# New Radiocarbon Ages on Percussion-Fractured and Flaked Proboscidean Limb Bones from Yukon, Canada

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ABSTRACT. Proboscidean limb bones discovered in Yukon during the 1960s and 1970s exhibit fracture patterns, notches, and bone flakes that are characteristic of percussion. Because of the unique properties of thick cortical proboscidean bone (probably woolly mammoth *Mammuthus primigenius* or less likely American mastodon *Mammut americanum*), some researchers hypothesized that these fracture patterns represent intentional hammerstone modification by humans for marrow extraction and bone tool production. As such, these fracture patterns represent evidence of early human dispersal into Eastern Beringia. Radiocarbon dating in the late 1980s indicated that the bone breakage occurred between about 25 000 and 40 000 radiocarbon years before present (^{14}C yr BP). We report 11 new radiocarbon ages using ultra-filtration methods on a different sample of similarly fractured and flaked bones from Yukon. Only two of the radiocarbon ages fall within the expected range of 25 000 to 40 000 ^{14}C yr BP. Six other ages are non-finite, with five being more than 49 100 ^{14}C yr BP. Three finite ages range between 46 500 and 50 500 ^{14}C yr BP with large standard deviations, and these ages may also be non-finite. Two testable hypotheses to explain the observed breakage patterns were developed, the first being that humans broke the bones and the second that some presently unknown geological process broke the bones. Further research is needed to test these two hypotheses.

Key words: Proboscidea; woolly mammoths; *Mammuthus primigenius*; percussion-flaked bone; radiocarbon dating; Yukon; Old Crow Basin; Klondike

RÉSUMÉ. Des ossements de membres de proboscidiens découverts au Yukon dans les années 1960 et 1970 présentent des structures de fractures, des encoches et des traces d'enlèvements d'éclats caractéristiques de la percussion. En raison des propriétés uniques de l'os cortical proboscidien (provenant probablement d'un mammouth laineux *Mammuthus primigenius* ou, ce qui est moins probable, d'un mastodonte américain *Mammut americanum*), certains chercheurs ont avancé une hypothèse selon laquelle ces structures représentent des modifications intentionnelles faites au marteau en pierre par des humains, à des fins d'extraction de la moelle et de production d'outils en os. En tant que telles, ces structures de fractures témoignent de la présence ancienne d'humains dans l'est de la Béringie. Vers la fin des années 1980, la datation au radiocarbone a permis de déterminer que les fractures auraient été faites il y a environ 25 000 à 40 000 années radiocarbones avant le présent (^{14}C ans BP). Nous faisons état de 11 nouveaux âges au radiocarbone établis au moyen de méthodes d'ultrafiltration sur un échantillon différent d'os provenant également du Yukon et présentant de semblables fractures et traces d'enlèvements d'éclats. Seulement deux des âges au radiocarbone font partie de la gamme attendue variant entre 25 000 et 40 000 ^{14}C ans BP. Six autres âges sont non finis, dont cinq ayant plus de 49 100 ^{14}C ans BP. Trois âges finis varient entre 46 500 et 50 500 ^{14}C ans BP et ont d'importants écarts-types, et ces âges pourraient également être non finis. Deux hypothèses testables ont été émises afin d'expliquer les structures de fractures observées, la première étant que les fractures ont été causées par des humains et la seconde étant que les fractures sont le résultat d'un processus géologique inconnu à ce jour. Des recherches plus approfondies s'imposent afin de mettre ces deux hypothèses à l'épreuve.

Mots clés : proboscidiens; mammouths laineux; *Mammuthus primigenius*; os avec traces d'enlèvements d'éclats issus de la percussion; datation au radiocarbone; Yukon; bassin de Old Crow; Klondike

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## INTRODUCTION

In the late 1960s and 1970s, several researchers discovered proboscidean limb bones from the Old Crow River area, Yukon, that were interpreted to have been modified by humans using percussion technology to produce notches and bone flakes (Harington et al., 1975; Irving, 1978; Bonnichsen, 1979; Morlan, 1980; Morlan and Cinq-Mars, 1982; Irving et al., 1986; Cinq-Mars and Morlan, 1999). Nearly all of these bones were found in secondary deposits on gravel bars of the Old Crow River although a few came from excavated contexts. Radiocarbon dating of the

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modified limb bones provided an age range of ca. 25 000 to 40 000 ^{14}C yr BP (Morlan, 2003), although one research group suggested that some of the modified elements dated to the last interglacial (Sangamon) Oxygen Isotope Stage 5, or Illinoian, Oxygen Isotope Stage 6 (Irving et al., 1986).

Here we report on finite and non-finite radiocarbon ages on percussion-fractured and flaked proboscidean limb bones from the Yukon, five from the Old Crow River area and six from the Klondike area near Dawson City. Radiocarbon ages were determined using the ultrafiltration collagen purification method (Brown et al., 1988; Beaumont et al., 2010). Non-finite dates indicate that the radiocarbon ages are beyond the capabilities of measuring by the radiocarbon dating method, which is usually in the range of 45 000 – 50 000 years ago. Finite ages indicate that the age can be determined by radiocarbon dating. Recent studies of the same types of fracture patterns on mammoth limb bone excavated in situ from loess and fine-grained alluvial deposits in the central Great Plains of North America support the hypothesis that humans were the modifying agent (Holen, 2006, 2007; Holen, S.R., and Holen, K., 2012, 2014), as does the presence of the same types of fracture patterns on mammoth limb bone from late Pleistocene fluted-point sites in the western United States (Hannus, 1989, 1990; Miller, 1989).

*Previous Research*

An extensive paleontological project in the Old Crow River basin begun by Richard Harington in 1965 amassed a large collection of elements from extinct fauna, mostly from secondary deposits on sand and gravel bars. Harington (2011, see particularly Conclusions 7 and 8 and Fig. 12) also provided background information on the case for human presence in Eastern Beringia following 40 000 ^{14}C yr BP. Numerous faunal elements from extinct species that appeared to be modified by humans were identified by Irving (1968). Later, bone apatite from some patterned artifacts was radiocarbon dated to the mid-Wisconsin (Irving and Harington, 1973); however, the patterned artifacts were later dated to the Holocene by accelerator mass spectrometry (AMS) dating using collagen from the same specimens (Nelson et al., 1986).

Two major archaeological projects were initiated in the Old Crow River basin in the 1970s. The first was the Northern Yukon Research Programme led by William Irving of the University of Toronto, and the second, the Yukon Refugium Project led by Richard Morlan, Yukon Archaeologist with the Archaeological Survey of Canada, National Museum of Man (now Canadian Museum of History). Both projects produced major collections of extinct Pleistocene fauna from the Old Crow River basin, as did the project under Harington's direction. These collections are now preserved in the Canadian Museum of Nature.

The first major taphonomic studies of these collections reaffirmed the interpretations that some of the proboscidean bone was modified by humans (Bonnichsen, 1979; Morlan, 1980). Criteria used to identify humanly modified proboscidean limb bone included bone flakes and percussion notches. Flakes were removed from thick cortical limb segments. Percussion notches on these thick limb bones exhibit negative cones of percussion. Some limb bone fragments exhibit fractures produced by a blow delivered in one direction, after which one or more blows broke the bone from different directions. These fracture patterns have not been identified in natural elephant death sites (Holen, 2006).

In the late 1980s, an extensive AMS radiocarbon dating project was initiated by Morlan and Nelson (Morlan et al., 1990). The results of this dating project demonstrated that proboscidean elements thought to have been fractured and flaked by humans dated from 25 000 to 40 000 ^{14}C yr BP (Morlan et al., 1990; Morlan, 2003). The limit of radiocarbon dating capability at the time was thought to be 50 000 ^{14}C yr BP, indicating that the older radiocarbon ages on proboscidean limb bone were indeed finite. This dating project led Morlan to hypothesize that humans were a new taphonomic agent that entered the paleontological record ca. 40 000 years ago. He suggested that only humans with hammerstones could break proboscidean bone at mid-shaft and cause impact fractures and flaking. Morlan further supported his conclusion by presenting taphonomic evidence that Clovis-age mammoth sites in North America displayed the same type of percussion notches and bone flaking as the Old Crow specimens. Morlan (2003) did not accept the suggested Sangamon or pre-Sangamon ages for evidence of humans in the Yukon (Jopling et al., 1981; Irving et al., 1986, 1989).

Research by Harington in the Klondike gold fields near Dawson City also identified percussion-fractured and flaked proboscidean limb bones. These specimens have not received previous study although a percussion-fractured bison tibia thought to have been modified by humans was dated to 30 810 ± 975 ^{14}C yr BP (Harington and Morlan, 2002). All of the specimens from the Klondike gold fields were found in secondary deposits in placer gold mines. Our study expands the dating of modified proboscidean limb bones to the Klondike gold fields. Recent research in Yukon at Bluefish Caves suggests, on the basis of cutmarks on faunal specimens from the caves, that humans were present during the Last Glacial Maximum (Bourgeon et al., 2017).

## SELECTION OF SPECIMENS FOR RADIOCARBON DATING

We selected proboscidean limb fragments for dating using the same criteria used by Morlan (2003): the presence of percussion notches and evidence of bone flaking produced by percussion. An additional criterion, the presence of a percussion event, was also used. The following definitions were used in sample selection, and examples of each defined term can be found in the figures.

TABLE 1. Measurable percussion notches on impact-fractured proboscidean bone from Yukon.[1]

| Specimen number | Figure number | Bone element | Cortex thickness | NB | ND | SB' | SB[m] | SD | NB/ND |
|---|---|---|---|---|---|---|---|---|---|
| CMN 57090 11A/70; 1290-85 | 2 | Limb | 31.86 | 49.54 | 7.54 | 45.13 | 51.34 | 14.64 | 6.57 |
| CMN 57092 11A/76; 2882 | 4a, b | Limb | 15.72 | 27.09 | 8.22 | – | – | – | 3.3 |
| CMN 57094, 22/78-19 | 6 | Limb | 20.14 | 37.43 | 4.2 | – | 96.32 | 15.78 | 8.9 |
| CMN 36114 | 7 | Femur | – | 13.19 | 2.67 | – | 115.25+ | 29.10 | 4.94 |
| CMN 34555 | 8 | Femur | 23.5 | 26.48 | 3.24 | 68.58 | 73.14 | 12.11 | 8.17 |
| CMN 35753 | No image | Limb | 10.55 | 32.53 | 2.97 | 32.41 | 43.07 | 9.56 | 10.92 |
| CMN 35747 | 10 | Fibula | 18.30 | 33.7 | 5.67 | 36.17 | 101.07+ | 12.95 | 5.94 |
| CMN 47323 | 11 | Tibia | 19.62 | 36.35 | 9.35 | 47.96 | 55.57 | 11.26 | 3.89 |

[1] All measurements in mm. NB = notch breadth, ND = notch depth, SB' = scar breadth at the base of the notch as seen on the medullary surface, SB[m] = scar breadth at its maximum width, SD = scar depth, NB/ND = ratio of notch breadth to notch depth indicating notch shape.

*Percussion notches* – arcuate notches on the fracture surface of a limb bone as seen from the cortical surface that result in breakage into the medullary cavity, leaving a negative cone of percussion on the interior surface of the bone. Helical fracture planes emanate from the percussion notch.

*Cone flakes* – thin flakes formed in concentric rings around percussion notches as a result of dynamic impact, sometimes exhibiting negative cones of percussion on the ventral face and small amounts of the cortical surface on the platform. Cone flakes can be detached or still attached to the interior surface of the percussion notch.

*Percussion events* – locations of percussion impact that induce helical fracture planes but exhibit a positive bulb of percussion and no percussion notch.

*Flake scars* – shallow concave surface features indicating the removal of a portion of the cortical thickness by percussion, producing a negative bulb of percussion on the core and exhibiting either a feathered or a hinged termination.

*Rebound flake scars* - flake scars around an impact notch on the cortical surface of limb bone caused by the upward rebound of the hammerstone removing flakes.

*Bone flakes* – thin fragments of thick cortical bone removed by impact that exhibit bulbs of percussion and feathered or hinged terminations. Bone flakes occur as two types, longitudinal or lateral (side-struck).

All selected bone fragments demonstrate helical fractures with smooth fracture planes, evidence they were broken while fresh. The cortical thickness ranged from 10.55 to 31.86 mm (mean = 19.9 mm). Evidence that dynamic impact produced the fragments is present in the form of bulbs of percussion, hackle marks, incipient percussion notches with attached cone flakes, broad flake scars, and step-fractured flake scar surfaces (Johnson, 1985). Broad arcuate percussion notches, shown by large notch breadth to notch depth (NB/ND) ratios, also suggest that dynamic loading broke the limb bones (Capaldo and Blumenschine, 1994). Percussion notches with these measurable features are reported in Table 1, and notch breadth to notch depth ratios (Fig. 1) were compared to notches on mammoth limb
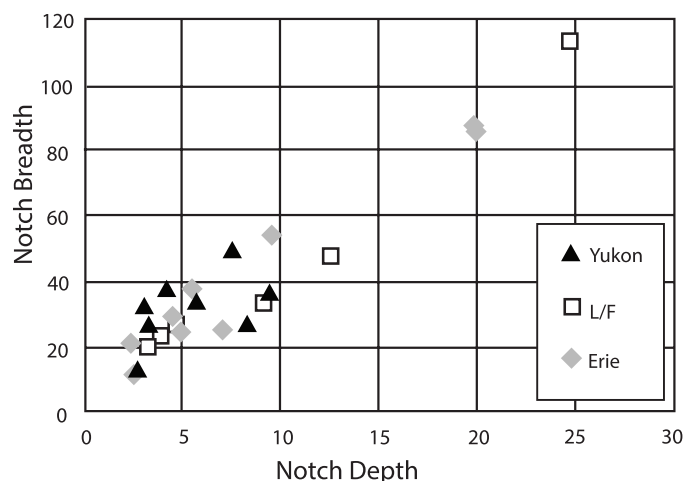


FIG. 1. Comparison of Yukon bone notch shapes with Pleistocene and experimental proboscidean notch shapes. Notch breadths and depths measured according to the method developed by Capaldo and Blumenschine (1994). The triangle represents notch breadth/notch depth (NB/ND) ratios of notches from the Yukon sample of proboscidean limb bones; the square represents NB/ND of notches present on mammoth limb bone fragments from the Lange/Ferguson site in South Dakota, USA; and the diamond represents NB/ND of notches made experimentally using hammerstone percussion on modern elephant limb bone in Erie, Colorado, USA.

bone from a late Pleistocene Clovis archaeological site (Hannus, 1989, 1990) and experimental notches produced on modern elephant limb bone by hammerstone percussion (Holen, K., and Holen, S.R., 2012).

Seven arcuate percussion notches were identified on thick cortical limb bone that exhibits negative cones of percussion. One incipient notch with an attached percussion (cone) flake was recorded. An impact event was identified that consists of a bulb of percussion on thick cortical limb bone. All nine of these impacts indicate that the bone was struck with a hard object that left evidence of percussion. One bone flake and one flake scar representative of percussion were also identified. Dated specimens in this paper were selected from the Paleontological Collections at the Canadian Museum of Nature, while the samples reported by Morlan et al. (1990) and Morlan (2003) were from specimens curated at the Canadian Museum of

TABLE 2. Radiocarbon and stable isotope data for the Yukon proboscidean bone specimens. Radiocarbon concentrations are given as fractions of the Modern standard and conventional radiocarbon age, following the conventions of Stuiver and Polach (1977). Sample preparation backgrounds have been subtracted on the basis of measurements of $^{14}$C-free whalebone. Note that $^{14}$C/$^{12}$C ratios for several of these samples were very close to zero after background subtraction, and the corresponding radiocarbon ages are quoted as lower limits at 2 sigma. Stable isotope values shown are quoted in the standard δ notation and were measured to a precision of < 0.1‰ on aliquots of ultrafiltered collagen.

| UCIAMS # | Sample name | $\delta^{13}$C (‰) | $\delta^{15}$N (‰) | fraction modern | ± | $^{14}$C age(BP) | ± |
|---|---|---|---|---|---|---|---|
| 101424 | Loc. 11A-11A/70 1290 & 1285 | −20.6 | 6.7 | 0.0028 | 0.0008 | 47100 | 2400 |
| 101425 | Loc. 22-22-78-19 | −22.1 | 6.3 | −0.0014 | −0.0032 | > 40600 | |
| 101426 | Loc. 11A-11A/76 S20 E125 2002 | −21.2 | 6.8 | 0.0030 | 0.0008 | 46500 | 2200 |
| 101427 | Loc. 11A-11A/76 S25 E140 2882 | −21.3 | 7.3 | 0.0006 | 0.0008 | > 49100 | |
| 101428 | Loc. 15 15/78-52 | −21.7 | 8.5 | 0.0001 | 0.0008 | > 51200 | |
| 101429 | CMN 36114 | −20.8 | 6 | 0.0006 | 0.0008 | > 49100 | |
| 101430 | CMN 47323 | −20.5 | 6.3 | 0.0138 | 0.0008 | 34420 | 490 |
| 101431 | CMN 35746 | −20.4 | 6.7 | 0.0019 | 0.0008 | 50500 | 3600 |
| 101432 | CMN 35753 | −20.9 | 6.2 | −0.0003 | −0.0008 | > 51700 | |
| 101433 | CMN 35747 | −20.9 | 8.6 | −0.0003 | −0.0008 | > 51700 | |
| 101434 | CMN 34555 | −21.2 | 6.5 | 0.0056 | 0.0008 | 41600 | 1200 |
| 101435 | 14N-79 A1383 | −21.2 | 5.9 | 0.0177 | 0.0008 | 32410 | 380 |
| 101436 | CMN 17969 | −18.6 | 4.7 | 0.0023 | 0.0008 | 48700 | 2900 |
| 101437 | 11A77 S35E109 3369 | −21.3 | 7.2 | 0.0373 | 0.0008 | 26420 | 180 |

TABLE 3. Collagen yield and quality indices for the dated specimens.

| UCIAMS # | Sample name | > 30k D collagen yield (%) | %N | %C | C/N (wt%/wt%) | C/N (atomic) |
|---|---|---|---|---|---|---|
| 101424 | Loc. 11A-11A/70 1290 & 1285 | 4.3 | 14.8 | 42.0 | 2.82 | 3.29 |
| 101425 | Loc. 22-22-78-19 | 1.5 | 13.1 | 40.7 | 3.1 | 3.62 |
| 101426 | Loc. 11A-11A/76 S20 E125 2002 | 3.8 | 14.8 | 42.8 | 2.88 | 3.36 |
| 101427 | Loc. 11A-11A/76 S25 E140 2882 | 3.2 | 14.5 | 41.0 | 2.82 | 3.29 |
| 101428 | Loc. 15 15/78-52 | 3.6 | 15.4 | 43.5 | 2.82 | 3.29 |
| 101429 | CMN 36114 | 9.7 | 16.1 | 44.2 | 2.75 | 3.21 |
| 101430 | CMN 47323 | 7.5 | 15.9 | 44.9 | 2.81 | 3.28 |
| 101431 | CMN 35746 | 8.0 | 15.7 | 44.4 | 2.82 | 3.29 |
| 101432 | CMN 35753 | 7.8 | 15.4 | 42.9 | 2.78 | 3.24 |
| 101433 | CMN 35747 | 6.9 | 15.8 | 43.9 | 2.77 | 3.23 |
| 101434 | CMN 34555 | 3.9 | 15.9 | 44.3 | 2.77 | 3.23 |
| 101435 | 14N-79 A1383 | 3.5 | 15.4 | 43.0 | 2.78 | 3.24 |
| 101436 | CMN 17969 | 5.3 | 15.6 | 43.6 | 2.80 | 3.27 |
| 101437 | 11A77 S35E109 3369 | 8.2 | 15.7 | 43.0 | 2.74 | 3.20 |

Civilization (now Canadian Museum of History), many of which had been transferred there from the collection at the Canadian Museum of Nature. Therefore, we are not re-dating specimens previously dated by Morlan, but instead conducting an independent study using different specimens exhibiting the same types of fracture patterns. In Morlan's study, 11 proboscidean fractured limb bones and 13 proboscidean bone cores and flakes from secondary deposits at Old Crow were dated using a slight modification of the standard collagen extraction method (Longin, 1971) by a team from Simon Fraser University, Department of Anthropology, using the McMaster University Tandem Accelerator Laboratory. The team also used an ultrafiltration method (Brown et al., 1988) to redate three of the bone cores. Both methods provided ages of 25 000 and 40 000 radiocarbon years ago on proboscidean bone specimens thought to have been modified by humans, although there was sometimes a ca. 5000 year discrepancy between the two methods. Specimens in the present study were dated by J.R. Southon at the Keck Carbon Cycle AMS Facility, University of California, Irvine, using the same ultrafiltration method used on some samples in the original study. Southon (pers. comm. 2015) was one of the team members in the original dating study. We predicted that the radiocarbon ages would fall within the same age range of 25 000 to 40 000 $^{14}$C yr BP for the Old Crow localities as hypothesized by Morlan (2003). Radiocarbon ages for the specimens used in this study are listed in Table 2, and data regarding collagen yield and quality are listed in Table 3.

## DESCRIPTION OF COLLECTING LOCALITIES

### Old Crow River Localities

The Old Crow Basin is the richest area for ice age vertebrate remains in Canada, having yielded more than 50 000 specimens representing nearly 80 mammal species. The bones are mainly exposed through natural erosion of the winding Old Crow River. They range from about 1.4 Ma (million years ago) to Late Wisconsin (about 12 000 $^{14}$C yr BP). About 150 fossil localities are known within the basin
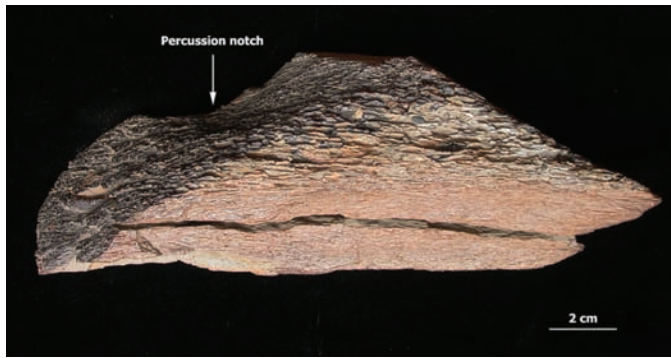
FIG. 2. Sample CMN 57090, 11A/70 1290 and 1285. Ventral view of mammoth limb bone (two refitted bone pieces) collected from Loc. 11A, Old Crow, Yukon. An age of 47 100 ± 2400 $^{14}$C yr BP (UCIAMS-101424) was obtained. Note broad arcuate percussion notch.



FIG. 3. Sample CMN 57091, 11A/76 S20 E125 2002. Dorsal view of mammoth limb bone flake collected from Loc. 11A, Old Crow, Yukon. An age of 46 500 ± 2200 $^{14}$C yr BP (UCIAMS-101426) was obtained. Note the two flake scars indicated by arrows.

(Harington, 2011). A composite section showing the layers of sediments from oldest to youngest is found in Morlan and Matthews (1978: Fig. 1). Stratigraphic details for Old Crow Loc. 12 and Loc. 15 are provided in Jopling et al. (1981) and Morlan (1996), respectively. A description of the point bar at Old Crow Loc. 11A is provided in Harington (1987).

*Klondike Gold Field Localities*

Ice age vertebrate remains near Dawson City are mainly exposed during placer mining for gold. Nearly 70 fossil localities are recorded in the region. Most of the bones, when found in place, occur in frozen organic silt ("muck" is the miner's term) just above the surface of gold-bearing gravel. It is worth noting that Dawson Tephra (about 25 000 $^{14}$C yr BP) has covered original grassy surfaces at several Dawson area localities (e.g., Nugget Gulch, where fossils on a grassy terrain surface indicate the presence of humans, wolves, Yukon horses, Dall sheep, and steppe bison about 30 000 $^{14}$C yr BP; Quartz Creek; Trail Gulch; Bear Creek; and Goldbottom Creek [Harington, 2011]).

DESCRIPTION OF SPECIMENS
AND LOCALITY INFORMATION

*Old Crow Locality 11A (67˚49′ N, 139˚54′ W)*

CMN (Canadian Museum of Nature) 57090 (originally designated by members of the Northern Yukon Research Programme as 11A/70, 1290 and 1285) is a lateral thick cortical limb segment probably from a woolly mammoth (*Mammuthus primigenius*). It was refit from two pieces that were cataloged separately and later were found to refit along a dry bone longitudinal fracture (Fig. 2). It exhibits a broad arcuate percussion notch (Table 1) with spiral fractures emanating from it that were produced when the bone was still fresh.

CMN 57091 (originally designated by members of the Northern Yukon Research Programme as 11A/76, S20 E125 2002) is a bone flake probably from a woolly mammoth

produced by percussion on thick cortical limb bone while the bone was still fresh (Fig. 3). The flake exhibits a platform, bulb of percussion, and hackle marks. Its maximum length is 139.1 mm, maximum width is 60.8 mm, maximum thickness of the specimen at the bulb is 20.7 mm, and the platform width is 14.9 mm. There are two flake scars on the dorsal cortical face of the flake produced by percussion. The first flake scar is 59.85 mm long by 22 mm wide and it ends in a feathered termination. The second flake scar is 40.98 mm long by 15.31 mm wide and ends in a V-shaped hinge termination. The second flake removed part of the first flake scar.

CMN 57092 (originally designated by members of the Northern Yukon Research Programme as 11A/76 S25 E140 2882) is a flat cortical limb segment probably from a woolly mammoth that exhibits an impact notch (Table 1) with a bulb of percussion on the medullary face (Fig. 4a) and a broad flake scar with hackle marks on the cortical face that removed a large area of the cortical surface (Fig. 4b). There is a second smaller flake scar on the cortical surface. A second flake scar on the medullary face was struck on a spiral fracture plane after the element was initially broken.

*Old Crow Locality 15 (67˚51′ N, 139˚49′ W)*

CMN 57093 (originally designated by members of the Northern Yukon Research Programme as 15/78-52) is a lateral segment of a thick cortical limb bone, possibly a femur of a woolly mammoth, with long helical oblique fracture planes. The segment exhibits an impact event with a bulb of percussion and hackle marks (Fig. 5). A flake scar removed part of the cortical surface.

*Old Crow Locality 22 (68˚03′ N, 139˚36′ W)*

CMN 57094 (originally designated by members of the Northern Yukon Research Programme as 22/78-19) is a lateral segment of thick cortical limb bone with an oblique spiral fracture and acute fracture planes. It exhibits an incipient notch (Table 1) that retains an attached cone flake (Fig. 6). There is evidence of probable anvil use consisting
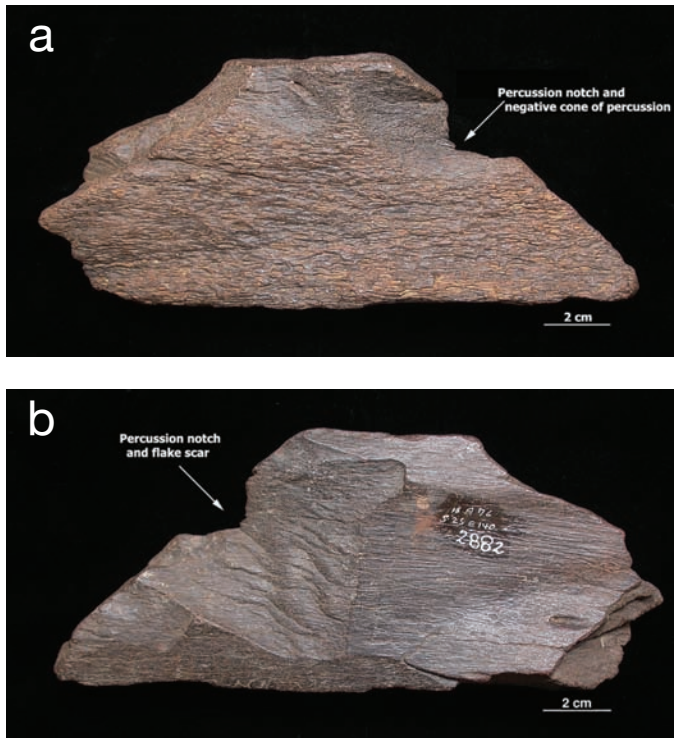
FIG. 4. a) Sample CMN 57092, 11A/76 S25 E140 2882. Ventral view of mammoth limb bone collected from Loc. 11A, Old Crow, Yukon. A non-finite age of > 49 100 ^{14}C yr BP (UCIAMS-101427) was obtained. Note ventral view of percussion notch and negative cone of percussion. b) Sample CMN 57092, 11A/76 S25 E140 2882. Dorsal view of mammoth limb bone collected from Loc. 11A, Old Crow, Yukon. Note dorsal view of percussion notch and flake scar.



FIG. 5. Sample CMN 57093, 15/78-52. Ventral view of mammoth limb bone collected from Loc. 15, Old Crow, Yukon. A non-finite age of > 51 200 ^{14}C yr BP (UCIAMS-101428) was obtained. Note spiral fractures and bulb of percussion.

of a broad bulge on the opposite broken plane across from the impact event.

*Dawson Area Locality 52 (63°52′ N, 139°16′ W), Eldorado Creek*

CMN 36114 is a lateral segment of a limb bone, probably a woolly mammoth femur, which exhibits broad oblique fractures with acute angles. A percussion notch (Table 1) with a small negative cone of percussion is present (Fig. 7). There is a rebound flake removed from the cortical surface at the point of impact.

*Dawson Area Locality 32 (63°43′ N, 138°40′ W) Gold Run Creek*

CMN 34555 is a lateral segment of a limb bone, probably a woolly mammoth femur, with broad oblique spiral fractures with acute fracture planes (Fig. 8). This cortical segment exhibits a percussion notch (Table 1).

*Dawson Area Locality 10 (64°4′ N, 139°22′ W), Hunker Creek*

CMN 35746 is a long lateral limb bone segment, probably from a woolly mammoth, that exhibits a side-struck flake

scar with a negative cone of percussion that terminates in step fractures (Fig. 9). The flake platform was a broken spiral fracture plane indicating that the flake was struck after the bone was initially broken. The flake scar length is 35.88 mm and the maximum flake width is 144 mm.

CMN 35753 is a cortical limb bone segment, probably from a woolly mammoth, that exhibits a percussion notch with two rebound flake removals on the cortical surface at the point of impact. There is a second percussion event consisting of an attached cone flake with step fractures. A rebound flake scar emanating from this impact point is 48 mm long. (No figure available.)

CMN 35747 is the mid-section of a fibula, probably from a woolly mammoth, with indications of dynamic impact at both broken ends (Fig. 10). The percussion notch (Table 1) exhibits a broad negative cone of percussion. The other end exhibits a long flake scar that terminates in a hinge fracture.

*Dawson Area Locality 12 (63°28′ N, 138°58′ W), Hunker Creek*

CMN 47323 is a lateral limb bone segment possibly from a woolly mammoth tibia. It exhibits a broad arcuate percussion notch (Table 1). The negative cone of percussion exhibits step fractures (Fig. 11). Anvil damage across from the point of impact consists of a triangular-shaped projection with the cortical surface removed by small flake scars.

## FURTHER TESTING OF THE BONE MODIFICATION HYPOTHESIS FOR HUMAN PRESENCE

The new radiocarbon ages on impact-fractured and flaked proboscidean limb bone indicate that two possible hypotheses can be developed to explain the observed breakage patterns on proboscidean limb bones in the Yukon: 1) humans caused the observed fracture patterns and thus entered Beringia sometime before 50 000 ^{14}C yr BP, and 2) there is some unknown geological process that causes these fracture patterns. We had previously rejected carnivore activity and trampling as the cause of the observed fracture patterns (Holen, 2006).
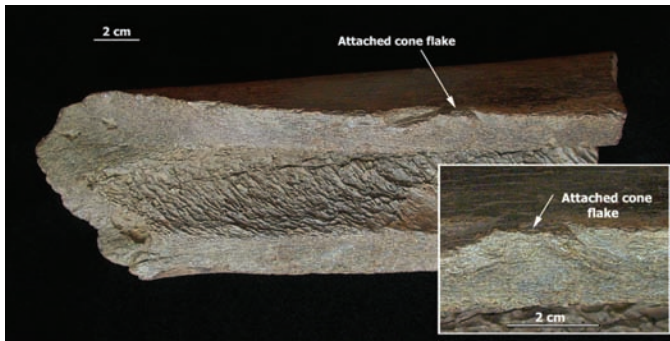
FIG. 6. Sample CMN 57094, 22/78-19. Ventral view of mammoth limb bone collected from Loc. 22, Old Crow, Yukon. A non-finite age of > 40 600 $^{14}$C yr BP (UCIAMS-101425) was obtained. Note attached cone flake. Inset photograph shows enlarged view of the attached cone flake.



FIG. 8. Sample CMN 34555. Dorsal view of mammoth femur collected from Loc. 32, Dawson area (Klondike), Gold Run Creek, Yukon, in 1968–69. An age of 41 600 ± 1200 $^{14}$C yr BP (UCIAMS-101434) was obtained. Note percussion notch.



FIG. 7. Sample CMN 36114. Ventral view of mammoth femur collected from Loc. 52, Dawson area (Klondike), Eldorado Creek, Yukon, in 1979. A non-finite age of > 49 100 $^{14}$C yr BP (UCIAMS-101429) was obtained. Note percussion notch. Inset photograph shows dorsal face of percussion notch with rebound flake scar.



FIG. 9. Sample CMN 35746. Dorsal view of mammoth limb bone collected from Loc. 10, Dawson area (Klondike), Hunker Creek, Yukon, in 1970. An age of 50 500 ± 3600 $^{14}$C yr BP (UCIAMS-101431) was obtained. Note side-struck flake scar terminating in step fractures.

For about 15 years, the first and third authors have been testing the hypothesis that when humans first entered North America, the taphonomy of proboscidean bone changed. This research is ongoing. To date, we have conducted extensive research in more than 20 paleontological and archaeological collections over the western half of the United States, in Mexico, and in Canada. The fractured patterns observed on the Yukon bone fragments are sometimes found on proboscidean limb bone from faunal collections that are listed as being from the Rancholabrean Land Mammal Age (LMA). However, we have never recorded these fracture patterns on proboscidean limb bones that are listed as being from the Irvingtonian LMA. In two collections, we have found these fracture patterns on proboscidean limb bone listed as Sangamon in age (Oxygen Isotope Stage 5). During this research, we developed a null hypothesis stating that if these fracture patterns were found on proboscidean bones from Irvingtonian-age deposits, this finding would suggest that some natural process was probably also making these types of fracture patterns because it seems improbable that humans were present then. While the beginning of the Rancholabrean

LMA has not been extensively dated, the best age estimate for the beginning of this LMA is between 210 000 and 160 000 years ago, when *Bison* sp. first entered the area of North America south of 55° N Latitude (Bell et al., 2004). Our research indicates that this type of fracture pattern enters the paleontological record sometime after 210 000 years ago, but was not present before that time. While this observation does not demonstrate that humans were responsible for the breakage patterns, it does indicate that some new taphonomic agent entered the paleontological record after the beginning of the Rancholabrean LMA. Humans in North America during terminal Pleistocene Clovis occupations (Hannus, 1989, 1990; Miller, 1989) and pre-Clovis occupations (Holen, 2006, 2007; Holen and Holen, 2014) also produced these same fracture patterns. These breakage patterns have been replicated by experimental breakage of elephant limb bone using hammerstone percussion (Stanford et al., 1981; Holen, K., and Holen, S.R., 2012). This evidence suggests that the first hypothesis cannot be rejected and that there is some evidence supporting it.

The second hypothesis is more difficult to test because the full range of proboscidean bone breakage by geological processes has not been studied extensively. The geological contexts of proboscidean sites we have studied have consistently ruled out geological processes as the agent of
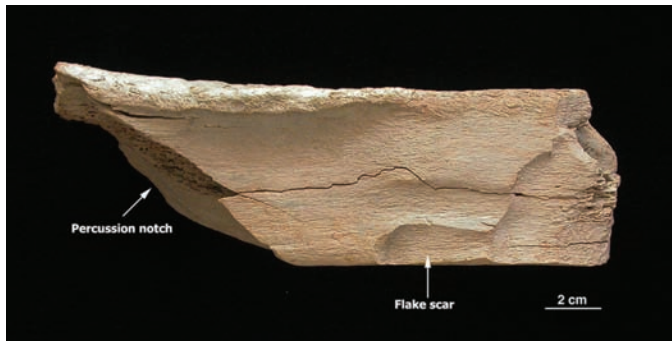
FIG. 10. Sample CMN 35747. Dorsal view of mammoth fibula collected from Loc. 10, Dawson area (Klondike), Hunker Creek, Yukon, in 1978. A non-finite age of > 51 700 ^{14}C yr BP (UCIAMS-101433) was obtained. Note percussion notch on the left and the flake scar on the right terminating in a hinge fracture.



FIG. 11. Sample CMN 47323. Ventral view of mammoth tibia collected from Loc. 12, Dawson area (Klondike), Hunker Creek, Yukon, in 1989. An age of 34 420 ± 490 ^{14}C yr BP (UCIAMS-101430) was obtained. Note the percussion notch at the top and a triangular-shaped projection on the bottom with small flake scars.

fracturing and flaking of fresh limb bone. These breakage patterns are not produced by low-energy geological processes that form loess and fine-grained alluvium (Holen, 2006, 2007; Holen, S.R., and Holen, K., 2012). Proboscidean limb bones might be broken when they strike stone cobbles in high-energy alluvial events; however, no evidence supporting this hypothesis has been published.

Further testing of these two hypotheses should be conducted in museum collections, including those from 2008 excavations at several sites in the Old Crow basin, some of which date to more than 200 000 years old (Kuzmina et al., 2014), and in collections from excavations in deposits of Sangamon and Irvingtonian ages, as described in Irving et al. (1986) and Jopling et al. (1981). Additional excavations of in situ proboscidean sites in geological deposits of Rancholabrean and Irvingtonian Land Mammal Ages in the Yukon should be conducted to study these taphonomic patterns in more detail and to determine whether these types of fracture patterns on proboscidean limb bones occur in very old geological deposits.

CONCLUSION

Radiocarbon ages reported in the present study (Table 2) do not support the hypothesis that bones modified by percussion technology are observed only in geological or paleontological deposits with ages of less than 40 000 ^{14}C yr BP (Morlan, 2003). Six of the radiocarbon ages are non-finite, and five of those are greater than 49 100 ^{14}C yr BP. Three other ages range from 46 500 to 50 500 ^{14}C yr BP with large standard deviations, and these ages may also represent non-finite ages. Only one radiocarbon age of 34 420 ± 490 ^{14}C yr BP falls within the predicted age range. One other radiocarbon age of 41 600 ± 1200 ^{14}C yr BP falls within two standard deviations of the predicted age range.

On the basis of this series of radiocarbon ages, we reject the hypothesis that percussion-induced notches and bone flaking enter the paleontological record only less than 40 000 radiocarbon years ago. Our data suggest that
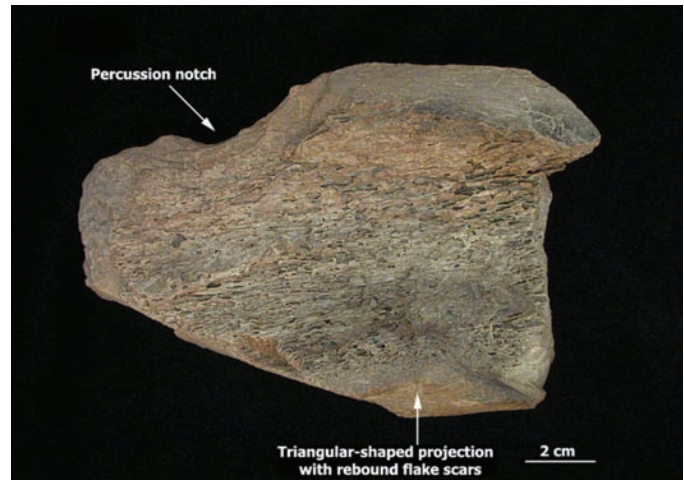
these percussion fracture patterns enter the paleontological record at some time prior to 50 000 radiocarbon years ago. To accurately date the specimens older than 50 000 years, we must turn to other dating techniques such as uranium-series, or specimens must be found in situ and the sediments dated by tephrochronology or some form of optically stimulated luminescence. For proboscidean fragments older than 50 000 radiocarbon years, unless DNA analysis can be applied, the identification of the species is not possible because mastodons as well as mammoths were present in the Yukon during the last interglacial (Sangamon, Oxygen Isotope Stage 5, 125 000 – 75 000 BP) (Zazula et al., 2014).

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