Taphonomy of two last glacial maximum mammoth sites in the central Great Plains of North America: A preliminary report on La Sena and Lovewell

Steven R. Holen

Curator of Archaeology, Denver Museum of Nature & Science, 2001 Colorado Blvd. Denver, Colorado 80205, USA

Available online 24 May 2005

Abstract

Two mammoth sites from the central Great Plains of North America, each containing one adult Columbian mammoth (*Mammuthus columbi*), were excavated from Last Glacial Maximum (LGM) loess and fine-grained alluvial deposits, respectively. Taphonomic data from both sites indicate that the mammoth skeletons exhibit numerous spirally fractured limb elements. Dynamic loading points are present on midshafts of large limb bones. Bone flakes produced from the partial thickness of thick cortical bone are also present. Hypotheses of carnivore activity, mammoth trampling, and human-induced fracturing are evaluated as possible causes of the fractured limb bone. Testing the hypotheses using modern data from actualistic taphonomic studies of elephant skeletons, paleontological data from two proboscidean natural death sites, experimental data from elephant bone fracturing, and archaeologically derived data concerning late Pleistocene human modification of mammoth limb bone indicates that the first two hypotheses can be rejected, while the third hypothesis is supported.

© 2005 Elsevier Ltd and INQUA. All rights reserved.

1. Introduction

Several late Pleistocene mammoth sites on the central Great Plains of North America (Fig. 1) exhibit spirally fractured limb bone. This study discusses two of the most recently excavated mammoth sites that offer the opportunity to study taphonomic processes that alter mammoth bone situated in fine-grained eolian and alluvial sediments. Excavation at the La Sena mammoth site is complete and the faunal remains are presently undergoing laboratory analysis in preparation of the final report. Excavation at the Lovewell mammoth site will be completed in 2004 and the final report completed in 2005. This preliminary report offers a discussion of the site contexts and the taphonomy of mammoth elements, especially the fractured limb bones from both sites. Three hypotheses are developed that might explain the presence of these fractured elements in fine-grained sediments. The three hypotheses are carnivore gnawing, mammoth trampling, and human-induced fracturing. Only one hypothesis is supported by this taphonomic study.

2. The La Sena mammoth site

The La Sena mammoth site (Holen and May, 2002) consists of a partial adult mammoth skeleton buried 3.5 m deep in late Wisconsin loess overlying alluvial terrace fill along Medicine Creek Reservoir. Local stratigraphy at the site is well-dated (Fig. 2) and fits well within the regional stratigraphic context (Martin, 1993; May and Holen, 1993). At the base of the exposed section, 2.5 m below the mammoth, is alluvium of the Gilman Canyon Formation. A radiocarbon age from humates collected near the base of the 30-cm-thick A horizon of the Farmdale Interstadial Soil that is developed in uppermost Gilman Canyon is $20,870 \pm 1280$ rcybp (Tx-6707). A second radiocarbon age, $24,830 \pm 1340$ (Tx-6709), was obtained from soil
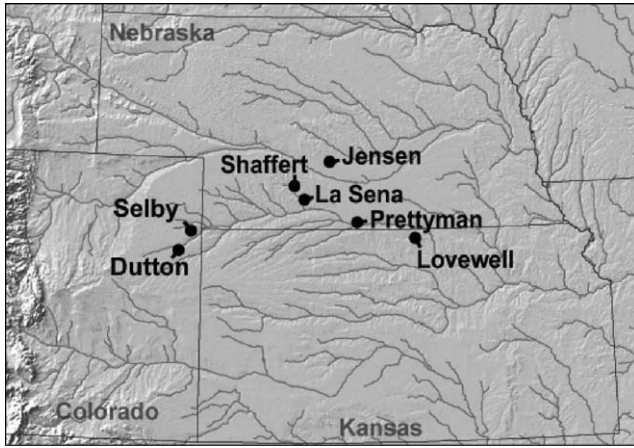
E-mail address: sholen@dmns.org.

Fig. 1. Location of mammoth sites in the central Great Plains of North America that contain spirally fractured limb bones. The La Sena mammoth site and the Lovewell mammoth site are the primary sites discussed in this report.
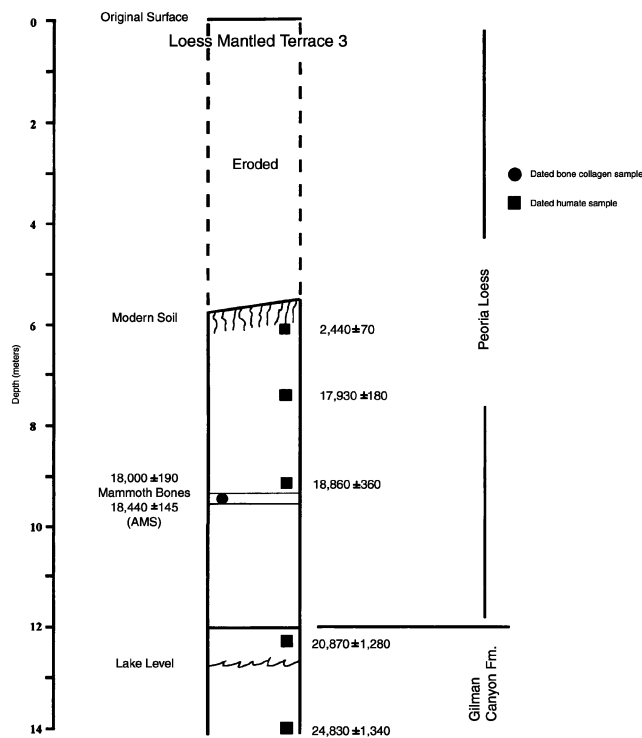

Fig. 2. Stratigraphic section and radiocarbon ages at the La Sena mammoth site (after Holen and May, 2002).

humates derived from slightly organic silt lower in the stratigraphic section, 4.5 m below the mammoth bone level.

Mammoth bone was excavated from the top of a weakly developed, and perhaps local, Bt argillic soil horizon present in late Wisconsin Peoria Loess 2.5 m above the Farmdale Interstadial Soil. Humates in this soil horizon are $16,730 \pm 490$ rcybp (Tx-6707), while humates in a larger bulk sample from 18 to 23 cm above the soil horizon and mammoth bones are $18,860 \pm 360$ rcybp (Tx-7006) (May and Holen, 1993; Holen and May, 2002). Both humate ages should be regarded as minimum ages (see Holliday, 1995: p. 10) because the soil humin fraction was not dated. The older radiocarbon age is thought to be the more accurate of the two humate ages (Holen and May, 2002: p. 27−28). Additional radiocarbon ages were obtained from loess 2 m above the mammoth. The radiocarbon age from soil humates is $17,930 \pm 180$ rcybp (Tx-8182a) and from soil humins is $18,280 \pm 200$ rcybp (Tx-8182b) (Holen and May 2002: p. 29). About 6 m of late Wisconsin loess at the top of the section have been removed by Holocene erosion and a radiocarbon age of 2440 ± 70 rcybp (Tx-7005) from the base of the modern topsoil indicates when this surface stabilized.

Two radiocarbon ages, $18,000 \pm 190$ rcybp (Beta 28728) and $18,440 \pm 145$ (AA-6972), were also obtained from collagen preserved in thick mammoth limb bone. The latter age is considered to be the most accurate age for the mammoth because it was obtained from highly purified collagen from the laboratory of Thomas Stafford using his methodology for removing contaminants from bone (Stafford et al., 1987).

Some microfauna species represented in the mammoth bone level now live at higher latitude and altitude indicating a cooler climate at the time the mammoth died (Burres, 1995). Gastropod analysis also indicates a cooler climate and the local flora was dominated by cool weather grasses according to the phytolith analysis. Regional paleoecological data from microfauna, macrofauna, phytoliths, and gastropods indicate this area of the central Great Plains was a cool dry steppe during the Last Glacial Maximum (LGM) (Oxygen Isotope Stage 2).

Excavation produced faunal remains of one 50-plus-year-old adult mammoth, the age calculated from a heavily worn M3 molar. Natural taphonomic processes altering the faunal elements include light root etching, a very small amount of rodent gnawing, and sediment loading that fractured two ribs transversely. Weathering on faunal elements is light indicating relatively rapid burial by wind-blown silts, probably within a matter of a few years.

The skeletal remains are completely disarticulated and scattered over an area at least $20\,m \times 10\,m$. There is no evidence of butchering and no stone tools were found in good context with the skeletal material. Numerous pieces of spirally fractured cortical limb bone are present (Figs. 3 and 4). One molar, small fragments of ivory and skull, complete and broken vertebrae and ribs, complete phalanges, one fibula, and the proximal halves of both femurs have been identified to date. Both femurs are heavily broken with numerous spirally fractured fragments, while the much lighter fibula was found in two
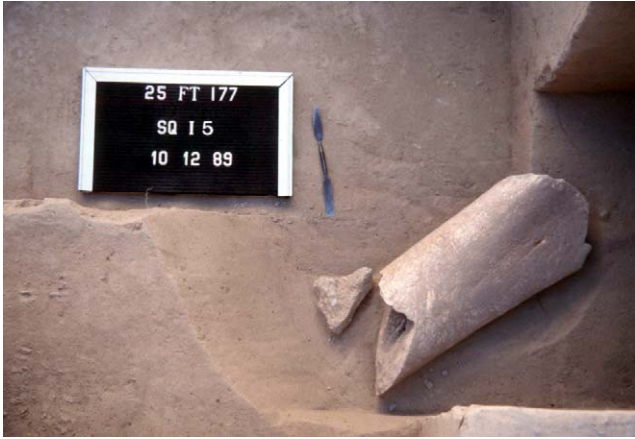
Fig. 3. Spirally fractured limb bone at the La Sena mammoth site. The large fragment of femur on the right is the largest piece of limb bone recovered.
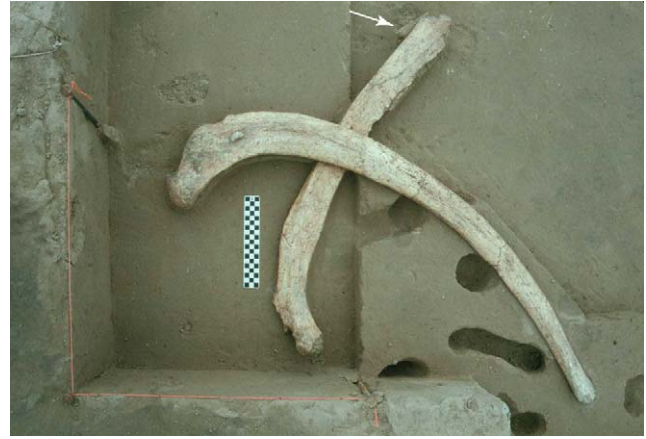

Fig. 5. Two complete ribs and a small spirally fractured limb bone fragment underlying the distal end of the shorter rib. Arrow points to the limb bone fragment.

Fig. 4. Spirally fractured limb bone fragments at the La Sena mammoth site. These fragments represent common size fragments.

Fig. 6. Refit of four pieces of spirally fractured femur showing a dynamic loading point and spiral fractures emanating from the impact point. The arrow points to a cone flake.

segments. Fractured limb bone fragments are found intermixed with complete and less heavily broken vertebrae and ribs. In one instance, two complete ribs overlie a fragment of spirally fractured limb bone (Fig. 5).

Dynamic loading points are found on both femurs. These dynamic loading points were produced by an object about 5 cm in diameter at the point of impact. Fig. 6 shows a refit of four fragments of cortical limb bone reconstructed to show an impact point 5 cm in diameter measured across the gap between the two sides of the impact point. This impact point was on the proximal half of the femur. A prominent negative bulb of percussion is present on the cone flake (Fig. 7) that formed at the edge of the impact point. The negative bulb of percussion forms an oblique angle to the cortical surface and is 8 cm wide where it intersects the medullary cavity. A reconstructed proximal femur exhibits three alternating impact points each

separated by 25 cm (Fig. 8). Neither distal femur was found.

Bone flakes are formed from the partial thickness of cortical limb bones. Flakes are produced longitudinally on the limb bone. One flake exhibits a platform, a bulb of percussion, an undulating ripple as the energy of the blow dissipated, and a hinge termination (Fig. 9). These features are all characteristics of percussion impact.

The most unusual taphonomic situation at the site is a broken vertebra. It was difficult to identify upon discovery because the broken surface was standing upright in contrast to the other excavated vertebrae, which were lying horizontally on the old soil surface. The transverse process was broken to a sharp point that extended 6 cm below the original ground surface (Fig. 10). The broken upper surface of the vertebra was smooth and worn. A heavy concentration of small spirally fractured limb bone fragments was excavated in the square meter next to the vertebra (Fig. 11).

Fig. 7. Negative cone of percussion on the cone flake below the dynamic loading point.
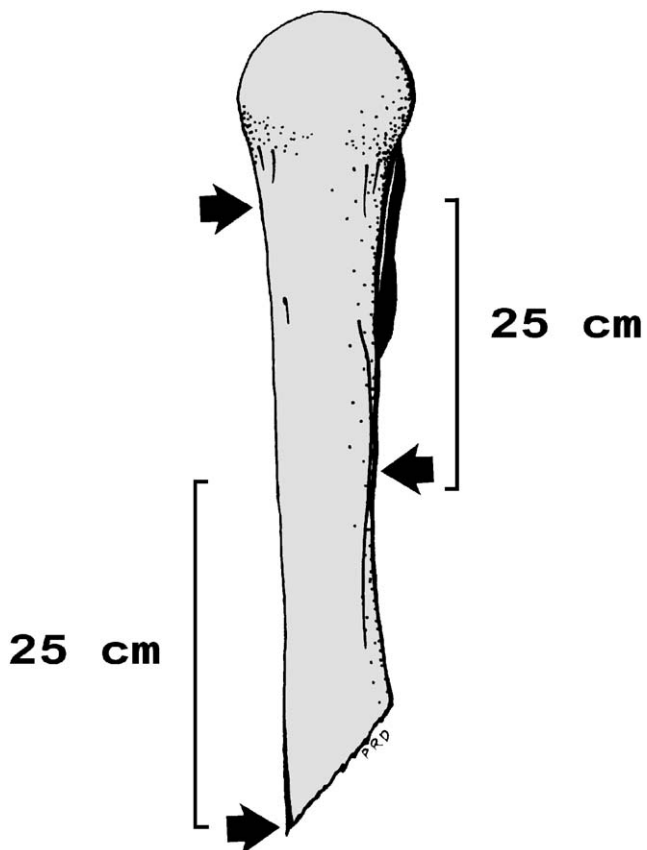

Fig. 8. Alternating dynamic loading points on one mammoth femur.

Fig. 9. Ventral face of a bone flake formed on the partial thickness of thick cortical bone. Note the platform, bulb of percussion, undulating ripples, and hinge fracture at the distal end.

Fig. 10. Broken vertebra standing vertically with transverse process extending 6 cm below the original ground surface indicated by the dotted line.

Fig. 11. Spirally fractured cortical limb bone fragments in the square meter next to vertical-standing vertebra.

3. The Lovewell mammoth site

The Lovewell mammoth site (Holen, 1996, 1997) in north-central Kansas is situated in fine-grained alluvium, consisting of silt and fine sand, along the north shore of Lovewell Reservoir on White Rock Creek. It was first excavated in 1969 by archaeologists who noted the numerous spiral fractures and some stacking of the faunal elements (Fig. 12). Photographs from the 1969 excavation indicate that the skull and some limb bones

are largely intact, and that the skeletal material formed a tight concentration. A geologist informed the archaeologists that the deposits were older than 100,000 years old, at which point they ceased excavation and did not collect the faunal material (Holen, 1997). The reservoir flooded the site for 22 years. Fieldwork in 1989 at a Clovis locality about 1 km from the mammoth in the same terrace fill suggested the Lovewell mammoth was probably not more than 100,000 years old as indicated by the geologist. In 1991, the mammoth was exposed

Fig. 12. 1969 excavation of the Lovewell Mammoth, note the nearly complete skull and large limb and ribs.

again for the first time since 1969 and a small portion of the remaining mammoth bone was excavated (Holen, 1996, 1997). Most of the main bone bed had eroded away but a small portion remained intact. More extensive excavation was undertaken in 2002, the next time the mammoth was exposed.

Numerous small fragments of mammoth bone excavated in 1991 and 2002 included many that were spirally fractured. They were contained in a small, shallow Pleistocene gully fill that formed at the edge of and below the main bone bed, which was destroyed by erosion between 1969 and 1991.

Recent excavations and photographs and records from the 1969 excavation indicate the presence of one adult Columbian mammoth. The XAD-treated KOH-extracted collagen hydrolyzate fraction of thick cortical limb bone from in situ deposits was radiocarbon-dated to $18,250 \pm 90$ rcybp (CAMS-15636). This age is stratigraphically consistent with radiocarbon ages of charcoal and bone collagen from an extinct form of horse (*Equus* sp.) excavated from the same terrace fill along the north shore of this reservoir (Holen et al., 1995; Holen, 1996, 1997; Mandel, 2002).

Common fracture patterns on limb bones include spirally fractured segments with multiple intersecting fracture planes. Dynamic loading points produced by an object about 3 cm in diameter are present and one cone flake was found. Bone flakes and negative flake scars are present (Figs. 13 and 14). One cortical segment is bifacially flaked with two long flakes on one face and two short flakes on the reverse face (Fig. 15). This flaking produced a sinuous edge like those on bifacially flaked lithic cores.
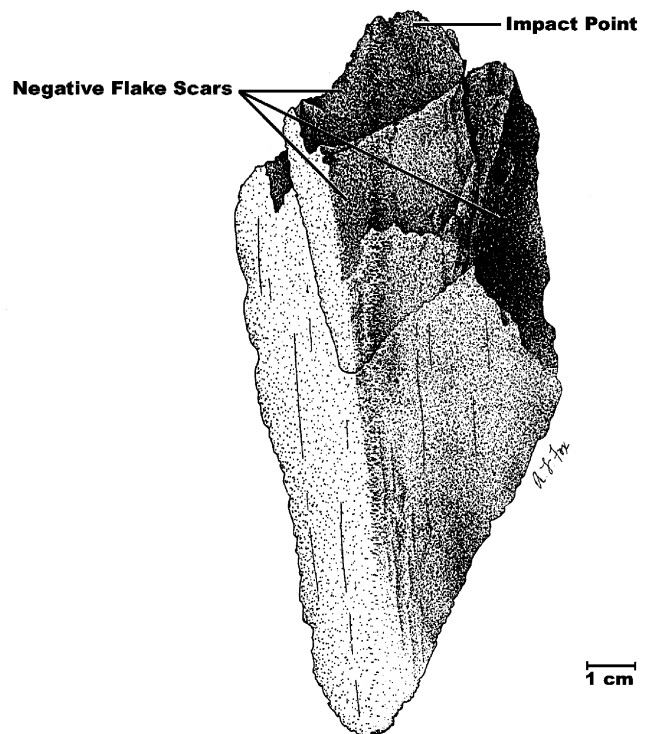

Fig. 13. Bone flake from the Lovewell mammoth site showing negative flake scars.

A small highly polished cylindrical bone object (Fig. 16) was discovered in the 1991 excavation (Holen, 1996, 1997). It has a transverse dry bone fracture at the distal end. A snap fracture at the tip is partially obscured by heavy wear and polish. The bone object was not found in situ. It was excavated from a heavy

Negative Flake Scars
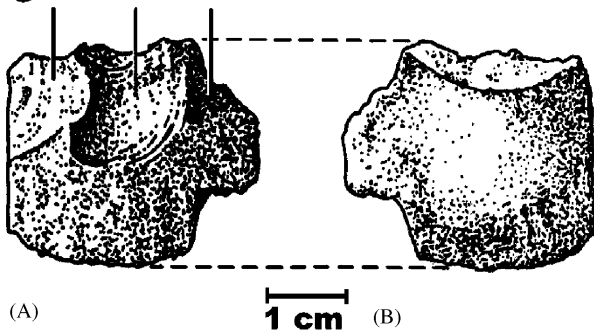

(A)   ⊢ **1 cm** ⊣   (B)

Fig. 14. Bone flake from the Lovewell mammoth site with bulb of percussion on Face B.

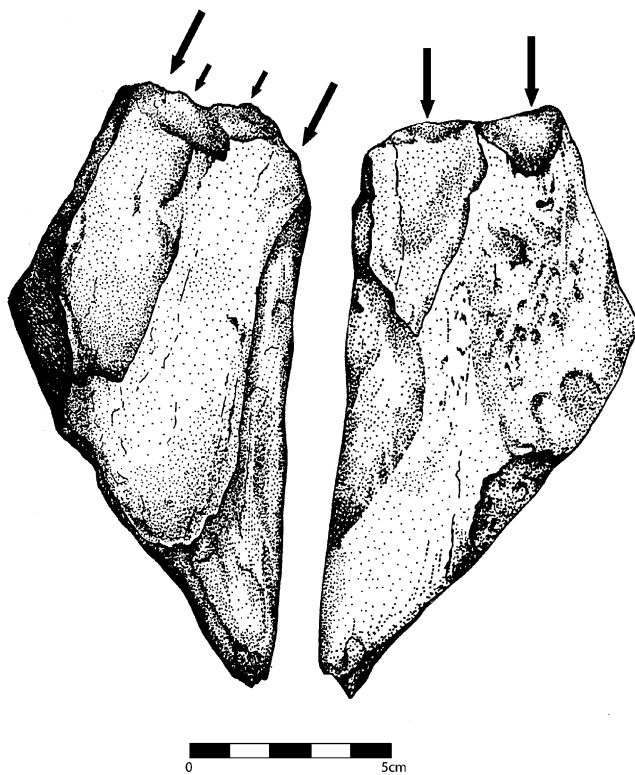Fig. 16. Highly polished bone object from the Lovewell mammoth site.

Fig. 15. Bifacially flaked cortical segment of mammoth limb bone, arrows point to flake scars on opposite faces.

concentration of small spirally fractured elements that formed a lag deposit in the upper 4 cm representing disturbed deposit just above a heavy concentration of in situ fractured bone fragments.

4. Hypotheses developed to explain the fractured limb bone

Three hypotheses have been developed that might explain the presence of fractured limb bone and the bone flakes at mammoth sites. These hypotheses were developed from modern actualistic studies of elephant

taphonomy (Crader, 1983; Haynes, 1984, 1988, 1991, 2002), the paleontological record of prosboscidean taphonomy at natural death sites, experimental archaeology relating to elephant bone fracturing by humans (Stanford et al., 1981) and from the archaeological literature regarding late Pleistocene Clovis-era modification of mammoth bone (Hannus, 1989, 1990; Johnson, 1985, 1989; Miller, 1989; Steele and Carlson, 1989). The three hypotheses are (1) large late Pleistocene carnivores caused the fractured limb bones; (2) mammoth trampling fractured the limb bones; and (3) humans wielding tools fractured limb bones.

Several hypotheses that have been presented previously to explain mammoth limb bone breakage can be rejected because of the stratigraphic position of the mammoth bone in eolian loess and fine-grained alluvium. Dixon (1984: pp. 213) points out, "Context is the most important factor in determining the age, nature, meaning, and origin of modified faunal remains." The fine-grained eolian and alluvial context of these mammoth bones allows the researcher to eliminate many of the geological causes proposed for mammoth bone breakage. For example, transport in river ice and alluvial action in rivers (Thorson and Guthrie, 1984) and taphonomic processes associated with cave environments (Dixon, 1984) can be eliminated as factors in the La Sena and Lovewell mammoth sites.

5. Comparison with Pleistocene proboscidean natural death sites

Two proboscidean natural death sites in the central Great Plains of North America were selected in order to make taphonomic comparisons with the two late Wisconsinan mammoth sites. The Williams stegomastodon is 1–1.5 million years old, too ancient to be

associated with hominids in North America. The Crawford mammoth site represents an unusual albeit natural death of two late Pleistocene male Columbian mammoths that locked their tusks together while fighting.

5.1. The Williams Stegomastodon

The Williams stegomastodon was excavated in 1997 by paleontologists from the University of Nebraska State Museum from alluvial sand and small gravel deposited by an early Pleistocene stream in western Nebraska. This old male stegomastodon died on a gravel bar and was soon buried. While fluvial transport moved some faunal elements downstream a short distance, most of the skeleton was recovered. Several articulations are present including the scapula, humerus, and radius. Also, one femur–tibia and a few vertebrae were articulated. All limb bones were unbroken.

No significant carnivore activity is evident on the skeleton although several large carnivores were present during this period (Kurten and Anderson, 1980). The largest carnivore is a bear of the genus Arctodus. This species was in the size range of a large grizzly and was smaller than the late Wisconsinan Arctodus simus. Saber-toothed cats the size of a lioness, and a small wolf, were also part of the carnivore guild during this period.

5.2. The Crawford mammoth site

This site was excavated in 1962 by University of Nebraska State Museum paleontologists. Two adult male Columbian mammoths about 40 years old died after their tusks became locked during combat (Agenbroad and Mead, 1994). The mammoths were excavated from fine-grained late Pleistocene alluvium consisting of locally redeposited loess. Both mammoths were generally articulated and two nearly complete skeletons were recovered. All limb bones were complete and in good condition in spite of the tremendous trauma of the battle. There were no spiral fractures present on the limb bones. One limb element exhibits a dry bone transverse fracture, but both halves articulate at the break. Sediment loading is thought to be the cause of the dry bone fracture. Relatively rapid burial by alluvium within a few years after death is indicated.

No significant carnivore activity is present even though the giant short-faced bear (Arctodus simus), the American lion (Panthera atrox), and dire wolf (Canis dirus) were present on the Great Plains during the late Pleistocene (Kurten and Anderson, 1980).

The two Pleistocene natural death sites of mature adult proboscideans in alluvium near or in streambeds do not exhibit trampling or carnivore damage to limb bones. These two sites are in similar topographic and geologic situations to the La Sena and Lovewell mammoth sites, yet the taphonomic situation with regard to limb bone breakage is quite different.

6. The carnivore gnawing hypothesis

Late Pleistocene carnivores in the North American Great Plains included the dire wolf (Canis dirus), thought to be adapted to bone crushing; the American lion (Panthera atrox); and the largest carnivore, giant short-faced bear (Arctodus simus) (Kurten and Anderson, 1980). Arctodus was much larger than a grizzly bear, and it has been suggested that it was a breaker and flaker of large Pleistocene ungulate bone (Voorheis and Corner, 1986). Matheus (1995) argues convincingly that Arctodus was a scavenger instead of a predator and has suggested that mammoth was one of the main scavenged species. But even this large carnivore could not break adult mammoth limb bones at midshaft causing multiple intersecting spiral fractures because it did not have the right type of masticatory apparatus (Johnson, 1985). Regarding Pleistocene carnivores like Arctodus, Haynes (1980, 1984, 1988, 1991, 2002), who has studied carnivore modification of faunal elements in several different locations and environments, states

> in the case of large bones such as those of Mammuthus the effort required to break up fresh cortical tissue would have been enormous but probably not beyond the capabilities of hungry animals, especially on elements with epiphyses partly removed during earlier gnawing. Nonetheless, hypothetical gnawing by bears seems to me a far-fetched explanation for the existence of fragmented mammoth bones in any assemblage …. The size and thickness of mammoth limb bones probably presented even the largest and hungriest Pleistocene scavengers with gnawing problems too formidable to allow fragmentation (Haynes, 1984: p. 109).

Thus, the smaller American lion and dire wolf logically could not break these mammoth limb bones at midshaft either.

Carnivores attack limb bones by gnawing at an articular end and then proceeding into the limb bone shaft (Haynes, 1980). Modern actualistic studies of African carnivore activity on elephant faunal remains have been recorded by Haynes who states

> In Africa, hyenas and lions also break apart fresh limb bones of prey weighing up to 1000 kg. When feeding on elephants, hyenas can fracture long bones after first eating epiphyses, then grasping the remaining shaft with jaws and levering off large pieces of compact bone …. Long bone elements that do suffer breakage during carnivore feeding are usually derived

from still growing prey individuals (emphasis added). Many limb bones of elephants that are less than 30–35 years old are not fully grown, and epiphyses are not fused to the diaphyses. Consequently, when exposed to feeding carnivores, these bones are structurally weaker than are fully grown and fused elements, and can be more easily broken (Haynes, 1988: pp. 144).

Haynes (1991: pp. 189–190) describes the process of bone "flakes" being pulled from the limb bones of younger elephants by hyenas as follows, "In their attempts to reach even deeper into these bones, hyenas levered off large flakes of long-bone walls. The largest flakes I measured were over 30 cm long by about 10 cm wide. Each flake had one thick end where a hyena had grabbed the exposed end of a shaft, and one thin or feathered termination where the flake had separated from the shaft."

Crader (1983) examined seven single adult elephant death sites in Zambia, Africa. Most bone scatters were in or very near old cultivated fields along stream courses. All of the elephants had been killed and butchered by Bisa hunters and subsequently the faunal elements were altered by lions and hyenas. She noted that Bisa hunters do not break elephant limb bones. Crader (1983: pp. 127) stated, "Very few of the limb bones are fractured; missing portions, such as epiphyseal ends, are generally chewed away rather than broken off." She also noted the typical pattern of carnivore gnawing first on the articular ends of limb bones.

Three lines of evidence suggest the carnivore gnawing hypothesis cannot be supported in explaining the fractured limb bones from the La Sena and Lovewell mammoths. First, both mammoths are mature adults with fused epiphyses on the limb bones. Based on the actualistic studies, carnivores cannot successfully attack the articular ends of mature elephant limb bones and then proceed to gnaw into the shaft.

The second line of evidence that refutes this hypothesis is that while the articular ends of mammoth limb bones excavated at the La Sena mammoth site exhibit some possible gnawing, they are largely intact. Carnivores did not gnaw away the articular end of the femur and then proceed to gnaw into the femoral shaft. Instead, the limb bones are broken at multiple places at midshaft by percussion as evidenced by negative bulbs of percussion and the presence of cone flakes. The size of the impact points at La Sena, about 5 cm in diameter and at Lovewell, about 3 cm in diameter preclude carnivore breakage of the limb bone. Morlan (1980: p. 48−49) and Johnson (1985: p. 197) point out that the size of the depression cone can differentiate between carnivore damage that causes smaller diameter cones and impacts by hammerstones that form larger diameter depression cones. Other authors have noted that

hammerstones produce much broader internal flake scars on the negative cones of percussion than carnivores produce, for example Bunn (1981: p. 575) states, "Hammerstone blows produce broad internal flake scars on limb shaft pieces … Damage resulting from breakage by carnivores is similar, but the scars … are much smaller." Villa et al. (1986: p. 436) state concerning hammerstone blows, "Perhaps the most significant criteria of dynamic loading are wide impact scars." Blumenschine and Selvaggio (1991: p. 30) state, "Percussion notches are usually broad and arcuate, with an acute release angle and negative flake scars …. They are usually quite distinctive from notches produced by carnivore teeth, which tend to be narrower, more semicircular in plan form and have a release angle closer to perpendicular."

Capaldo and Blumenschine (1994) used quantitative methods to successfully differentiate between notches produced experimentally with hammerstones and notches produced by carnivores on bovid limb bones. They state, "In comparison to notches produced by carnivores statically loading bones, those produced by dynamic loading through hammerstone-on-anvil impact tend to have more arcuate plan forms, broader negative flake scars, and more oblique platform angles" (Capaldo and Blumenschine, 1994: p. 739).

The 5 cm in diameter dynamic loading point on the La Sena femurs are much larger than any late Pleistocene carnivore tooth and, therefore, are not the product of carnivores breaking mammoth limb bones at midshaft. The dynamic loading points also preserve broad negative flake scars with an oblique angle to the bone thickness (Fig. 7) and therefore fit the description of negative cones of percussion produced by hammerstones as opposed to those produced by carnivores.

Any discussion of carnivores causing the bone flakes present at the La Sena mammoth site is not relevant because the bone "flakes" described by Haynes (1991) are the result of carnivores gnawing into the limb bone shaft *after* removing the articular end by gnawing. The proximal articular ends of both femora are generally intact at the La Sena mammoth site and fracture planes originate at midshaft. Carnivore activity is not a major factor affecting the mammoth limb bones at the La Sena mammoth site. The head of one rib may have been gnawed by a small carnivore, but there are no major tooth gouges or scrapes. While the articular ends of both femurs exhibit some damage that may be the result of carnivore gnawing, carnivore damage cannot positively be identified as the cause of the damage. Lack of tooth puncture marks and grooves throughout the assemblage indicates that it was not heavily altered by large carnivores.

Last, there is no conclusive evidence of major carnivore damage at either the La Sena or the Lovewell mammoth site. Large carnivores produce clear evidence

if they are responsible for taphonomic changes in any faunal assemblage. The carnivore gnawing hypothesis can be eliminated from consideration as the taphonomic process that caused the highly fracture limb bones at the two mammoth sites.

7. The mammoth trampling hypothesis

Mammoth trampling has been suggested as a cause of mammoth limb bone breakage. Recent taphonomic studies of single elephant carcasses in Africa by Crader (1983) and Haynes (1984, 1988, 1991, 2002) offer the most appropriate analogy for understanding the late Wisconsin mammoth bone fracturing at the two single mammoth death sites in the central Great Plains of North America. The majority of Haynes's studies involved the mass die-offs of elephants around water-holes during drought situations and at the sites of mass culling of elephant herds. Mass elephant mortality sites around water holes and mass culling death sites are not appropriate analogies to single mammoth death sites in comparing taphonomic patterns. Haynes (1988: p. 139) recognizes the difference in types of elephant death sites when he states, "Trampling effects on bones are different under these different circumstances." Even single elephant death sites directly at water sources may not exhibit heavy trampling. Haynes (1988: p. 139) notes in these instances that "kicking and trampling are hit or miss processes, unless elephants return in large numbers to the site seasonally, in which case bones may be widely scattered and broken." After discussing taphonomic processes that affect bones where there are abundant carcasses at water sources, abundant carcasses near water sources, and single death sites at water sources, he discusses single death sites away from water sources as follows, "When elephants die one at a time away from water sources … trampling and kicking are hit or miss processes and rarely affect bones as severely as around water sources." Crader's (1983) study of seven single adult elephant death sites, some very near stream courses in cultivated fields, did not record any evidence of trampling damage. Two spirally fractured bones were thought to have been the result of traumatic injury when the animals were thrashing about during death throes after they had been shot. Crader (1983, p. 127) noted that "the paucity of such fractured limbs in the scatters suggests that not much trampling or natural fracturing of weathered bone has occurred on the sites." Crader (1983) and Haynes (1988) document very rare or no trampling breakage of elephant limb bone in single elephant death sites.

Even if broken limb bones at mass death sites around water holes were considered in this analogy, they do not fit the pattern of mature adult limb bones that are fragmented into numerous spirally fractured pieces.

Most of the elephant skeletons studied by Haynes (1988) were younger animals with unfused limb bone epiphyses. These limb bones are more subject to destruction than ones on which the epiphyses have fused. Haynes (1988) discusses the structurally weakened limb bones that have lost unfused epiphyses. Trampling of these limb bones causes more breakage than would trampling of complete adult limb bones. Haynes (1988, p. 147) states that, "In a few cases, I have recorded spirally fractured long bones broken by trampling or manipulative elephants while the bones were still partly enclosed in connective tissue." Apparently, the fracturing of limb bones is quite rare while they are still very fresh, even at mass death sites. There are a few fractures apparently caused by traumatic events associated with death throes as suggested by Crader (1983).

Evidence from paleontological sites that represent proboscidean natural death localities in the central Great Plains and evidence from actualistic studies of modern taphonomic processes that alter African elephant bone indicate that the mammoth trampling hypothesis is invalid for explaining heavily fractured limb bones at single mammoth death sites. Large adult proboscidean limb bones at single death sites are very seldom broken while still fresh.

One additional piece of evidence does not support the trampling hypothesis. Limb bones at the La Sena mammoth site are more heavily fragmented than much lighter elements, for example ribs, vertebrae, and the fibula. This pattern does not fit the taphonomic pattern of bone breakage even at mass death sites with major trampling damage noted by Haynes (1988: p. 139). He documented that ribs are broken first during the "dry/bleaching stage" and only later in this stage are the ribs broken further and some limb bones fractured by trampling. This evidence does not fit the fracture pattern where limb bones are much more highly fragmented than ribs and vertebrae at the La Sena mammoth site. The mammoth trampling hypothesis is rejected because proboscidean limb bones at single death sites are rarely if ever broken by trampling and because the lighter bones at La Sena are less fragmented than the limb bones.

8. The human-induced fracturing hypothesis

The presence of spirally fractured mammoth limb bone, dynamic loading points, and bone flaking from in situ deposits, present at both La Sena and Lovewell mammoth sites, could be representative of human modification of mammoth bone. Proboscidean limb bones modified by humans are known from the archaeological record beginning at least by the Middle Pleistocene of Europe (Biddittu et al., 1979: p. 22; Villa, 1991). Some of these bone tools are patterned bifaces

with numerous flake scars on each face. The bifaces are produced from proboscidean limb bone segments. Upper Paleolithic cultures of Europe and Siberia also utilized a bone flaking technology (Morlan, 2003: p. 129) and manufactured a suite of highly patterned bone and ivory tools from mammoth limb bones and tusks (Soffer, 1985). Clovis groups in North America manufactured the same types of tools; for example, foreshafts, projectile points, and shaft wrenches from proboscidean limb bone (Stanford, 1991). This manufacturing process would have necessitated the reduction of proboscidean limb bones. Reduction of mammoth limb bones into cores and preforms in the most efficient manner would require impacting them with hammerstones and flaking them into preforms. In North America, several authors have observed mammoth limb bone reduction strategies and suggested that humans caused the observed fractured and flaked bone (Bonnichsen, 1979; Stanford, 1979; Morlan, 1980, 1984, 1986, 2003; Johnson, 1985, 1989; Stanford and Graham, 1985; Hannus, 1989, 1990; Miller, 1989; Steele and Carlson, 1989; Cinq-Mars 1990). Two sites, Dutton and Selby in northeast Colorado, exhibit the same type of dynamic loading points and bone flaking on mammoth limb bone (Stanford, 1979; Stanford and Graham, 1985) in late Wisconsin geological contexts in the Central Great Plains. These mammoth elements were excavated from the lacustrine levels of upland playa lakes with bracketing radiocarbon ages of $13,600 \pm 485$ rcybp (SI-5186) from underlying Peorian loess and $11,710 \pm 150$ rcybp (SI-2877) from an overlying soil.

Modern humans can produce the types of dynamic loading points and bone flakes present at La Sena and Lovewell mammoth sites. The most notable study is the Ginsberg experiment (Stanford et al., 1981) in which an elephant was butchered and the limb bones broken with large rocks that produced dynamic loading points. Cortical flakes were produced by percussion from thick limb bone shaft segments. These were then used as effective expedient butchering tools.

Archaeological evidence from North America indicates that hunter-gatherers at the end of the Pleistocene hunted mammoths and/or scavenged mammoths and fractured and flaked the limb bone. Four Clovis-age sites offer evidence for limb bone utilization and bone flaking. These sites are Lange-Ferguson in South Dakota (Hannus, 1989, 1990), the Wasden Site in Idaho (Miller, 1989), and the Duewall-Newberry (Steele and Carlson, 1989) and the Lubbock Lake Landmark (Johnson, 1985, 1989; Johnson and Holliday, 1985) in Texas. The Lange-Ferguson and Wasden sites have good association of lithic artifacts with fractured mammoth limb bones and flaked cortical bone, while Duewall-Newberry and the locality at Lubbock Lake do not have a lithic tool association. Fracture patterns at all four sites include dynamic loading points on mammoth limb bones broken at midshaft. Lange-Ferguson, Wasden and Bluefish Cave (Cinq-Mars, 1990) have evidence of bone flakes that refit onto cores.

Archaeological evidence from four Clovis-age sites indicate that limb bones were broken by percussion with resulting dynamic loading points with negative bulbs of percussion. Cone flakes were also produced in concentric rings around the point of impact. These "flakes" are produced as a by-product of the dynamic loading of limb bones (Johnson, 1985: p. 197) and do not represent the intentional production of flakes for use.

Human-induced fracturing and flaking of mammoth limb bone at Clovis-age sites has been accepted by many archaeologists who have directly excavated the sites where this pattern of bone breakage and flaking exists (Johnson, 1985, 1989; Johnson and Holliday, 1985; Hannus, 1989, 1990; Miller, 1989; Steele and Carlson, 1989). Cogent arguments for human-induced fracturing of Clovis-age limb bone have been offered by Hannus (1989, 1990) and especially by Johnson (1985, 1989). Earlier suggestions of mid-Wisconsin human-induced fracturing of mammoth limb bones found in secondary deposits in the Old Crow River in the Yukon (Bonnichsen, 1979; Morlan, 1980, 1984, 1986) have been met with strong objections (Guthrie, 1984) or have been generally ignored when discussing the early peopling of North America. The primary reason for the skepticism regarding the interpretation that humans caused the Old Crow fractured mammoth limb bone is that these faunal elements were found in secondary contexts on point bars in the river. The present study documents the same type of fracture patterns on mammoth limb bone in situ in fine-grained eolian and alluvial contexts.

Haynes has challenged the human-induced fracturing of mammoth limb bone at most North American sites and has suggested these are merely natural fractures caused by carnivores, mammoth trampling, or other natural causes (Haynes, 1991: pp. 248−251, 2002: pp. 142−149). However, Haynes's taphonomic work on modern African elephants when used in conjunction with other data sets can help differentiate human versus naturally fractured mammoth limb bone.

9. Interpretation of the limb bone fracture patterns at the La Sena and Lovewell mammoth sites

Taphonomic data from La Sena and Lovewell mammoth sites was compared with taphonomic studies of naturally induced fracture patterns on modern African elephant bone. Both carnivore gnawing and trampling can be eliminated as factors in mammoth limb bone fracturing and flaking at La Sena and Lovewell based on this evidence. Other possible geological bone-modifying factors were eliminated because of the

context of the mammoth bone situated in fine-grained eolian and alluvial deposits. There are no other known natural taphonomic processes that can break thick cortical bone in these patterns. Humans, however, have produced these fracture patterns using hammerstones for thousands of years.

Human modification of the mammoth limb bone at both sites is supported by data from replicative studies of elephant and bovid bone reduction by humans using hammerstones and analysis of the taphonomy of mammoth bone from known Clovis-age archaeological sites, two of which contain good association with stone tools. These lines of evidence strongly suggest the La Sena and Lovewell mammoth limb bone was processed by human hunter-gatherers during the LGM on the central Great Plains of North America. If one were to mix the assemblages of fractured and flaked limb bones from the Clovis-age Lange-Ferguson site in South Dakota and the 18,000-year-old La Sena mammoth site in Nebraska, it would not be possible to sort out the fracture patterns in two assemblages based on tapho-nomic and technological criteria. Reduction of mammoth limb bone in both instances represents the same technological tradition characterized by dynamic loading to partition the limb bone and subsequent bone flaking.

The La Sena mammoth site represents a natural death site of an old adult mammoth. There is no evidence that the mammoth was hunted or butchered. Based on the selective breakage of large limb bones it appears that the skeleton was used as a quarry source (Johnson, 1985: pp. 201−202) to produce cores and preforms for the production of patterned bone tools that are important parts of Upper Paleolithic and Clovis toolkits. The broken vertebra standing vertically, associated with a concentration of small spirally fractured limb elements, is interpreted as the anvil designed for limb bone reduction using hammerstones. Bone breaks much more efficiently when using an anvil than when the bone is lying directly on the ground.

The Lovewell mammoth site has a more complex history that led to the destruction of most of the site by erosion. However, enough of the mammoth bone remains to define the same type of dynamic loading points and bone flaking present at La Sena. Bifacial flaking on one thick cortical limb bone segment demonstrates a sophisticated flaking technology beyond the removal of single flakes. The fragment of a polished bone object fits within the morphologic and metric variability of Clovis bone rods variously called fore-shafts and projectile points. Before the site and nearby stratigraphic sections were radiocarbon dated, it was thought that the Lovewell mammoth site might be a Clovis-mammoth association based on the presence of dynamic loading points on limb bone, the presence of bone flakes, and the polished bone object

10. Conclusion

The hypothesized presence of humans on the Great Plains at 18,000–19,000 rcybp as suggested by this research has important connotations for the peopling of the New World. The LGM ice sheet blocked human entrance into lower North America from about 21,000–12,000 rcybp based on radiocarbon ages of Pleistocene fauna that bracket this range and the lack of dated Pleistocene fauna during this period in central Alberta (Burns, 1996). Cosmogenic chlorine dates on glacial erratics from central Alberta also indicate this area was blocked by glacial ice during the late Wisconsin (Jackson et al., 1997). This evidence suggests that a steppe-adapted Upper Paleolithic population migrated overland from Siberia to Beringia and then southward into the central Great Plains sometime between 21,000 and 40,000 rcybp, before glaciation in Canada closed the migration route. This small population slowly moved through North America and adapted to the vast grassland that extended to central Mexico. These groups maintained a steppe-adapted technology consisting of a sophisticated bone and ivory technology, and a bifacial and blade lithic technology that lasted into the Clovis era. About 11,500 rcybp during a dramatic climate shift, these Upper Paleolithic populations developed into Clovis culture.

Mammoth bone technology such as that discussed in this study is also present in the Old Crow Basin, northern Yukon (Bonnichsen, 1979; Morlan, 1980, 1984, 1986) dated to 25,000 to 40,000 rcybp (Morlan, 2003). Cutmarks from a stone tool on two bison bones that have been dated to 36,500 and 42,000 rcybp are also found in the Yukon (Morlan, 2003). Morlan (2003) points out that neither type of evidence has been adequately refuted, and the hypothesis that humans were in eastern Beringia by 40,000 rcybp has not been falsified. Instead it is generally ignored in the literature. Evidence from La Sena and Lovewell support Morlan's (2003) hypothesis that mammoth limb bone taphonomy changes when humans enter North America. Dynamic loading points several centimeters in diameter and bone flakes with bulbs of percussion and other features caused by percussion are not documented from prehuman North American proboscidean sites.

References

Agenbroad, L.D., Mead, J.I., 1994. The Hot Springs Mammoth Site: A Decade of Field and Laboratory Research in the Paleontology, Geology, and Paleoecology. The Mammoth Site of South Dakota, Inc. Hot Springs, South Dakota.

Biddittu, I., Cassoli, P.F., Radicati di Brozolo, F., Segre, A.G., Naldini, E., Villa, I., 1979. Anagni, a K-Ar dated lower and middle paleolithic site, central Italy: preliminary report. Quaternaria 21, 53–71.

Blumenschine, R.J., Selvaggio, M.M., 1991. On the marks of marrow bone processing by hammerstones and hyenas: their anatomical patterning and archaeological implications. In: Clark, J.D. (Ed.), Cultural Beginnings. Dr. R. Habelt GMBH, Bonn, pp. 17–32.

Bonnichsen, R., 1979. Pleistocene Bone Technology in the Beringian Refugium. Mercury Series Paper No. 89. Archaeological Survey of Canada, National Museum of Man, Ottawa.

Bunn, H.T., 1981. Archaeological evidence for meat-eating by Plio-Pleistocene Hominids from Koobi Fora and Olduvai Gorge. Nature 291, 574–577.

Burns, J., 1996. Vertebrate paleontology and the alleged ice-free corridor: the meat of the matter. Quaternary International 32, 107–112.

Burres, C.L., 1995. Microtaphonomy and paleoecology of the La Sena Mammoth Site. Master's Thesis, University of Kansas.

Capaldo, S.D., Blumenschine, R.J., 1994. A quantitative diagnosis of notches made by hammerstone percussion and carnivore gnawing on bovid long bones. American Antiquity 59 (4), 724–748.

Cinq-Mars, J., 1990. La place de grottes du Poisson-Blue dans la prehistoire beringienne. Revisita de Arqueologia Americana 1, 9–32.

Crader, D., 1983. Recent single-carcass bone scatters and the problem of "butchery" sites in the archaeological record. In: Clutton-Brock, J., Grigson. C. (Eds.), Animals and Archeology, Vol. 1. Hunters and Their Prey. BAR International Series No. 163. Oxford, pp. 107–141.

Dixon, E.J., 1984. Context and environment in taphonomic analysis: examples from Alaska's Porcupine River caves. Quaternary Research 22, 201–215.

Guthrie, R.D., 1984. The evidence for middle-Wisconsin peopling of Beringia: an evaluation. Quaternary Research 22, 231–241.

Hannus, L.A., 1989. Flaked mammoth bone from the Lange/Ferguson Site, White River Badlands area, South Dakota. In: Bonnichsen, R., Sorg, M.H. (Eds.), Bone Modification. Center for the Study of First Americans, University of Maine, Orono, pp. 395–412.

Hannus, L.A., 1990. The Lange-Ferguson site: A case for mammoth bone-butchering tools. In: Agenbroad, L.D., Mead, J.I., Nelson, L.W. (Eds.), Megafauna and Man: Discovery of America's Heartland. The Mammoth Site of Hot Springs, South Dakota, Inc., pp. 86–99.

Haynes, G., 1980. Evidence of carnivore gnawing on Pleistocene and Recent mammalian bones. Paleobiology 6, 341–351.

Haynes, G., 1984. Frequencies of spiral and green-bone fractures of ungulate limb bones in modern surface assemblages. American Antiquity 48 (1), 102–114.

Haynes, G., 1988. Longitudinal studies of African elephant death and bone deposits. Journal of Archaeological Science 15, 131–157.

Haynes, G., 1991. Mammoths, Mastodonts, & Elephants: Biology, Behavior, and the Fossil Record. Cambridge University Press, Cambridge.

Haynes, G., 2002. The Early Settlement of North America: The Clovis Era. Cambridge University Press, Cambridge.

Holen, S.R., 1996. The Lovewell mammoth: A late Wisconsinan site in north-central Kansas. Current Research in the Pleistocene 13, 69–70.

Holen, S.R., 1997. The Lovewell mammoth: A late Wisconsinan mammoth processing site in north-central Kansas. Nebraska Archaeological Survey, Technical Report 97-01, University of Nebraska State Museum, Lincoln.

Holen, S.R., May, D.W., 2002. The La Sena and Shaffert mammoth sites: history of investigations, 1987–1998. In: Roper, D. (Ed.), Medicine Creek: Seventy Years of Archaeological Research. The University of Alabama Press, Tuscaloosa and London, pp. 20–36.

Holen, S.R., Corner, R.G., Mandel, R.D., 1995. A late Farmdalian–Woodfordian fauna from Lovewell Reservoir, Jewell County, Kansas. Current Research in the Pleistocene 12, 98–99.

Holliday, V.T., 1995. Stratigraphy and paleoenvironments of late Quaternary valley fills on the Southern High Plains. Geological Society of America Memoir 186.

Jackson, L.E., Shimamura, K., Phillips, F.M., Little, E.C., 1997. Cosmogenic ^{36}Cl dating of the foothills erratics train, Alberta, Canada. Geology 25 (3), 195–198.

Johnson, E., 1985. Current developments in bone technology. In: Schiffer, M.B. (Ed.), Advances in Archaeological Method and Theory, vol. 8. Academic Press, New York, pp. 157–235.

Johnson, E., 1989. Human modified bones from early Southern Plains sites. In: Bonnichsen, R., Sorg, M.H. (Eds.), Bone Modification. Center for the Study of the First Americans, University of Maine, Orono, pp. 431–472.

Johnson, E., Holliday, V.T., 1985. A Clovis-age megafaunal processing station at the Lubbock Lake landmark. Current Research in the Pleistocene 2, 17–19.

Kurten, B., Anderson, E., 1980. Pleistocene Mammals of North America. Columbia University Press, New York.

Mandel, R.D., 2002. Geomorphology of the north shore of Lovewell Reservoir, north-central Kansas: implications for archaeological and paleontological research. Nebraska Archaeological Survey, Technical Report 2002-01, University of Nebraska State Museum, Lincoln.

Martin, C.W., 1993. Radiocarbon ages on late Pleistocene loess stratigraphy of Nebraska and Kansas, Central Great Plains. USA Quaternary Science Reviews 12, 179–188.

Matheus, P.F., 1995. Diet and co-ecology of Pleistocene short-faced bears and brown bears in eastern Beringia. Quaternary Research 44, 447–453.

May, D.W., Holen, S.R., 1993. Radiocarbon ages of soils and charcoal in late Wisconsinan loess, south-central Nebraska. Quaternary Research 39, 55–58.

Miller, S.J., 1989. Characteristics of mammoth bone reduction at Owl Cave, the Wasden Site, Idaho. In: Bonnichsen, R., Sorg, M.H. (Eds.), Bone Modification. Center for the Study of the First Americans, University of Maine-Orono, Orono, pp. 381–395.

Morlan, R.E., 1980. Taphonomy and Archaeology in the Upper Pleistocene of the Northern Yukon Territory: A Glimpse of the Peopling of the New World. Mercury Series Paper No. 94. Archaeological Survey of Canada, National Museum of Man, Ottawa.

Morlan, R.E., 1984. Toward the definition of criteria for the recognition of artificial bone alterations. Quaternary Research 22, 160–171.

Morlan, R.E., 1986. Pleistocene archaeology in Old Crow Basin: a critical reappraisal. In: Bryan, A.L. (Ed.), New Evidence for the Pleistocene Peopling of the Americas. Center for the Study of First Americans, University of Maine, Orono, pp. 27–48.

Morlan, R.E., 2003. Current perspectives on the Pleistocene archaeology of eastern Beringia. Quaternary Research 60, 123–132.

Soffer, O., 1985. The Upper Paleolithic of the Central Russian Plain. Academic Press, New York.

Stafford Jr., T.W., Jull, A.J.T., Brendel, K., Duhamel, R.C., Donohue, D., 1987. Study of bone radiocarbon dating accuracy at the University of Arizona NSF Accelerator Facility for Radioisotope Analysis. Radiocarbon 29, 24–44.

Stanford, D., 1979. The Selby and Dutton sites: evidence for a possible pre-Clovis occupation in the High Plains. In: Humphrey, R., Stanford, D. (Eds.), Pre-Llano Cultures of the Americas. Anthropological Society of Washington, Washington, DC, pp. 101–123.

Stanford, D., 1991. Clovis origins and adaptations: an introductory perspective. In: Bonnichsen, R., Turnmire, K.L. (Eds.), Clovis: Origins and Adaptations. Center for the Study of First Americans, Oregon State University, Corvallis.

Stanford, D., Graham, R.W., 1985. Archaeological investigations of the Selby and Dutton mammoth kill sites, Yuma, Colorado. National Geographic Research Reports 19, 519–541.

Stanford, D., Bonnichsen, R., Morlan, R.E., 1981. The Ginsberg experiment: modern and prehistoric evidence of a bone-flaking technology. Science 212, 438–440.

Steele, D.G., Carlson, D.L., 1989. Excavation and taphonomy of mammoth remains from the Duewall-Newberry Site, Brazos County, Texas. In: Bonnichsen, R., Sorg, M.H. (Eds.), Bone Modification. Center for the Study of First Americans, University of Maine-Orono, Orono, pp. 413–430.

Thorson, R.M., Guthrie, R.D., 1984. River ice as a taphonomic agent: an alternate hypothesis for bone artifacts. Quaternary Research 22, 172–188.

Villa, P., 1991. Middle Pleistocene prehistory in southwestern Europe: the state of our knowledge. Journal of Anthropological Research 47 (2), 193–218.

Villa, P., Bouville, J., Courtin, J., Helmer, D., Mahieu, E., Shipman, P., Belluomini, G., Branca, M., 1986. Cannibalism in the Neolithic. Science 233, 431–436.

Voorheis, M.R., Corner, R.G., 1986. The giant bear *Arctodus* as a potential breaker and flaker of late Pleistocene megafaunal remains. Current Research in the Pleistocene 3, 49–51.