

16. UNDERWATER CARCASS STORAGE AND PROCESSING OF MARROW, BRAINS, AND DENTAL PULP: EVIDENCE FOR THE ROLE OF PROBOSCIDEANS IN HUMAN SUBSISTENCE

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ABSTRACT

Skeletal material of Late Pleistocene proboscideans in the North American Great Lakes region is often preserved in fine-grained, organic-rich sediment characteristic of small lakes and wetlands. Patterns of spatial distribution and articulation of bones often suggest that carcass parts were emplaced as multiple clusters of anatomically disparate butchery units, each including multiple bones. Clusters of skeletal material are sometimes associated with features that may have served as anchors intended to keep carcass parts tethered to a selected location within a pond, despite gas accumulation within soft tissues. One type of anchor consists of lithic material ranging from sand to gravel, where these sediments appear to have occupied a cylindrical container that was probably a length of intestine from the butchered animal. One site with well-documented “clastic anchors” also preserved two “marking posts” (an inverted main axis of spruce and an unidentified lateral axis) extending

into sediment below the bone horizon but truncated by decomposition at the bone horizon. Each post probably extended to the pond surface at the time of emplacement and would have been visible from shore. These features suggest a practice of securing, concealing, and returning to utilize groups of nutritionally significant carcass parts stored underwater. Ethnographic parallels and rationales (extended time and reduced uncertainty of resource access) for this behavior are known, and experimental studies of subaqueous meat storage using deer heads, legs of lamb, and an adult draft horse show it to be effective over timescales ranging from months to years.

16.1 INTRODUCTION

In 1945 and for almost three decades thereafter, vertebrate palaeontology at the University of Michigan was represented mainly by Claude W. Hibbard. “Hibbie’s” principal interests were in



Pliocene–Pleistocene small-mammal faunas of the North American Great Plains, but like his predecessors, E. C. Case and (briefly) J. T. Gregory, he also dealt, somewhat reluctantly, with finds of Pleistocene megafauna encountered locally by farmers and excavators pursuing their normal activities. Most of these specimens were mastodons (*Mammut americanum*), but there were a few mammoths (often referred to *Mammuthus jeffersonii*). Looking back over almost 70 years of his unit's history, and a collection that then included over a hundred accessioned proboscideans, ranging in completeness from single teeth or bones to significant portions of skeletons, Hibbard observed late in his career (pers. comm., A. Holman August 1984; G. R. Smith October 2019) that hardly a year had passed without another report of a proboscidean from somewhere in the southern half of Michigan's Lower Peninsula. Most of these were in depressions on the late glacial landscape, typically in peat or marl that had formed in kettle lakes, small ponds, or wetlands. Exasperated at how often recovery of such specimens took him or his staff away from projects on the small mammal faunas he loved, he was heard on multiple occasions to "swear that there is a ... mastodon in every ... low spot in Michigan!" His colleagues never held his hyperbole (or his swearing) against him, as it seemed clear to most that many mastodons were simply unfortunate enough to have fallen through winter ice and become stuck or drowned in boggy areas or ponds. No mainstream vertebrate palaeontologist at the time anticipated issues that would have warranted mapping such specimens *in situ* or undertaking taphonomic analyses. Hibbard's work ethic was legendary, and his contributions to his field seminal, but mastodons were never his focus.

Fast-forward a few more years, and other young palaeontologists joined the University of Michigan faculty, again bringing with them interests that did not include mastodons, but within the first two months of employment for one of them, two more mastodons were reported, one of which presented such an unexpected suite of features that it catalyzed a growing curiosity. The Pleasant Lake

site yielded bones (preserved in peat) with disarticulation marks, cutmarks, green-bone fracturing, use wear, impact features, and evidence of burning (12,576–11,841 calBP, calibrated years Before Present; Fisher, 1984a). These features were unexpected for an animal suspected of having died by accidental entrapment, and undergone disarticulation solely through processes of soft-tissue decomposition, without intervention from any external agent of disruption. Within a few more years (bringing another few mastodons; Fisher, 1984b), it began to seem that a number of these partial carcasses preserved traces of butchery activity by humans. However, even this unorthodox proposition did not fully explain the character of these occurrences. For one thing, their depositional settings were almost uniformly aquatic. The "bone horizon" within sediment sequences was typically well marked by the stratigraphic positions of medium-density elements, such as vertebrae, and where palaeo-depth could be estimated, it seemed that water on the order of 1–2 meters deep must have covered the pond bottoms on which those bones had lain. Surely, humans did not process carcasses underwater!

If humans had processed these carcasses, where and how had the butchery taken place, and how (and why) did carcass parts end up on pond bottoms? There might have been some point to throwing bones (from which meat had already been removed) into a pond, diminishing the odds that olfactory cues might attract scavengers intent on their own demands for trophic resources. However, many of the larger bones, not to mention sets of bones that retained anatomical associations, seemed too large to fit a model involving only casual disposal. What site formation processes could account for the character and complexity of much of our record of Pleistocene proboscideans?

At the request of symposium organizers, this paper is a retrospective account of the context and origin of a brief report introducing ideas on underwater meat storage (Fisher, 1995) and a preliminary review of more recent discoveries that bear on these ideas. I will also attempt to address issues that remain open and require new studies.

16.2 BIRTH OF AN IDEA

The Heisler mastodon site, in Calhoun County (south-central), Michigan, began as a modest investigation of a small number of bones discovered by a father-son farming team. They had been digging trenches to lay new, perforated plastic “tile line” through a low area on one of their fields, to replace the older system of cylindrical clay tile that had “silted-up” and no longer carried the water that often accumulated there, off to the edge of their field. The Heislars remembered encountering a few “big bones” when they had installed the old clay tile, and now more bones were turning up in the same depression. They finished laying their new tile lines but were curious enough to report their discovery. Initially accompanying Al Holman of Michigan State University and Ron Kapp of Alma College, the University of Michigan began to explore this site as thoroughly as possible. The Heisler’s operation was large enough that they were able to let us attempt to recover more of this animal, as long as we backfilled our excavation as we went, limiting our impact at any given time. Most such sites had been dealt with quickly, as palaeontological salvage operations, but the Heisler site offered an opportunity for a different approach.

Over the next eleven years (1984–1994), working mostly on weekends, spring through autumn, with a few student helpers and a small but dedicated crew from the Huron Valley Chapter of the Michigan Archaeological Society, we excavated much of the Late Pleistocene pond that underlay this low area on the Heisler farm. In doing so, we recovered over 50% of the skeleton of a male mastodon, about 16 years old at death. The largest surprise of the early phases of this work was that the parts of this animal were not in just one area of the pond. Instead, they were in multiple areas within the pond. The animal was preserved mostly as diffuse scatters of disarticulated bones, separated from other such scatters. However, there was one discrete concentration, much smaller in area than the diffuse scatters. This locus preserved bones of what appeared to have been three body parts, all

within an area less than a meter across. Each part was represented by a suite of anatomically contiguous bones, still associated, but most no longer articulated. Figure 16.1 shows one of these units (right ribs 1–4) as it would have appeared after removal from the carcass. Can we rule out transport of each rib to the pond independently? Perhaps not, but interpreting them as having moved as a unit is a more parsimonious explanation for their joint presence at one location. As such, they probably arrived at the pond, held together only by associated soft tissues, because neither the intervening thoracic vertebrae nor the sternebrae that would have connected them in life were present in the cluster. The other bones in this cluster were a sequence of cervical vertebrae and a sequence of thoracic vertebrae from just behind right ribs 1–4. Following the same reasoning as before, these suites of bones were probably also transported as units. However, given the limited soft-tissue connections between two noncontiguous segments of axial skeleton and an intervening slab of four ribs and associated tissue, this cluster is unlikely to represent fewer than three units.

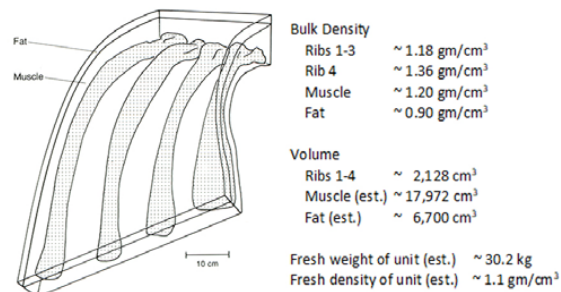


Figure 16.1: Schematic drawing of right ribs 1–4 of the Heisler mastodon (UM 61888), as they might have appeared as a freshly extracted butchery unit, surrounded by soft tissue at the time of emplacement in the pond where parts of the carcass of this animal were stored. Tissue volume and density estimates permit rough calculation of the fresh weight (~30.2 kg) and bulk density (~1.1 gm/cm³) of this butchery unit.

The diagram in Figure 16.1 was prepared decades ago (Fisher, 1989) and is re-used here to show the history of the idea rather than to defend details of the physical model it summarizes. Knowing more about proboscidean osteology than I did

then, I would now draw the ventral ends of these ribs closer together, reducing the implied volume of intercostal musculature and better representing the imbricate relationships of ribs in the lateral wall of the anterior portion of the proboscidean thorax. In other ways as well, I may have over-estimated the volume of soft tissue associated with this carcass unit, and I never meant the partitioning of muscle and fat to be anything more than a graphic approach to placing reasonable constraints on the fresh mass and bulk density of this unit. Even allowing for some reduction of soft tissue volume, this is not a carcass part that could have been tossed casually from the shore of the pond to its resting place. Once submerged in pond water, this unit would likely have been negatively buoyant, remaining at least initially on the pond bottom, but why and how did it get there in the first place?

Not far from the concentration of carcass parts described above was another surprise, a vertically oriented main axis of spruce (*Picea* sp.), about 10 cm in diameter at its upper end (Fig. 16.2), where it was truncated by decomposition, at the local level of the bone horizon, about a meter below the surface. From here, the main axis extended about 80 cm further into underlying sediment. Tracing the trunk downward while it was still *in situ*, its diameter got smaller, and its side branches all angled outward and down, showing that the apex of the



Figure 16.2: Oblique view of vertically embedded spruce main axis in lacustrine marl at the Heisler mastodon site. Upper end of axis is truncated by decomposition at the stratigraphic level of the main bone horizon. This feature is interpreted as a “marking post” that would have originally been visible from shore, indicating the location of stored carcass parts within the pond. Lower margin of chalkboard provides scale (cm).

main axis was lowermost. Overall, wood was not common in the pond sediments, but it did often occur in association with bones of the mastodon. In these cases, it was typically unburned branches of spruce (although some partially burned branches were also found), and it almost always lay parallel to bedding. In only one other instance, located near a diffuse scatter of bones in the pond, did we find wood (in this case a lateral axis) oriented vertically. What mechanism apart from human activity could account for this orientation?

Perhaps the strangest type of feature at the Heisler site was again associated with concentrations of carcass parts, but explaining its discovery requires describing our excavation methods. We realized that this site might be extensive and that we needed methods that permitted recovery of small items, while also allowing us to finish the job before our careers ended. Our approach involved five modes of processing sediment:

1. Reconnaissance: For our first pass over a given portion of the site, we used stainless steel probes about 2 meters long, inserted into the surface of the field on a hexagonal pattern at ca. 15–20 cm spacing. This gave us advance warning of large bones, although it only occasionally registered small bones.
2. Coarse recovery: Our standard approach for excavation was a technique we called peeling—forcing a shovel blade horizontally through sediment 2–5 cm below the current surface. This cut through sediment and risked marking a bone, but by listening closely and gauging resistance, we avoided excessive damage.
3. Fine recovery: This was typical use of trowels to slice sediment horizontally, again using all senses to avoid damage to specimens, shifting to use of bamboo or other wooden probes to protect bone surfaces.
4. Delicate recovery: In the immediate vicinity of specimens that were difficult to understand from visual cues, we defaulted to using only bare fingertips and small wooden probes.
5. Bulk recovery: To preserve complex relation-

ships, we undercut and removed blocks of sediment, returning them to the lab for archiving or for dissection under more controlled conditions.

The feature illustrated in Figure 16.3 was discovered while peeling down from the surface. Below the plow zone was a peat stratum that extended throughout the pond basin. This peat consistently displayed a hexagonal pattern of desiccation features that provided visual confirmation that the stratigraphic sequence was locally intact. All penetrations of the peat stratum, such as the Heislars' tile-line trenches, were immediately recognizable by their truncation of both the peat and its desiccation features. A pollen analysis by Bearss and Kapp (1987) established that the peat was early Holocene in age, and the desiccation was probably

mid-Holocene. Underlying the peat was a marl sequence, the uppermost portion of which generally preserved the lower ends of desiccation fractures passing through the peat and in-filled with dark muck soil from above the peat. The bone horizon was within the marl sequence and typically below desiccation features (except near the pond margin). As noted above, it was usually about a meter below the surface, but it deepened toward the pond center and rose toward the pond margin. A normal array of desiccation features was present in this location.

Approaching the bone horizon in the area shown in Figure 16.3, we reduced peeling depth to 2–3 cm. On one peeled surface (level #1 in Fig. 16.3C), only marl was exposed, but just 3 cm below this, the shovel's motion produced the

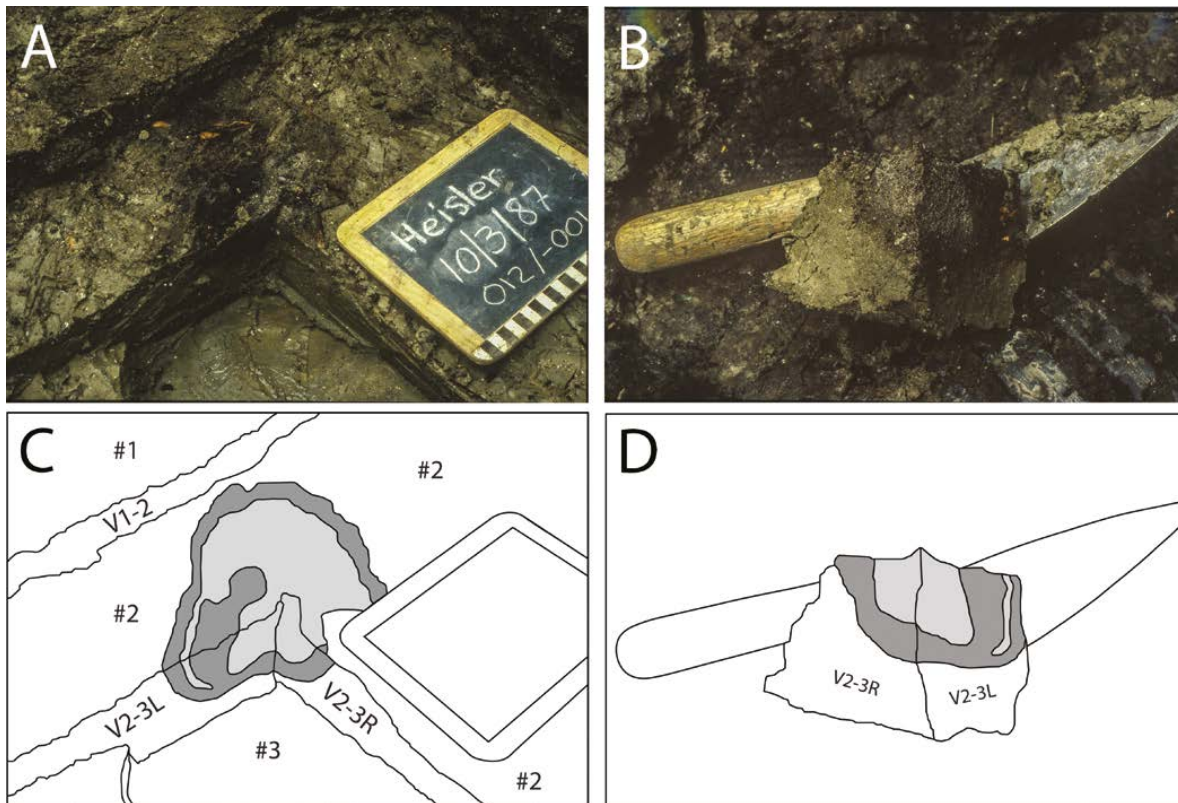


Figure 16.3: *In situ* "clastic anchor" at the Heisler mastodon site. **A**, lower margin of chalkboard shows scale (cm); chalkboard lists site data. **B**, quadrant of "clastic anchor" resting against trowel (28 cm total length) after removal from foreground in A. **C**, interpretive diagram of image in A. Numbered surfaces represent successive stratigraphic levels: #1, just above level at which feature appeared; #2, surface at which feature appeared, minimally cleared; #3, level below feature, accessed to remove quadrant shown in B. V1-2, vertical surface between levels #1 and #2; V2-3L, vertical surface between levels #2 and #3, exposure left of quadrant corner; V2-3R, as before, but right of quadrant corner. Dark gray tone, zone of brown plant material surrounding feature; light gray tone, feature interior of sand, gravel, charcoal, and wood fragments. **D**, tracing of quadrant removed in B. Graphical symbols as in C, but vertical surfaces R and L reversed because of rotation of quadrant.

scraping sound of steel-on-sand. Switching to a trowel, a roughly horizontal surface just below this was minimally cleared, revealing a roughly oval area of dark brown to black finely-ground plant material, light gray sand, scattered gravel clasts, and fragments of wood and charcoal, all surrounded by undisturbed marl (level #2 in Fig. 16.3C). A schematic diagram of a horizontal section (just below level #2, with major and minor diameters of 35 and 25 cm) through the feature was published in Rhodes et al. (1998: fig. 1). Additional details are provided in Figures 16.3C and D, showing two vertical sections and a third, horizontal slice (level #3) cut with the trowel to remove one quadrant of the feature (Fig. 16.3D). Based on the profiles revealed there, the mass as a whole had the form of the lower hemisphere of what might originally have been an ovoid object sitting on the ancient pond bottom, nestled into soft marl. This interpretation was corroborated by removal of additional sections of the structure, after which the whole feature was returned to the lab for dissection and archiving.

Our field observations showed that this feature was isolated from any other source of sand or gravel or any accumulation of plant material within the local stratigraphic section. The contact between marl and the peripheral zone of plant material was sharp, with no evident mixing of these materials. The zone of plant material was in most places 1–2 cm thick around the entire downward-facing surface of the hemisphere. Its boundary with the generally inorganic interior of the mass was more irregular, or even gradational. One complication of this contact was a lobe of plant material that was darker in color (varying from brown to black, with included charcoal) and extended into the space otherwise occupied by sand (left side of feature in Fig. 16.3C).

Even after observing the geometry of this feature, we had no more than a hunch as to how it could have originated, what accounted for its internal zonation, or what had happened to the upper hemisphere of this putatively ovoid mass. The part of the problem that seemed most tractable was

the nature of the brown zone of plant material. I recalled published accounts of intestinal material encountered during mastodon excavations (e.g., Dreimanis, 1968), but in such cases the plant material was coarser, and it was not associated with sand or gravel. Because Ron Kapp had recently done a palynological study of the Heisler site (Bearss and Kapp, 1987), I asked if he would analyze a sample of the marl immediately outside the hemispherical mass to compare its pollen content with that of a sample from the zone of brown plant material around the periphery of the mass. As recounted in Birks et al. (2019), the marl yielded the same pollen profile documented by Bearss and Kapp (1987), representing the year-round pollen rain that had accumulated elsewhere within pond sediments. However, in the peripheral brown zone, Ron found only pollen produced in late summer and autumn. Spruce pollen, which forms and disperses in spring and had been common in the marl, was conspicuously absent.

By the time I heard this report, I had made and analyzed a thin section from the proximal end of the Heisler mastodon's left tusk, which we had found (out of its alveolus) with another scatter of material, not associated with the skull. The season of death (deduced from analysis of the last-formed incremental features of tusk dentin) was autumn (Fisher, 1987), consistent with Ron's pollen analysis. This strengthened the "hunch" mentioned above, to the point that I dared formulate a more complete hypothesis for the nature of the feature in Figure 16.3. The peripheral zone of plant material probably reflected chewed and partly digested contents adhering to the inner wall of a piece of the Heisler mastodon's large intestine. The autumn pollen profile of this material would be expected in vegetation of the season, ingested shortly before death. The sand and other material filling the lumen of the intestine was unexpected, but could have been introduced by humans to transform a short length of intestine (from which most of the normal contents had been removed) into a moderately dense container that might function as an anchor. Assuming we learn why humans were in-

terested in making an anchor, an issue to which we return below, the “lower hemisphere” we recovered could have been simply the portion of the original anchor that was preserved because it settled into the soft, anoxic setting of marl on the pond bottom. The upper hemisphere of the anchor would have protruded into better-oxygenated water above the pond bottom, where it would have been subject to scavenging by frogs, fish, and possibly turtles, allowing its confining intestinal tissue to disintegrate, and the upper half of its contents to disperse before additional sedimentation could protect that part of the anchor. The intestinal tissue confining the lower half would have disintegrated as well, but this simply juxtaposed, without mixing, the anchor contents and surrounding marl. A final footnote on this interpretation is that the lobe of dark plant material extending into the sand on the left side of the feature in Figure 16.3A and C could reflect miscellaneous contents compressed between intestinal walls pulled into an overhand knot used to secure one end of the length of intestine. How the other end was secured, or even how long the anchor was originally, is unknown.

In full disclosure, a recent attempt to improve knowledge of plant remains from intestinal contents of the Heisler mastodon produced results that conflict with the above account (Birks et al., 2019). A different sample, from a second anchor-like feature at the Heisler site yielded pollen characteristic of spring rather than autumn. Unfortunately, revisiting Ron Kapp’s analysis was not an option. Several years after he notified me of his finding (pers. comm., R. Kapp December 1987) he was diagnosed with a brain tumor, from which he succumbed before he could publish his work. Attempts to follow up with his family and a collaborator yielded no new documentation. Birks et al. (2019) discuss three possible reasons for the different outcomes of their analysis and prior analyses, but at this time, this problem remains unresolved. Overall, the Heisler site yielded two other anchor-like features that were similar in character, and a fourth was probably present as well. One of our volunteers, after witnessing the attention fo-

cused on the feature in Figure 16.3, commented that he “probably should mention” that an hour or so earlier, while working in another locus, he had encountered something “like that one, except made only of gravel.” Not realizing its potential significance, he had shovelled through it.

Before continuing, we should return to the skull, mentioned briefly above. The mandible was no longer part of the same unit; it was found elsewhere at the site and more than a meter deeper in the sediment, where it had settled through the entire marl sequence until its dense cortical bone reached hydraulic equilibrium with underlying silty clay. As noted above, the left tusk had been removed, but the right tusk was still inside its alveolus and had been rotated forcefully until it jammed. The palate and basicranium are the densest parts of the skull, and with the mandible out of the way and the rotated right tusk extending roughly parallel to the pond bottom, the left side of the basicranium had settled more deeply into the marl. This meant that the dorsal aspect of the skull roof was inclined laterally. On removing sediment from the skull roof, we saw an array of gouges (cleaned out only with a gentle spray of water) that could all have been made by the same object (Fisher, 1987) perhaps while removing hide, or a layer of subcutaneous fat, from the skull roof. Another instance of minor damage was that one of the unfused exoccipitals had been removed, transforming the foramen magnum into a larger opening through which one hand of an adult human could have just fit, allowing access to the brain.

Brief descriptions of the Heisler site have been included in several previous publications (e.g., Fisher, 1987, 1995, 2009), but the site as a whole has not yet been described. Multiple dates are available, most notably, an AMS date on bone collagen (XAD-purified gelatin hydrolysate), returning a calibrated age of 13,825–13,361 calBP and an AMS date on plant material in the anchor-like feature in Figure 16.3, yielding a range of 13,476–13,009 calBP (Birks et al., 2019). What remains to discuss here, before moving to other sites and issues, is how the observations above influence a de-

veloping model of site formation processes. First, why would carcass parts like the one represented by right ribs 1–4 have been brought from a mastodon death and butchery site and deposited in a pond? We need not be unduly concerned about how far such parts were transported. The post-glacial landscape of this region was dotted with similar ponds, so if stashing carcass parts in ponds was normal practice, a pond might have been found near almost anywhere a mastodon might have died. The two vertical posts suggest that deposition of carcass parts in ponds was not just a matter of disposal. Time and energy would have been required to install such posts. If the posts were installed in autumn, the time of death supported by tusk analysis, the simplest method would be for someone to swim with a post to the selected location in the pond, point the post's smaller end downward into the marl, and thrust it deeper in several abrupt, inertial movements. The upper ends of posts would have initially projected above the air-water interface and could have been used as visual cues to return to and retrieve carcass parts on the pond bottom. In time, the wood immersed in oxygenated pond water decomposed, while the portion of each post embedded in marl was preserved. This suggests that the carcass parts that were brought to and deposited in the pond would remain a valuable resource for some time. Is this really a viable strategy for meat storage? Over what time interval would it operate, and what other costs and benefits might emerge? The density calculation for the carcass part associated with right ribs did not suggest it would require any type of anchor during its early phase of storage, but carcass parts with a larger fraction of fat might be different in this regard. It quickly became clear that parts of this problem would be difficult to resolve without turning to a more experimental approach, which I discuss below.

On the other hand, parts of the problem might be explored as “thought experiments.” If nothing else, these might clarify questions that should be formulated explicitly in hope that new data might bear on them. For example, why were carcass parts deposited in multiple locations in a pond, each

separated from others by some distance? I have not yet shown this directly because completing a general map of the Heisler site is a task requiring more time than is available for this paper, but my impression is that the Heisler site involved at least six locations in the pond. At one end of a spectrum of patterns of element distribution, we have the dense concentration including right ribs 1–4. These were apparently deposited, but never retrieved or utilized. At the other end of the spectrum are larger groups of carcass parts that were apparently retrieved and utilized, but not in a way that removed them from the pond setting. Some of these bones show marks suggesting tissue removal, and were found scattered in the pond—the “diffuse scatters” noted above. However, distinguishing “diffuse scatters” from each other is a statistical problem requiring a quantitative approach. Some utilization of stored parts could have occurred in a season, and in a manner (e.g., retrieving parts in winter, through a hole in ice, followed by dragging parts onshore) that would have removed bones from the pond setting. This could be one explanation for parts of the carcass we did not recover.

In general, multiple locations for a stored resource suggests a strategy of risk reduction—that leaving the entire resource in one location might somehow raise the odds of losing it to a competitor. Was that competitor a non-human scavenger? Or was it one or more other human occupants of the region? The former category might have included now-extinct taxa such as the short-faced bear (*Arctodus simus*), about whose behavior we know relatively little. On the other hand, human ingenuity might be even more likely to short-circuit the “marking post” strategy used at least twice at the Heisler site, so whether that behavioral element was used rarely or routinely may have implications for the agency of competition. Even more broadly, risk reduction in the context of managing nutritional resources speaks to the reality of the prospect of at least seasonal nutritional stress for humans in Late Pleistocene North America, and it highlights the important role that proboscideans may have played in human subsistence.

One topic I intend to leave largely “on the side” in this discussion is the matter of resource acquisition. This is not because I view the issue as unimportant. It is rather because I have addressed the issue previously and would prefer here to focus here on different questions. I still regard Fisher (1987) as a source of data and probabilistic arguments favoring the idea that a significant number of Late Pleistocene mastodons in the Great Lakes region of North America were more likely hunted than scavenged. This applies especially to those that show evidence of butchery, that were male, that died relatively young, and that turn out to have died in autumn. The most significant expansion of this interpretation was proposed in Fisher (2009) and came about mainly because of discoveries at sites that had not been considered previously. One new site category yielded mainly crania, some of which were male and some female, some of which were found in almost perfect condition and others that preserve little more than the palate and basicranium (Barondess, 1996). I suspect these were mostly natural deaths on which little externally accessible tissue remained, but they were evidently procured and considered worth storing in ponds for later recovery and extraction of brain and nasal mucosa, as first represented by the St. Johns mastodon (Fisher, 2009). The second newly recognized phenomenon involved adult males that had died in late spring or early summer, as victims of musth conflict. These individuals seem to have died during their own reproductive quest, after which some were apparently scavenged by humans.

A final set of questions that already demand answers concerns the logistics of bringing carcass parts to the pond, installing them underwater, and retrieving them for later use. One of the goals of strategic disarticulation in the earliest stages of butchery would be to reduce the original carcass to manageable units. What is “manageable” depends mostly on how many people are involved, leavened with a little ingenuity. Numerous transport options exist, like dragging a piece of hide loaded with carcass parts, and if snow had fallen, the task only becomes easier. Even without snow, a make-

shift travois would reduce friction while still supporting much of the weight through contact with the ground. However engineered, large portions of a mastodon, including its skull, mandible and tusks (even if it was a young individual), did end up in pieces on the bottom of a pond.

As for how humans installed carcass parts in ponds, autumn death suggests that a frozen pond was not required. The single largest element being installed was the skull and tusks, and although a fresh skull is heavy, the extensive system of paranasal sinuses in proboscidean skulls makes them float readily (Frison and Todd, 1986). The problem is thus not how to move a skull to the “right place” in a pond (swimming alongside it will do), but how to sink it when you get there. The answer to this is likewise direct—simply puncture the thin cortical bone of the cranial roof to allow air to escape and permit water to flood the sinus system. The skull roof of the Heisler mastodon has several such holes, leaving only the question of which were made when sinking it and which were made later, at the time of recovery and further processing. Other carcass parts would not have been so accommodating, but neither was their bulk density great enough to pose insurmountable problems. I suspect that buoyancy was again an ally. A dead proboscidean is more than a massive nutritional resource. It also yields tissues and materials suitable for use in various stages of processing. Lengths of intestine could have been removed and most of their contents discarded. Humans could then tie off one end, inflate the intestine with air, tie off the other end, and bend the inflated column around to circumscribe a larger area. Lashing this circular bladder together and adding strips of rawhide across the center would provide support to several carcass parts while ferrying them to their drop-off spot. The most effective approach for this would be to let carcass parts “ride low” in the water so that most of their mass was buoyed by displaced pond water. All that had to be supported by floatation was the fraction of a gram per cubic centimeter by which the density of the fresh carcass part exceeded that of water. Where appropriate, an anchor could

likewise have been delivered, with a tether of rawhide connecting it to carcass parts in need of its service.

And lastly, how would these parts have been retrieved and utilized? The task might be easiest if the pond was frozen in winter. Even a nondescript chopper made of bone or stone would have sufficed to start a hole in ice, which could then be enlarged (not to mention the sunlit-boulder option summarized in Fisher, 1995). By choosing the spot with reference to the emergent upper end of a marking post, and remembering the deployment of parts on the pond bottom, one could in principle make a prior selection of carcass parts to retrieve. If parts had been installed in pairs or triplets, tied together with moderate lengths of rawhide, a “snagging pole” not much longer than two meters, with a “hook” fashioned from a side branch, could be lowered through the hole in the ice and swept across the marl bottom to snag a rawhide tether and pull two or three carcass parts to the surface. Once up on the ice, an assistant might remove meat from the bone while the “snagger” reprised their role. If exposure to cold or developing hunger became an issue, a fire might be started on the ice, to warm cold hands and prepare retrieved meat and fat. Leaving the pond when the job was done, unused fire-wood, along with wood that was partly burned, would be left on the ice, along with bones now separated from their cover of meat. By spring, all would return to the pond bottom, as we found them. And what if no ice was present when hunger brought people back to the pond? Planning and anticipation are as critical for survival as making the right decision under pressure. By deflating the intestinal flotation bladder and anchoring it under a rock in shallow water, it could be retrieved, re-inflated, and used again for ferrying carcass parts from storage locations to shore. The job of retrieval would again require swimming (unless a small boat were devised), and the swimmer would likely become thoroughly chilled. The fire might need to be larger and would be located onshore. Bones might then be abandoned onshore as well and if so, would probably never be preserved. Skeptics may

consider this exercise in imagination futile and ultimately untestable, but this misses my intent. I am under no illusion that these ideas probe the full range of possibilities, let alone reveal the best. My goal in this exercise is rather to confirm that some plausible sequence of behaviors exists that would allow the core activity of underwater preservation of carcass parts to be implemented. Without such assurance, an elaborate program of experiments to test the efficacy of underwater meat preservation would be unwarranted.

16.3 A REPLICATE CASE?

In December 1989, my teaching duties had just wrapped up for the semester, and we had secured the Heisler site for the winter, with plans to return next spring, when I was contacted by Brad Lepper of the Ohio Historical Society. Brad told me of a recently discovered mastodon in Licking County, in central Ohio. The mastodon had been found by a dragline operator removing peat from a Late Pleistocene kettle lake basin to create a water feature for the Burning Tree Golf Course, then being expanded. On short notice, Brad and Paul Hooge of the Licking County Archaeology and Landmarks Society (along with a number of volunteers) had been invited to extract the mastodon skeleton. Both archaeologists were well trained for working in cultural contexts, but both assumed that this was going to be just another of those well-known cases where a mastodon had become mired in peaty sediment or fallen through ice and drowned. The schedule would be too tight for them to follow standard archaeological procedures for documenting the site, but the opportunity still seemed potentially informative. Initially, they were given only one day to recover the skeleton, but with below-freezing temperatures and severe wind chill, the landowner relented and gave them a second day. There was at least some time to snap photos of bones from various angles, but they mostly pressed ahead through long days in the harsh weather, pulling bones from the peat and shuttling them

to safety. By the time Brad called me, the site was closed, and the bones had been moved to a quickly organized field lab. His invitation was simply for me to come help them identify what bones had been recovered and decide how best to handle their conservation, especially since they seemed unusually well preserved.

Upon arrival in Licking County, I was struck first by the excellent condition of the specimen. It was a mature male, large even for its age (as judged from its molar dentition, its tusks, and its degree of epiphysis fusion), and significantly more complete than the Heisler mastodon with which I had become familiar. We would later determine that this animal was about 33 years old at death. While sorting and identifying bones, Brad and I enjoyed a running conversation, with me peppering him with questions about the overall character and organization of the Burning Tree site, and him plying me with requests for comparisons with other sites I had observed. One of the first impressions to emerge was that the Burning Tree bones had not been distributed randomly over the site. The dragline operator had stopped work shortly after striking the posterior aspect of the skull with his bucket, so the site was barely disturbed when Brad and Paul had been introduced to it. Yet the bones already beginning to be exposed were closely juxtaposed, some overlying others. In fact, it did not take an osteologist to recognize the anatomical incongruence of the parts assembled there. The skull and tusks were at the bottom of the pile, although the cranium projected higher and was already partly exposed. Sprawled across the tusks was the massive pelvis. Nearby, but not articulated, was the only femur recovered, and elsewhere in the pile were both scapulae, each essentially complete, but with similar damage to their spinous process and along their vertebral and posterior margins. Other aspects of site configuration are best communicated by Figure 16.4. Except for one feature added here, this is only a modestly updated version of the site diagram published in Fisher et al. (1994: fig. 3.4). I refer to it as a “diagram” rather than a “map” because spatial relationships were not directly measured *in situ*, but

were reconstructed by consulting all photos from the recovery operation, identifying all bones that were clearly enough exposed in these, and triangulating to estimate their relative locations. This was a joint activity in which we retained only elements on which direct participants agreed. For example, we know both scapulae were associated with the skull and pelvis, but no photo turned up in which they were visible. Participants were unanimous that all bones not recovered in the “skull cluster” were found in one of two additional clusters located meters from each other and from the skull. In Fisher et al. (1994) this diagram was accompanied by an osteological diagram (fig. 3.2) in which bones were given overlay patterns attributing them to one of five categories. Bones were either recognized as derived from one of the three clusters, left in a category of unknown cluster affiliation, or grouped as bones not recovered. The second and third clusters both contained bones that were articulated as in life, along with others that were disarticulated. Occurrence of the Burning Tree bones in fibrous peat may explain the more complete retention of articular relationships than was typical for Heisler

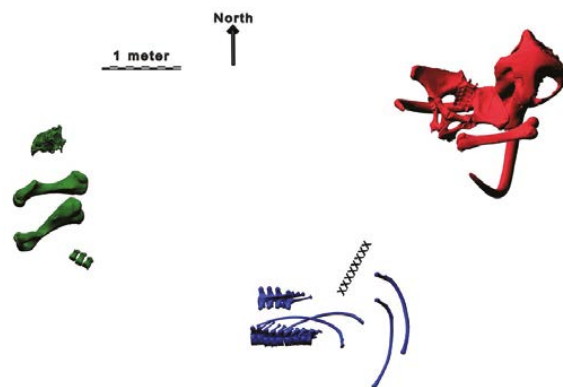


Figure 16.4: Relative locations and positions of bones of the Burning Tree mastodon, reconstructed from photos taken during the recovery operation. This diagram is updated from Fisher et al. (1994: fig. 3.4), most notably by inclusion of an array of x’s showing the relative location of a cylindrical mass of intestinal material (pers. comm., B. Lepper February 2020). The green cluster (in addition to both humeri) includes an articulated series of cervical vertebrae (not including the first, or atlas vertebra) and articulated metacarpals, and the blue cluster includes two sequences of articulated thoracic vertebrae, in addition to four disarticulated ribs.

bones, all of which occurred in marl. Still, the overall configuration of both sites was similar.

Most new elements of Figure 16.4 are essentially cosmetic. Older line drawings of bones are swapped for rendered 3D models of bones, not from the Burning Tree mastodon itself, but from a specimen that emerged later on our timeline. Clusters are here given signature colors, coordinating with a color version of the osteological diagram not included here. However, a substantive new element is the array of x's showing the approximate location of a cylindrical mass of plant material recognized by Lepper while working near the articulated thoracic vertebrae of the "blue cluster." This mass was "(ca. 60 × 12 cm) distinguished from the surrounding dark brown peat by its reddish-brown color and pungent odor" (Lepper et al., 1991: p. 122). Even in the rush of recovery, this was provisionally identified as intestinal contents, and later work confirmed that its botanical remains were distinct from those of surrounding peat (Lepper et al., 1991; Birks et al., 2019). However, no trace of sand or gravel was present.

Observations and inferences concerning the Burning Tree mastodon add new support for the idea that humans were agents of postmortem bone modification and transport at this site (Fisher et al., 1994). When dates became available, they were no great surprise. An AMS date on bone collagen (XAD-purified gelatin hydrolysate) yielded a calibrated age of 13,397–13,085 calBP, and two assays on twigs from the intestinal contents returned calibrated ages of 13,441–13,141 calBP and 13,748–13,276 calBP (Fisher et al., 1994). Readers of this account will recognize that similarities between the Burning Tree and Heisler sites raise the possibility of comparable site formation processes, and yet differences between the sites challenge any simple equation of the two. The Burning Tree intestinal mass was narrower and longer than the ovoid mass at the Heisler site, more likely representing small intestine than large intestine. More importantly though, the Burning Tree mass had no dense clastic component, which seems to preclude the possibility that it functioned as any type of anchor. Did

it represent simply a bit of intestine left attached incidentally to one of the articulated series of thoracic vertebrae? There was also nothing resembling a vertical marking post. Picking up other practical issues, would preservation of carcass parts in a peat-forming lacustrine setting parallel whatever might happen in a marl-bottomed pond? A substrate of plant remains maturing to become peat would probably be easier for humans to negotiate on foot than a marl substrate. For someone transporting a burden, a marl substrate with underlying clay could have posed significant risks. As noted above, many such questions cry out for experimental evaluation.

16.4 MICROBIOLOGICAL ANALYSES

A central component of interpretations forwarded here is that the ovoidal and cylindrical accumulations of plant material recovered at the Heisler and Burning Tree sites, respectively, represent intestinal contents of the mastodons found at each site. Although this idea is by no means implausible, it certainly qualifies as a "bold hypothesis", inviting a concerted effort at refutation, if not falsification (Popper, 1935). Indeed, it would have been easy enough for this hypothesis to have failed completely. Instead, it seems to have been corroborated (Lepper et al., 1991). The first step in this process was the threefold outcome of successfully culturing *Enterobacter cloacae* from the cylindrical mass at the Burning Tree site, failing to find this taxon in control samples from the surrounding peat, and recognizing in those control samples two bacterial taxa that are common in streams and freshwater environments. In contrast, *E. cloacae* is routinely encountered in the intestinal tracts of mammals.

As if this were not enough, we later undertook a more detailed analysis, with higher standards for species-level identification (Rhodes et al., 1998), for which the outcome was fundamentally similar. In this study, we identified a much greater diversity of organisms in Burning Tree intestinal samples. We used two sets of control samples: peat from the

same stratigraphic setting as the intestinal sample but that was not located near it, and yet was found near bones; and peat from the same stratigraphic setting but not near either bones or the intestinal sample. In both cases, we found different organisms, indicative of different microenvironments. In this study, Burning Tree intestinal samples yielded a much stronger signal of mammalian enterics. This also helped to reduce the likelihood that the bacterial taxa we recovered were simply part of the normal microbiota of this type of environment that had somehow colonized Burning Tree samples long after the death, deposition, and decomposition of the mastodon.

Heisler intestinal and control samples examined by Rhodes et al. (1998) showed the same general patterns as had the Burning Tree samples. Intestinal samples again yielded bacterial taxa normally found in mammalian intestinal tracts, but the Heisler enteric assemblage was less diverse than that of the Burning Tree small intestine. This difference could be due to a variety of factors, but we suspect it mainly reflects the disturbance to the enteric environment caused by introducing sand and gravel to transform a piece of mastodon large intestine into a "clastic anchor." Control samples of Heisler marl were again different from intestinal samples, but because of the lower overall diversity, the distinction was less clear in quantitative terms.

16.5 EXPERIMENTS IN UNDERWATER STORAGE OF CARCASS PARTS

The first formal description of experiments on underwater storage of carcass parts was in a presentation at the 1989 Annual Meeting of the Geological Society of America (Fisher, 1989). The idea for such experiments had been gestating since early in our work at the Heisler site and had matured with exposure to many of the other mastodon sites I had come to know. This is not to say that every mastodon site fit the same pattern. Indeed, some clearly did not (an early example was the Johnson mastodon site, UM 57648, discussed in Fisher,

1984b). Nonetheless, the explanatory power of the idea of underwater meat caching was unlikely to be understood or acknowledged without a concerted effort to test its feasibility. Moreover, experimental approaches often bring to light unanticipated factors that complicate, threaten, or even synergistically support the ideas that originally motivated experiments. I could not travel back in time, but I should be able to find environmental settings that approximated those represented by the lithologies and stratigraphic sequences common at mastodon sites.

The University of Michigan's Department of Ecology and Evolutionary Biology, in which I have an appointment, manages a fenced experimental facility, the E. S. George Reserve, near the small town of Hell, Michigan. Tourists never tire of sending "Wish you were here!" postcards from Hell, Michigan, but just a few miles away, field ecologists are often quietly at work inside the locked gates of the George Reserve. After arranging permission, I explored two sites. The first was Crane Pond, a shallow pond similar in size to the former Heisler pond. Its water was the color of tea, with dissolved tannins that I expected might help with meat preservation. On its bottom, I found areas of both silt and marl deposition and an aquatic snail fauna that matched taxa common in the Heisler marl. The second site was Big Cassandra Bog, where a *Sphagnum* peat bog approximated the depositional environments of both the Pleasant Lake mastodon and the Burning Tree mastodon.

In addition to protected natural environments, the George Reserve has a "managed" population of white-tailed deer (*Odocoileus virginianus*), but no stable population of natural predators. Every two years, marksmen are hired to cull the population. Most of the meat is donated or sold locally, but heads that would otherwise be discarded can be obtained on request. Thus, in the fall of 1988, I obtained my first experimental subjects. Deer heads offered nothing like the quantities of meat I wanted to investigate, but their numbers made up for what they lacked in mass. I placed multiple heads in each of the two environments,

to try out multiple “treatments” in each setting. I planned to check some heads at intervals of weeks to months, but to be sure this much activity did not itself complicate matters, I planned to leave other heads unchecked until the following spring, summer, or longer. I used artificial anchors to hold each experimental subject in place, realizing that even in George Reserve, small- to medium-sized scavengers (especially snapping turtles, *Chelydra serpentina*) might remove or consume specimens that I had intended to revisit. As further insurance, and to better discern what size of scavenger might be responsible for any damage I observed, replicate specimens in Crane Pond were placed within stainless steel cages. Finally, as a step in the direction of considering larger masses of meat, I purchased several legs of lamb—a “carcass part” that I could obtain commercially and that better represented a significant, even if still modest, mass of meat, fat, and bone.

Installation of meat caches in Crane Pond was easier for me than it would have been for humans at the Heisler site. I did not have a floatation bladder, but did have a kayak. I waited until October to install autumn meat caches, to be sure that snapping turtles had entered dormancy, allowing my experiment at least to start without their interference. In open-water seasons, I could paddle out to my stations, marked with a small buoy, and either install or check my caches, averaging visits every 2–4 weeks. When the pond first began to freeze, I could break through ice with my paddle and lurch forward like an ice-breaker, but the job actually became easier when the ice thickened. Trading my paddle for two rock hammers, I used them symmetrically to grab purchase on the ice surface, then pull myself forward in long, smooth slides. I had learned in the autumn that there were “warm” spots where spring-water bubbled up from below, making the ice thickness variable from one area to another. For convenience and safety when I was there alone, I routinely used the kayak for this work, but I have done enough winter swimming in cold regions to regard retrieval of stored meat possible even without a boat. In early April, I saw the

season’s first snapping turtles, and in short order, all my uncaged Crane Pond meat caches had vanished.

As anticipated, installation and checking of meat caches in Big Cassandra Bog was much easier. I could walk out on the bog surface, dig into it deeply enough to bury my subjects securely, and check them (once a month) to monitor their progress. I realized that installing or retrieving a large carcass part would be a wet job, but what important activities of subsistence and survival do not entail some challenge? I did not have what I considered an effective cage for meat caches in peat, but I buried caches under at least 30 cm of wet peat and never experienced losses to scavengers in Big Cassandra Bog. It seems likely that wet peat would act to inhibit diffusion and release of microbially produced odors (from the meat) that might attract scavengers, but prior to running the experiments, I did little to investigate this further. I knew that no fence would exclude avian scavengers, and recent inquiry (pers. comm., E. E. Werner July 2020) has clarified that exclusion of mammalian carnivores from the Reserve is far from complete, thanks to multiple places where they can wriggle under the fence. Red foxes (*Vulpes fulva*) and smaller carnivorans are seen frequently, and even coyotes (*Canis latrans*) appear occasionally. It thus seems likely that burial of meat in peat greatly reduces the odds of loss to scavengers.

Most monitoring of caches was decidedly “low tech.” My field kit included a utility knife, a pair of dissecting scissors, a metric folding rule for depth measurements, a general-purpose lab thermometer precise to 0.5° C, several litmus paper dispensers (with precision of at least ± 0.5 on the pH scale), miscellaneous sample containers, and a field notebook. Temperature readings were taken for air (in shade), the medium in which meat was stored (bottom water or peat), and the interior of a meat mass (by inserting the thermometer bulb into a slit cut with the knife). Measurements of pH were taken by applying pH paper to a freshly cut tissue surface (or into water). On two occasions, I borrowed a dissolved oxygen meter and found that water directly around my samples had low, but variable

oxygen levels, whereas bottom water was effectively dysaerobic (0.1–1.0 ml dissolved oxygen per liter of water). Data reported here are gleaned from summary reports and notes; original data are in on-campus files to which I have no access during the COVID-19 pandemic lock-down. In retrospect, the greatest shortcoming of the experiments on meat storage described here is their almost exclusive focus on qualitative aspects of preservation that collectively address the issue of whether underwater storage “works” to preserve carcass parts over time intervals that are meaningful for human subsistence. Left mostly unaddressed are details of taxonomic composition of the microbial communities responsible for the transformation of tissue properties over the course of the first year or so of preservation. This partly reflects the preliminary nature of these experiments, but more fundamentally, my own lack of training in microbiology. It was not until I began to collaborate with J. M. Tiedje and colleagues at Michigan State University that I gained a greater appreciation for what might have been possible. A well-controlled, tissue-specific microbiological study of carcass preservation in natural environments would require replication of parts of this work, but discussions are currently underway that could lead in this direction.

As summarized in Fisher (1995), the condition of fresh meat changed very little from mid-autumn through mid-winter. I did not try eating the deer heads, since I had essentially no control over their earlier history, but based on my visual, tactile, and olfactory assessment, especially in light of later developments, I am confident that fresh deer handled in this fashion would have remained in edible condition. By mid-winter, where muscle tissue was exposed, a zone of incipient degradation had formed, marked by translucence and a flaccid texture dominated by connective tissue and extending inward about a centimeter. Meat just inside of this translucent zone was slightly softer (than it had been before), and its color had begun to fade. Inside of the translucent+faded zone, the meat looked as fresh as before, but had begun to smell slightly sour. Where fat was exposed, this surficial

degradation was barely discernible. By mid-April, a trajectory of transformation had been established and only became more pronounced. Green and red filamentous algae were by then established on the outer surface (whether it was muscle or fat), and the outer transition (translucent+faded) zone (still mainly developed on muscle) remained, thickening moderately. The pink color of the interior remained, but the sour smell was stronger and was now joined by the smell of strong blue or Stilton cheese. By May, the strong cheese smell dominated. Brain tissue in the deer heads was only examined relatively late in their storage history (April–July). By this time, it had a tofu-like consistency and the same strong smell as muscle tissue. The legs of lamb experienced exactly the same transitions observed in deer muscle and fat. It was in fact easier with the lamb to observe the zonation and changes in texture, given the larger starting mass and simpler geometry (Fig. 16.5). Lamb samples included more conspicuous deposits of fat than were present on the deer heads, and this tended to retain its firm texture longer, whereas muscle became notably softer and easier to tear apart, or even, in advanced stages, to tear off the bone.

In April of 1992, several years into the project and already with strong suspicions as to what was going on, I submitted two samples of “cured” lamb to Analytic & Biological Laboratories, a commercial food testing firm in Farmington Hills, Michigan, along with a control sample cut from one of my legs of lamb and stored in my home freezer since the day it had been purchased. The only pathogens noted in the lab report were from the control sample, but they were present in such small concentrations that they were interpreted as the sort of minor contamination that affects much of our commercial food supply and is normally killed by proper cooking. By comparison, the pond-cured lamb showed only non-pathogenic organisms, such as lactobacilli. It seems probable that it was their growth in the meat mass that was responsible for its sour, cheesy smell. Although the testing was done on a leg of lamb from Crane Pond, both deer and lamb from Big Cassandra Bog be-

haved identically. Following these test results, and encouraged by the consistency of all experimental outcomes and reinforcing themes in the food science literature (e.g., Pierson et al., 1970), I started to consume small quantities of Crane-Pond-cured lamb and never had any adverse effect. The culmination of this work was a nine-month replication of a cured lamb experiment for which the underwater recovery, processing, and eating were filmed for a television documentary.



Figure 16.5: Kayak-assisted inspection of a cured leg of lamb in Crane Pond, April, 1992. Meat mass, attached weight, marker buoy, and sampling tools on the deck of the kayak.

The George Reserve experiments were helpful, but after several repetitions, my thinking began to focus more on the questions that remained. Even these experiments left me ignorant of what might happen in much larger carcass parts, and the significance of the column of intestinal contents at the Burning Tree site was still a mystery.

In late January, 1993, I was contacted by friends and colleagues, G. R. Smith and C. E. Badgley with news that one of their Belgian draft horses, a 28-year-old mare, had died (of natural, age-related causes). If I was interested, they were willing to allow me to make her the focus of meat storage experiments. With winter already in full force, we met the next morning. There was a small pond on their property, about a meter deep. We knew little about its biota or chemistry but it resembled many other small ponds on the landscape. We butchered the horse using a combination of knapped stone and modern tools. Confident that stone tools would have worked, I was actually

more interested in replicating some of the disarticulation strategies for which I had seen indirect evidence at my sites. Paramount, however, was getting the carcass processed and installed in the pond that day. As the carcass was segmented, each part was weighed, yielding a total body weight for the horse: 680 kg. Carcass parts as large as 78 kg were installed in the pond by dropping them through holes in the ice, mimicking the Heisler site with several different clusters. The new element of these experiments was the size of meat masses. In the interest of completing the job in time, we did not attach anchors to any of the carcass parts but we did produce anchors for evaluation. Initial densities of all carcass segments were great enough that they settled immediately onto the pond bottom.

We first used horse intestines (Fig. 16.6) to replicate sand anchors like those at the Heisler site, making them with pieces of large and small intestine about a meter long. One end of one piece was tied off with nylon rope to be sure it would remain closed, but two other replicates were constructed using a single overhand knot to close the first end of one anchor and a strip of intestinal wall to close the first end of the second. Contents were then shaken out, but with no concerted effort to remove everything. We then added several kilograms of wet sand and tied off the second ends. To facilitate episodic checking, we added a float to each anchor, on a long lead (so that it would never raise the anchor off the bottom), but for ease of management, the anchors were left as solitary features. Replicating the cylinder of (mastodon) small intestine at the Burning Tree site brought up another issue—the horse small intestine was more slender than mastodon small intestine. To explore options, I performed this replication with horse small and large intestine. I decided also to vary their lengths, making one cylinder from small intestine about a meter long, and two others from large intestine, each about 2 m long. I did not remove intestinal contents from any of these, but simply tied off both ends and placed them in the pond (again, with floats on long leads).

Our first check on the stored meat was two



Figure 16.6: Removal of intestines from a 680-kg Belgian draft horse in preparation for production of clastic anchors similar to those at the Heisler mastodon site and intestinal cylinders like the one at the Burning Tree mastodon site. G. R. Smith holds the visceral cavity open by raising the right hind leg, while D. C. Fisher gently removes intestines.

weeks after installation (mid-February). This required reopening our holes in the ice, as they had re-frozen promptly. Muscle masses were not perceptibly different from their original conditions. To facilitate future checking, we added marker floats on long leads to a few carcass parts and stuffed the floats back under the ice. Given the good condition of the meat, we decided to feed several pieces to three wolf x German shepherd hybrids who at the time were members of the Smith-Badgley household. They ate it enthusiastically. Two weeks later (end of February), our canid participants ate more of the meat and showed no ill effects, so I chewed on a small piece and then spit it out. To a lover of yoghurt and sourdough bread, its hint of a sour taste was interesting, but on advice from my wife (a nurse), I agreed to be cautious. Two weeks later still (mid-March), the canids and I were all in good shape, so I decided it was time to consume some of the meat. Ice was still in place on the pond, despite some surface melting. Through a freshly chopped hole, I snagged the lead of a marker buoy and hauled out a 14-kg quadriceps mass (Fig. 16.7). Its surface now sported a thin crop of filamentous green algae on the grayish-white outer transition zone. Cutting into the meat, I was not surprised (it was déjà vu after the George Reserve experiments), but gratified, to find that the meat inside was still a rich red color and firm to the touch. Slicing off

a thick steak and smelling it, the sour hints were now stronger and more complex, accompanied by the unmistakable smell of strong cheese, such as a Stilton. I had brought along some firewood, explicitly to have a fire on the ice, repeating a pattern I had inferred for the Heisler site. When the fire burned down, I laid my steak directly on glowing coals, cooking it quickly on each side. As long as the moisture content remained high (I recommend not going beyond “medium-rare”), heat was conducted quickly inward, with little or no surface burning. A final task for the day was to check the intestinal experiments in the pond. The clastic anchors remained intact and at original density (judged by weighing them while still underwater). The real surprise was the two longer pieces of unweighted intestine. Despite having been placed on the pond bottom, they were now standing “at attention”! Their contents—what the horse had eaten as one of her last meals—had evidently started to ferment, and gas had accumulated toward one end of the closed length of intestine, lifting that end toward the surface. In response, the remaining contents had slid down to the other end, still on the pond bottom. The inflated top end of each column must at first have been trapped under ice, but it later emerged (melted?) through the ice as a rugby-ball-shaped balloon. C. Badgley reported seeing footprints of a red fox in the snow around these openings in the ice. Evidently, the intestinal



Figure 16.7: Pond-cured meat of a Belgian draft horse. Quadriceps femoris muscle group, removed from the front of one thigh by chopping through the patellar tendon, a practice for which there was evidence at multiple mastodon sites. Condition in mid-March, 1993, after six weeks of pond storage.

balloon had been interesting enough to smell, but not interesting enough to bite into.

The next time I visited the pond was in early April, 1993. The ice was gone, and all marker buoys had become moot, because almost the entire experiment was floating at the surface of the pond! The meat was softer in texture than before, and “expanded”, much like a sourdough starter culture, although nothing had been added to it. The surface temperature of meat masses was the same as that of the water (no surprise), but 10–15 cm inside the surface, meat was 1°C. warmer. When the meat had been fresh, its pH had been about 6.5, but by the time it was floating, it was 5.5 (identical to the pond water), and later in April it was down to 5.25 (pond water still at 5.5). Gas was accumulating interstitially within meat masses, much as it had built up inside the lumen of the intestinal cylinders, but with an important difference. The fermentation process inside intestinal segments no doubt involved partially digested vegetation, but no vegetation was associated with meat masses. Instead, the ever-stronger smell of strong cheese suggested involvement of lactobacilli, and the accumulating gas was probably carbon dioxide. The intestinal cylinders, for their part, were more inflated than before. When their inflated ends had first come to the surface (mid-March), the tissue exposed was light-colored, moist to the touch, and low in profile. Just two weeks later (Fig. 16.8; early April), the inflated ends protruded farther out of water, and their upper surfaces had become “sunburned” and tough, leaving only their water-lines white and moist where ripples lapped against them. My first response to all these changes was consternation. At George Reserve, my meat masses were not large enough to produce and retain this much gas, or if they had, I had not noticed it. Securely anchored as they were, none had floated. Now I was concerned that segments of horse carcass floating on the pond surface would degrade with exposure to the atmosphere. At first, I considered simply adding more weights, but if this were the answer, even more anchors would have been needed at the Heisler site. Neither Pleasant Lake

nor Burning Tree presented a comparable problem, because floatation would not be an issue for carcass parts covered by peat. Pressing down on some of the floating carcass segments, I realized how heavy and complicated an anchoring system would have to be to return all carcass parts to the pond bottom. Early humans in this area must have discovered a better approach.



Figure 16.8: Area of “horse pond” where segments of the small and large intestine had been placed, as seen in early April, 1993, after most ice had melted. In middle foreground are two brown, bulbous profiles (#1, #2), white along their waterlines. These are upper ends of two 2-m-long segments of large intestine in which fermentation gases accumulated at one end, lifting it to the surface, while intestinal contents slid to the opposite end, filling the intestinal lumen.

Within the next weeks, we had several spring storms, one of which brought severe winds. After this, I learned from my friends that we had another problem. Wind had blown several floating, un-anchored carcass parts ashore, where their canid companions had found and devoured two units. Of course, there was still plenty of horse in the pond, but it was now clear how a food reserve could be lost—if it floats and blows ashore, scavengers may well steal it. How could we prevent that? Thinking of relatives on the East Coast, where many people keep boats moored in a harbor, winds come up all the time, but only the worst winds blow many boats ashore. Moreover, anchoring boats never involves forcing them to lie on the sea-bottom! The strategy of a boat anchor is to keep a small weight (relative to the boat’s mass) at the end of a long lead, such that the traction force exerted by the wind acts along a vector that almost parallels the

ocean bottom. A relatively small anchor can then resist displacement. All I needed was to think of anchors as tether-points and meat as boats. Floating meat masses would never present a large profile to wind blowing across a pond, so the traction force that would need to be resisted would not be large.

In early May, I installed several small anchors and light tethers connected to each floating meat mass. It was still not clear that this would solve the problem of hungry scavengers, but we would see. When the canids were next out in our presence, they came eagerly to see if their humans had left any more of the horse for them. Nothing was on the shore, but they could smell the meat, floating on the pond. Swimming out to it, they tried to take bites, but as anyone who has “bobbed for apples” knows, biting into an unrestrained, resistant, freely floating object is not easy. The canids tired, and the floating meat masses were now secure from scavenging.

Additional visits to the pond followed, but subsequent changes were all gradational (Fig. 16.9). Meat masses gained further buoyancy, raising the importance of confirming what gas was being produced. A large syringe and hypodermic needle was used to extract gas, which was then transferred to a vacutainer and analyzed by quadrupole mass spectrometer by W. Patterson (pers. comm., June 1993), who reported that the gas was mostly carbon dioxide, consistent with the idea that lactobacilli were responsible for most of the fermentation. Water and meat temperatures increased with the progression of the season, but the meat interior retained its lead of 1°C. Meat pH also declined until it reached an observed minimum of 4.5 (cf. pond water, 6.4) at the end of July. Having decided to keep the skull intact, we did not investigate the brain. We enjoyed a series of celebratory “tastings”, extending the experience to other colleagues. I acknowledge that only a few genuinely enjoyed it, but most others considered it a taste that “might possibly be acquired” with sufficient hunger. I know of no one who suffered any gastric distress.

The ultimate resolution of the “problem of



Figure 16.9: More pond-cured meat from the draft horse. Unidentified meat mass in late May, after almost four months of pond storage. Meat mass is floating, buoyed by accumulated carbon dioxide produced by lactobacilli and trapped within tissue. A piece of meat has been cut almost free and flipped onto the gunwale of an aluminum canoe used to monitor the experiment.

floating meat” is that it never became a problem. The micro-environment created by lactobacilli, through their lactic acid production and carbon dioxide generation, was maintained so securely that no pathogenic microbiota could gain a foothold. The meat remained distinctively tasty and nutritious, only becoming impractical to eat when it began to break down further in late July and August. And what did we learn from the intestinal cylinders? They were not anchors at all, but “marker-buoys” tethered to their own base!

Although I did not undertake detailed chemical or microbiological characterization of carcass parts undergoing fermentation in pond or bog settings, I did develop tentative hypotheses concerning processes that may be involved in this transformation. I suspect that key observations are the presence of lactobacilli (lactic-acid-producing bacteria) within muscle tissue, the low pH of the tissue mass (presumably due to the presence of lactic acid), and the sustained production of carbon dioxide (a normal product of fermentation by lactobacilli) that permeates and is initially retained within the tissue. Small amounts of carbonic acid derived from carbon dioxide may also be present. I also regard the strong, cheese-like smell as a telling indicator of the involvement of lactobacilli. The combination of low pH and anaerobic conditions (maintained by sustained production of carbon di-

oxide) appears to control the microenvironment of muscle tissue and adjacent fat, excluding bacterial taxa that might have taken over under more basic and/or aerobic conditions. Fat shows a more subtle change in texture than does muscle, becoming slightly “smoother”, perhaps as connective tissue is “digested” by fermentation. Lipids themselves appear to remain stable at low pH, yielding a product reminiscent of the Russian delicacy “сапо” [sa-la], which it closely resembles.

The development of algal cover on carcass parts is probably encouraged both by nutrients available within the tissue and by carbon dioxide production within the tissue mass. The “transition zone” at the surface of carcass parts probably develops due to the ease of diffusive loss of both lactic acid and carbon dioxide near the water/tissue interface, leading to more neutral (if not basic) and oxidizing conditions, promoting tissue degradation. The final breakdown of tissues probably coincides with loss of integrity of connective tissue, permitting more thorough dilution of lactic acid and loss of carbon dioxide, after which the microbial community responsible for fermentation may no longer be able to maintain its microenvironment. Muscle tissue appears to be lost first, but fats are eventually saponified (suggesting basic conditions) resulting in their transformation to adipocere. These interpretations are consistent with my limited reading of literature in the field of food technology (e.g., Pierson et al., 1970; Gill, 1983), but work dealing directly with circumstances relevant to my experiments has not been easy to find.

Another episode worthy of mention in this account of experiments in meat preservation was an “accidental experiment.” In 1997, I was asked to recover the remains of a captive elephant that had died 17 years earlier and been buried in a substrate of lacustrine clay. The body had remained deeply buried since death, and even I assumed that all soft tissues would have decomposed over the intervening years. Imagine our surprise when our shovels exposed moist hide, inside of which was muscle, fat, and an essentially intact carcass. The odor was even stronger than anything the horse had gener-

ated, but its chemical affinity with the cheesy smell I knew so well was unmistakable. Equally interesting, in the handful of days devoted to recovery, transport, and “processing” of this elephant, all my steel excavation tools rusted more deeply than has ever happened in decades of recovering mastodons and mammoths—an indelible trace of contact with acidic tissue. As for why the carcass remained as nearly intact as it did, for as long as it did, my best supposition is that its secure repose within impermeable clay allowed its acidic and anaerobic microenvironment to remain unchallenged. However, even after the carcass was disarticulated, and much of the tissue was removed and allowed to decompose in an aerobic (outdoor) environment, it still took several years to break down, possibly because of metabolites that remained, or acid fixation of proteins (Gersten et al., 1985).

Finally, I would be remiss not to mention in this context the “natural experiment” of Lyuba, a woolly mammoth (*Mammuthus primigenius*) calf from the Yamal Peninsula (Fisher et al., 2012), whose exceptional preservation owed much to postmortem colonization of her body by lactic-acid-producing bacteria. In her case, lactic-acid-driven denaturing of Type I collagen (Dung et al., 1994) resulted in loss of a major structural component of both periodontal ligament and the tendinous attachment of muscles to bone (Fisher et al., 2012), hinting that this could be part of how and why pond-cured meat softens and detaches more easily from bone.

16.6 ADDITIONAL PLEISTOCENE REPLICATES

I would now like to address several Pleistocene sites in the Great Lakes region where new examples of some of the themes introduced above have come to light. Even generous time and space allowances permit only token treatment, but this should give a sense of developments to be explored in more detail in the future.

Although I have already discussed muscle tis-

sue and fat, I have not yet addressed marrow. The first site mentioned, the Pleasant Lake mastodon site, had an intriguing record of bone breakage, but this appeared to be mostly associated with use of cortical bone for making expedient bone tools (Fisher, 1984a, b). No clear evidence of marrow processing was found there, or at the Heisler or Burning Tree sites. Nonetheless, marrow processing may have varied in importance according to circumstances. The Riley mammoth, excavated in 2009–2010 in central, southern Michigan, presented a strikingly different picture. This mammoth was an adult male, about 45 years old at death, with an AMS date of 14,390–14,080 calBP (Fisher et al., 2017). Season of death was early summer, during a musth episode (analyzed in tusk dentin), so the cause of death appears to have been a musth battle. The depositional setting was within, but near the margin of, a shallow pond on the Late Pleistocene landscape, and the remains consist of some whole bones and one complete tusk, accompanied by thousands of fragments of the cranium and various limb bone diaphyses, among other parts of the skeleton. The broken cranium and extracted tusks are consistent with harvesting of the brain and nasal mucosa, as proposed in Fisher (2009), and also with use of tusk pulp tissue. However, when the cranium is so extensively damaged, it is hard to point to evidence of processing beyond the fresh condition of bone when broken. However, limb bone diaphyses are more tractable. Multiple long bones of the Riley mammoth were split longitudinally, after which the marrow-containing cancellous interior of diaphyses was gouged out, leaving almost empty cortical-wall segments. One of these is illustrated in four views, each 90° apart, in Figure 16.10A. The interior of the cortical wall is best seen in the second image from the top, and a close-up of the point of impact and tell-tale “stacked” impact fractures are shown in Figure 16.10B. Perhaps the most interesting point is that marrow recovery from many similar fragments was not necessarily the last step in their utilization. All fragments stripped of marrow were piled close to one another in shallow water near the pond mar-

gin, apparently to preserve access to them, perhaps for use as fuel. This presumes that long bone epiphyses, along with the cancellous interior of diaphyses, had already been processed for lipid extraction. The impressive utility of the pond setting was that it facilitated extended access to raw materials suited for multiple successive episodes of use.

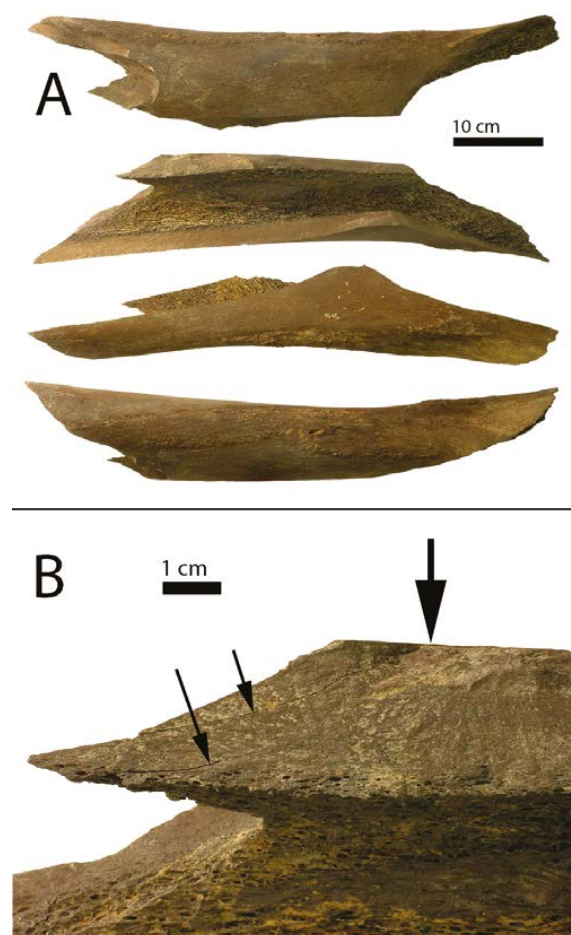


Figure 16.10: Green-bone-fractured segment of a femoral diaphysis of the Riley mammoth (UM 116967; Fisher et al., 2017). **A**, segment shown in four views, each rotated 90° relative to previous view. Marrow-containing cancellous bone has been removed from the interior of the cortical cylinder. All fractures were made on fresh, un-weathered bone. Upper-left corner of second image from top is enlarged in **B**. **B**, detail from **A**, showing point of impact (large arrow) and “stacked” conical fractures (small arrows) characteristic of impact fracturing by humans.

Another remarkable mammoth recovered recently is the Bristle mammoth (UM 117677), found on the Bristle farm, near Chelsea, Michigan, just west of Ann Arbor. A brief introduction can be

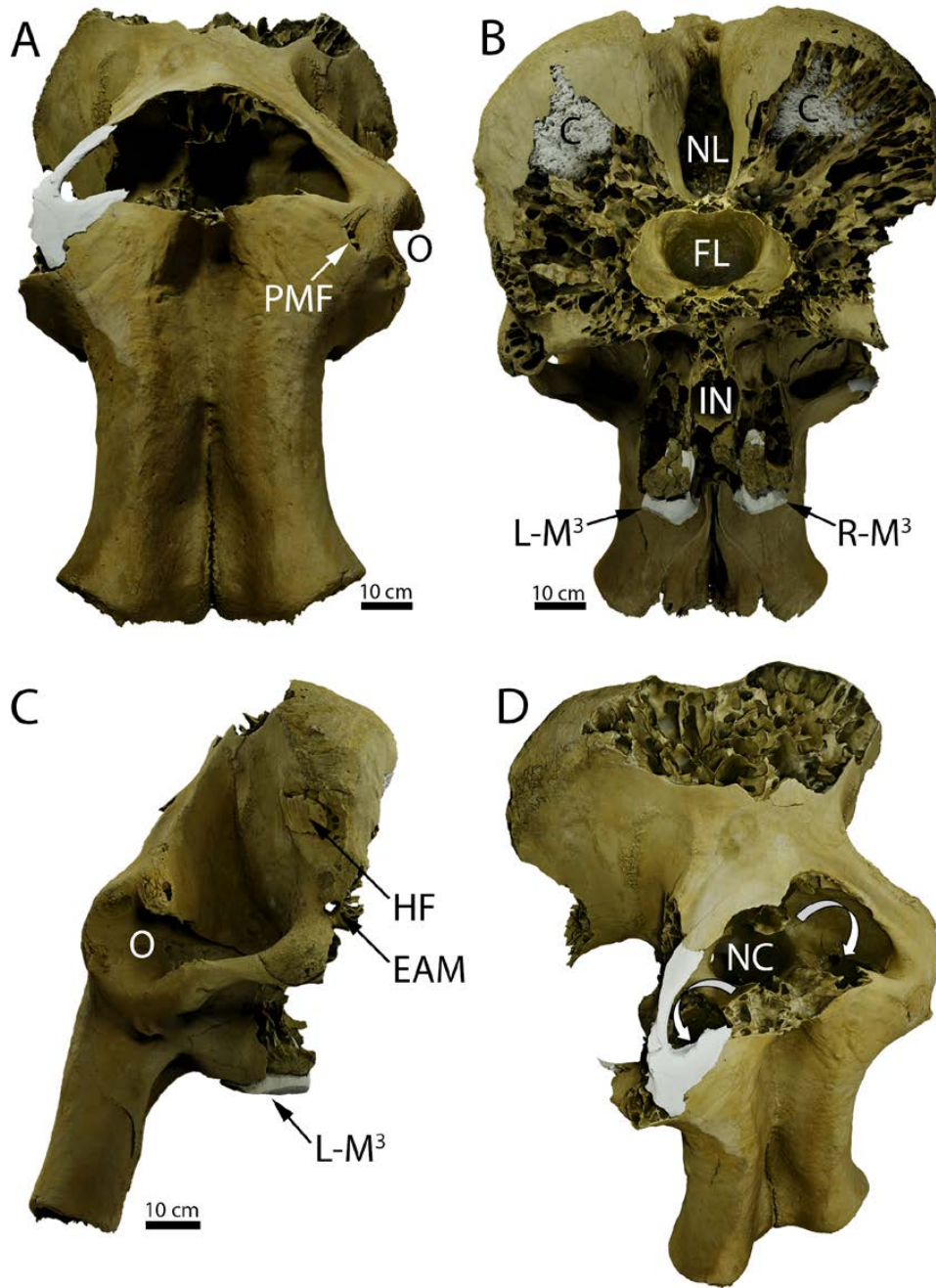


Figure 16.11: Multiple views of the Bristle mammoth (UM 117677) skull. **A**, anterior aspect, viewed along an anteroposterior axis parallel to the occlusal plane of upper molars L-M3 and R-M3 (white casts, visible in B and C). O: position of left eye (orbit) located at widest point on skull in this view. Perimortem damage over right orbit is repaired using 3D-printed replicas (white) of bone fragments. Opening on forehead just above level of orbit is the external narial recess, where the narial canals (within the trunk) descend toward the internal nares (IN) at the back of the oral cavity; PMF: perimortem fracture located just medial to left orbit. **B**, posterior aspect, viewed along same axis as A, but in opposite direction. C: light gray areas mark delicate regions, strengthened by consolidated beads of B-72 (acrylic polymer) used as supports for mounting; NL: nuchal ligament pit on posterior aspect of skull; FL: anterior portion of cranial vault occupied in life by frontal lobes of brain; IN: position of internal nares where narial canals open into the back of the oral-pharyngeal cavity. **C**, lateral view, with anteroposterior axis horizontal. O: location of left orbit; HF: healed fracture on lateral aspect of cranium, from an earlier musth battle; EAM: external auditory meatus (opening to inner ear). **D**, oblique anterodorsal view of skull, permitting a view into the passage for the narial canals (NC) connecting the external narial recess to the internal nares (IN). On both sides of the external narial recess (follow curved, white arrows) the boney “floor” separating the external narial recess from the interior of the tusk alveoli has been broken, permitting removal of pulp tissue from the base of each tusk without removal of tusks themselves.

viewed at the following internet address: <<https://www.youtube.com/watch?v=XbekbGz1cEY>>. The passing reference to a possible stone tool turned out to be mistaken, and we now know the mammoth was a Columbian x woolly hybrid, but other elements of this description held firm. Like the Riley mammoth, this male was a musth death. Most important is that the skull shows evidence of utilization by humans. Figure 16.11 offers a series of perspective views, rendered from a 12-million-face photogrammetric model of the specimen. White polyester resin casts of the upper molars were installed so that the real teeth could be kept separate for study. For the same reason, bone fragments from over the right orbit are replaced by 3D-printed replicas (white). The anterior view (Fig. 16.11A) shows one of several perimortem fractures (PMF) representing injuries sustained during the musth battle. The diametrically opposed posterior view (Fig. 16.11B) shows how the posteroventral portion of the cranium has been cleaved away (see also the lateral view in Fig. 16.11C) along a plane that extends from just below the nuchal ligament (NL, a massive elastic structure that runs posteriorly to the neural spines of anterior thoracic vertebrae), through the cranial vault, to exit the basicranium just behind the internal nares (IN) that mark the posterodorsal boundary of the oral-pharyngeal cavity. This fracture plane lopped off the posterior two thirds of the cranial vault, leaving only the space for the frontal lobes (FL) of the brain in this portion of the skull, framed by the smooth, boney surface that conforms to the anterior aspect of the brain's temporal lobes. This fracture plane would have provided direct access to the entire cranial vault, allowing easy extraction of the brain. Finally, the oblique view of the skull (Fig. 16.11D) provides a "bird's-eye-view" from above, in front of, and slightly to the right of the skull. Looking downward toward the external narial recess in the forehead, the dark passage marked NC is the route by which the narial canals passed from the base of the trunk down to the internal nares (IN). Aside from this passage, there is normally no other exit from the external narial recess. However, in this speci-

men, the normally solid boney floor of the external narial recess has been breached on the left and right (follow both curved white arrows), providing access to the interior of each tusk alveolus (socket). Through these two passages, massive cones of pulp tissue could have been removed from the base of each tusk. All this could have been accomplished by breaking into the external narial recess through the broken area over the right orbit (white replica fragments). All of this breakage seems too precisely targeted to be explained as nothing more than incidental postmortem damage. For a better understanding of the structure of this specimen, I encourage readers to visit the University of Michigan Online Repository of Fossils (UMOR), where a version of this model can be explored: <https://umorf.ummp.lsa.umich.edu/wp/specimen-data/?Model_ID=1306>. Click on the static image to open the 3D viewer. After reading navigation instructions, close that panel and explore the model. Both tusks of this mammoth were found in their alveoli when the skull was discovered. We removed them for conservation following excavation, but all damage discussed above was present on the freshly exposed specimen. *In situ*, the anterior aspect of the skull faced downward on the soft marl bottom of the former pond. We therefore interpret the damage as targeted recovery of nutritionally valuable tissue by anatomically knowledgeable carcass processors. Our AMS age assay based on well-preserved collagen from dense cortical bone is 15,710–15,380 calBP (Beta-434390).

A final site is that of the Fowler Center mastodon (UM 118277), found near Mayville, Michigan. A photogrammetric 3D model made after some material had already been collected, may be viewed on UMORF at: <https://umorf.ummp.lsa.umich.edu/wp/specimen-data/?Model_ID=1298>. Although this model shows only about half of one cluster of material and none of a second, smaller cluster that together comprise the main portion of the site, it is still easy to recognize (note the ulna, nestled under the right innominate) that despite instances of residual articulation, multiple disjunct carcass segments are represented



Figure 16.12: Fowler Center mastodon site (UM 118277), revisited 18 March 2018. **A**, view toward previously excavated portion of site, marked by X, located about 40 meters south of current location. Just visible near the lower margin of image (indicated by white arrow) is a partially exposed rib from the posterior portion of a mastodon thorax, possibly representing a secondary locus of material from the same individual. **B**, closer view of rib, still *in situ* but further exposed (proximal end indicated by black arrow). Trowel points toward north. Excavation has almost reached stratigraphic level of rib.

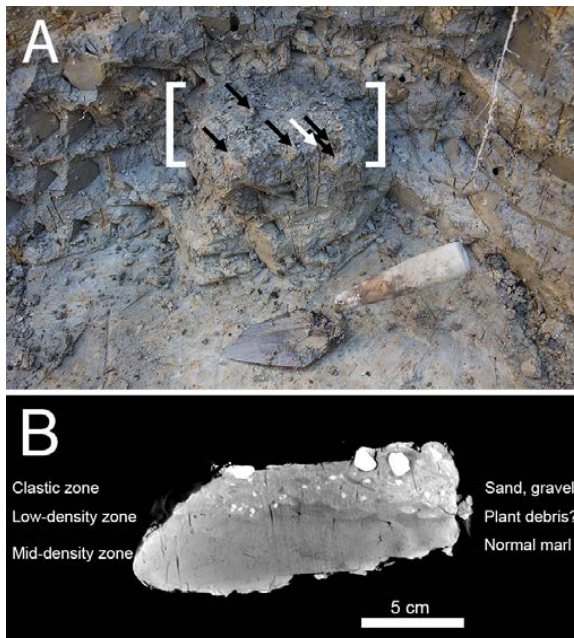


Figure 16.13: Terminus of apparent “clastic anchor” located near northern locus of material recovered from Fowler Center mastodon site, illustrated in Figure 16.12. **A**, trowel points toward north; view is toward ESE; rib is behind current camera position, at stratigraphic level indicated by white brackets, which embrace the constricted terminus of a concentration of gravel and sand that may represent the remains of a clastic anchor used to tether carcass parts to this location in the ancient pond. Black arrows indicate exposed gravel clasts. White arrow indicates one of several root traces that show that the gray marl exposed at this horizon has not been subjected to recent disturbance. Round holes about 1 cm in diameter (e.g., near top center of image) mark insertion points of stainless steel probe, testing for presence of gravel beyond the apparent terminus. **B**, one frame from a “slice-sequence” animation of the CT scan of the Fowler Center clastic anchor recovered from the site locus in Figure 16.12, where only a single rib remained.

here. This is again a male, older ontogenetically than the Heisler mastodon but younger than Burning Tree. He has a partly healed wound from a musth battle, but seems otherwise to have been in good condition. He is not yet dated, and we have not yet determined a season of death. Months after completing the excavation of this part of the site, I was contacted by S. Colling, who had helped with the excavation. He reported that at the same stratigraphic level as the original site, a single rib had begun to weather out of an exposure located about 40 m to the north of our earlier excavation (Fig. 16.12).

We met the next morning under freezing, late-winter conditions, to investigate this new locus. We decided to excavate from the frozen surface (Fig. 16.12A) all the way to the bone horizon, not wanting to miss anything with which the rib might be associated. The rib was in good condition, and not one of those already recovered for this animal (Fig. 16.12B), but no other bones seemed to be present. Troweling over a broader area to be sure there was nothing else, we encountered gravel less than a meter to the east of the rib. This gravel was not just a few clasts, but a deposit of some magnitude, covering roughly 1.5 m², with lateral limits tapering toward an abrupt termination in the southeast corner of our excavation (Fig. 16.13A).

This gravel was sedimentologically anomalous in the marl of this former pond. Most of the deposit was troweled into buckets, of which coarse clasts only comprise an estimated 16 kg out of a total mass of 36 kg of gravel and other sediment. After collecting all but the termination of this deposit, we troweled deeper to be sure nothing lay deeper in the sequence. We then used a stainless steel probe on the floor and side walls of the excavation to rule out the possibility that the gravel was part of some larger, more continuous deposit. No further gravel was encountered. Finally, the terminus itself was trimmed at its margins, undercut with a trowel, and transferred to a box for travel to the lab. Some of the gravel came loose during transit, but more (with its sandy matrix) was retained *in situ*, after which the remaining block was frozen. Later, we used polyurethane foam to encapsulate it, then dried and CT-scanned it. Figure 16.13B reveals, in stratigraphic order (from below, upward), a mid-density zone reflecting normal marl, a low-density zone (darker) that we suspect is plant debris, probably intestinal contents of the Fowler Center mastodon, followed by a clastic zone (bright white clasts) of sand and gravel. This is essentially a replication of the “lower hemisphere” of a Heisler-like clastic anchor, though larger and implemented in gravel. As such, it represents the most nearly intact clastic anchor to show up in 35 years.

16.7 DISCUSSION AND SUMMARY

Before considering what new insights the work discussed here may yield, I must acknowledge that most observations reported here are part of one “preliminary” study or another. Most of the sites need further documentation, and even the experiments could have been designed to provide a more complete record of events and interactions. That said, are there interpretations that used to be considered self-evident but that now seem less secure? My best answer to this question is the notion that Pleistocene proboscideans were miserably inept

and prone to meet a soggy end, unable to extricate themselves from one of the wetland settings that were so common in their normal habitat. I cannot say this never happened, but I have yet to encounter a site that securely fits this description.

The flip-side of the existence question posed above is whether any question that used to defy resolution can now be answered more confidently? Here we need only look at one of the sites discussed above, such as Pleasant Lake, Heisler, or Burning Tree, and ask what site formation processes (if not pure ineptitude on the part of the proboscidean) could account for the overall site configuration? For this, I think we now at least have an interesting candidate involving underwater storage of carcass parts by Late Pleistocene humans. To be sure, this explanation depends on propositions that could never have been taken for granted initially, such as the feasibility of using underwater storage to significantly extend access to a resource composed of meat, fat, and “accessory” tissues. Nonetheless, this practice now seems grounded in dependable aspects of the natural history of microbial systems. Such evidence builds on ethnographic cases of underwater meat storage cited previously (Fisher, 1995), involving “Labrador Eskimos” visited by William Turner in 1780 (Taylor, 1969). Based on their location, these hunter-gatherers may have been earlier generations of the Innu discussed by Tanner (this volume).

Beyond delivering yes or no answers on singular propositions, discovering new aspects of human subsistence behavior has the potential to shed light on numerous facets of hunter-gatherer ecology. Reasons humans engage in one practice or another are usually much more complex than simply “Does the action achieve the intended goal?” Alternatively, it might be more useful to acknowledge that we usually need to manage a number of goals in parallel, each associated with different time scales of investment and return, and different risk/reward probability distributions. We want to “get the job done”, but in a way that conserves time and energy, minimizes risk, and maximizes flexibility and multiplicity of downstream options. In that spirit,

I have reflected on the value of underwater meat storage previously (e.g., Fisher, 1995). It requires minimal investment of time, once the resource has been procured. With helpers knowledgeable of the routine, even a large carcass might be dealt with in a day or two, requiring no further oversight, nor any risk incurred to protect the resource, until the occasion of first recovery. Any additional processing required can be done when the need becomes acute, and the rest remains secure—for a time. A stored resource may affect the calculus governing decisions about mobility, but it may also represent the difference between life and death in a time of stress. The useful life of the resource appears to extend at least until the end of the first summer following emplacement, but under colder Pleistocene conditions, it might have lasted longer. Almost inevitably, “shelf life” was sometimes exceeded, and when it was, the resource was abandoned. For Pleistocene humans, this was just part of the risk structure, and for us, this is how some of our record of such subsistence behavior develops. This is just one of many opportunities for reciprocal illumination, by which I mean that whenever we learn something about ancient human behavior, we also stand a chance for new insights into the nature of our historical record. If underwater storage of carcass parts was as common as I suspect it was, we probably have a much richer record of human interaction with megafauna (involving cases of both hunting and scavenging) than many archaeologists anticipate. Likewise, we may have a rationale for why recovery of lithic artifacts in association with stored carcass parts is not the norm, changing our understanding of the kinds of evidence that may be possible, vs. the kinds of evidence we choose to consider essential, for recognizing cases of human-megafaunal association. Pressing this issue, I argue above that human dexterity and ingenuity is implicated in the processing of the Bristle mammoth skull. I reported our AMS age estimate for this specimen without any fanfare, but some may consider this age “too early” for the North American Midcontinent. Further discussion is always warranted, but I encourage readers to ponder this

conundrum. What data do you accept on their merits, and what do you accept only when other conditions are met? We are not necessarily mistaken to perceive a complex web of contingency among interrelated propositions, but we must be careful not to impose *a priori* limits on our reasoning to the extent that we are unable to recognize novelty when we stumble upon it.

One of the most interesting recent developments relevant to this work is John Speth’s (2017) paper on what he refers to as “putrid meat.” He and I have discussed such topics on multiple occasions, and we share a great deal of common ground. I completely agree with his emphasis that “just because meat is putrid does not mean it contains unsafe levels of pathogens” (Speth, 2017, p. 49), and he correctly recognizes this as a position supported by my “pond storage” experiments. At the same time, he refers frequently to “fermentation and putrefaction” (2017, p. 45) in a way that leaves me uncertain as to how he distinguishes these processes or if indeed he thinks of them as positions along a gradient. Both are said to induce breakdown of proteins and fats that is functionally similar to cooking, suggesting that this may afford an “energetic benefit” (2017, p. 48) to the consumer of such tissue. I am completely open to this suggestion, but I suspect we would all benefit from a more thorough treatment of the “systematics” of alteration paths to which fresh tissue is exposed, articulating what transformations normally occur, and what states do, and do not, usually convert to one another. My knowledge is probably fragmentary, but I tend to think of fermentation as an anaerobic process that when mediated by lactic-acid-producing bacteria, maintaining low pH, yields products for which examples are found throughout my catalog of experiments. On the other hand, typical “road-kill” occupying an aerobic environment and characterized by neutral to basic conditions, yields products with which I am indeed familiar (some of which I think of as “putrefied”), but are nothing like pond-cured meat or fat. In any event, Speth goes on to suggest that putrefaction, by which he here seems to refer to anaerobic, acidic, fermenta-

tion mediated by lactic-acid-bacteria (Speth, 2017, 2019a), tends to preserve concentrations of vitamin C that can be found in some, but not all, fresh tissues. This obviously would represent an important, unanticipated, contribution from eating fermented tissues. Speth was later obliged to respond (2019b) to criticism from Guil-Guerrero (2019), but made a solid case for his proposal. I would ordinarily not presume to step into such a discussion after the fact. However, by chance, at a time when I was too fully occupied to follow up, a colleague who knew of my meat storage experiments recounted an insight (pers. comm., D. M. Raup† November 2000) from his father, a botanist who had done extensive field work in the North American Arctic and had often worked with indigenous informants. His recommendation? “Vitamin C is a major factor!”

For one more suggestion on the possible significance of pond storage of carcass parts, proboscideans have a reputation for being “ecosystem engineers” (Fritz, 2017), but Late Pleistocene human hunters and foragers probably dabbled in this practice as well, taking steps to configure an environment that suited their needs. Al Holman, above all else, was a herpetologist, and as we began to work at the Heisler site, I remember him wondering aloud, why were there no Pleistocene specimens of snapping turtles in the Great Lakes region, despite every indication that the environment then would have suited them well. At the time, neither of us had an answer, but I wonder now whether early humans in this area, dependent on consumption of pond-cured resources, trained their children to collect the round white eggs of snapping turtles, praising the skill of those who succeeded and thus protected the family’s access to critical carcass units.

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