A 9,000-year-old caribou hunting structure beneath Lake Huron

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Some of the most pivotal questions in human history necessitate the investigation of archaeological sites that are now under water. Nine thousand years ago, the Alpena-Amberley Ridge (AAR) beneath modern Lake Huron was a dry land corridor that connected northeast Michigan to southern Ontario. The newly discovered Drop 45 Drive Lane is the most complex hunting structure found to date beneath the Great Lakes. The site and its associated artifacts provide unprecedented insight into the social and seasonal organization of prehistoric caribou hunting. When combined with environmental and simulation studies, it is suggested that distinctly different seasonal strategies were used by early hunters on the AAR, with autumn hunting being carried out by small groups, and spring hunts being conducted by larger groups of cooperating hunters.

underwater archaeology | hunter–gatherer subsistence | virtual world simulation

Some of the most pivotal questions in human prehistory necessitate the investigation of archaeological sites that are now under water (1–3). The advance and retreat of glacial ice throughout the period of human development and dispersal, and the associated global changes in sea level, repeatedly exposed, and then submerged, significant coastal land masses. As a result, questions as diverse as the origins of early human culture, the spread of hominids out of Africa, and the colonization of the New World all hinge on evidence that is under water. Although the discovery and investigation of such sites presents methodological challenges, these contexts also have unique potential for preserving ancient sites without disturbance from later human occupation (4). The Alpena-Amberley Ridge (AAR) beneath modern Lake Huron in the North American Great Lakes provides just such a setting and offers unique evidence of prehistoric caribou hunters.

During the Lake Stanley low stand (11,500–7,000 cal B.P.), lake levels were as much as 100 m lower than present (5, 6), and the AAR was a dry, narrow land corridor extending from northern Michigan to southcentral Ontario (Fig. 1A). Research on the AAR by a multidisciplinary team of archaeologists, environmental scientists, maritime engineers, and computer scientists has created a model of this ancient landscape and the movement of caribou across it. Given the midlake location of the AAR (56 km from the modern shore), there is little recent sediment cover of the archaeological materials, and preserved ancient sediments contain a range of environmental indicators including pollen, testate amoebae, charcoal, preserved wood, and trees. The presence of distinct marsh testate amoebae assemblages (e.g., *Cyphoderia ampulla, Hyalosphenia papilio*) (7) and moss spores indicates that the AAR was a stable land surface that was rapidly flooded after 8,000 years B.P. and has remained relatively intact without significant further sedimentation since inundation.

Paleoenvironmental analysis indicates that the area was a subarctic environment consisting of sphagnum moss, tamarack larch and spruce trees, along with small lakes, rivers, and wetlands (Table S1). Radiocarbon dates on preserved wood yielded dates from 8,900–8,640 cal B.P., whereas charcoal recovered from the middle of a circle of small stones yielded a date of 9,020 cal B.P. (Table S2). The environment that emerges from these studies is one that would have been ideal for migrating caribou and for their human pursuers.

Humans and caribou have a long history of interaction, dating back to at least the Middle Paleolithic (8, 9). Over time, caribou hunters and herders became aware of the tendency of caribou, like many ungulates, to follow linear features (10). As such, the construction of linear features of stone or brush provides an effective means of channeling the movement of animals into predetermined kill zones. Numerous historical and ethnographic examples of these hunting structures and associated features are known in the Arctic (11, 12). In more temperate regions of the globe, traces of such structures rarely survive intact (13). What is known of caribou hunting in the Great Lakes region is based on stone tool technology, archaeological site locations, and the very rare preservation of faunal materials (14). The submerged character of the AAR offers both the potential for preserving these structures that do not survive in the terrestrial archaeological record and for their discovery via acoustic survey techniques.

Since 2008, more than 60 stone constructions on the AAR have been identified and visually inspected within two targeted research areas (Fig. S1). Targets of potential interest identified during acoustic survey are examined via video provided by a remote operated vehicle (ROV) and, if warranted, are directly mapped and sampled by self-contained underwater breathing apparatus (scuba)-trained archaeologists. To distinguish human modified features from natural occurrences,

Significance

Some of the most pivotal questions in human history necessitate the investigation of archaeological sites that are now under water. These contexts have unique potentials for preserving ancient sites without disturbance from later human occupation. The Alpena-Amberley Ridge beneath modern Lake Huron in the Great Lakes offers unique evidence of prehistoric caribou hunters for a time period that is very poorly known on land. The newly discovered Drop 45 Drive Lane and associated artifacts presented here provide unprecedented insight into the social and seasonal organization of early peoples in the Great Lakes region, while the interdisciplinary research program provides a model for the archaeological investigation of submerged prehistoric landscapes.
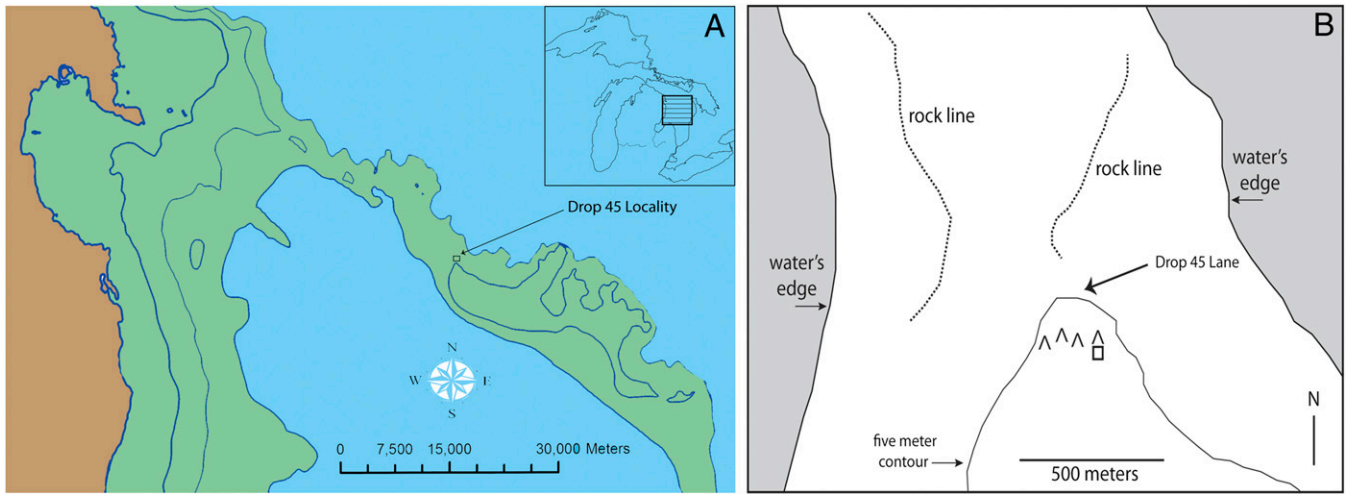
Fig. 1. The location of the Drop 45 Drive Lane. (*A*) The American portion of the AAR during the later Lake Stanley low water phase (after ref. 14). Modern land is shown in brown, whereas areas of exposed dry land during Lake Stanley are green. Areas of water are presented in blue. The contour interval is 20 m, with the modern lake shore represented as 176 m above mean sea level (amsl). (*B*) The topographic setting of the Drop 45 Drive Lane. Solid black lines represent 5-m contours reported in meters amsl. The blue area depicts areas that would have been under water at the time of use. This shoreline represents the Late Lake Stanley lake level and reflects the last stable Lake Stanley elevation, roughly 40 m amsl. The dotted lines represent low lines of stones channeling the movement of animals toward the middle of the landform. Inverted V symbols represent the location of V-shaped hunting blinds with their orientation reflected by the vertex of the V. The square symbol represents the location of a rectangular structure thought to represent a caching facility.

the form and setting of each structure is assessed to determine whether it is part of a shore or ice thrust feature, or geologic formation, and to identify repeated nonrandom patterns of construction. The environmental context, position on the landscape, and presence of associated cultural material is also evaluated for each potential structure. This process mirrors the practices used to identify terrestrial hunting structures.

Following these criteria, the identified cultural structures on the AAR range from simple, small V-shaped hunting blinds to more complex features with stone drive lanes, multiple hunting
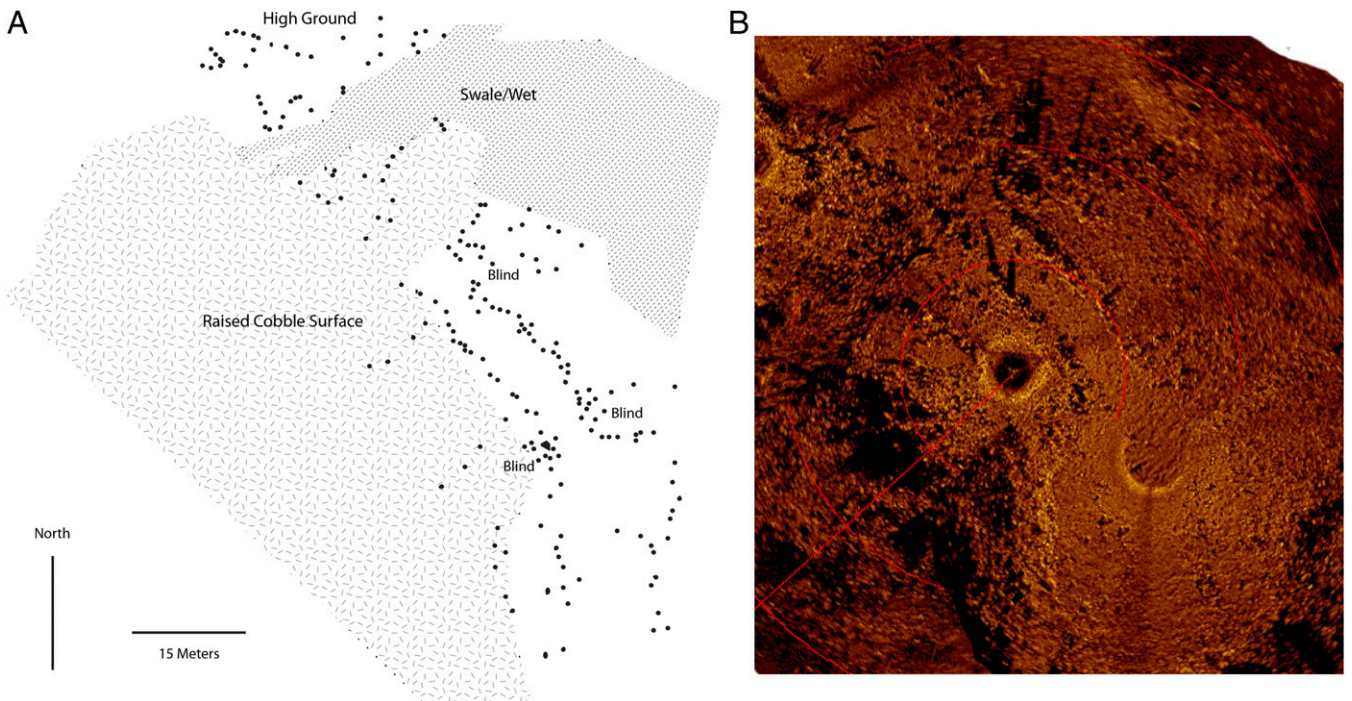

Fig. 2. The Drop 45 Drive Lane. (*A*) A plan showing the major topographic and cultural features associated with the drive lane. Black dots represent the location of placed stones. The hunting blinds incorporated within the main drive lane feature are labeled. The raised cobble surface to the north and west of the drive lane varies from 1 to 2 m higher than the bedrock on which the drive lane stones are located. This plan was produced as an overlay of the acoustic image. (*B*) An acoustic image of the drive lane produced via a mosaic of scanning sonar images. The scanning unit is the black circular area near the center of the image, and the red circles surrounding have radii that increase by 15 m. A trace of the second scanning sonar location is visible in the southeast of the image. Light colored objects are stones that produce a strong acoustic signature, whereas dark areas are acoustic shadows.

blinds, and associated structures (14, 15). Although other prey species were certainly pursued by Late Paleoindian and Early Archaic foragers, caribou would have represented the main prey species given the environmental conditions on the AAR and were likely the target for the constructed stone features. The discovery of the Drop 45 Drive Lane and its associated artifacts, described here, provides unprecedented insight into prehistoric hunting in the Great Lakes region during a poorly known time period.

Results

The Drop 45 Drive Lane is the most complex hunting structure identified to date in the Great Lakes region. It is located in 37 m of water, 56 km southeast of Alpena, MI (Fig. 1A). The site lies on a narrow (less than 2 km) southeast to northwest upward sloping isthmus (Fig. 1B). This locality, comprising only 8 ha, has an unusually high density of confirmed hunting features, including at least four V-shaped hunting blinds (14) and a rectangular construction that, following ethnographic parallels, may represent a meat cache (13). Down slope, acoustic imagery suggests the presence of two long converging stone lines that narrow to a gap of approximately 400 m just below the location of the hunting blinds.

The Drop 45 Drive Lane is located near the top of the slope, but below the crest. It is bounded by a raised cobble pavement on the west and a marsh to the east. The feature is constructed on level limestone bedrock and is comprised of two parallel lines of stones leading toward an effective cul-de-sac formed by the natural cobble pavement (Fig. 2). The stone lane is 8 m wide and 30 m long. The drive lane has three associated circular hunting blinds that are built into the stone lines and a series of perpendicular flanking lines on its west side. To the northwest of the drive lane and on top of the raised cobble feature are additional stone alignments that may also have served as blinds and obstructions for corralling caribou. Further to the northwest is a low boggy swale and beyond that a second crest, which is also populated by a perpendicular arrangement of boulders. Taking all these elements together, the total length of the area within which caribou would have been ambushed is roughly 100 m in length and 28 m wide (0.28 ha).

The interior of the drive lane is devoid of rocks and covered with clean sand to a depth of approximately 6 cm overlaying the limestone bedrock. Systematic sampling along the length of the lane yielded a total of 11 chipped stone flakes (Fig. 3A). These flakes exhibited sharp edges, and elements of standard flake morphology and cultural manufacture such as platforms, bulbs of percussion, and crushing. Seven flakes were located in the southern opening of the drive lane, and two each were found in two of the associated hunting blinds (Fig. 3B). An additional 17 test units along the drive lane did not yield culturally modified material. This absence is significant because the constrained spatial distribution of flakes underscores their cultural, as opposed to natural, production and deposition. The majority of the flakes ($n = 8$) are gray-brown cherts common in the local Devonian Age Traverse Formation (16). The remaining three flakes are an unnamed high-quality black and orange chert, which similarly appears to have its origin in the local Traverse Formation. Given their size and morphology, the recovered flakes do not appear to represent primary tool manufacture but rather the expedient repair or maintenance of stone tools. The recovery of artifacts in the immediate vicinity of caribou hunting structures is exceedingly rare at both historically and archaeologically documented kill sites (11, 12). The discovery of 11 flakes, given the limited sampling conducted, may suggest that tool maintenance activity regularly occurred in this locality as hunters anticipated the arrival of caribou herds.

In addition to the archaeological investigations, computer simulation has been used to better understand the movement of caribou and caribou hunters on the AAR. Drawing on the
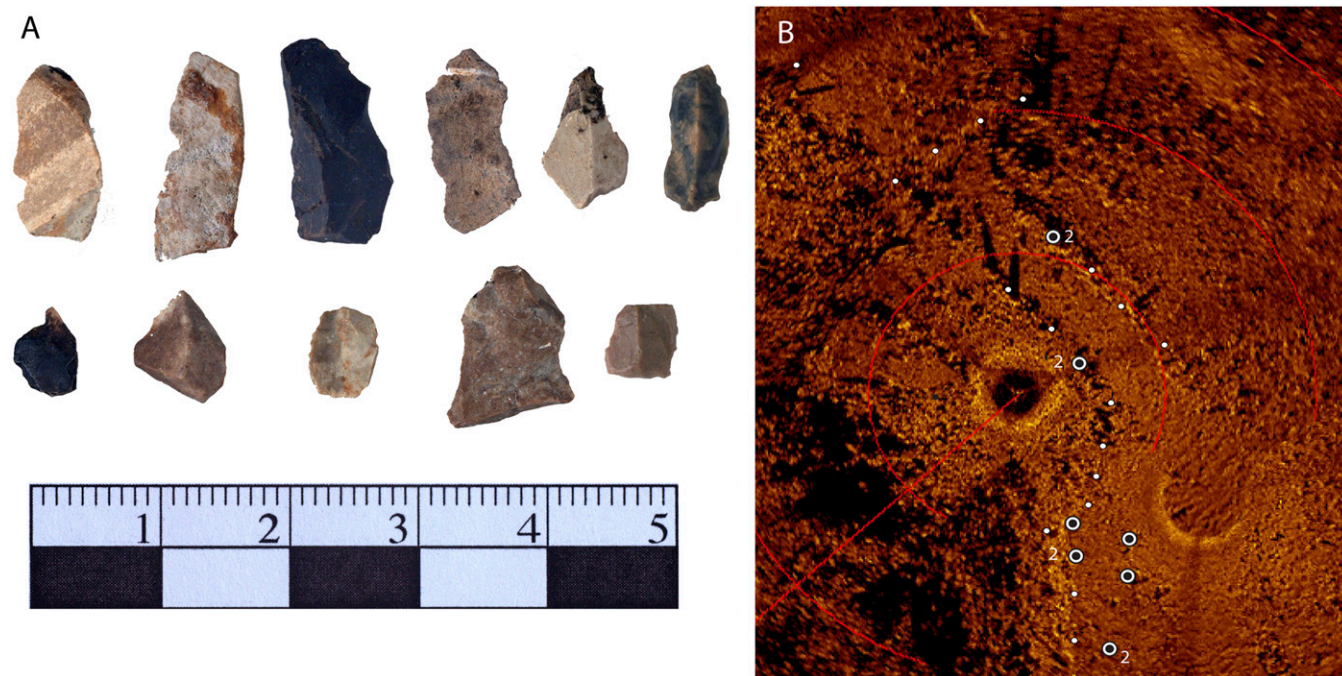
Fig. 3. Stone tool debris from the Drop 45 Drive Lane. (A) Composite photograph showing the 11 chert flakes recovered from the Drop 45 Drive Lane. (B) The location of archaeological tests on the Drop 45 Drive Lane superimposed on the acoustic image (Fig. 2B). Small white circles represent test locations that did not generate identifiable archaeological debris. Large white circles with black centers represent locations that produced lithic debris. Black centers with adjacent numerals indicate locations that generated multiple lithic remains. North is to the top of the image, and the red circular rings surrounding the scanning sonar placement are incremented in units of 15 m.

environmental reconstruction and a detailed map produced from side-scan and multibeam sonars, an agent-based simulation of caribou herd movement across the AAR was developed (17, 18). This simulation provided a level of social intelligence to the individual animals as they iteratively transited and learned the landscape over time. A machine learning tool, Cultural Algorithms, based on models of Cultural Evolution generated "hot spots" representing areas that were likely to contain hunting structures by using the caribou herd movement simulation data and ethnographic information (19).

An important result of the simulation was the prediction that there should be distinctive routes for the autumn and spring migrations (Fig. 4). The simulation also highlighted two critical choke points within the study area where all preferred migrations routes for both seasons converge. Drop 45 is located at one of these predicted choke points.

Although the computer simulation predicted seasonal patterns of movement, the physical placement and orientation of hunting structures provides an independent indicator for season of use (14). Given the orientation of Drop 45, it would only have been effective if the animals were moving in a northwesterly direction, i.e., during the spring migration from modern day Ontario. Although the majority of hunting structures on the AAR, as with virtually all ethnographic cases, suggest that autumn was the preferred season for hunting (20–23), the spring orientation of Drop 45 coincides with the seasonal association of the one other complex

hunting structure located to date, the Funnel Drive (14). It is noteworthy that the V-shaped hunting blinds that are located upslope from Drop 45 are oriented to intercept animals moving to the southeast in the autumn. This concentration of differing types of hunting structures associated with alternative seasons of migration is consistent with the simulation's prediction that the area was a convergence point along different migration routes, where the landform tended to compress the animals in both the spring and autumn. This predictability and natural channeling of caribou herds provided by the overall shape of the AAR landform and the narrow width of this particular area would have been highly significant to ancient hunters and no doubt led to the proliferation of hunting structures at this location.

Discussion

Complex multielement structures such as Drop 45 not only provide unambiguous evidence for intentional human construction, they also provide important insight into the social and economic organization of the ancient hunters that used the AAR. The larger size and multiple parts of the complex drive lanes would have necessitated a larger cooperating group of individuals involved in the hunt. Although the smaller V-shaped hunting blinds could be operated by very small family groups relying on the natural shape of the landform to channel caribou toward them, complex structures like Drop 45 that contain multiple blinds and auxiliary structures to channel the animals into the kill zone necessitated larger groups of hunters and their families cooperating. In this sense, the complex drive lanes bear a greater resemblance to the better known terrestrial jumps (e.g., refs. 24–30).

The Drop 45 discovery and other hunting features beneath Lake Huron provide a testable model of seasonal organization of prehistoric hunters. If increased hunting group size is coupled with the season of use, the AAR structures can be seen to represent distinctive spring and autumn hunting strategies. In the autumn, animals in prime condition were taken sequentially along the AAR by small groups of hunters before moving into winter camps. In contrast, spring hunting sees larger aggregations of individuals cooperating in what are presumably larger kills.

The discovery of a 9,000-year-old caribou hunting structure beneath modern Lake Huron offers a unique window into the organization of prehistoric hunting for a time period that is very poorly known from terrestrial sites in the Great Lakes region. It further demonstrates that archaeological sites of great antiquity are preserved underwater and that they have the potential to fill important gaps in our understanding of the deep human past.

Materials and Methods

To discover sites within the AAR setting, a multilayered search strategy was developed. An initial survey was conducted by using side-scan sonar within two pilot search areas (Fig. S1), one a square 7.5 km to a side and the second a square of 4.5 km per side. Subsequently, a partially overlapping area of 115 km^2 was mapped by using multibeam sonar. Side-scan survey was conducted by using a digital side-scan sonar unit (Imagenex), at a frequency of 330 kHz and a depth of 20 m, mapping overlapping swaths of roughly 200 m. Multibeam survey was conducted by using an R2Sonic 2024 multibeam echo sounder with an F180 vessel attitude and position system. Targets of interest were examined in more detail by using a remote operated vehicle (ROV). The current work used an Outland 1000, equipped with UWL-500 LED lights, UWC-360D dual high-definition video cameras (color and black and white), and a manipulator. The ROV also carried a Tritech MicroNav100 tracking sonar to allow its location to be recorded in real time. Detailed acoustic mapping of the Drop 45 Drive Lane and the Funnel Structure was performed by using a Kongsberg MS1000 scanning sonar unit (model 1171), supplemented by direct measurement by scuba-trained archaeologists. Bottom sampling, in the form of hand core samples, grab samples, and systematic tests, was similarly conducted by scuba-trained archaeologists.

Hand core samples were collected by pushing a 15 × 5 cm clear plastic tube into the sediment. The cores were then transported to the laboratory where they were split in half lengthwise and logged in detail. Grab sediment
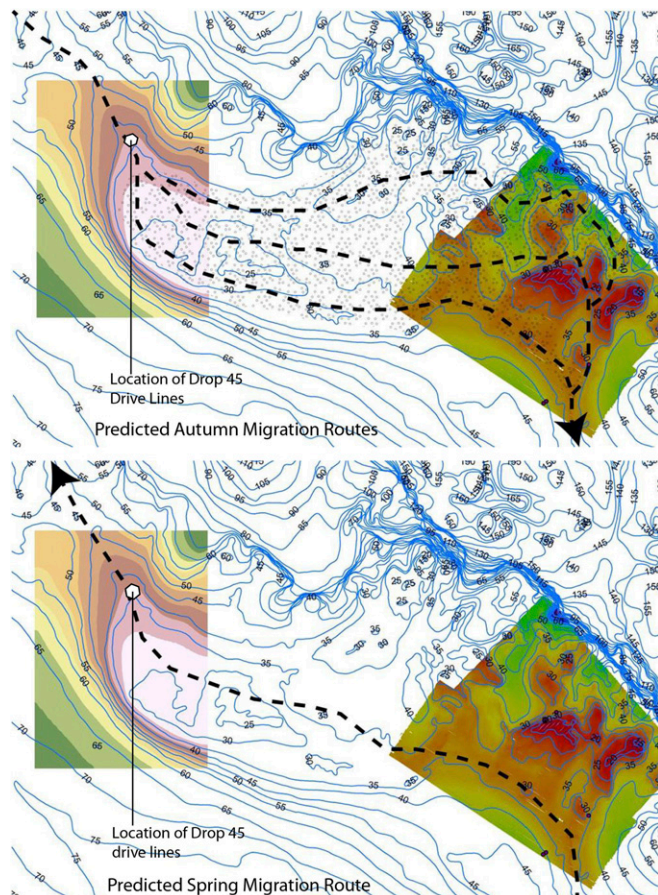

Fig. 4. Predicted caribou migration patterns across the AAR. Figure contrasts the predicted autumn and spring patterns of caribou herd movement across the central portion of the AAR. The contour interval is 5 m, which are colored in the two focal research areas. The location of the Drop 45 Drive Lane is marked in both representations.

samples were collected by divers into a 100-mL plastic tube for particle size, shape and material, organic and carbonate content, and microfossil (testate amoebae, pollen) analysis. These samples were georeferenced by using a marker placed at the sample location, and then the ROV's locator was used to obtain latitude and longitude of each sample. Systematic archaeological sampling at Drop 45 was performed via the scraping of bottom sediments down to bedrock (approximately 6 cm) within a 30 × 30 cm test unit at 3-m intervals along test transects. Each sample was manually screened by using # 3 one-quarter–inch (6.3 mm) scientific sieves on the bottom. All sediments collected in the sieve were bagged and labeled; samples were then dried and investigated for larger lithics and organic materials in the laboratory.

The bulk samples were processed through 1-mm, and 250-, 106-, and 10-μm sieves. Twenty milliliters of sample was left for bulk processing (grain size and loss on ignition). Grain size was performed on untreated samples on a Coulter LS 230 laser diffraction particle size analyzer. Sorting and sediment type were determined by using the Gradistat program (31). The 1-mm section was visually analyzed for lithic debris, charcoal, and fauna. The 250-μm sample was randomly split into one-16th fractions, and 1,000 grains were used for particle type and shape analysis under light microscope at 25× magnification. The 10-μm sample was randomly split into one-eighth fractions by using a wet splitter for testate amoebae analysis (32). Species were identified following the methods outlined in Scott et al. (33), and Kumar and Dalby (34) under light microscope at 80× magnification. Assemblages were determined by Q-mode cluster analysis in the PAST program (35).

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Supporting Information
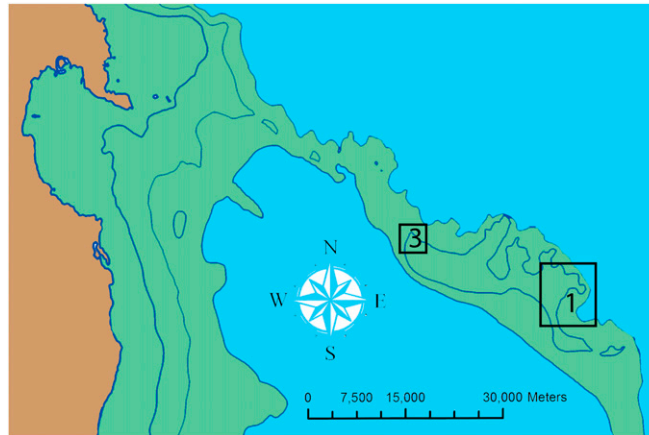
O'Shea et al. 10.1073/pnas.1404404111

Fig. S1. The location of research areas on the Alpena-Amberley Ridge (AAR). The figure illustrates the American portion of the AAR during the later Lake Stanley low water phase (after ref. 1). Modern land is shown in brown, whereas areas of exposed dry land during Lake Stanley are green. Areas of water are presented in blue. The contour interval is 20 m, with the modern lake shore represented as 176 m amsl. Rectangular boxes indicate the two areas in which active archaeological and paleoenvironmental work has been conducted.

1. O'Shea J, Lemke AK, Reynolds RG (2013) "Nobody knows the way of the caribou": Rangifer hunting at 45° North Latitude. *Quat Int* 29:36–44.

Table S1. Summary of Paleoenvironmental results from the AAR

Analysis	Summary of results	Paleoenvironmental implications
Testate amoebae	6 distinct assemblages based on cluster analysis; Oligotrophic Pond (*Difflugia oblonga*)	Variety of microenvironments, including fens, sphagnum moss bogs, and inland lakes
Dominant or indicator species	Kettle Hole Mire (*Centropyxids*)	
	Sphagnum Fen (*Cyphoderia ampulla*)	
	Sphagnum Bog (*Hyalosphenia papilio*)	
	Spruce/Tamarack Swamp (*Difflugia globulus*)	
	Eutrophic Pond (*Curcurbitella tricuspis*)	
Particle size	Sand—66.16%	Deep lake sediments are normally silts and clays;
Percentage of total samples	Silt—23.09%	abundance of sand indicates little deposition
	Mud—10.77%	after inundation
Particle sorting	Well sorted—1.54%	Variety of sorting indicates different sedimentary
Percentage of total samples	Moderately well-sorted—21.54%	regimes; less well sorted samples indicate lack of
	Moderately sorted—26.15%	transport and variety indicates preservation
	Poorly sorted—35.38%	
	Very poorly sorted—15.38%	
Particle shape	Very angular to subangular—70%	Lack of rounded sediments indicate sediments
Percentage of total samples	Subrounded to well-rounded—30%	have not traveled
Particle material	Area 1—Quartz, 65%; Chert, 12%; other, 23%	In Area 3 where lithics are found, higher amounts
Percentage of total samples	Area 3—Quartz, 50%; Chert, 25%; other, 25%	of chert available; glacial sediment with possible chert cobbles used for tool production

Table S2.   Carbon dates for late Lake Stanley stage on the AAR

Laboratory no.	Sample unit	Years B.P.	SD	Calibrated years B.P.	Delta ^{13}C	Material
X20851*	AA95226/Wood 1	8,038	46	8,900	−25.50	Spruce pole
OS-99473	Wood 4	7,960	55	8,829	−25.12	Rooted spruce
OS-100524	Wood 5	7,840	40	8,640	−26.12	Tamarack pole
OS-100526	92912F	8,080	35	9,020	−26.54	Charcoal in rock ring

*Sample was run at the University of Arizona Accelerator Mass Spectrometry (AMS) laboratory. Remaining three dates were run at the National Ocean Sciences AMS facility at Woods Hole.