAMS-120666 ^c	45,100	1,400	-21.42	7.80	45,100	1,400	46,299	...	x	(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-1102	UAMES	9823	vertebra	CAMS-121748 ^c	46,900	1,400	-21.40	7.80	46,900	1,400	44,430	50,485		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-250	UAMES	11964	tibia	CAMS-120643 ^c	47,300	1,500	-21.49	6.68	47,300	1,500	44,667	51,243		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-1013	UAMES	9934	scapula	CAMS-120722 ^c	47,300	1,800	-21.82	7.35	47,300	1,800	44,181	52,468		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-201	UAMES	11715	molar	CAMS-92085	48,040	2,000	-21.39	8.17	48,040	2,000	44,601	54,181		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-250	UAMES	11964	tibia	CAMS-120718 ^c	48,760	2,200	-21.49	6.68	48,760	2,200	45,010	56,022		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-291	n/a	n/a	tusk	CAMS-120645 ^c	48,900	1,900	-21.22	8.24	48,900	1,900	45,621	54,536		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-166	UAMES	11821	ulna	CAMS-120716	49,310	1,950	-20.85	6.55	49,310	1,950	45,950	55,195		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-355	UAMES	12004	vertebra	CAMS-120648 ^c	49,400	2,400	-21.66	n/a	49,400	2,400	45,353	57,952		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-147	UAMES	12001	femur	CAMS-92080	49,490	2,400	-21.32	n/a	49,490	2,400	45,443	58,042		(1)

Genus	species	field ID	depository ^a	catalog number	skeletal element	¹⁴ CLab [#] and number	¹⁴ C date reported (yrs BP)		δ ¹³ C ‰ (VPDB)	δ ¹⁵ N ‰ (AIR)	δ ¹³ C-normalized date used for calibration		95.4% calibrated range		used in Monte Carlo (x)	source
							¹⁴ C date	std dev ^e			¹⁴ C date	std dev ^e	(cal yr BP) ^f			
Mammuthus	primigenius	IK98-1033	UAMES	9970	scapula	CAMS-120665	49,700	2,500	-21.43	7.42	49,700	2,500	45,513	58,957		(1)
Mammuthus	primigenius	IK98-1195	UAMES	9811	radius	CAMS-120667c	50,400	2,700	-21.09	6.08	50,400	2,700	45,958	61,173		(1)
Mammuthus	primigenius	IK98-1012	UAMES	9933	cranium	CAMS-120664	50,800	2,400	-21.39	7.07	50,800	2,400	46,753	59,352		(1)
Mammuthus	primigenius	IK01-291	n/a	n/a	tusk	CAMS-121732 ^c	51,000	2,400	-21.20	8.24	51,000	2,400	46,953	59,552		(1)
Mammuthus	primigenius	IK99-524	UAMES	11007	molar	CAMS-91811	51,000	2,900	-21.78	9.68	51,000	2,900	46,341	63,391		(1)
Mammuthus	primigenius	IK98-1243	UAMES	9945	radius	CAMS-121750 ^c	51,800	2,700	-21.70	6.81	51,800	2,700	47,358	62,573		(1)
Mammuthus	primigenius	IK02-173	UAMES	10458	fibula	CAMS-91963	51,900	3,200	-21.33	6.38	51,900	3,200	46,988	66,781		(1)
Mammuthus	primigenius	IK99-070	UAMES	10694	mandible	CAMS-91778 ^c	51,900	3,200	-22.32	9.48	51,900	3,200	46,988	66,781		(1)
Mammuthus	primigenius	IK01-355	UAMES	12004	vertebra	CAMS-121735 ^c	52,800	3,000	-21.70	n/a	52,800	3,000	48,047	66,018		(1)
Mammuthus	primigenius	IK01-274	n/a	n/a	femur	CAMS-92088	53,000	3,700	-21.42	9.84	53,000	3,700	47,823	71,903		(1)
Mammuthus	primigenius	IK98-1243	UAMES	9945	radius	CAMS-120668 ^c	53,400	3,900	-21.72	6.81	53,400	3,900	48,154	73,826		(1)
Mammuthus	primigenius	IK01-170	UAMES	11824	molar	CAMS-92082	53,600	3,900	-21.82	n/a	53,600	3,900	48,354	74,026		(1)
Mammuthus	primigenius	IK98-1013	UAMES	9934	scapula	CAMS-121747 ^c	55,700	4,300	-21.80	7.35	55,700	4,300	50,355	79,040		(1)
Mammuthus	primigenius	IK27	n/a	n/a	n.r. ^b	AA-17610	>31,000		-21.00	n/a	>31,000		n/a	n/a		(7)
Mammuthus	primigenius	n/a	n/a	n/a	n.r. ^b	I-9342	>35,000 ^d		-21.50*	n/a	>35,057		n/a	n/a		(9)
Mammuthus	primigenius	IK16	n/a	n/a	n.r. ^b	AA-17612	>35,700		-20.50	n/a	>35,700		n/a	n/a		(7)
Mammuthus	primigenius	IK23	n/a	n/a	n.r. ^b	AA-17626	>36,800		-21.21	n/a	>36,800		n/a	n/a		(7)
Mammuthus	primigenius	IK31	n/a	n/a	n.r. ^b	AA-17603	>37,000		-22.71	n/a	>37,000		n/a	n/a		(7)
Mammuthus	primigenius	IK22	n/a	n/a	n.r. ^b	AA-17613	>37,200		-21.60	n/a	>37,200		n/a	n/a		(7)
Mammuthus	primigenius	IK29	n/a	n/a	n.r. ^b	AA-17611	>37,500		-22.69	n/a	>37,500		n/a	n/a		(7)
Mammuthus	primigenius	IK15	n/a	n/a	n.r. ^b	AA-17617	>37,600		-22.07	n/a	>37,600		n/a	n/a		(7)
Mammuthus	primigenius	IK36	n/a	n/a	n.r. ^b	AA-17604	>37,600		-21.89	n/a	>37,600		n/a	n/a		(7)
Mammuthus	primigenius	IK32	n/a	n/a	n.r. ^b	AA-17609	>38,100		-20.76	n/a	>38,100		n/a	n/a		(7)
Mammuthus	primigenius	IK26	n/a	n/a	n.r. ^b	AA-17608	>39,000		-21.78	n/a	>39,000		n/a	n/a		(7)
Mammuthus	primigenius	AK72-4	UAMES	28848	n.r. ^b	AA-14959 ^x	>39,400		-21.70	n/a	>39,400		n/a	n/a		(7)
Mammuthus	primigenius	IK34	n/a	n/a	n.r. ^b	AA-17607	>39,500		-22.02	n/a	>39,500		n/a	n/a		(7)
Mammuthus	primigenius	IK30	n/a	n/a	n.r. ^b	AA-17606	>40,000		-21.85	n/a	>40,000		n/a	n/a		(7)
Mammuthus	primigenius	AKV-72-5	UAMES	29356	n.r. ^b	AA-14961	>40,700		-22.00	n/a	>40,700		n/a	n/a		(7)
Mammuthus	primigenius	Tusk	n/a	n/a	tusk	AA-22617	>40,800		-21.90	n/a	>40,800		n/a	n/a		(7)
Mammuthus	primigenius	IK5	n/a	n/a	n.r. ^b	AA-17625	>41,000		-21.98	n/a	>41,000		n/a	n/a		(7)

Genus	species	field ID	depository ^a	catalog number	skeletal element	¹⁴ CLab [#] and number	¹⁴ C date reported (yrs BP)		$\delta^{13}\text{C}$ ‰ (VPDB)	$\delta^{15}\text{N}$ ‰ (AIR)	$\delta^{13}\text{C}$ -normalized date used for calibration		95.4% calibrated range (cal yr BP) ^f		used in Monte Carlo (x)	source
							¹⁴ C date	std dev ^e			¹⁴ C date	std dev ^e				
<i>Mammuthus</i>	<i>primigenius</i>	V-30-76	UAMES	23334	molar	AA-22620	>41,000		-21.80	n/a	>41,000		n/a	n/a		(7)
<i>Mammuthus</i>	<i>primigenius</i>	A-5	n/a	n/a	n.r. ^b	AA-14953	>41,100		-22.30	n/a	>41,100		n/a	n/a		(7)
<i>Mammuthus</i>	<i>primigenius</i>	AK119-V-1	UAMES	28789	n.r. ^b	AA-14959 ^s	>41,100		-21.80	n/a	>41,100		n/a	n/a		(7)
<i>Mammuthus</i>	<i>primigenius</i>	IK1	n/a	n/a	n.r. ^b	AA-17621	>41,100		-22.33	n/a	>41,100		n/a	n/a		(7)
<i>Mammuthus</i>	<i>primigenius</i>	IK2	n/a	n/a	n.r. ^b	AA-17624	>41,100		-22.62	n/a	>41,100		n/a	n/a		(7)
<i>Mammuthus</i>	<i>primigenius</i>	IK7	n/a	n/a	n.r. ^b	AA-17618	>41,100		-22.41	n/a	>41,100		n/a	n/a		(7)
<i>Mammuthus</i>	<i>primigenius</i>	My Ikpiqu,	n/a	n/a	n.r. ^b	AA-14946	>41,100		-20.90	n/a	>41,100		n/a	n/a		(7)
<i>Mammuthus</i>	<i>primigenius</i>	IK09-07	n/a	n/a	tusk	Beta-263032	>42,000		-21.20	n/a	>42,000		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-CWB	n/a	n/a	tusk	Beta-283241	>43,500		-20.90	n/a	>43,500		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	KIK10-TT	n/a	n/a	tusk	Beta-283247	>43,500		-20.60	n/a	>43,500		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	Pelvis	n/a	n/a	pelvis	Beta-111034	>46,450		-21.60	n/a	>46,450		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-0957	n/a	n/a	long bone	CAMS-120662	>48,900		-20.74	8.06	>48,900		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK99-070	UAMES	10694	mandible	CAMS-91798 ^c	>49,000		-22.32	9.48	>49,000		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK99-236	UAMES	11111	molar	CAMS-91804	>49,000		-21.84	8.10	>49,000		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-079	UAMES	11646	rib	CAMS-120638 ^c	>49,100		-23.18	8.36	>49,100		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-132	UAMES	12035	radius	CAMS-120640 ^c	>49,100		-21.46	6.64	>49,100		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-256	UAMES	11972	molar	CAMS-92086	>49,200		-21.36	8.18	>49,200		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	T02-038	UAMES	8617	scapula	CAMS-91960	>49,200		-22.44	6.64	>49,200		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK02-121	UAMES	10523	radius	CAMS-120652	>49,300		-21.85	n/a	>49,300		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-200	UAMES	11684	molar	CAMS-92084	>50,000		-22.29	n/a	>50,000		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-255	UAMES	11971	femur	CAMS-120644 ^c	>50,000		-21.98	7.67	>50,000		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-1312	UAMES	9853	femur	CAMS-120672	>50,100		-22.04	6.86	>50,100		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK99-588	UAMES	10941	pelvis	CAMS-120723	>50,400		-22.03	n/a	>50,400		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-0298	UAMES	8889	radius	CAMS-120657	>50,600		-22.09	7.80	>50,600		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-082	n/a	n/a	tibia	CAMS-120639 ^c	>51,000		-20.80	5.07	>51,000		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK99-366	UAMES	11180	tusk	CAMS-120678	>51,000		-21.59	8.50	>51,000		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-1281	UAMES	9996	tibia	CAMS-120671	>51,100		-21.42	7.19	>51,100		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-1000	UAMES	9773	tusk	CAMS-120663	>51,300		-21.58	7.63	>51,300		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-1274	UAMES	10079	radius	CAMS-120669	>51,300		-21.72	7.18	>51,300		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK99-130	UAMES	11120	femur	CAMS-120674	>51,500		-21.35	6.77	>51,500		n/a	n/a		(1)

Genus	species	field ID	depository ^a	catalog number	skeletal element	¹⁴ CLab# and number	¹⁴ C date reported (yrs BP)		$\delta^{13}\text{C}$ ‰ (VPDB)	$\delta^{15}\text{N}$ ‰ (AIR)	$\delta^{13}\text{C}$ -normalized date used for calibration		95.4% calibrated range		used in Monte Carlo (x)	source
							¹⁴ C date	std dev ^e			¹⁴ C date	std dev ^e				
<i>Mammuthus</i>	<i>primigenius</i>	IK01-079	UAMES	11646	rib	CAMS-120713 ^c	>52,000		-23.18	8.36	>52,000		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK99-322	UAMES	10561	molar	CAMS-91807	>52,000		-21.88	9.35	>52,000		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-255	UAMES	11971	femur	CAMS-120719 ^c	>52,100		-21.98	7.67	>52,100		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-0759	UAMES	9541	scapula	CAMS-121743	>52,200		-21.20	9.31	>52,200		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK99-5000b	UAMES	7954	tusk	CAMS-92095	>52,500		-21.60	7.35	>52,500		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-0761	UAMES	9543	ulna	CAMS-121744	>53,400		-20.80	7.68	>53,400		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-359	UAMES	12008	molar	CAMS-92092	>54,000		-21.69	8.41	>54,000		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK02-042	n/a	n/a	pelvis	CAMS-91961	>54,000		-21.40	6.37	>54,000		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-1087	UAMES	9813	molar	CAMS-91795	>54,000		-21.76	8.65	>54,000		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-132	UAMES	12035	radius	CAMS-120715 ^c	>54,500		-21.46	6.64	>54,500		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK01-082	n/a	n/a	tibia	CAMS-120714 ^c	>55,100		-20.80	5.07	>55,100		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-0801	UAMES	9424	metapodial	CAMS-121746	>55,500		-20.80	7.88	>55,500		n/a	n/a		(1)
<i>Mammuthus</i>	<i>primigenius</i>	IK98-1195	UAMES	9811	radius	CAMS-121749 ^c	>55,500		-21.10	6.08	>55,500		n/a	n/a		(1)
<i>Ovibos</i> ^g	<i>moschatus</i>	ING-99-1001	UAMES	8638	cranium	AA-48776	226	59	-19.80	3.76	226	59	...	456		(1)
<i>Ovibos</i>	<i>moschatus</i>	Sing12-2	UAMES	30202	cranium	Beta-339445	250	30	-20.00	3.60	250	30	...	429		(1)
<i>Ovibos</i>	<i>moschatus</i>	TUN12-1	UAMES	30203	cranium	Beta-339278	340	30	-18.50	4.80	340	30	311	481		(1)
<i>Ovibos</i>	<i>moschatus</i>	NIG09-1	n/a	n/a	cranium	Beta-283248	350	40	-19.20	n/a	350	40	312	495		(1)
<i>Ovibos</i>	<i>moschatus</i>	KEA1	UAMES	29498	cranium	Beta-244761	900	40	-19.00	n/a	900	40	735	916		(1)
<i>Ovibos</i>	<i>moschatus</i>	KEA2	UAMES	29499	cranium	Beta-223266	1,140	40	-21.00	n/a	1,070	40	926	1,061		(1)
<i>Ovibos</i>	<i>moschatus</i>	KEA3	UAMES	29500	cranium	Beta-244762	1,080	40	-20.30	n/a	1,080	40	926	1,066		(1)
<i>Ovibos</i>	<i>moschatus</i>	ING-99-1002	UAMES	8639	cranium	AA-48283	1,148	42	-20.00	5.56	1,148	42	969	1,177		(1)
<i>Ovibos</i>	<i>moschatus</i>	IK99-353	UAMES	29501	cranium	AA-48263	7,127	59	-19.60	6.81	7,127	59	7,799	8,148		(1)
<i>Ovibos</i>	<i>moschatus</i>	IK98-1032	UAMES	10098	cranium	AA-48757	10,180	110	-19.80	3.71	10,180	110	11,356	12,379	x	(1)
<i>Ovibos</i>	<i>moschatus</i>	TIT05-08	UAMES	29502	tibia	Beta-223267	21,050	90	-20.80	n/a	21,050	90	25,155	25,640	x	(1)
<i>Ovibos</i>	<i>moschatus</i>	IK98-0819	UAMES	9673	metatarsal	AA-48753	21,670	370	-19.40	9.26	21,670	370	25,228	26,882	x	(1)
<i>Ovibos</i>	<i>moschatus</i>	IK98-0871	UAMES	9753	metatarsal	AA-48239	27,580	750	-19.60	9.31	27,580	750	30,545	33,582	x	(1)
<i>Ovibos</i>	<i>moschatus</i>	IK11-28	UAMES	29503	scapula	Beta-306116	27,640	150	-21.00	n/a	27,640	150	31,135	31,685	x	(1)
<i>Ovibos</i>	<i>moschatus</i>	TIT09-01	UAMES	29504	cranium	Beta-263036	30,950	240	-19.70	n/a	30,950	240	34,386	35,414	x	(1)
<i>Ovibos</i>	<i>moschatus</i>	TIT08-17	UAMES	29505	metatarsal	Beta-258464	31,430	240	-20.60	n/a	31,430	240	34,796	35,881	x	(1)
<i>Ovibos</i>	<i>moschatus</i>	TIT10-04	n/a	n/a	cranium	Beta-283251	33,960	240	-18.80	n/a	33,960	240	37,774	39,021	x	(1)

Genus	species	field ID	depository ^a	catalog number	skeletal element	¹⁴ CLab [#] and number	¹⁴ C date reported (yrs BP)		$\delta^{13}\text{C}$ ‰ (VPDB)	$\delta^{15}\text{N}$ ‰ (AIR)	$\delta^{13}\text{C}$ -normalized date used for calibration		95.4% calibrated range (cal yr BP) ^f		used in Monte Carlo (x)	source
							¹⁴ C date	std dev ^e			¹⁴ C date	std dev ^e				
Ovibos	moschatus	IK01-159	UAMES	11886	metatarsal	Beta-286418	34,570	250	-20.20	8.58	34,570	250	38,542	39,699	x	(1)
Ovibos	moschatus	IK01-313	UAMES	11685	metatarsal	AA-48277	35,920	930	-19.60	7.43	35,920	930	38,755	42,174	x	(1)
Ovibos	moschatus	IK01-294	UAMES	11628	metatarsal	AA-48276	36,400	770	-20.00	7.27	36,400	770	39,531	42,308	x	(1)
Ovibos	moschatus	IK99-179	UAMES	10709	mandible	Beta-286425	40,080	340	-20.00	n/a	40,080	340	43,075	44,400	x	(1)
Ovibos	moschatus	TIT08-13	UAMES	29506	cranium	Beta-258463	40,410	780	-21.20	n/a	40,410	780	42,827	45,445	x	(1)
Ovibos	moschatus	IK99-047	UAMES	10573	mandible	Beta-286423	40,950	570	-20.10	n/a	40,950	570	43,418	45,513	x	(1)
Ovibos	moschatus	IK97-501	UAMES	29507	cranium	Beta-117141	41,470	1,050	-23.80	n/a	41,470	1,050	43,147	47,254	x	(1)
Ovibos	moschatus	IK98-1173	n/a	n/a	axis	CAMS-53908	43,000	1,800	-19.90	4.25	43,000	1,800	44,215	49,997	x	(1)
Ovibos	moschatus	IK98-0393	UAMES	8813	metacarpal	AA-48748	>35,500		-19.10	8.20	>35,500		n/a	n/a		(1)
Ovibos	moschatus	IK98-0673	UAMES	9641	metatarsal	Beta-286422	>36,200		-20.70	5.25	>36,200		n/a	n/a		(1)
Ovibos	moschatus	IK98-0654	UAMES	9439	metacarpal	AA-48750	>37,100		-18.70	2.40	>37,100		n/a	n/a		(1)
Ovibos	moschatus	IK98-0469	UAMES	9259	metacarpal	Beta-286421	>37,300		-20.20	7.28	>37,300		n/a	n/a		(1)
Ovibos	moschatus	IK98-0387	UAMES	8786	cranium	Beta-286420	>39,500		-20.50	7.24	>39,500		n/a	n/a		(1)
Ovibos	moschatus	IK98-1221	UAMES	9875	metacarpal	AA-48258	>39,800		-20.10	5.32	>39,800		n/a	n/a		(1)
Ovibos	moschatus	IK98-1324	UAMES	9890	horn core	AA-48260	>39,900		-19.20	2.73	>39,900		n/a	n/a		(1)
Ovibos	moschatus	IK01-086	UAMES	11674	metatarsal	AA-48771	>40,000		-20.40	3.17	>40,000		n/a	n/a		(1)
Ovibos	moschatus	IK09-05	UAMES	29508	femur	Beta-263030	>40,000		-19.50	n/a	>40,000		n/a	n/a		(1)
Ovibos	moschatus	IK09-06	UAMES	29509	femur	Beta-263031	>40,000		-21.00	n/a	>40,000		n/a	n/a		(1)
Ovibos	moschatus	IK98-1028	UAMES	9959	cranium	AA-48756	>40,000		-19.90	8.84	>40,000		n/a	n/a		(1)
Ovibos	moschatus	IK98-1309	UAMES	9834	metacarpal	AA-48761	>40,000		-19.20	8.36	>40,000		n/a	n/a		(1)
Ovibos	moschatus	IK99-142	UAMES	10682	cranium	AA-48764	>40,000		-19.40	3.51	>40,000		n/a	n/a		(1)
Ovibos	moschatus	IK99-731	UAMES	10845	metatarsal	AA-48768	>40,000		-19.60	9.17	>40,000		n/a	n/a		(1)
Ovibos	moschatus	IK99-754	UAMES	10936	metatarsal	AA-48769	>40,000		-18.90	8.75	>40,000		n/a	n/a		(1)
Ovibos	moschatus	IK98-0028	UAMES	9068	metacarpal	AA-48252	>40,100		-19.30	4.21	>40,100		n/a	n/a		(1)
Ovibos	moschatus	IK98-0818	UAMES	9677	metatarsal	AA-48238	>40,100		-19.70	7.96	>40,100		n/a	n/a		(1)
Ovibos	moschatus	IK98-1288	UAMES	10017	metacarpal	AA-48259	>40,200		-19.40	6.89	>40,200		n/a	n/a		(1)
Ovibos	moschatus	IK98-0441	UAMES	8926	metacarpal	AA-48254	>40,300		-19.90	5.52	>40,300		n/a	n/a		(1)
Ovibos	moschatus	IK01-311	UAMES	11662	metacarpal	AA-48250	>40,700		-20.00	6.96	>40,700		n/a	n/a		(1)
Ovibos	moschatus	IK01-398	UAMES	11840	metacarpal	AA-48279	>40,900		-20.20	5.75	>40,900		n/a	n/a		(1)
Ovibos	moschatus	IK01-136	UAMES	11888	metatarsal	AA-48272	>41,000		-19.90	5.54	>41,000		n/a	n/a		(1)
Ovibos	moschatus	IK01-160	UAMES	11887	metatarsal	AA-48249	>41,000		-20.00	7.10	>41,000		n/a	n/a		(1)

Genus	species	field ID	depository ^a	catalog number	skeletal element	¹⁴ CLab# and number	¹⁴ C date reported (yrs BP)		$\delta^{13}\text{C}$ ‰ (VPDB)	$\delta^{15}\text{N}$ ‰ (AIR)	$\delta^{13}\text{C}$ -normalized date used for calibration		95.4% calibrated range (cal yr BP) ^f		used in Monte Carlo (x)	source
							¹⁴ C date	std dev ^e			¹⁴ C date	std dev ^e				
Ovibos	moschatus	IK98-0849	UAMES	9336	metacarpal	AA-48257	>41,000		-19.60	5.53	>41,000		n/a	n/a		(1)
Ovibos	moschatus	IK98-0980	UAMES	9740	metatarsal	AA-48755	>41,000		-20.40	n/a	>41,000		n/a	n/a		(1)
Ovibos	moschatus	IK99-729	UAMES	10843	metacarpal	AA-48265	>41,000		-19.70	9.17	>41,000		n/a	n/a		(1)
Ovibos	moschatus	IK01-073	UAMES	11862	cranium	AA-48267	>41,100		-19.80	5.62	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK98-0029	UAMES	9069	metacarpal	AA-48744	>41,100		-19.30	3.43	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK98-0049	UAMES	8911	metacarpal	AA-48745	>41,100		-19.20	10.71	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK98-0089	UAMES	9095	metacarpal	AA-48746	>41,100		-19.70	8.85	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK98-0133	UAMES	9122	metacarpal	AA-48747	>41,100		-20.20	7.69	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK98-0286	UAMES	8836	metacarpal	AA-48236	>41,100		-19.80	2.25	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK98-0461	UAMES	9251	metacarpal	AA-48237	>41,100		-19.90	6.01	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK98-0513	UAMES	9610	metatarsal	AA-48255	>41,100		-20.10	6.62	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK98-0653	UAMES	9438	metacarpal	AA-48256	>41,100		-19.60	5.97	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK98-0742	UAMES	9471	metatarsal	AA-48752	>41,100		-19.70	2.64	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK98-0930	UAMES	9504	metacarpal	AA-48754	>41,100		-20.10	6.57	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK98-1027	UAMES	9958	cranium	AA-48240	>41,100		-19.60	3.07	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK98-1044	UAMES	10044	metacarpal	AA-48241	>41,100		-19.00	7.37	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK98-1124	UAMES	9918	metacarpal	AA-48242	>41,100		-19.40	6.10	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK99-143	UAMES	10683	cranium	AA-48244	>41,100		-20.40	4.66	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK99-320	UAMES	10559	metacarpal	AA-48245	>41,100		-20.10	3.80	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK99-504	UAMES	10883	metatarsal	AA-48264	>41,100		-20.00	8.79	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK98-1123	UAMES	9922	metacarpal	AA-48758	>41,100		-19.90	6.46	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK98-1289	UAMES	10018	metacarpal	AA-48760	>41,100		-20.60	7.30	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK98-1267	UAMES	10058	cranium	AA-48759	>41,100		-20.50	6.41	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK99-045	UAMES	11130	cranium	AA-48762	>41,100		-19.60	n/a	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK99-096	UAMES	10729	metatarsal	AA-48763	>41,100		-20.60	n/a	>41,100		n/a	n/a		(1)
Ovibos	moschatus	IK99-255	UAMES	10645	metacarpal	AA-48765	>41,100		-19.50	9.14	>41,100		n/a	n/a		(1)
Ovibos	moschatus	KIK09-01	UAMES	29510	cranium	Beta-263034	>41,500		-20.60	n/a	>41,500		n/a	n/a		(1)
Ovibos	moschatus	IK09-08	UAMES	29511	mandible	Beta-263033	>42,000		-18.60	n/a	>42,000		n/a	n/a		(1)
Ovibos	moschatus	IK10-04	UAMES	29512	cranium	Beta-283245	>43,500		-19.70	n/a	>43,500		n/a	n/a		(1)
Ovibos	moschatus	IK99-133	UAMES	10832	mandible	Beta-286424	>43,500		-19.70	n/a	>43,500		n/a	n/a		(1)
Ovibos	moschatus	IK08-17	UAMES	29514	mandible	Beta-258459	>44,000		-20.20	n/a	>44,000		n/a	n/a		(1)

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							¹⁴ C date	std dev ^e			¹⁴ C date	std dev ^e				
<i>Ovibos</i>	<i>moschatus</i>	IK08-33	UAMES	29515	cranium	Beta-258460	>44,000		-20.20	n/a	>44,000		n/a	n/a		(1)
<i>Ovibos</i>	<i>moschatus</i>	IK98-1220	UAMES	9874	phalange	Beta-175459	>45,720		-20.50	6.41	>45,720		n/a	n/a		(1)
<i>Ovibos</i>	<i>moschatus</i>	IK99-142	UAMES	10682	cranium	Beta-175460	>48,420		-19.90	3.51	>48,420		n/a	n/a		(1)
<i>Ovibos</i>	<i>moschatus</i>	TIT05-06.1	UAMES	29516	cranium	Beta-223269	>49,800		-20.70	n/a	>49,800		n/a	n/a		(1)
<i>Panthera</i>	<i>spelaea</i>	IK98-278	UAMES	8807	mandible	CAMS-53909	11,290	50	-18.60	4.89	11,290	50	13,064	13,256	x	(1)
<i>Panthera</i>	<i>spelaea</i>	IK01-409	UAMES	12041	humerus	OxA-13473 ^c	12,630	60	-18.50	8.03	12,630	60	14,716	15,231	x	(10)
<i>Panthera</i>	<i>spelaea</i>	IK01-409	UAMES	12041	humerus	AA-48280 ^c	12,930	130	-18.40	8.03	12,930	130	15,099	15,878	x	(1)
<i>Panthera</i>	<i>spelaea</i>	MAY12-24	UAMES	29517	humerus	Beta-331881	15,990	60	-18.50	8.80	15,990	60	19,084	19,516	x	(1)
<i>Panthera</i>	<i>spelaea</i>	TIT12-07	UAMES	30204	calcaneus	Beta-339277	30,520	180	-18.70	9.20	30,520	180	34,107	34,835	x	(1)
<i>Panthera</i>	<i>spelaea</i>	IK06-18	UAMES	29518	humerus	Beta-286419	33,260	230	-18.60	n/a	33,260	230	36,710	38,321	x	(1)
<i>Panthera</i>	<i>spelaea</i>	IK97-1001	UAMES	11013	humerus	Beta-117142	35,710	1,180	-22.50	8.53	35,670	1,180	38,040	42,628	x	(1)
<i>Panthera</i>	<i>spelaea</i>	IK98-436	UAMES	8983	phalanx	CAMS-53910	40,900	1,140	-18.10	8.78	40,900	1,140	42,697	46,891	x	(1)
<i>Panthera</i>	<i>spelaea</i>	IK02-164	UAMES	10389	humerus	CAMS-91784	48,300	2,100	-19.47	10.97	48,300	2,100	44,704	54,980		(1)
<i>Panthera</i>	<i>spelaea</i>	IK01-112	UAMES	12045	humerus	AA-48271	>41,100		-18.80	7.79	>41,100		n/a	n/a		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0804	UAMES	9426	mandible	CAMS-64413	160	40	-19.19	3.80	150	40	...	285		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0589	UAMES	9283	humerus	CAMS-64409	200	50	-18.26	2.14	190	50	...	308		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0875	UAMES	9496	mandible	CAMS-64416	220	40	-18.66	2.91	210	40	...	421		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK99-421	UAMES	10579	humerus	CAMS-64465	350	30	-18.67	2.30	340	40	308	489		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0385	UAMES	8784	humerus	CAMS-64403	390	40	-18.15	2.74	370	40	315	505		(1)
<i>Rangifer</i>	<i>tarandus</i>	XCL-010	n/a	n/a	n.r. ^b	GaK-2304	1,470 ^d	80	-18.70*	n/a	573	80	499	676		(8)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0155	n/a	n/a	metapodial	CAMS-64397	1,120	40	-18.11	2.49	1,100	40	929	1,173		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK99-314	UAMES	10766	mandible	CAMS-64462	1,190	30	-18.18	2.29	1,170	40	978	1,221		(1)
<i>Rangifer</i>	<i>tarandus</i>	XPH-003	n/a	n/a	n.r. ^b	P-98	1,619 ^d	210	-18.70*	n/a	1,722	210	1,264	2,291		(8)
<i>Rangifer</i>	<i>tarandus</i>	IK98-1284	UAMES	10013	humerus	CAMS-64453	2,140	40	-18.52	2.65	2,130	40	1,995	2,304		(1)
<i>Rangifer</i>	<i>tarandus</i>	XBP-007	n/a	n/a	n.r. ^b	Uga-3719	2,075 ^d	70	-18.70*	n/a	2,178	70	2,004	2,336		(8)
<i>Rangifer</i>	<i>tarandus</i>	IK98-1038	UAMES	9983	metatarsal	CAMS-64420	2,600	40	-17.59	2.36	2,580	50	2,490	2,785		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0898	n/a	n/a	n.r. ^b	CAMS-64418	2,640	50	-20.60	-0.49	2,640	50	2,548	2,868		(1)
<i>Rangifer</i>	<i>tarandus</i>	XCL-002	n/a	n/a	n.r. ^b	SM-917	3,042 ^d	188	-18.70*	n/a	3,145	188	2,878	3,828		(8)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0083	UAMES	8988	mandible	CAMS-64395	7,830	40	-19.11	2.42	7,820	50	8,455	8,765		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK99-397	UAMES	10740	humerus	CAMS-64463	8,830	40	-18.10	1.74	8,810	40	9,684	10,147		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK99-044	UAMES	10571	metatarsal	CAMS-64454	8,890	50	-17.81	1.36	8,870	50	9,765	10,180		(1)

Genus	species	field ID	depository ^a	catalog number	skeletal element	¹⁴ CLab# and number	¹⁴ C date reported (yrs BP)		$\delta^{13}\text{C}$ ‰ (VPDB)	$\delta^{15}\text{N}$ ‰ (AIR)	$\delta^{13}\text{C}$ -normalized date used for calibration		95.4% calibrated range		used in Monte Carlo (x)	source
							¹⁴ C date	std dev ^e			¹⁴ C date	std dev ^e				
<i>Rangifer</i>	<i>tarandus</i>	IK98-0627	UAMES	9601	metapodial	CAMS-64410	12,370	50	-18.79	2.80	12,360	50	14,120	14,720	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK97-601	n/a	n/a	n.r. ^b	Beta-117140	12,710	100	-23.30	n/a	12,680	100	14,558	15,435	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK99-594	UAMES	11000	metacarpal	CAMS-64470	13,250	50	-18.94	3.06	13,240	50	15,730	16,101	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0585	UAMES	9704	metacarpal	CAMS-64408	14,380	50	-19.25	3.00	14,370	50	17,307	17,696	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0879	UAMES	3296	metacarpal	CAMS-64417	16,950	50	-18.88	9.17	16,940	60	20,210	20,624	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0846	UAMES	9325	humerus	CAMS-64415	17,610	60	-19.16	7.56	17,600	60	21,014	21,519	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK99-089	UAMES	10654	metatarsal	CAMS-64456	18,410	60	-18.88	5.90	18,400	60	22,027	22,453	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0265	UAMES	9186	humerus	CAMS-64398	20,480	80	-18.95	7.15	20,470	80	24,329	24,983	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0031	UAMES	9089	metacarpal	CAMS-64392	24,750	110	-19.87	8.70	24,750	110	28,498	29,060	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	M-98-064	UAMES	9110	mandible	CAMS-64475	24,940	110	-19.17	6.23	24,940	110	28,676	29,316	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK97-402	n/a	n/a	n.r. ^b	Beta-117139	25,190	190	-22.70	n/a	25,190	190	28,775	29,706	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0690	UAMES	9598	humerus	CAMS-64412	27,420	190	-17.86	6.27	27,400	190	31,006	31,535	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0311	UAMES	8944	humerus	CAMS-64400	28,760	160	-18.36	3.73	28,740	170	32,240	33,465	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0833	UAMES	9300	humerus	CAMS-64414	28,930	170	-18.51	7.02	28,920	170	32,631	33,606	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0079	UAMES	8900	metacarpal	CAMS-64394	30,050	210	-18.34	3.34	30,040	210	33,751	34,528	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-1207	UAMES	9831	mandible	CAMS-64471	30,270	200	-18.21	3.75	30,250	200	33,905	34,665	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK99-171	UAMES	10994	metacarpal	CAMS-64457	30,820	200	-19.00	3.92	30,810	200	34,300	35,143	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK99-570	UAMES	10847	cranium	CAMS-64468	31,830	330	-17.73	2.26	31,820	330	34,995	36,381	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK99-409	UAMES	3281	humerus	CAMS-64464	31,920	240	-18.16	3.95	31,900	240	35,240	36,310	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0983	UAMES	9743	humerus	CAMS-64419	32,570	250	-18.64	2.59	32,550	250	35,877	37,372	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0479	UAMES	9270	metapodial	CAMS-64406	37,570	580	-17.65	1.61	37,570	580	41,093	42,810	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK99-543	UAMES	10919	metacarpal	CAMS-64466	38,830	540	-18.12	3.77	38,810	540	42,026	43,667	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK99-066	UAMES	10547	humerus	CAMS-64455	40,840	950	-18.11	5.40	40,820	950	42,870	46,192	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0350	UAMES	9107	metatarsal	CAMS-64401	41,100	1,100	-18.03	0.95	41,100	1,100	42,859	46,979	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0450	UAMES	9032	metatarsal	CAMS-64404	42,040	800	-19.38	2.39	42,030	800	44,021	47,180	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK99-764	UAMES	11016	humerus	CAMS-64473	42,500	1,200	-18.50	1.82	42,500	1,200	43,930	48,913	x	(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0478	UAMES	9269	metapodial	CAMS-64405	44,200	1,000	-17.30	2.99	44,200	1,000	45,824	49,729		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0041	UAMES	9204	metacarpal	CAMS-64393	44,300	1,100	-17.76	1.16	44,300	1,100	45,889	49,875		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0687	UAMES	9596	metapodial	CAMS-64411	45,500	1,200	-17.22	1.88	45,460	1,210	46,777	...		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-1051	UAMES	10065	metatarsal	CAMS-64421	46,300	1,400	-18.72	3.85	46,300	1,400	47,169	...		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-1108	UAMES	9867	metapodial	CAMS-64422	46,500	1,600	-18.09	3.32	46,500	1,600	43,705	50,824		(1)

Genus	species	field ID	depository ^a	catalog number	skeletal element	¹⁴ CLab# and number	¹⁴ C date reported (yrs BP)		$\delta^{13}\text{C}$ ‰ (VPDB)	$\delta^{15}\text{N}$ ‰ (AIR)	$\delta^{13}\text{C}$ -normalized date used for calibration		95.4% calibrated range (cal yr BP) ^f		used in Monte Carlo (x)	source
							¹⁴ C date	std dev ^e			¹⁴ C date	std dev ^e				
<i>Rangifer</i>	<i>tarandus</i>	IK98-0351	UAMES	9108	metatarsal	CAMS-64402	48,000	2,600	-18.87	4.32	48,000	2,600	43,681	58,001		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0153	UAMES	9045	humerus	CAMS-64396	48,300	1,700	-18.11	1.65	48,300	1,700	45,343	53,031		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK99-247	UAMES	10566	humerus	CAMS-64460	52,000	2,700	-18.51	4.60	52,000	2,700	47,558	62,773		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK99-199	UAMES	12288	metapodial	CAMS-64458	52,600	3,500	-17.61	1.75	52,600	3,500	47,511	69,932		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK99-740	UAMES	10876	humerus	CAMS-64472	53,300	3,800	-16.97	2.91	53,200	3,800	47,987	72,873		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0310	UAMES	8943	humerus	CAMS-64399	>46,900		-19.71	5.03	>46,900		n/a	n/a		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-1227	UAMES	9903	humerus	CAMS-64424	>47,200		-18.50	1.73	>47,200		n/a	n/a		(1)
<i>Rangifer</i>	<i>tarandus</i>	TIT05-09	UAMES	29519	tibia	Beta-223268	>49,800		-18.50	n/a	>49,800		n/a	n/a		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-1228	UAMES	9876	humerus	CAMS-64425	>49,900		-18.03	4.34	>49,900		n/a	n/a		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK99-286	UAMES	10726	humerus	CAMS-64461	>49,900		-17.51	2.01	>49,900		n/a	n/a		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-1158	UAMES	10053	tibia	CAMS-64423	>51,200		-17.45	0.14	>51,200		n/a	n/a		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK99-585	UAMES	10938	mandible	CAMS-64469	>51,700		-17.17	2.28	>51,700		n/a	n/a		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-0573	UAMES	9457	mandible	CAMS-64407	>52,800		-19.71	3.10	>52,800		n/a	n/a		(1)
<i>Rangifer</i>	<i>tarandus</i>	IK98-1230	UAMES	9921	metatarsal	CAMS-64426	>54,000		-17.84	1.52	>54,000		n/a	n/a		(1)
<i>Saiga</i>	<i>tatarica</i>	n/a	n/a	n/a	cranium	AA-3073	28,930	560	n/a	n/a	28,930	560	31,584	34,072	x	(11)
<i>Saiga</i>	<i>tatarica</i>	USGS M1422	n/a	n/a	cranium	GSC-3050	37,000	990	n/a	n/a	37,000	990	39,694	43,123	x	(2)
<i>Ursus</i>	<i>arctos</i>	IK98-1065	UAMES	10003	radius	CAMS-53913	36,310	780	-18.40	n/a	36,310	780	39,411	42,262	x	(1)
<i>Ursus</i>	<i>arctos</i>	n/a	n/a	n/a	n.r. ^b	AA-17510	48,164	3,224	n/a	n/a	48,164	3,224	43,235	63,245		(12)
<i>Ursus</i>	<i>maritimus</i>	Coast09-1	UAMES	29513	cranium	Beta-283240	>43,500		-11.70	n/a	>43,500		n/a	n/a		(1)

^a UAMES=University of Alaska Museum of the North Earth Sciences Collection

^b Dated skeletal element not recorded by source.

^c Duplicate dates were obtained for some samples. Both dates are reported here. The mean of both dates was used in analyses.

^d ¹⁴C age not normalized for $\delta^{13}\text{C}$ by laboratory.

^e Standard deviations for isotope and ¹⁴C are one sigma, with the exception of ", " which indicate infinite date returned from laboratory.

^f 95.4% Calibrated probability range calculated using OxCal 4.2 and the IntCal13 calibration curve.

^g Although it is often challenging to distinguish *Mammuthus/Mammot* and *Ovibos/Bootherium* using postcranial elements, *Mammot* and *Bootherium* were both forest-dependent animals and there were no trees growing north of the Brooks range during the interval studied here (12-45 cal ka BP) (all dated black spruce and poplar logs from the study site yield non-finite ¹⁴C ages); we therefore classify appropriate postcranial elements as either *Mammuthus* or *Ovibos*.

* $\delta^{13}\text{C}$ values not reported from dating laboratory; this value was estimated based on mean of measured $\delta^{13}\text{C}$ values for that genus from this data set and used for

normalizing dates prior to calibration.

^x These laboratory numbers each appear twice in Guthrie (2004) and are probably transcription errors. Because the rest of each record is distinct, we include both dates here.

[#] Laboratory Codes: AA=Arizona Accelerator Mass Spectrometry Laboratory , USA; AAR=University of Aarhus, Denmark; Beta=Beta Analytic, USA; CAMS=Lawrence Livermore National Laboratory Center for Accelerator Mass Spectrometry , USA; GaK=Gakushuin University, Japan; GSC=Geological Survey, Canada; GX=Geochron Laboratories, USA; I=Teledyne Isotopes, USA; OxA=Oxford Radiocarbon Accelerator Unit, England; P=Univ. of Pennsylvania, USA; Shell=Shell Development Co., USA; SM=Mobil Oil Corp., Dallas, USA; TO=IsoTrace Laboratory, Canada; UCIAMS=University of California, Irvine Keck Carbon Cycle Accelerator Mass Spectrometry Laboratory, USA; UGa=University of Georgia, USA; USGS=USGS, Menlo Park, USA.

2- RANGE ECOLOGY IN ARCTIC ALASKA DURING THE ICE AGE

As Guthrie (9, 11) emphasized, the relatively high species diversity and abundance of megafaunal herbivores that were present in Alaska when it supported mammoth steppe vegetation indicate that range quality was much higher than it is today (1, 13). Moreover, these mammals invested heavily in large tusks, horns, and antlers that could only have been fueled by a productive landscape (14). We also know that the average size of horses rapidly shrank as mammoth steppe vegetation was replaced by shrub tundra at the end of the Pleistocene in Interior Alaska (15). Species diversity, biomass, investments in energy-expensive anatomy, and trends in body size all support the idea that the nutritional status of the mammoth steppe was much higher than that of the present-day vegetation cover, at least during brief episodes of maximum megafaunal abundance.

The nutritional value of vegetation is directly influenced by soil processes, and nitrogen (N) availability illustrates some of the complexities involved (16). N is important because it is a crucial component of protein. In the Arctic, N cycling is slow in moss-dominated vegetation growing on cold, wet soils because of the low nutrient content of the plant litter and the slow rates of decomposition and hence of nutrient turnover (17). Restricted N cycling is probably one of the reasons why horse bone collagen $\delta^{15}\text{N}$ values became less positive at the end of the ice age, as organic soils spread (Fig. 5). N cycling was probably significantly faster in the well-drained soils and moss-scarce vegetation cover of the mammoth steppe.

The availability of nutrients like N to herbivores is further conditioned by the highly evolved, anti-herbivore strategies of plants. The total amount of available N matters less for herbivores than does its form and palatability (9). For instance, foliar N concentrations in moist acidic tundra (a widespread vegetation type on the North Slope today) are about the same as in moist non-acidic tundra (a drier, less peaty vegetation type growing in some areas of the North Slope). Nonetheless, megafaunal herbivores like caribou prefer the latter (18). Hence, a nutrient's distribution in time and space can be less important than the palatability of the plants containing that nutrient.

Many of the plant species growing in the moist acidic tundra vegetation that covers much of the North Slope of Alaska today are well-defended from grazers by unpalatable secondary compounds (17, 19). Such defenses are necessary for these plants' persistence because paludified soils tend to be cold, wet, and nutrient poor. Consequently, resident plant species must pursue conservative growth strategies restricted by the scant supply of nutrients (13, 20). To maintain this conservative strategy, they must avoid being eaten, and so there has been ecological sorting favoring plants whose secondary compounds make them unavailable to herbivores (18, 21).

Further clues about the grazing system that operated on the mammoth steppe come from the nature of the present-day, moist non-acidic tundra (22), that non-peat-accumulating vegetation type found on some parts of the North Slope where loess deposition still occurs. Caribou prefer this vegetation type over the more peat-rich, moist acidic tundra because

it contains relatively palatable plants. Moist non-acidic tundra is relatively high in calcium, an important nutrient in animal growth. Today, caribou heavily rely on this type throughout the year, especially during the calving season (18).

The nutritional value of vegetation is indirectly influenced by the foraging efficiency of the herbivore utilizing that vegetation, and foraging efficiency depends in part on the efficacy of locomotion, especially in rangelands like the mammoth steppe where primary productivity was probably relatively low, highly seasonal, and widely dispersed in space. Firm footing would have enabled large-bodied animals like horse, mammoth, and bison that had relatively small feet to range widely and hence forage efficiently even in cold, dry rangelands. But as tundra vegetation and organic soils replaced the mammoth steppe and the ground surface became boggy and peat-covered, mobility was inhibited and required more food energy for taxa with high indices of foot-loading (9).

To summarize, the relatively high species diversity and large biomass of Pleistocene megafauna on the North Slope testifies to the relatively high productivity of this vanished biome. Our results suggest these peaks in primary productivity and megafaunal biomass occurred infrequently and episodically, but nonetheless did occur. Today's cold, wet soils restrict nutrient cycling and create nutrient limitations that favor plants investing in long-lived foliage, and hence in chemical and physical traits discouraging herbivory. Animal mobility and forage quality are closely interconnected because restrictions on movement increase nutritional demands. As Guthrie (9) emphasized, the spread of organic soils and concomitant increases in snow depths during the Pleistocene-Holocene transition would have challenged the mobility of megafauna like horse, bison, and mammoth who possessed high foot-loading indices at the same time that the spread of peat-associated plants lowered the nutritional quality of their arctic rangelands.

3- COLLAGEN EXTRACTION, ULTRAFILTRATION, AND CORRECTING ¹⁴C-CALIBRADION NOISE

Collagen extraction Without exception, every bone we attempted to date. This high degree of preservation is attributable to the anoxic and/or frozen state in which these bones were stored in nature. For the samples we dated, the bone collagen was prepared for dating as follows. Bones were manually inspected, and outer surfaces were cleaned by abrasion. All the bones we dated were freshly collected from the field and therefore had no surface contamination requiring solvent extraction. Two to ten grams of abraded bone were placed in a beaker with 0.2N HCl at 20 degrees Celsius (< pH 1). The sample was inspected several times daily to monitor demineralization and collagen evolution. Where possible, the initially evolved collagen was removed and discarded to reduce physical contamination. The underlying collagen was then collected for further pretreatment. Once sufficient collagen was available, it was separated from the remaining mineral fraction and rinsed to neutrality with deionized water. It was then placed in 1-2 % reagent grade NaOH for two hours. The actual concentration and exposure of each sample to the alkali solution was regulated depending on the preservation state of the collagen. Any extraneous matter (roots, sand, etc.) was simultaneously removed during repetitions of this step. This was repeated until the solution was clear or until diminishing returns on the collagen remaining was reached.

Ultrafiltration

In permafrost and fluvial settings, where plant roots rarely penetrate more than several decimeters into the ground, the most problematic aspect of ¹⁴C-dating bone collagen is contamination by younger organic matter carried by groundwater. As a bone decomposes, its collagen can bind with younger humic substances, which are abundant in certain settings (23). Contamination of older bones by younger humic substances is generally unimportant when the bone is relatively young, say < 20,000 years, but it can significantly skew the dating result when the true age of the bone is > 40,000 years because by this time approximately seven ¹⁴C half-lives have passed, and only about 0.8% of the initial ¹⁴C remains. Humic compounds derived from older organic matter also can contaminate bone collagen, but contamination by older carbon has comparatively minor effects on the resultant ¹⁴C age (24).

The main laboratory technique used to counter the potential effects of contamination of collagen by younger organic compounds is ultrafiltration (25). Ultrafiltration separates the higher molecular weight components of the gelatinized collagen from the lower molecular weight components that include humic and fulvic acids bound to partly degraded collagen (26, 27). In some depositional settings, such as limestone caves located in the temperate zone, the use of ultrafiltration to remove the younger, organic contaminants from bone samples has resulted in ages 2,000 to 7,000 years older than non- ultrafiltered dates on the same samples (28-30).

Although first devised more than twenty years ago (25), the ultrafiltration technique continues to evolve, and has only become commercially available in the last several years. Its utility is still debated. In cases where bone preservation is excellent and

contamination by younger organics is minimal, ultrafiltration may be unnecessary (31, 32). Further subsampling of already tiny amounts of ^{14}C increases the risks of other types of contamination. In some instances, the filter membrane itself has been found to introduce younger carbon into samples (33, 34).

Before ultrafiltration became commercially available, large numbers of ^{14}C dates were obtained on bone collagen using non-ultrafiltration techniques. For instance, we (1) reported finite ages for 245 bones of Pleistocene megafauna from the North Slope of Alaska and used these ages to infer paleoenvironments and extinction causes. Given what is now known about ultrafiltration techniques, it is reasonable to ask whether these non-ultrafiltered dates are valid.

The presence of permafrost creates very different preservational environments for bone than the limestone caves of Europe studied by Highham et al. (28, 29). Apart from one, recent study (6), there have been no large-scale comparisons between ultrafiltered and non-ultrafiltered ^{14}C ages estimated from bones from arctic settings. That study re-dated six mastodon (*Mammuth americanum*) bones from Alaska and the Yukon previously dated using non-ultrafiltration methods. Of the six mastodon teeth collected on Alaska's North Slope, non-ultrafiltration methods produced three non-finite ^{14}C ages and three ^{14}C ages ranging between 31,780 and 38,800 cal yr BP (6). Repeated dating of ultrafiltered collagen resulted in non-finite ages for these three teeth as well, suggesting that these first dates had been contaminated by young carbon.

Mastodon teeth preserved in the sediment of an arctic river provide an ideal setting for humic contamination of bone collagen. The risk of obtaining an erroneous, younger date on bone collagen because of contamination by younger humic substances is greatest when a bone whose own ^{14}C has long since decayed away is exposed to dissolved organic compounds with younger ^{14}C content over tens of thousands of years. Hence using ultrafiltration to re-date the collagen of a taxon like mastodon that has been locally extinct for at least 75,000 years has a high likelihood of revising the ^{14}C age upward. The likelihood is much lower that ultrafiltration will significantly revise ^{14}C ages obtained by non-ultrafiltration methods on the bones of animals that were alive <45,000 years ago. Preliminary results of a study we are now engaged in support this assertion.

To examine the effects of using ultrafiltration in dating of permafrost bones, we randomly selected 30 bones of *Equus*, *Bison*, and *Ovibos* collected along the Ikpikpuk River whose non-ultrafiltered ^{14}C ages ranged between 11 and 46 ^{14}C ka BP. These non-ultrafiltered dates on bone collagen were obtained using accelerator mass spectrometry at Beta Analytic Inc. in the years prior to 2013. Starting in 2013, we submitted additional bone samples from these same thirty bones to Beta Analytic for ultrafiltration and AMS dating of collagen.

Results show that differences between ultrafiltered and non-ultrafiltered dates increase at ages greater than 30,000 ^{14}C years BP (roughly 5 half lives), when remaining ^{14}C content drops below a few percent of its initial value (Fig. S1). Interestingly, the age differences between the two techniques are equally spread in both directions. In ten of the date pairs, the non-ultrafiltered date was older than the ultrafiltered one; while in eleven of the date

pairs, the ultrafiltered date was younger. This project is still in progress, but these preliminary results indicate that the use of ultrafiltration in ^{14}C dating of bone collagen sourced from permafrost settings like Alaska's North Slope does not systematically "correct" ^{14}C dates obtained using non-ultrafiltration methods, and so ultrafiltration is unwarranted when dating bone collagen from this particular depositional environment.

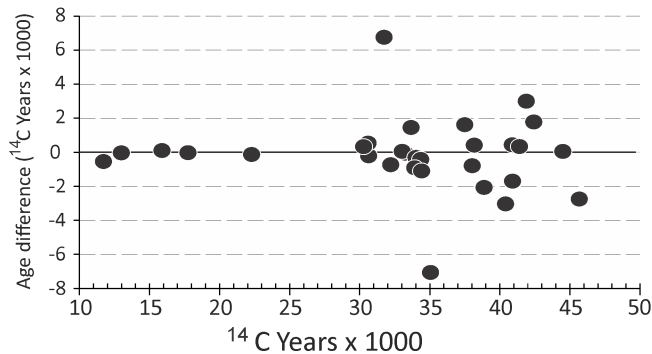


Fig. S1. Differences in ^{14}C ages obtained after ultrafiltration and non-ultrafiltration pretreatment of collagen from the same megafauna bones. Thirty bones (ten each of horse, bison, and musk ox) from the North Slope were chosen to span the age range from 10 to 45 cal ka BP based on their initial, non-ultrafiltered ^{14}C ages. Age differences are calculated by subtracting the ultrafiltered from non-ultrafiltered dates. Although previous studies in some temperate- zone settings have found that ultrafiltration can remove younger contaminants that cause systematic "younging" of ^{14}C ages, these results indicate ultrafiltration is not necessary for dating bones < 45,000 years old that are sourced from permafrost environments.

Coping with calibration noise in the cumulative probability distributions of ^{14}C dates

^{14}C dates are frequently combined into cumulative probability distributions for time-series analyses following their calibration to calendar years (35, 36). These cumulative probability distributions (CPDs) depict changes in the abundance of dated samples through time. Some peaks and valleys in cumulative probability distributions of calibrated ^{14}C dates are artifacts resulting from the calibration process (Fig. S2) (36, 37). At steep parts of the curve, multiple ^{14}C dates can correspond to nearly identical calendar ages. On plateaus, ^{14}C ages can correspond to widely spaced calendar ages, some of which may be reversed in age relative to their corresponding ^{14}C ages.

Various methods have been proposed to remove calibration artifacts from the CPDs of ^{14}C dates. Williams (36) used moving averages to reduce calibration effects. Johnstone et al. (38) subtracted a curve generated from a uniform distribution based on the observed CPD. Hoffman et al. (39) suggested dividing the observed CPD by a CPD derived from a uniform distribution or dividing the CPD derived from a subset of the data by the CPD of the entire dataset. Chiverrell et al. (40) and Perry et al. (41) suggested avoiding use of CPDs altogether.

These previous methods of dealing with calibration artifacts in the CPDs of ^{14}C dates all have their limitations. For studies like ours, where our goal is to compare a CPD to

climate history, moving averages smooth out the very peaks we seek to compare, while comparisons between observed CPD and theoretical CPDs - like those derived from uniformly distributed radiocarbon dates - do not entirely remove the calibration effect.

Although structured as a Monte Carlo hypothesis test, we consider our new method to be a data- exploration technique in the sense of Tukey (42) for identifying events that are unlikely to occur by chance, rather than a test with a rigid *accept-reject* significance criterion (43). Note that this Monte Carlo approach is vulnerable to type II errors (failing to detect an effect that is actually present) because of the limited number of dated bones. If we had 1000 instead of just 263 bones, additional peaks in the CPD curve would undoubtedly prove to be significantly different from the simulated background. Minima in the CPD are particularly vulnerable to type II errors because they represent the periods where dates are rare in an already small dataset. Therefore it is the presences rather than the absences of statistically significant peaks in bone abundance that provide the most informative temporal patterns.

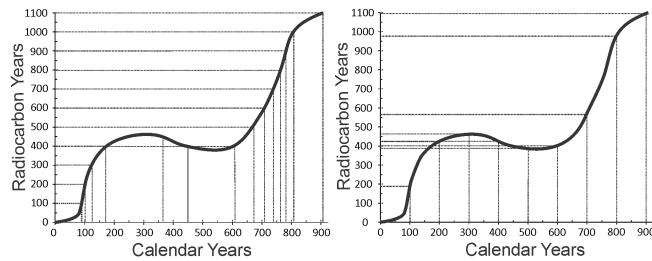


Fig. S2. Hypothetical radiocarbon-calibration curves being used to correct ^{14}C dates to calendar years. Because the amount of radiocarbon in Earth's atmosphere has fluctuated, the ^{14}C -calibration curve wiggles through time. As a result, evenly spaced ^{14}C ages (*left*) correspond to clusters of calibrated (calendar) ages at the steep portions of the calibration curve. Evenly spaced calendar ages (*right*) correspond ^{14}C ages clustering on plateaus in the curve. These calibration effects generate peaks in any cumulative probability distribution (CPD) composed of a large series of calibrated ^{14}C dates and need to be taken into account before making any inferences based on temporal patterns displayed by the CPD.

4- TAPHONOMY

The megafaunal bones we studied come from low-energy floodplains in an arctic, permafrost environment. Their often exceptional states of morphological and chemical preservation regardless of age, combined with the rarity of specimens displaying root etching, indicate most of them were never exposed to chemical weathering in soils. Instead, most of these bones appear to have been stored in anoxic and/or permanently frozen states for millennia.

As detailed in an earlier paper (1), there are two main pathways for bone deposition and preservation in the Ikpikpuk and Titaluk River valleys where most of these bones originate. Upstream of the loess belt (a 50-km wide area where windblown silts accumulated downwind of the now stabilized Ikpikpuk Sand Sea), most bones were deposited in the active stream channel. The rarity of scavenger gnawing suggests rapid burial by sediment. Concentrations of bones occur where the channel crosses beds of clay, suggesting these are places where animals were bogged down. A different mechanism of bone accumulation operated within the loess belt where large ice wedges provided another type of natural trap. Ongoing loess deposition buried these remains, and lateral erosion of river channels later carved into these loess deposits, reworking bones into the active channel. This process can occasionally be seen occurring today along eroding cut banks.

Once entering the river channel through either of the two pathways, bones gradually work their way downward through the sediment column through a process of elutriation until they end up concentrated below the water table under anoxic conditions. If the active channel shifts elsewhere on the floodplain, the bones become incorporated in permafrost. Given the sheer number of bones, the fact that the collections span two different drainage basins, the diversity of bone ages, and the complexity of the taphonomic pathways, we think it unlikely that multiple bones of the same individual of any taxon have been dated in this study.

Most of the bones we dated come from upstream of the loess belt, so we think that death-in-the- channel has been the dominant taphonomic pathway. Unlike the loess belt, where bone preservation probably varied according to the rate of aeolian sedimentation, bones have been incorporated, elutriated, and stored in the floodplains regardless of whether the channels were aggrading or incising. The upper reaches of both the Ikpikpuk and Titaluk Rivers have progressively incised their floodplains since ca. 7500 years ago (44), yet abundant wood and bones of moose, muskoxen and caribou continue to enter via this taphonomic pathway. We have found no support for the alternate hypothesis that the highs and lows in bone abundance through time are the result of differential weathering under different vegetation covers or from differential deposition/preservation under differing geomorphic regimes.

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