



Magnetic detection of archaeological hearths in Alaska: A tool for investigating the full span of human presence at the gateway to North America

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ABSTRACT

Magnetic survey methods have recently shown tremendous potential for the detection of archaeological hearths in Eastern Beringia, ranging from intermittent open-air camp fires to larger heat intensive activity areas. Here we present an overview of the method along with eight supporting case studies from seven U.S. National Park Service units in the U.S. state of Alaska, covering diverse geographic settings and time-periods. Together, these case studies demonstrate the capabilities of magnetic detection instruments in various modes of operation for finding datable archaeological deposits that span the breadth of known human occupation of this region. The examples range from the simplest use of the magnetometer as a single sensor reconnaissance instrument in a “search mode”, to use as a gradiometer in conjunction with other geophysical methods such as ground-penetrating radar, to record precise measurements and inform nuanced interpretations. Examples presented here range from the terminal Pleistocene to historic periods, spanning 12,000 years of human activity in Eastern Beringia, and encompassing the arrival, emergence, and expansion of multiple human groups or cultural traditions in the New World.

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1. Introduction

Migration routes from Western Beringia (modern Russian Far East) to Eastern Beringia (modern Alaska and non-glaciated parts of the Yukon Territory) are well established as primary avenues for the initial peopling of the Americas at the end of the last Ice Age, as well as multiple subsequent episodes of migration and ongoing human

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interactions between the New World and the Old that continue to this day (e.g., West, 1996; Goebel et al., 2008; Meltzer, 2010; Hoffecker et al., 2014; Hoffecker et al., 2016; Moreno-Mayar et al., 2018a; Moreno-Mayar et al., 2018b). Native people came to occupy all corners of the vast and varied tracts of Alaska, but were among the last to meet with Euro-American contact due to the remoteness of the region and the rigors of high latitude climate and travel. Today, for many of the same reasons, much of the region's archaeology remains superficially understood. Many of Beringia's archaeological sites, particularly the earlier ones, likely remain either undiscovered or under-investigated. Here we review the recent use of magnetic surveying in closing this knowledge gap, largely by allowing for the rapid discovery of datable archaeological materials associated with a tool of fundamental importance to all human cultural groups: fire.

Intentional use of fire appears to be ubiquitous among anatomically modern humans, and substantial evidence suggests that earlier hominins also used fire (e.g., Shahack-Gross et al., 2014; Berna et al., 2012; Henry et al., 2011; Goldberg et al., 2009; Goren-Inbar et al., 2004; Weiner et al., 1998; Brain and Sillen, 1988; Clark and Harris, 1985; Oakley, 1961, 1957, 1956, 1955, 1954). Deliberately burnt areas and materials have therefore long garnered the attention of archaeologists. For decades and worldwide, magnetic survey methods have seen extensive use in archaeology (Aspinall et al., 2008), including for the detection of features associated with burning, such as hearths and kilns (e.g., Aitken, 1958; Jones and Munson, 2005; Urban et al., 2014; Andreou et al., 2017). Owing to the fact that many natural materials found at archaeological sites contain iron oxides (e.g., soils, rocks), exposure of these materials to intense heat can result in a detectable magnetic anomaly that can remain for thousands of years after the initial heating took place. A local magnetic dipole or cluster of dipoles will often result in the case of burnt rocks or tightly contained and undisturbed areas of burnt soil (Fig. 1), or a general area of increased magnetic susceptibility may result in cases where burnt soil has been disturbed or spread more broadly within an activity area. The latter is due to changes in magnetic oxides related to burning (Le Borgne, 1955, 1960). Thermoremanent (TRM) magnetization generally makes up a major component of an *in situ* hearth magnetic anomaly, characterized by a permanent magnetic direction that was set at the time of cooling (representing the ambient magnetic field from the last firing event). The intense magnetic anomalies associated with hearths can be largely attributed to TRM (Fassbinder, 2017).

The most notable early success in this application of magnetometry occurred when Oxford University physicist, Martin Aitken, adapted a proton-procession magnetometer to detect kilns at the Roman site of Water Newton in the United Kingdom (Aitken, 1958). Shortly after Aitken's success, the same approach was used by American archaeologists J. Louis Giddings and Douglas D. Anderson (a co-author of this paper) in an attempt to detect hearths in northwest Alaska (Urban 2012, 2019; Urban et al., 2012), including at locations presented in this paper. Although unsuccessful in this initial attempt, the work of Giddings and Anderson was among the first archaeological uses of magnetometry in North America; contemporary with the first published North American archaeological magnetic survey conducted by Black and Johnson (1962) at Angel Mounds, Indiana. In the years that followed, magnetic survey methods achieved widespread use in North American archaeology for the detection and investigation of many types of archaeological features ranging from the large-scale such as earthworks, to micro-scale features such as footprints (e.g., Kvamme, 2003, 2006; Urban et al., 2018). In spite of the early work of Giddings and Anderson, the method saw less extensive use in Arctic and sub-Arctic regions of N. America until fairly recently. Successful cases from high latitude regions of Alaska and Canada have appeared infrequently in

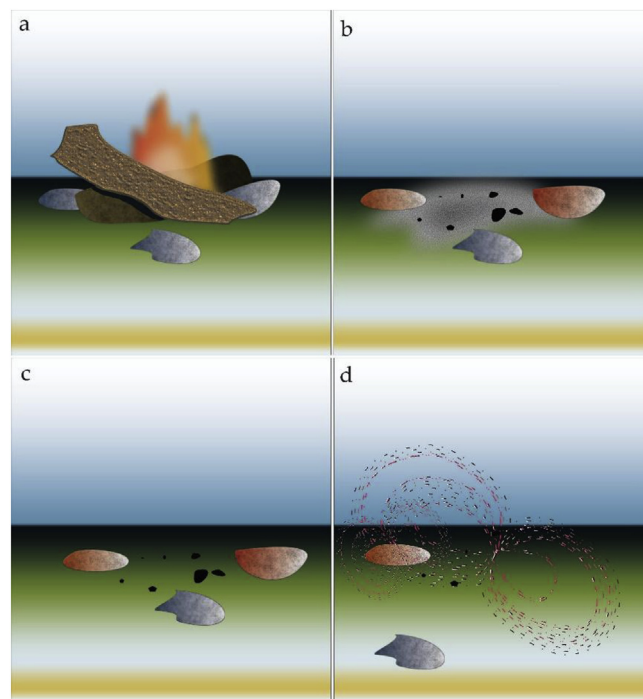


Fig. 1. Formation of a hearth magnetic anomaly for the simplest case of an open-air campfire – (a) a small surface fire is made, sometimes containing stones (either intentionally placed there or naturally present) and sometimes using a small depression. (b) The fuel source is consumed leaving behind a lens of ash and charcoal while heated rocks became fire reddened or cracked. (c) Ash and charcoal may blow away and the feature may be covered over time by turf. Some artifacts may either remain nearby or get brought up to the surface by taphonomic processes. (d) Soil and stones that were heated by the fire were magnetized and now the location of the hearth can be detected on the basis of a local magnetic anomaly even when those materials are no longer visible at the surface and even though thousands of years have passed since the burning took place.

the peer-reviewed literature, with most published cases appearing only in the last decade (e.g., Hodgetts et al., 2011; Urban et al., 2012; Wolff and Urban, 2013; Wolff and Urban, 2014; Landry et al., 2015; Urban et al., 2016a; Hodgetts and Eastaugh, 2017; Landry et al., 2017; Urban, 2019).

Here we present a number of recent, successful case-studies which apply magnetic surveys to the detection of archaeological hearths across a wide range of settings and time-periods in Alaska. These examples range from the Gulf of Alaska to the Arctic Circle and extend temporally from the terminal Pleistocene to more recent historic contact—a period spanning the last twelve-thousand years. In this paper, we take the archaeological meaning of “hearth” to include intentional fires ranging from the simplest open-air camp fires (such as the case with the terminal Pleistocene Sluiceway complex) to more broadly burnt activity areas associated with semi-permanent residential structures intended for sustained use (such as the case with the proto-Thule Birnirk culture). The range of examples therefore includes the use of magnetic surveying as a larger scale reconnaissance technique for the detection of hearths with little or no surface manifestation or other indications of cultural activity, to the detection of unseen or deeply buried activity areas within previously identified sites to pinpoint datable material or demarcate differential use of space within such sites.

In some of the cases presented here, magnetometry is used as a stand-alone method, and in others it is used in tandem with other geophysical techniques, particularly ground-penetrating radar (GPR). False positives and high latitude magnetic disturbances are also described to help define some of the limitations encountered

with magnetic surveying for hearths in this part of the world. Implications for scientific research and cultural resource management are discussed to highlight the far-reaching potential of the method.

1.1. Cultural traditions and time-periods represented by the case studies

The span of human presence in Eastern Beringia extends back to the late Pleistocene with foragers crossing Bering Land Bridge from Eurasia (Potter et al., 2017; Hoffecker et al., 2016). A handful of broadly defined cultural traditions (with varied local expressions in different regions) have been designated by archaeologists, ranging from the Paleoarctic groups that straddled the Pleistocene–Holocene boundary to more recent Thule groups which comprise the immediate ancestors of modern Inupiat and Inuit peoples across the N. American Arctic. These cultural traditions are defined by specific subsistence modes and artifact types, and as with periodization in most areas of archaeology, the boundaries and nuances are subject to continuous debate and revision.

The case-studies presented in this paper offer examples from most of the major cultural traditions seen in Eastern Beringia, in the broadest sense, with at least one example each representing the Paleoarctic tradition, Northern Archaic tradition, Ocean Bay tradition, Arctic Small Tool tradition, Norton tradition, Thule tradition (proto-Thule Birnirk), and early-contact (post-Thule Inupiat in this case) (Fig. 2). Dates associated with the specific features or sites used as examples in this paper are summarized in Table 1 and Fig. 3.

These broad traditions represent peoples that spread far, from the initial Pleistocene peopling that contributed to much of the native ancestry of both North and South America, to various Holocene peoples that later arrived in Alaska (from Siberia) or emerged in Alaska (descendent from earlier migrants) and then spread eastward into Canada, settling as far east as Greenland (e.g., Anderson 1968; Dikov, 1993; Dumond, 1995; King and Slobodin, 1996; Roosevelt et al., 1996; Raghavan et al., 2014; Raff et al., 2015; Moreno-Mayar et al., 2018a; Moreno-Mayar et al., 2018b). These latter migrants and their descendent cultures were likely the first native peoples of the New World to encounter Europeans, with

Norse explorers and settlers reaching areas of Greenland and Newfoundland during the European Middle Ages. In contrast, it would be many centuries later before the earliest known European contact with Thule descendent peoples in Eastern Beringia. This latter event is represented here by our most recent case study from an Inupiat village site, presented as our first example, with following examples progressing further back in time until reaching the paleo-traditions represented in this paper by the Sluiceway complex.

2. Methods

All case-studies presented in this paper used a cesium-vapor magnetometer with either one or two sensors mounted on a hand-carried aluminum staff (Fig. 4). We could operate the system either in “search” mode, with no data being logged, or in survey mode where we collected data in a grid pattern. While gridded survey is generally preferred, allowing for more detailed inspection of the horizontal form of anomalies and reducing the chance of missing a smaller or weaker anomaly, in some cases only rapid reconnaissance was possible. This was most often related to time constraints at the most remote sites which required helicopter access, itself often limited by inclement weather. In such cases, more ground could be covered using the more rapid search approach, which we felt was a reasonable trade-off to improve our odds for success. Also with such sites, returning to ground-truth anomalies was not guaranteed, so these were tested in real-time (i.e. immediately after being flagged by the magnetometer operator).

We found success in hearth detection with various sensor configurations (Fig. 4). While the instrument easily detects hearths with the sensor cylinders (s) oriented perpendicular to the ground (a commonly used configuration), positioning the sensors at a 45° angle to the surface results in fewer sensor drop-outs (when signal is temporarily lost, specific to cesium sensors) at the site latitudes discussed in this paper, and is therefore more efficient. Incidentally, this is also the currently recommended sensor orientation for optimum signal at locations used in this paper on the basis of the most

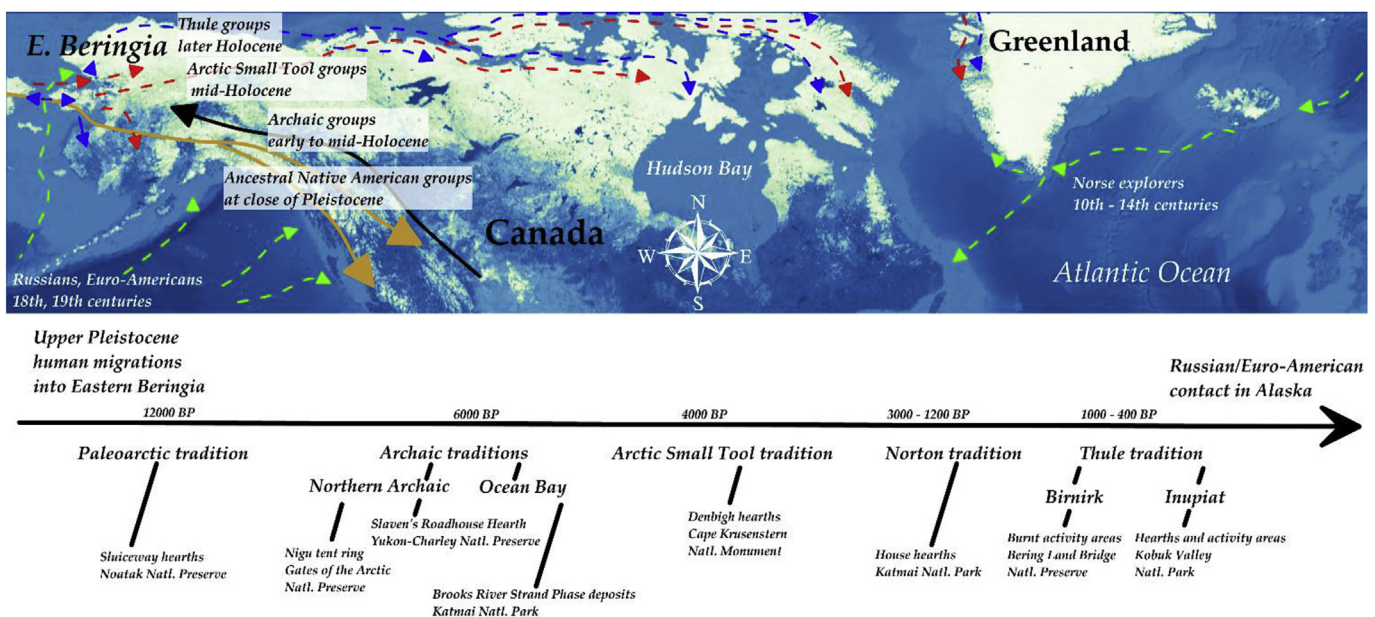


Fig. 2. Top: Illustration of the dispersal of people into and out of E. Beringia from the Upper Pleistocene through to Old World contact. Bottom: Timeline of Alaska's archaeological cultural traditions alongside associated finds discussed in this paper.

Table 1
Radiocarbon dates from sites described in this paper.

NPS Unit	Cultural tradition/site #	Lab code	Material	Radiocarbon age BP	Calibrated age BP ^c
Noatak	Paleoarctic MIS - 00515	Beta-489403	charcoal	10150 ± 30	12,011–11,700 11,669–11,645
Noatak	Paleoarctic MIS - 00515	Beta-489404	charcoal	9720 ± 40	11232–11088 10922–10893
Noatak	Paleoarctic DEL - 00391	Beta-489401	charcoal	9880 ± 40	11,364–11,213 11,390–11,376
Noatak	Paleoarctic DEL - 00391	Beta-489402	charcoal	9690 ± 30	11,200–11,095
Yukon-Charley	Northern Archaic CHR - 00030	CAMS-169216	charcoal	4356 ± 30	4930 ± 50
Yukon-Charley	Northern Archaic CHR - 00030	BETA-258421	charcoal	4060 ± 40	4440–4580
Yukon-Charley	Northern Archaic CHR - 00030	BETA-258420	charcoal	3970 ± 40	4410–4520
Katmai	Ocean Bay XMK - 050	I-1634	charcoal	4240 ± 250	4818 ± 350
Noatak	Arctic Small Tool MIS - 00515	Beta-489405	charcoal	3780 ± 30	4245–4081 4031–4009
Noatak	Arctic Small Tool MIS - 00515	Beta-489406	charcoal	3740 ± 30	4158–3984 4224–4205
C. Krusenstern (2017)	Arctic Small Tool NOA - 00XX	UGAMS-32376-7-8	charcoal (3)	3530 - 3770 ± 30	3790–4140
C. Krusenstern (2018)	Arctic Small Tool NOA - 00XX	UGAMS-38441-2-4-5-6-7-8	charcoal (6)	3170- 3710 ± 20	3300–4050
Katmai	Norton XMK - 050	VERA-6279	charcoal	1509 ± 27	1608–1396
Katmai	Norton XMK - 050	VERA-6280	charcoal	1564 ± 37	1608–1396
Katmai	Norton XMK - 050	VERA-6281	charcoal	1515 ± 28	1608–1396
Bering Land Bridge	Birnirk KTZ-304	Various ^a	caribou bone and wood	800 ± 50–905 ± 20	
Kobuk Valley	Inupiat XBM - 047	GX-33433 AMS	charcoal	280 ± 30	350 ± 70
Kobuk Valley	Inupiat XBM - 047	GX-33434 AMS	charcoal	230 ± 30	220 ± 90
Kobuk Valley	Inupiat XBM - 047	dendro	Structural wood	ca. 200 ^b	

^a see [Alix et al., \(2017\)](#).

^b see [Griggs et al., \(2019\)](#) In [Anderson and Anderson 2019](#).

^c IntCal13 atmospheric curve ([Reimer et al., 2013](#)).

recent International Geomagnetic Reference Field Model (IGRF 12th edition). We were able to successfully detect hearths with gridded surveys using both single sensor operation and with gradient operation (differential measurement of two sensors vertically separated) as well as in search mode with either one or two sensors, though a second sensor is generally unnecessary in search mode. In cases of single sensor gridded surveys, base stations (i.e. sequentially reoccupied collection points used to establish temporal changes) were collected in order to remove diurnal trends from the data.

The most efficient set-up in terms of speed, battery conservation, and reduced sensor drop-outs proved to be search mode with a single sensor positioned at a 45° angle to the survey surface. When operating in search mode, anomalies were identified in real time from the live oscilloscope-like trend line that appears on the instrument console ([Fig. 5](#)). Though noting that single sensor operation is what rendered the earlier magnetic surveys of Giddings and Anderson unusable (the differential measurement of the gradient would likely have solved their problems with background noise ([Urban, 2012](#))), we have found that as long as appropriate base station corrections are undertaken (with logged data) and inappropriate survey times are avoided (e.g. noisiest times of the solar day; predicted magnetic storms), then single sensor operation is wholly suitable for hearth detection at high latitudes.

General instrument and survey parameters are listed in [Table 2](#).

Data editing and diurnal trend removal (in cases where base stations were used) were done using MagMap 2000[®], and data gridding done using Surfer 14[®]. Plan view images were produced with Surfer 14[®] and 3-D images incorporating magnetic and ground-penetrating radar data were produced with Voxler 4[®], both by Golden Software Inc. GPR collection and processing parameters for data presented in this paper are published in [Urban et al., \(2016a\) and b](#).

2.1. Considerations for magnetic surveying at high latitudes

Magnetic surveying of the type used for the examples in this paper is a passive geophysical method, meaning that the operator does not control the parameters of the source field, comprised rather of Earth's magnetic field and other natural or anthropogenic local fields therein. Earth's magnetic field exhibits diurnal variations ([Price, 1969](#)) as well as seasonal variations that drive the intensity of magnetic disturbances ([Roosen, 1966](#)), with both variations and associated disturbances being more extreme at higher latitudes ([Campbell, 1997](#)). The average daily range and average daily temporal rate of change in the magnetic field is most extreme at approx. 70° latitude in the corrected geomagnetic (CGM) coordinate frame ([Viljanen and Tanskanen, 2013](#)), within which all points along a magnetic field line have the same geomagnetic latitude and longitude. The CGM latitudes calculated

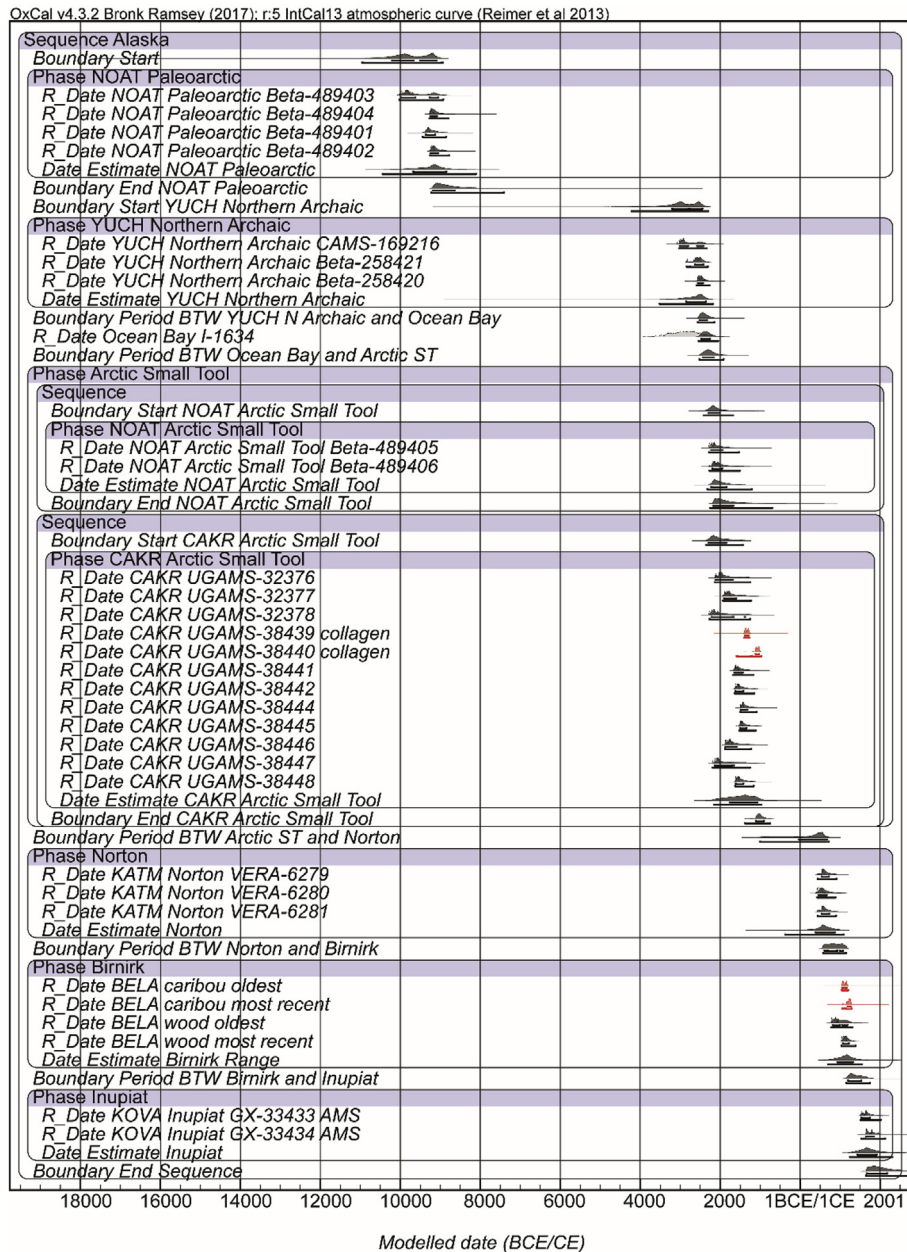


Fig. 3. Approximate radiocarbon-based timescale for the sites discussed in this paper. Available radiocarbon dates (Table 1) were assessed in terms of their culture and site Phases in a time Sequence from Paleoarctic through to the recent Inupiat site employing the OxCal software (Bronk Ramsey, 1995, 2009) with IntCal13 (Reimer et al., 2013). The Charcoal Outlier Plus model is applied to the dates on charcoal/wood to try to allow for the in-built age typically involved with such samples (Dee and Bronk Ramsey, 2014). All dates in black are on charcoal/wood. Dates in red are on bone/collagen and should offer dates close to contemporary with the animal and use by humans. The solid distributions show the modelled calendar age probabilities. The lines under each probability distribution show the 68.2% and 95.45% ranges respectively. For the Birnirk phase where there are numerous dates we have employed the oldest and youngest of the dates on caribou bone and the oldest and youngest dates on wood samples to set an indicative dating range for the Phase. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

for the examples in this paper range from approx. 59° to approx. 61.5° (not to be confused with geocentric latitudes of the sites, which range to greater than 67° with our northernmost site).

The reason for this situation is the interaction between the Earth's magnetic field and the solar wind, which is more concentrated at the magnetic poles (Fig. 6). This induces time-varying magnetic fluctuations that can be both more rapid and intense than would be experienced at lower latitudes. The effect of solar induced magnetic storms are commonly experienced at high latitudes, producing rapid and often intense temporal magnetic field variations which can impact the operation of navigation and

communication equipment as well as rendering ground-based magnetometer work temporarily useless. These naturally occurring variations and disturbances must therefore be accounted for and subsequently either eliminated or reduced in order to assess residual anomalies related to the targets of interest, or altogether worked-around in the case of the worst disturbances. While accounting for these issues can be a concern at all latitudes, it is especially crucial at high latitudes because the negative effects will be greater.

Monitoring space weather and minding the diurnal cycle can mitigate problems by aiding with planning for the optimal timing

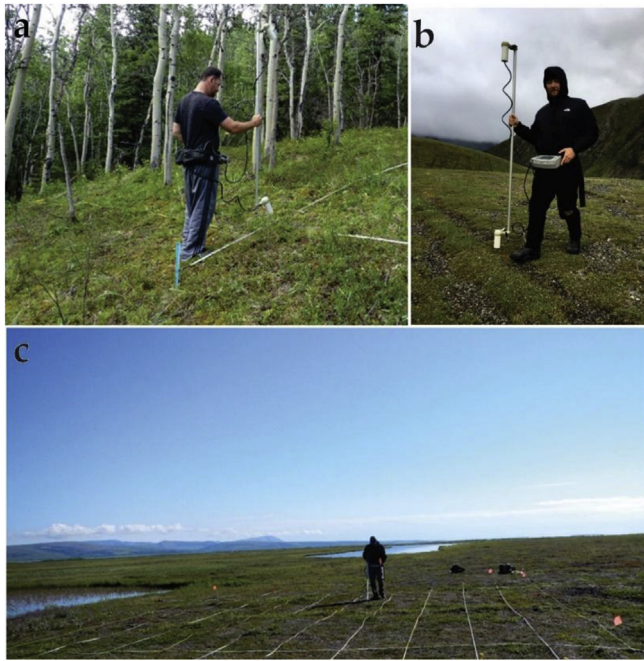


Fig. 4. (a) Magnetic gradiometer with sensors positioned at 45° angle (photo taken at Little Panguingue Creek site near Denali N.P. by Yan Axel Gomez Coutouly). (b) Gradiometer set-up with sensors positioned perpendicular to surface (photo taken at Noatak National Preserve by J. Rasic). (c) Single sensor magnetometer with sensor at 45° angle (photo taken at Cape Krusenstern by A. Tremayne). In the last case, base station corrections were used to remove the diurnal trend from the resulting survey data.

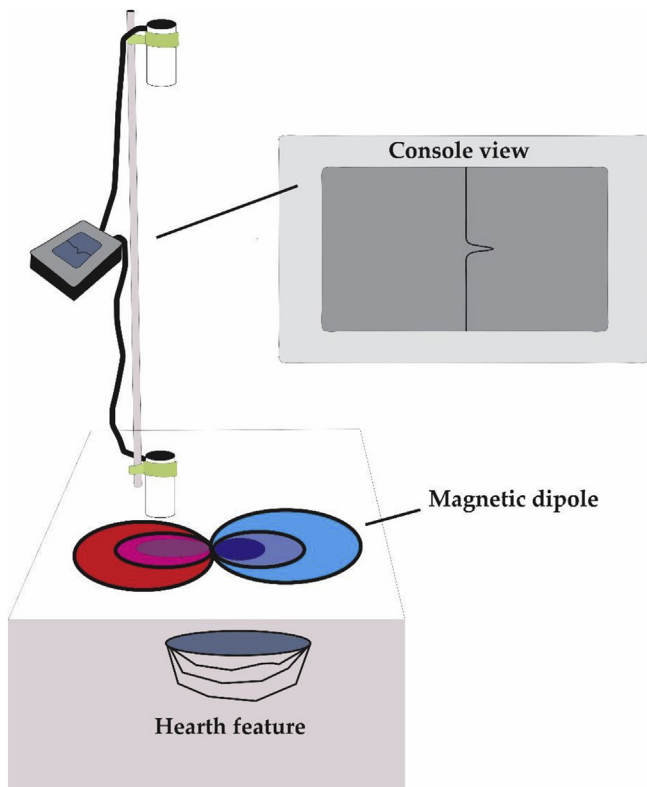


Fig. 5. Magnetometer response to a hearth feature. A gridded survey would result in either a mapped dipole or localized magnetic high. The live-response is shown in the console view above, representing what the instrument operator observes while approaching the hearth feature with the instrument in operation. The latter is how hearths are identified on search mode.

for surveys during magnetically quiet periods. Obtaining a space weather forecast prior to departing for a field site is therefore advisable particularly during the summer field season, when auroral effects are often at their strongest. Such forecasts are easily obtained prior to fieldwork from government agencies such as the National Air and Space Administration and the National Oceanographic and Atmospheric Administration (e.g., Space Weather Prediction Center, NOAA).

While this pre-fieldwork planning can help minimize downtime, survey operations may have to shut down temporarily during magnetic storms (which are easily detected during magnetometer operation). Depending on the specific instrument, these may be identified during data collection both visually on the console and with audio warnings, which can alert the operator to halt data collection. The instrument used for the case studies in this paper allowed for pausing data collection and monitoring the temporal magnetic disturbances while remaining stationary with the instrument in search mode, with normal data collection resuming when the temporal variation of the magnetic field stabilized. Depending on the cause of the magnetic disturbance, delays could be a matter of minutes, hours, or in more rare cases, days.

2.2. False positives and magnetic contamination from natural and anthropogenic sources

The potential for false positives is always a consideration for magnetic surveying. In the case of hearths in particular, because the form the magnetic anomaly takes is often a dipole, dipole cluster, or general magnetic high rather than something which bares actual resemblance to the causative body, a case of mistaken identity is always possible. In other words, things other than hearths, some natural and some anthropogenic, can produce magnetic anomalies similar to that of a hearth. Common culprits include things such as magnetic rocks of the appropriate size to produce a hearth-like dipole, or small iron objects of historic or modern origin. Many archaeological sites that have been the subject previous work will contain the latter in the form of old pin flags, nails, stakes, and rebar. The presence of such items can limit the use of a magnetometer (if the offending items cannot be removed or are unknown to the surveyors). Lightning strikes also generate magnetic anomalies, and can be rather common in certain settings. These can generally be distinguished from hearths on the basis of the intensity and form the magnetic anomaly takes – with a strike generally resulting in a star-shaped anomaly which can be significantly more magnetic (>200 nT) than nearby hearths (Maki, 2005; Fassbinder, 2017). Knowing about the potential presence of such sources in a given survey area can be helpful in mitigating the problem of faulty interpretation.

An interesting natural false-positive source that appeared to be common in one of our study areas were the centers of frost boils, a common geomorphologic feature in certain Arctic settings. The centers of these features in the Noatak region consistently yielded magnetic anomalies similar to those of hearths (Fig. 7). After excavating several and realizing that there were natural concentrations of iron oxides in the central nodes of the frost boils, we soon learned to visually identify these features at the surface and therefore avoid mistaking their associated magnetic anomalies for those of hearths; a good lesson that resulted in two of the oldest hearths presented in this paper being identified in a landscape where frost boils seemed to far outnumber hearths.

Another interesting (and consistent) false positive case occurred at Katmai National Park and Preserve, though in this instance the source was anthropogenic rather than natural. At a Norton house pit near Brooks Lake, a survey was conducted with magnetic gradiometry, yielding a very conspicuous magnetic anomaly initially

Table 2
Methods. * Ca. 5 samples/m.

NPS Unit	Instrument	Configuration/Survey type	Cycle time*	Line space	Cylinder	Base station	Processing
Noatak	G-858 optically pumped Cesium magnetometer, Geometrics Inc.	Vertical gradient, Gridded and Search mode, bi-directional	0.1 s	0.25 m	90°	No	MagMap2000 V 5.05 [®] Geometrics Inc, and Surfer 14 [®]
Yukon-Charley	G-858 optically pumped Cesium magnetometer, Geometrics Inc.	Vertical gradient, Gridded and Search mode, bi-directional	0.1 s	0.25 m	90°	Yes	MagMap2000 V 5.05 [®] Geometrics Inc, and Surfer 14 [®]
Gates of the Arctic	G-858 optically pumped Cesium magnetometer, Geometrics Inc.	Vertical gradient, Gridded and Search mode, bi-directional	0.1 s	0.5 m	90°	No	MagMap2000 V 5.05 [®] Geometrics Inc, and Surfer 14 [®]
Cape Krusenstern	G-858 optically pumped Cesium magnetometer, Geometrics Inc.	Vertical gradient, Total field (single sensor), Gridded and Search mode, bi-directional	0.1 s	0.5 m	45°	Yes	MagMap2000 V 5.05 [®] Geometrics Inc, and Surfer 14 [®]
Katmai	G-858 optically pumped Cesium magnetometer, Geometrics Inc.	Vertical gradient, Gridded and Search mode, bi-directional	0.1 s	0.25 m	90°	Yes	MagMap2000 V 5.05 [®] Geometrics Inc, and Surfer 14 [®]
Bering Land Bridge	G-858 optically pumped Cesium magnetometer, Geometrics Inc.	Total field (single sensor), Gridded and Search mode, bi-directional	0.1 s	0.5 m	45°	Yes	MagMap2000 V 5.05 [®] Geometrics Inc, and Surfer 14 [®]
Kobuk Valley	G-858 optically pumped Cesium magnetometer, Geometrics Inc.	Vertical gradient, Gridded and Search mode, bi-directional	0.1 s	0.25 m	90°	No	MagMap2000 V 5.05 [®] Geometrics Inc, and Surfer 14 [®]

thought to be the structure's hearth. Upon closer examination, it was found to be a large steel wrench placed in the house during an earlier test probe (Fig. 7). The heavily rusted wrench exhibited an degraded (weaker) magnetic anomaly. A small excavation, in fact, yielded no evidence of the house ever being occupied, perhaps indicating that it was abandoned prior to actual use for some unknown reason. While providing a comical example of an anthropogenic false-positive, the story was not over. Similar “wrench” anomalies were subsequently located in other house pits in the area during the course of our work, and our team became quick to look for and identify these, which actually yielded a stronger and more pinpointed response than the actual hearth anomalies within these features. In each case of a suspected “wrench” anomaly, the surface moss was pulled away, revealing evidence of an earlier test probe that had been covered by vegetation. Amazingly, a member of our team ran into archaeologist Dean Snow from the University of Pennsylvania, who happened to be visiting for the first time since 1963, when he worked with Don Dumond (University of Oregon) at Katmai. He confirmed that with Dumond's team, each test probe was left with metal objects for later relocation with a metal detector (Snow Pers. Comm. with L. Chisholm).

3. Case studies

Eight case studies drawn from seven U.S. National Park Service units, including Kobuk Valley National Park (KOVA), Cape Krusenstern National Monument (CAKR), Noatak National Preserve (NOAT), Gates of the Arctic National Park and Preserve (GAAR), Bering Land Bridge National Preserve (BELA), Yukon-Charley Rivers National Preserve (YUCH), and Katmai National Park and Preserve (KATM) (Fig. 8), are presented below, chronologically from the archaeologically most recent to the earliest. The examples in each case study were selected from nearly a decade of fieldwork, offering one or two good examples for a given location or time-period, that have in turn been extracted from a much larger body of work, including both published and unpublished material. The first two case studies, an early-contact Inupiat settlement on the Kobuk River (KOVA) and a Birnirk settlement at Cape Espenberg (BELA), bridge the broader Thule cultural tradition. This is followed by (in the paper), and preceded by (archaeologically) the Norton tradition, represented here by examples from the Brooks River

Archaeological District (KATM). These first three case studies are examples of pinpointing hearth locations within the well-defined boundaries of known archaeological houses, or activity areas external to house structures within known sites. Two of these examples come from sites in heavily forested areas (KOVA; KATM), which posed special challenges to magnetic surveying since the instrument is not easily maneuvered through thick vegetation and low branches. These sites therefore required some preparatory trimming and clearing. Since these first three cases (Inupiat; Birnirk; Norton) showcase hearths or activity areas associated with semi-subterranean structures, made obvious due to the presence of associated structural depressions or berms, they demonstrate the use of a magnetometer as a precision tool within known sites. The four cases that follow those, however, are drawn from earlier sites that have no house structures, with hearths being either open-air or tented camp fires. Surface indications in these cases are limited. Beginning with Denbigh hearths at Cape Krusenstern, part of the broader Arctic Small Tool tradition, we give an example of our best represented cultural tradition among the case studies with the detection of seventeen dateable hearths within a search area that stretched across many kilometers of coastal tundra. This is followed by the earlier archaic traditions, including an interior Northern Archaic hearth along the Yukon River (YUCH), and a likely Ocean Bay related activity area along the Brooks River (KATM), the latter associated with Strand phase deposits discovered decades ago by Don Dumond. We also present a case of an undated hearth found within the perimeter of a tent ring on the upper Nigu River (GAAR), with a diagnostic fragment of a notched point, suggesting the feature can be attributed to the Northern Archaic tradition. Finally, our earliest case study, presents two hearths associated with the terminal Pleistocene/early Holocene Sluiceway culture, part of the broader Paleoarctic tradition.

3.1. Early contact Inupiat village site in Kobuk Valley National Park (ca. 200 BP)

The Kobuk River valley (KOVA Fig. 8) has been the site of numerous human settlements spanning thousands of years (Larsen and Rainey, 1948; Giddings, 1952; 1956, and 1961a; Ford, 1959; Anderson, 1988). Among these is the Inupiat village site of *Igliq-tiqsiugvigruaq*, or Swift Water Place, along the Kobuk River. Swift

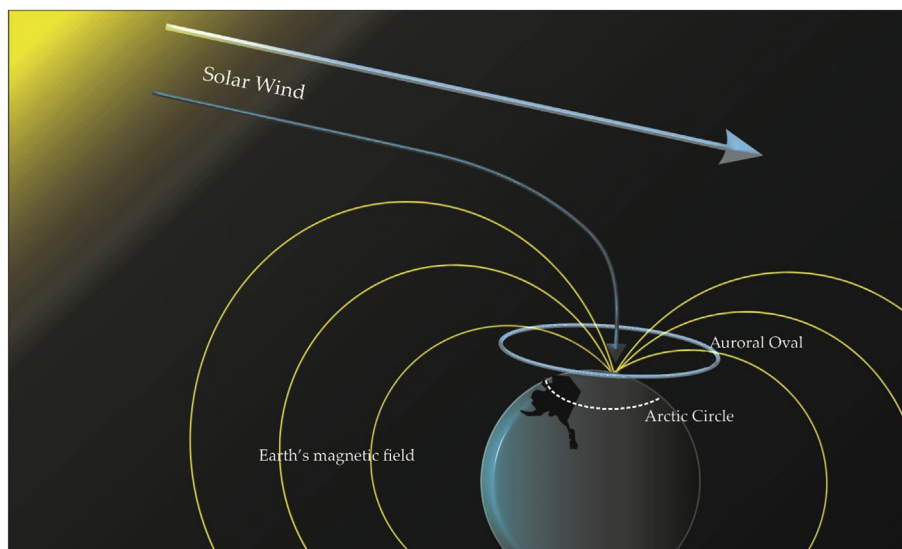


Fig. 6. Illustration of the relationship of latitude to magnetic disturbances in the northern hemisphere. The interaction of the solar wind and Earth's magnetosphere, a phenomenon that results in the aurora commonly observed at high latitudes, also leads to more frequent and intense interference with ground-based magnetic surveys at high latitudes. Obtaining a recent space weather forecast is therefore advisable during magnetic survey work at such locations. During a magnetic storm, surveys must be halted. Even without magnetic storms, normal diurnal field variations are more intense and abrupt at higher latitudes, and may require pausing survey operations at certain times of day depending on the location and conditions.

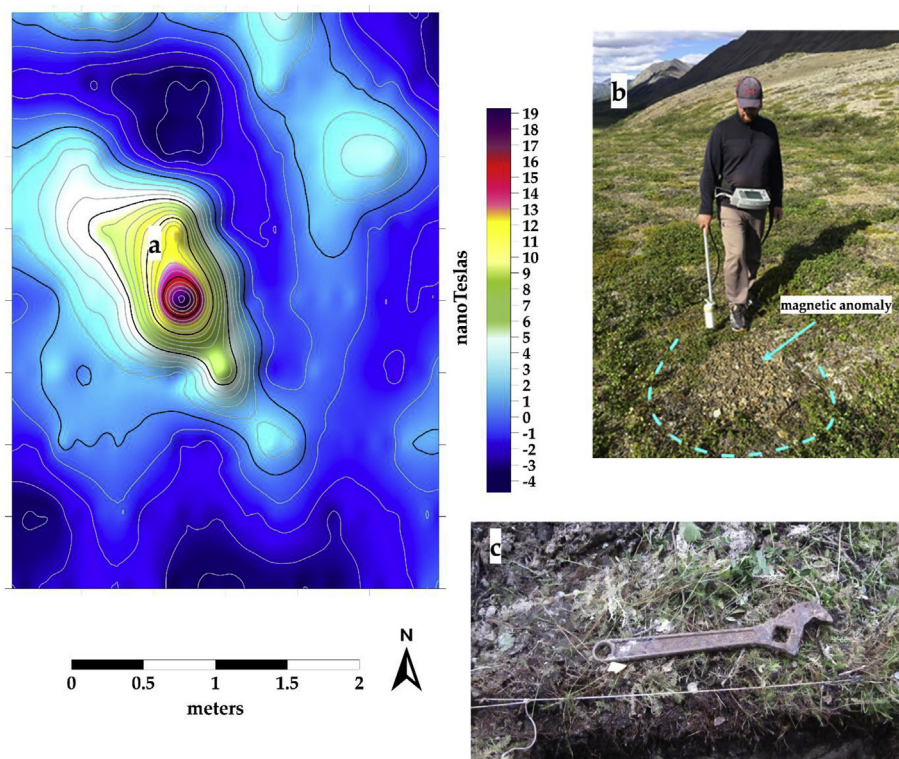


Fig. 7. (a) Magnetic survey of a frost boil in Noatak National Preserve exhibits a magnetic response that could easily be mistaken for a hearth. (b) The center of a frost boil is shown in the photograph on the right. (c) A wrench left behind intentionally during the 1960s to mark a test probe in a Norton house at Katmai National Park and Preserve.

Water Place is historically the most recent site presented in this paper. The site is an early contact village dated to the early 19th century (Griggs et al., 2019) with evidence of limited Euro-American contact in the form of some metal artifacts and glass beads (Anderson and Anderson, 2019). The site is also contemporary to the early Euro-American expeditions in the region e.g., Von

Kotzebue (1821); Beechey (1831). It is a large settlement, with at least twenty-six house depressions and more than one-hundred cache pits. The people of this village subsisted largely on fish, as shown by excavations and associated faunal analysis (DeAngelo and Weiss, 2019), and further supported by a dietary stable isotope study of human remains unearthed at the site (Ditchfield et al.,

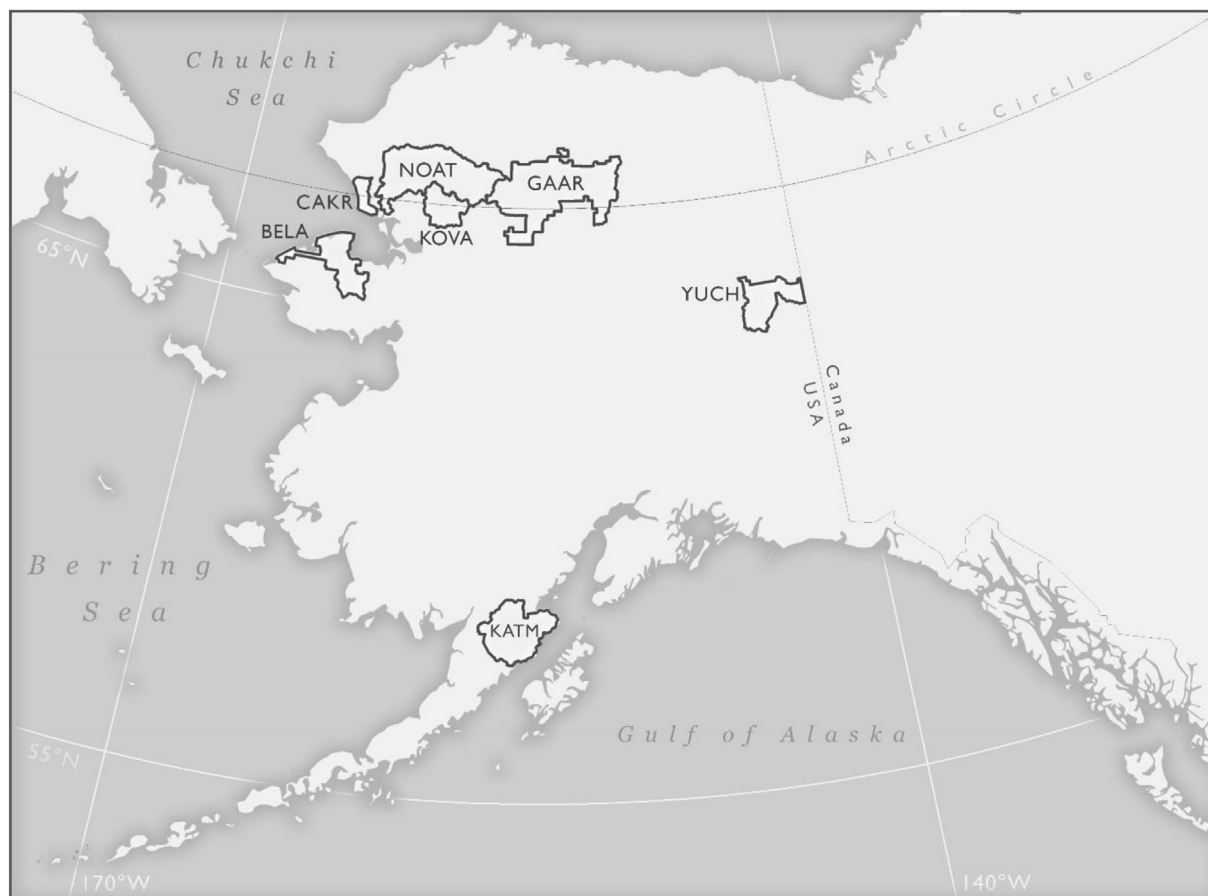


Fig. 8. Fig. 1. Map of Alaska showing National Park units used for this study: Kobuk Valley National Park (KOVA), Cape Krusenstern National Monument (CAKR), Noatak National Preserve (NOAT), Gates of the Arctic National Park and Preserve (GAAR), Bering Land Bridge National Preserve (BELA), Yukon-Charley Rivers National Preserve (YUCH), and Katmai National Park and Preserve (KATM). (Map by Adam Freeburg, NPS).

2019). A range of fishing equipment was found at the site, including a grayling hook with a metal barb, the latter being an indicator of either Russian or Euro-American trade.

Many people currently living at the nearby Inupiat village of Kiana are the descendants of people who lived at Swift Water Place (Anderson, 2019), who themselves were descendent from the broader Thule cultural tradition that originated in the Bering Straits region. Thule people expanded both east and west, eventually spanning from the Russian Far East across the higher latitudes of North America and on to the west coast of Greenland. These are the ancestors of all Yupik, Inupiat, and Inuit peoples that inhabit the same regions today (Raghavan et al., 2014; Raff et al., 2015).

Geophysical investigations at Swift Water Place involved three methods: ground-penetrating radar (GPR), magnetic gradiometry, and electromagnetic induction (EM). Insights derived from this work included not only understandings of the visible house pits and other village features (Urban et al., 2012; Urban, 2019), but also the discovery of a deeper, earlier settlement beneath the thawed active layer (Urban et al., 2016b; Urban, 2019). Among the interesting features of this village site were several very large depressions, likely community houses. Magnetic surveys of these features yielded very prominent hearth anomalies, easily seen in real time on the instrument console. When integrated with GPR data, it was realized that these features are fairly deep and consistent with large, lined hearths observed in the excavation of two other houses at the site (Fig. 9.). In addition to the multiple hearths located within house depressions at Swift Water Place, it

was found that some of the smaller “cache” pits were also magnetized, indicating some use other than storage, at least for some of these features (Fig. 10). One plausible scenario explaining these magnetized pits is pottery production, with the latter artifact type being abundant in the excavated areas.

3.2. Birnirk settlement complex at Cape Espenberg, Bering Land Bridge National Preserve (ca. 1000 BP)

The proto-Thule Birnirk culture appeared in Alaska around one-thousand years ago. It contributed to the formation of the Thule culture, which is in turn ancestral to the historical Inupiat population discussed in our first case-study (and all other Inuit peoples) (Anderson, 1979, 1980). Our Birnirk case study is drawn from fieldwork at the Cape Espenberg *Rising Whale* Site (KTZ-304), located in the Bering Land Bridge National Preserve at the northern tip of Seward Peninsula (BELA Fig. 8). The recognition of the *Rising Whale* site as a Birnirk settlement complex was relatively recent (Hoffecker and Mason, 2011), and preliminary work indicates that the site could be key to understanding the emergence of the Early Thule (Alix et al., 2017). Following a 200–300 year hiatus from a comparatively brief Ipiutak occupation dated prior to ca. AD 750 (Harritt, 1994), the settlement of the *Rising Whale* site was occupied at a pivotal cultural and environmental moment in Northwest Alaska and the larger Bering Sea region, at least as early as between 1040 and 1250 cal. BP and continuing into the Thule culture around the end of the 13th century. Cape Espenberg is a critical location to

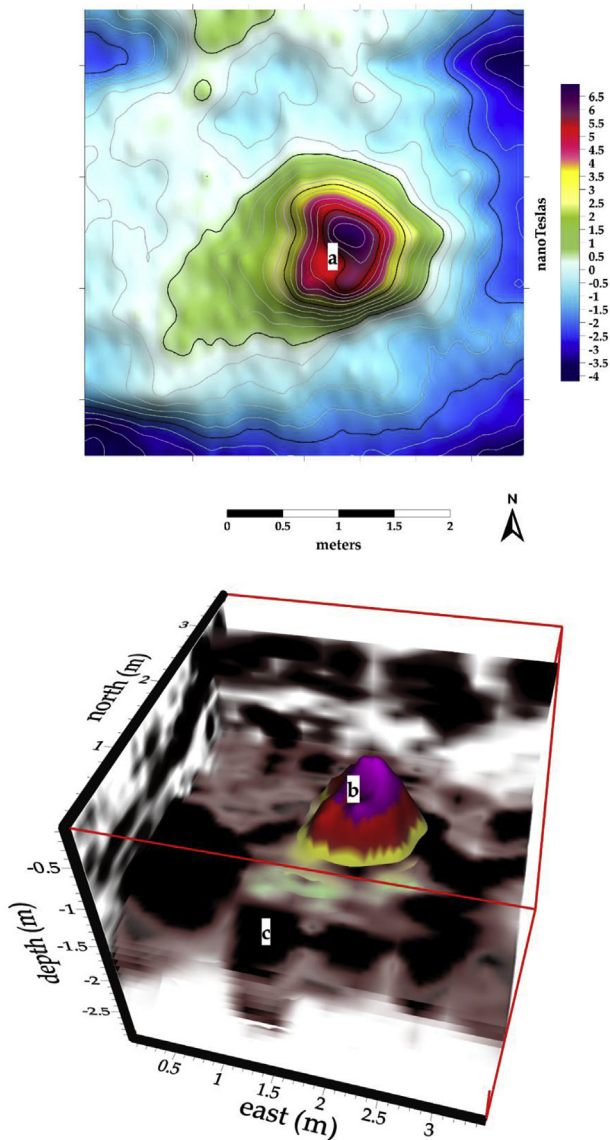


Fig. 9. Top: Magnetic hearth anomaly (a) inside a house depression. Bottom: 3-D visualization of the house depression combining the magnetic anomaly from the top (b), with GPR data showing internal structural elements of the house (c).

establish this cultural history due to the presence of Ipiutak, Birnirk and Thule archaeological occupations.

Unlike many semi-subterranean houses in Alaska, such as those described in the previous case study (Interior Kobuk River Inupiat), or the one to follow (Norton), the Birnirk and Thule houses at Cape Espenberg do not have clearly defined hearths; heat and light were provided by ceramic lamps. Excavation and magnetic surveying, however, do show clearly the presence of heat-intensive activity areas likely associated with cooking and other functions requiring fire (Crawford, 2012; Vanlandeghem, 2015). Rather than pin-pointed hearth anomalies, as seen with other cases in the paper, magnetic survey of the Birnirk complex at Cape Espenberg revealed more broadly magnetized spaces and activity areas, consistent with observations made during previous excavations. In some instances, entire rooms within a structural complex appear to be magnetized. This is further supported by the most recent excavation which revealed evidence of extensive burning and fire cracked rock in association with such anomalies. Many magnetic

anomalies were found both within structures and external to structures, spanning the entire Birnirk occupation at Cape Espenberg. An example of one such anomaly cluster in an unexcavated Birnirk feature complex is shown in Fig. 11, including magnetized rooms, pits, and discrete anomalies likely associated with scattered fire-cracked rock beneath the site surface.

3.3. Norton house depressions in Brooks River Archaeological District, Katmai National Park and Preserve (ca. 1500 BP)

Before the Thule cultural tradition began to emerge on the islands of Bering Strait, and before the existence of their immediate proto-Thule predecessors such as the Birnirk, an earlier cultural group appeared along the western coast of Alaska, the Norton tradition. The marine focused Norton tradition developed in coastal areas of western Alaska, beginning with the Choris culture (ca. 3000–2500 BP). Choris was followed by the more widespread Norton (ca. 2500–1200 BP). Unlike their predecessor, the Arctic Small Tool tradition, Norton material culture included pottery and oil-burning lamps. Their settlements were also more permanent than their predecessors, and included villages with substantial structures, including large ceremonial or community houses. The Norton tradition spread in Alaska well beyond the northwest coast (Holmes, 1982), and is well represented at the Brooks Camp site in Katmai National Park near Alaska's southern coast (Dumond, 1971, 1981, 1982; 1987, 1995; 2000, 2016) (KATM Fig. 8).

The Brooks Camp is part the Brooks River Archaeological District and is the southernmost of our study locations, though much of the occupational sequence of this region is nearly identical to the Arctic regions of northwest Alaska. While this district has yielded data of great scientific importance, including the greatest concentration of Arctic Small Tool tradition dwellings in Alaska, it is suspected that as much as 90% of the cultural resources remain undisturbed. Beginning several years ago, geophysical surveying was implemented at Brooks Camp and the surrounding areas as an aid to ongoing archaeological work.

Geophysical investigations at Brooks Camp have included ground-penetrating radar (GPR), electromagnetic induction (EM), and magnetic surveying. The latter was introduced primarily to locate hearth features within known house depressions. While multiple cultural traditions are represented in the area, many notable features of the Norton tradition are present. These include both standard house depressions and larger community or ceremonial houses. A series of these larger houses found in Brooks Camp were thought to contain no internal hearth features, as previous probes yielded no charcoal. Hearths were, however, detected in these large depressions with magnetic surveys (in some cases only a short distance from the decades old, null test probes). One was excavated and dated to the local Brooks River Period, with calibrated ages for three charcoal samples falling within a date range of 1608–1396 cal. BP. The hearth as well as other internal features of this particular community house were detected with multiple geophysical methods (Fig. 12). The locally designated Brooks River Period is an iteration of the broader Norton tradition. Such examples abound in the Brooks River Archaeological District, including more typical size houses such as the example shown in Fig. 13.

Because the Katmai region has been subjected to substantial volcanic activity, multiple tephra layers are found throughout Brooks Camp. These deposits are magnetic and so increase the general background magnetism in comparison to many of the other locations in this paper. The exterior berms surrounding certain house depressions at Brooks Camp manifest as magnetic highs, often more magnetic than house interiors and even hearth deposits. We believe that this is due to the magnetic tephra deposits

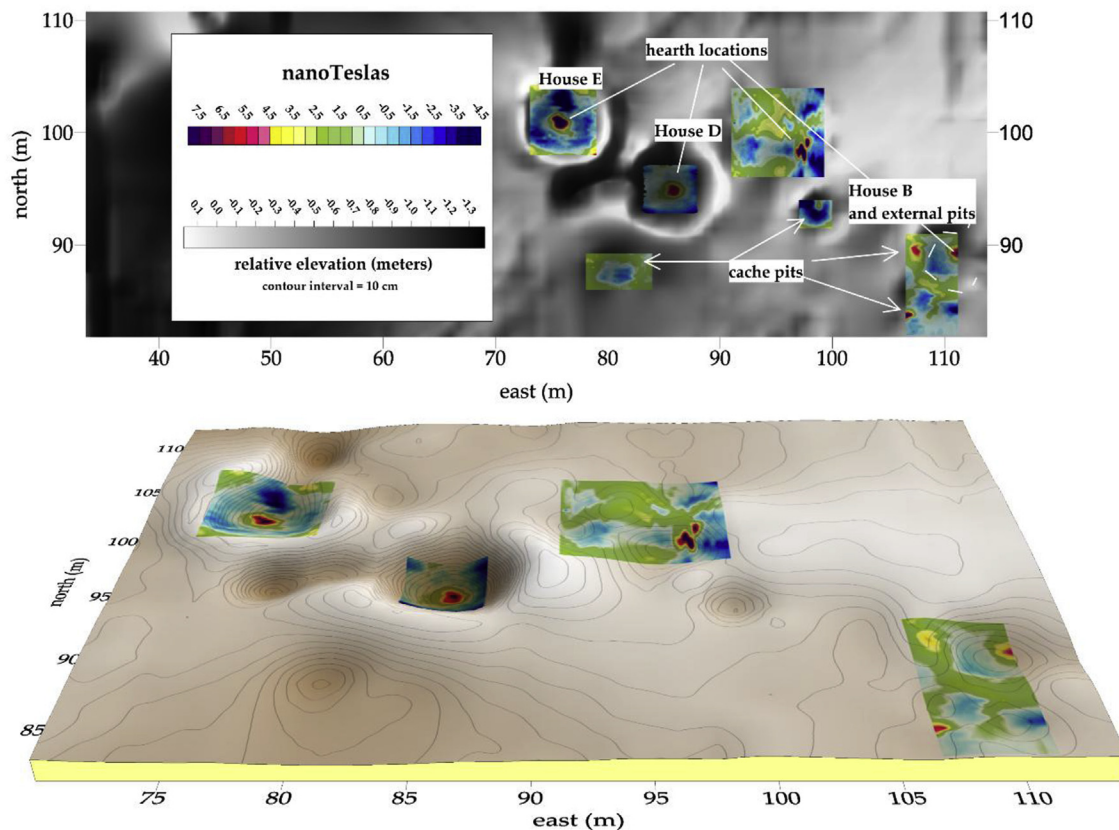


Fig. 10. Hearth anomalies situated within a cluster of surface depressions. The hearth shown in Fig. 9 is indicated above in the House D depression, among a cluster of other house depressions and smaller cache pits. Some of these smaller pits are magnetized, including two of the four external pits that surround House B. This indicates that not all of these small pits had been used for the same purpose.

being removed during house construction (i.e. being dug out) and then concentrated around the house. An example of this appears in Fig. 13 as two general magnetic highs north of the polarized hearth anomaly.

3.4. Denbigh hearths at Cape Krusenstern National Monument (ca. 4000–3000 BP)

The Cape Krusenstern beach ridge complex (CAKR Fig. 8) represents an archaeological district comprised of over 4000 years of human occupations that document human adaptation to coastal habitats in Arctic Alaska (Giddings and Anderson, 1986). Previous research has documented at least 189 archaeological sites and thousands of features at Cape Krusenstern, and researchers have recently completed an intensive radiocarbon dating program that produced a detailed chronology of the occupations and culture change for this area (Anderson and Freeburg, 2013; Freeburg and Anderson, 2012). However, the timing of earliest occupations by people at the CAKR beach ridge complex remains poorly understood. Currently, evidence for the oldest sites among the CAKR beach ridges are from the Denbigh Flint Complex, a regional iteration of the broader archaeological Arctic Small Tool tradition, ASTt (Giddings, 1951; 1961b, 1964; 1967; Tremayne and Rasic, 2016). ASTt is defined by a category of stone tools produced by people that migrated from Siberia and across the Arctic to become the first humans to colonize the Canadian High Arctic and Greenland (Dumond, 1987). The timing of the initial ASTt migration into Alaska and origins of their coastal adaptations are subjects of current debate. Some researchers consider their maritime adaptations

to be relatively recent and simplistic in design (Ackerman, 1998; Anderson, 1984; Dumond, 1982), while others have made the case that ASTt maritime adaptations have a deeper history than previously thought, and that marine resources were a critical component of their subsistence economy, which allowed for their rapid colonization of the Arctic (Tremayne, 2015, 2017; Tremayne and Brown, 2017; Tremayne and Winterhalder, 2017).

When Giddings and Anderson (1986) first began work at Cape Krusenstern in the 1960s, they discovered at least 46 hearth features and collected 405 stone tools subsequently used to help define the Denbigh Flint Complex. As large samples of charcoal and wood were required for radiocarbon dating at that time, the original research produced no dates from the Denbigh hearths. Instead, the researchers relied on dated deposits from other sites, primarily Onion Portage (Anderson, 1988) and Iyatayet (Giddings, 1964) as a guide for estimating the age of Denbigh camps and artifacts at the CAKR beach ridges. Shelby Anderson and Adam Freeburg (2014:75–76) produced the first radiocarbon samples from the Denbigh beach ridges at CAKR, with three dates at $3760 \pm 35^{14}\text{C}$ years BP, $3620 \pm 30^{14}\text{C}$ years BP, $3450 \pm 30^{14}\text{C}$ years BP. These dates fall squarely in the peak of the Denbigh occupations and towards the younger end of the span in Alaska. While these dates confirmed the general cultural sequence at CAKR, the sample size remained so small that it was difficult to assess the true span of Denbigh settlement chronology here. Knowing that another 43 hearths were located and tested by Giddings and Anderson (1986) the goal of our project was to relocate some of these hearths with a magnetic survey and retest them for additional artifacts and organic samples with which to date the sites. We instead found many new hearths

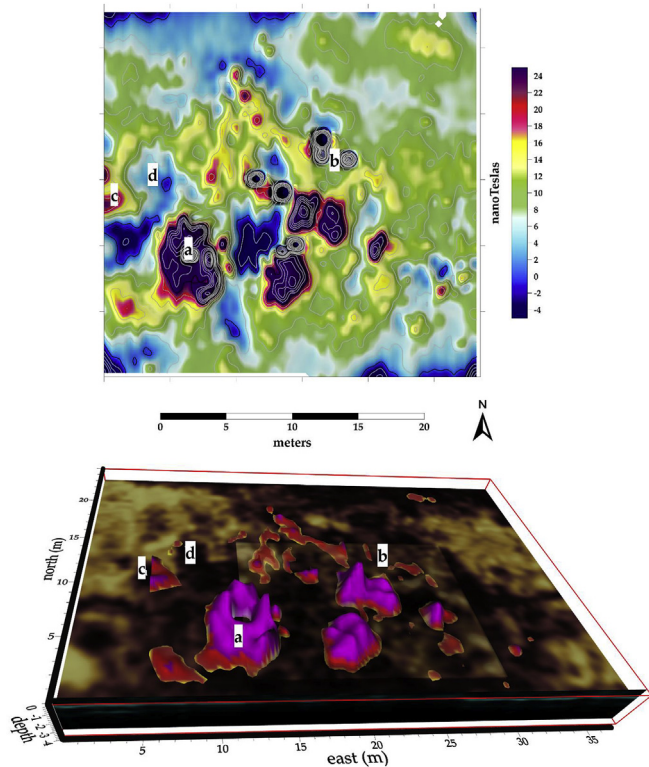


Fig. 11. An example of a Birnirk feature complex at Cape Espenberg. A number of magnetic anomalies were detected here, as they were throughout the broader site, including examples of broadly magnetized spaces (a) and discrete dipole anomalies or clusters of dipoles likely related to burnt rocks (b). The more broadly magnetized spaces can be co-located with pits and rooms seen in a GPR survey of the area (bottom). An example of a magnetized pit (c) is right next to a similar sized pit (d) that has not been magnetized, indicating that the two had different purposes.

that had clearly never before been tested.

Magnetic surveying of the Denbigh beach ridges at Cape Krusenstern has yielded more dateable hearths than any case study presented in this paper. Seventeen new hearths were detected, with datable material excavated from twelve of those hearths, yielding seventeen new radiocarbon dates (with additional dates currently pending). Subsequent analysis of the dates indicates the Denbigh Flint Complex culture persisted at Cape Krusenstern for many centuries longer than first thought, filling in a critical temporal gap in the transition from Denbigh to the Choris culture (i.e. the earliest of the Norton tradition), in this region. Fig. 14 shows an example of Denbigh magnetic hearth anomalies at Cape Krusenstern, along with an artifact assemblage recovered from a single hearth anomaly.

3.5. Gates of the Arctic undated Northern Archaic tent ring hearth (6000–4000 BP)

Within a 2016 National Park Service archaeological inventory in Gates of the Arctic National Park (GAAR Fig. 8), geophysical instruments were incorporated into the survey program as part of a pilot study to test how such methods could potentially contribute to cultural resource assessments in an area characterized by an archaeological record found primarily in shallow, rocky sediments in surface and near-surface contexts. These tests included magnetic gradiometry and ground-penetrating radar. These were generally found to be useful tools for extending the capabilities of the survey program. The magnetic method was used as a follow up to

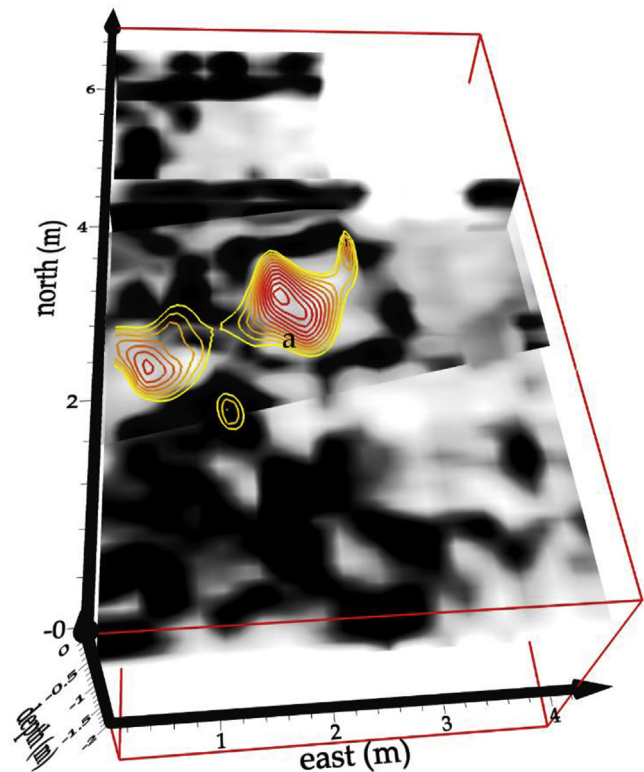


Fig. 12. An example of a large Norton community or ceremonial house that was imaged with multiple geophysical methods. A hearth anomaly was detected, shown as magnetic color contours (a) in relation to surrounding structural elements detected with GPR, including an apparent 1.5 × 2.0 m rectilinear feature surrounding (a). A test excavation at (a) yielded hearth deposits that were dated to the local Brooks River period of the broader Norton tradition. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

pedestrian surveys of various landforms in the area. In three locations where surface finds were recorded by the archaeological survey team, follow up magnetic surveys were conducted. In two of the three locations tested, several discrete magnetic anomalies were detected and mapped. In one of these locations, site XSP-00384, a magnetic anomaly was detected within the perimeter of a circular, stone tent ring feature, which also coincided with a dense and discrete surface scatter of chert flaking debris. Like all other examples given in this paper, the magnetic anomaly was visible in real time on the instrument console and marked with a plastic pin-flag. After completion of the magnetic survey, this anomaly was further explored on search mode from multiple directions. The anomaly was easily pinpointed in real time and delineated with plastic markers to an area of 0.5 to 0.5 m. Notably, it was one of only two such magnetic disturbances detected across the landform, a search area of approximately 1 ha. A test excavation of the flagged anomaly, done that same day, revealed strong evidence of a hearth feature in the form of dozens of burnt lithic artifacts, and fire-altered (oxidized and angularly fragmented) rocks. Several of the burnt stones recovered from the hearth were tested directly (after being removed from the hearth) with the magnetometer on search mode. These were found to yield a strong magnetic response far above the local magnetic background. In spite of the feature being an obvious hearth, no charcoal or faunal remains were preserved despite a careful microscopic examination of bulk sediment samples collected from the feature. This situation had been observed before and is likely due to the lighter charcoal being blown out by high winds while the heavier stones and artifacts are left behind. A

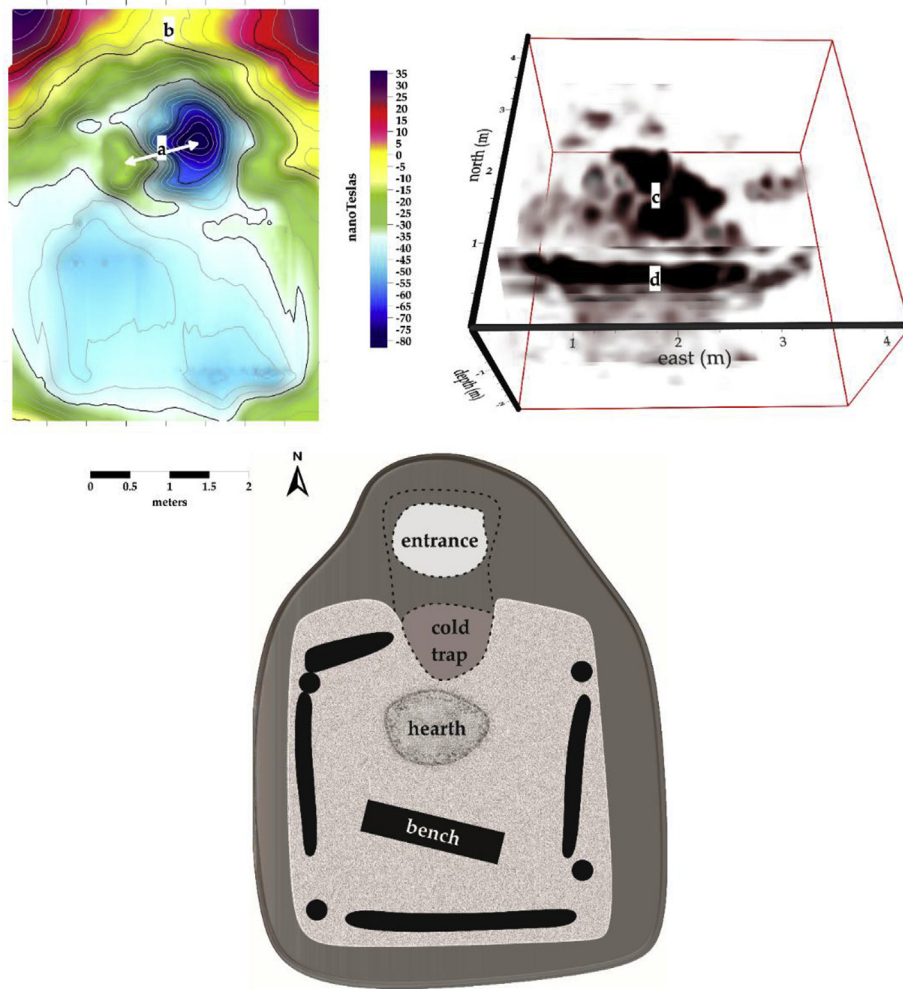


Fig. 13. An example of geophysical survey of a Norton house at Katmai, along with a drawn plan of a typical Norton house as seen through the excavations of Dumond and others. The magnetic survey yielded an obvious dipole (a) in a location that is typical for a hearth, just beyond the entrance/cold trap (b). The hearth feature also appears in a GPR survey of the same house, with anomaly (c) corresponding spatially to (a). Other anomalies in the GPR survey, such as (d) are likely related to structural timbers.

number of artifacts were recovered including many pieces of flaking debris and dozens of microblades. In the absence of datable organic remains, the age of the site is not precisely known. The site's age is, however, roughly known based on the presence of distinctive artifact technology, in this case a side-notched bifacial projectile point characteristic of the Northern Archaic Tradition (Esdale, 2008), which is dated to ca. 4000–6000 BP in this region. Other magnetic anomalies were found in GAAR at the hilltop site AMR-00043. Inclement weather forced an early helicopter departure, so the magnetic anomalies at AMR-00043 remain untested archaeologically, but are scheduled for future work. The Nigu River tent ring hearth anomaly is shown in Fig. 15.

3.6. Katmai National Park and Preserve, Brooks River Strand phase deposits (4000–5000 BP)

Between 8000 and 4000 BP a paleo/archaic maritime tradition emerged and spread through the Gulf of Alaska. Referred to broadly as the Ocean Bay tradition, it included various phases and regional sub-traditions, including the early Ocean Bay I and the late Ocean Bay II of the Kodiak Archipelago as well as the Takli Alder and Takli Birch phases seen on the Alaska peninsula (Clark, 1979). Among the local iterations of Ocean Bay is the Brooks River Strand phase, seen at Katmai National Park, believed to be associated with Kodiak

maritime hunters (Dumond, 1971) (KATM Fig. 8).

The 5000 year old Brooks River Strand phase deposits at Katmai were discovered by Don Dumond in the 1960s. Artifacts found by Dumond and his crew included large, polished slate tools resembling lance-points, stemmed points made by chipping, and broken stone oil lamps. The finds were interpreted as the remnants of camps, with evidence of hearth deposits such as extensive charcoal staining of the ground, but likely no structures more permanent than tents. The latter point is likely the reason that Strand phase deposits, unlike later occupations in the area, give no surface indications such as can be seen at Katmai for the many other human groups that dug semi-subterranean houses, leaving behind obvious depressions. The Strand phase finds at Katmai overlap temporally with a locally designated N. Archaic occupation, the Beach Ridge phase (3800–4000 rcybp). The Beach Ridge phase exhibited a more typical interior subsistence strategy, evinced by small, chipped stone points and scrapers more similar to Northern Archaic caribou hunters of Ugashik.

The artifacts of the Strand phase, on the other hand, were unlike any other material culture found in the area. They did, however, bear striking similarity to objects being found on Kodiak Island and the Pacific coast of Alaska – a tradition now referred to as Ocean Bay. Dumond surmised that the Strand phase deposits were not from an inland people, but from marine mammal hunters that

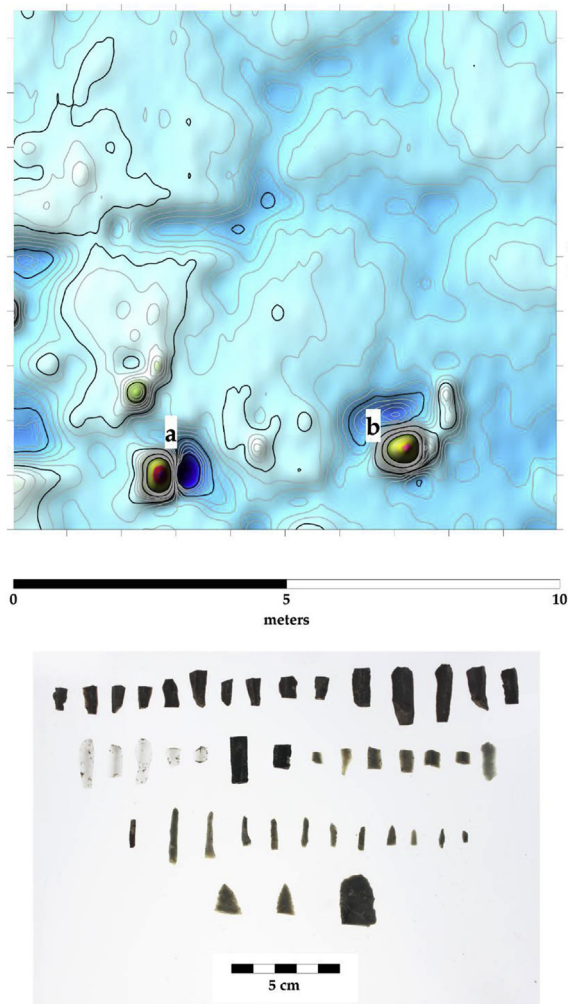


Fig. 14. Top: An example of Denbigh hearths detected at Cape Krusenstern. All seventeen hearths detected with our magnetic surveys appear as discrete dipoles, such as (a) and (b) above. Bottom: Denbigh stone tools recovered from a single hearth. Top row: brown chert microblades; Row 2: obsidian, black chert and gray chert microblades; Row 3: chert burin spalls; Bottom Row: side blade tip (from STP-07), side blade tip, bifacially worked flake tool. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

occasionally migrated inland from the Pacific coast in pursuit of game or other resources such as lithic sources or caribou antler.

In 1967, not far from the original Strand phase finds, Dumond discovered a small Strand phase habitation including a number of hearths, as well as oil lamps and artifacts as previously described for the Strand phase (Fig. 16). The deposits included scattered hearth material. Discovery of this habitation was by chance, while digging drainage ditches to channel water away from the excavation of a Norton house. Dumond's expansion of the excavation had to be abandoned due to torrential rains filling the excavation units (Dumond, 2008).

Since hearth deposits and stone oil lamps would be good magnetometer targets, as well as chipped basalt, which was also described during the excavations, we decided to test the vicinity with a magnetic survey. The survey attempted to expand on the earlier work of Dumond by assessing an adjacent area that was both undisturbed by previous excavations but also bore no evidence of house depressions from later occupations. The selected survey area exhibited a number of magnetic anomalies (Fig. 17). The magnetic anomalies may look superficially like shallow igneous bedrock,

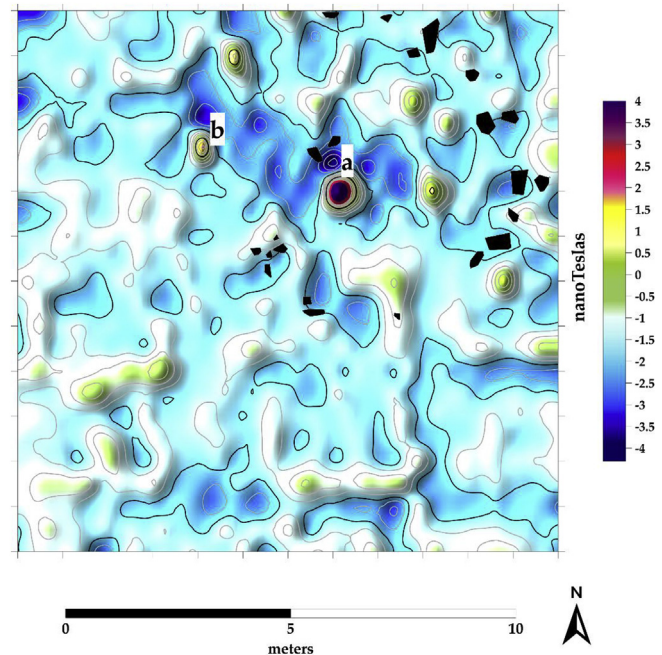


Fig. 15. (a) Nigu River hearth anomaly. Fire reddened stones found with numerous microblades were tested on site and found to be magnetized, though no charcoal was recovered. Several smaller magnetic anomalies, such as (b) were not tested archaeologically. The stones associated with the tent ring are annotated onto the image.

however, this area is underlain by deep sediments and gravels, with nearby archaeological deposits at depths of ca. 2.0 m, and with bedrock likely being tens of meters deep if consistent with nearby drilling and GPR profiles taken across the area. Further, the survey was conducted in the gradiometer configuration, which reduces such geologic trends by acting as a high pass filter (Fassbinder, 2017). Though these anomalies remain untested archaeologically, they are consistent with Dumond's observations of hearths and scattered hearth deposits, and suggest the possibility that the Strand phase camp may be more expansive than previously thought.

3.7. A Northern Archaic hearth at Slaven's road house: Yukon-Charley rivers National Preserve (ca. 5000–4000 BP)

The Slaven's Roadhouse site in Yukon-Charley Rivers National Preserve (YUCH Fig. 8), is known primarily for a historic cabin which is now a public-use cabin. The landform on which this cabin sits, however, has revealed an archaeological record extending back at least 5000 years. A shallow test excavation in 2008 yielded archaeological deposits dating to the Middle Holocene (Buvit and Rasic, 2011), and attributed to the Northern Archaic tradition. The Northern Archaic, often associated with notched points (as previously describe for the Nigu River tent ring hearth), coincides with a population increase in Alaska ca. 6000 BP and is likely tied to a northward migration of archaic groups from lower latitudes in N. America back into Beringia (Fig. 2), a contention supported by recent genetic evidence (Moreno-Mayar, J.V. et al., 2018b).

While the work undertaken in 2008 revealed a Northern Archaic component at a depth of only 0.5 m (Buvit and Rasic, 2011), the site rests upon a stratified river terrace with deposits extending 9 m deep, prompting an attempt to use geophysical survey methods to the search for additional features (Urban et al., 2016a). The geophysical work included GPR, EM induction, magnetic gradiometry, and DC electrical methods.

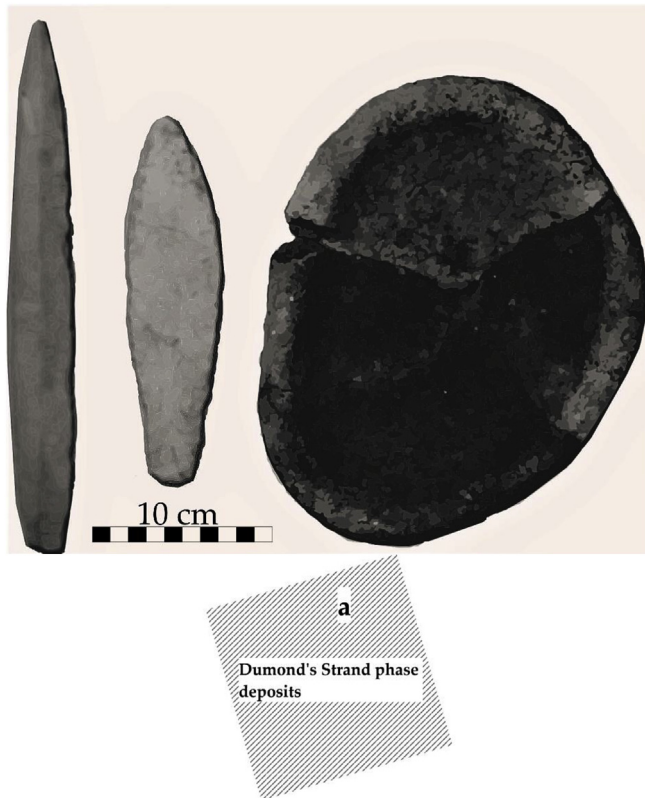


Fig. 16. Brooks River Strand phase artifacts recovered from Dumond's excavation. Left: Polished slate and chipped stone artifacts. Right: stone oil burning lamp found in three pieces. Image after Dumond (2005), Fig. 20, modified and used w. permission from D. Dumond.

Geophysical surveying in the vicinity of a 2008 test pit that yielded a Middle Holocene stone tool, also yielded an interesting cluster of geophysical anomalies, including a suspected hearth

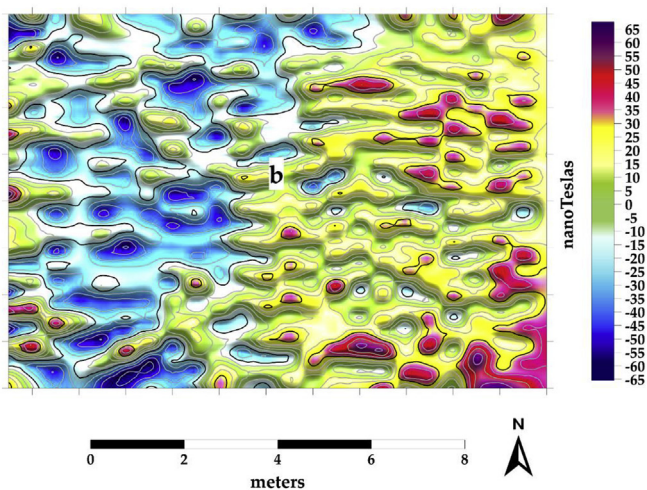


Fig. 17. (a) The area where Dumond found a Strand phase camp site. (b) Magnetic survey: A cluster of scattered magnetic anomalies (red) found in the vicinity of Strand phase artifacts (roughly contemporary to N. Archaic, with its own local variant being the Brooks River Beach Ridge phase). The Strand Phase occupation is a likely variant of the later Ocean Bay II tradition, noted for maritime adaptations. Finds in this survey unit suggest that any burnt material present here could be as old as 5000 BP, among the oldest of the Brooks River Archaeological District. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

(Fig. 18). The interpretation of this anomaly was complemented by the use of multiple geophysical methods. An EM induction survey was able to quickly identify several sources of historical iron (generated by shallow metal objects from historic use). Such items were removed prior to the magnetic survey. GPR done in the same grid was also useful for visualizing and estimating the depth of the feature. Combined, the three methods offered a powerful geophysical interpretation. An auger test collected over the suspected hearth feature yielded charcoal at a depth of 1.1 m, within the estimated depth range of the associated GPR and magnetic anomalies. A piece of this charcoal was dated to a ^{14}C age of 4356 ± 30 radiocarbon years, suggesting a Northern Archaic hearth.

Buvit and Rasic (2011) postulated that the relative scarcity of early sites along the upper Yukon is related to the shortcoming of archaeological sampling at deeply stratified sites, rather than the lack of an early human presence. Geophysical imaging, as demonstrated in this case study, could plausibly aid in overcoming this issue since, while the lone cultural feature previously found at the site was only 0.5 m below surface (Buvit and Rasic, 2011), the geophysical methods used here were able to detect natural features and stratigraphic details to a depth of 9.0 m below surface, well below the depth ascertained in most archaeological surveys which rely heavily on shovel testing. Dating of wood in the nearby river-bank escarpment suggested that nearly all of these sediments, starting at a depth of 0.5 m and continuing to more than 8.0 m, were deposited during the middle Holocene, and are contemporary to the Northern Archaic tradition with dates ranging from ca. 4,500–6,500 cal BP (Urban et al., 2016a). The hearth deposits detected with the magnetic survey extended more than 1.0 m deeper than the N. Archaic projectile point, but the date of the hearth deposits was no more than a few centuries earlier than the artifact, indicating that sites in such contexts could be buried by sediments fairly rapidly.

3.8. Sluiceway hearths at Noatak National Preserve (ca. 12,000–10,000 BP)

Among the early settlers of North America at the end of the Pleistocene is the Sluiceway complex, first identified in northwest Alaska (Goebel and Potter, 2016; Rasic, 2011). The Sluiceway complex, which spans geographically from northern Alaska into parts of Canada, has only recently been recognized and studied in comparison to the more widespread (and much better-known) Clovis and Folsom cultures seen throughout the lower latitudes of North America. In decades of research in the Noatak region of Northwest Alaska (NOAT Fig. 8), only four Sluiceway hearths had previously been found (Rasic, 2011).

A search conducted by Rasic and Urban in 2017 focused on landforms in Noatak N.P. where stone tools characteristic of Sluiceway technology had been observed and recorded during pedestrian surveys. These landforms were revisited by helicopter, and rapidly surveyed on search mode using a side-to-side sweeping technique along designated paths after defining the search areas of interest with non-metallic pin-flags. Anomalies were marked and excavated immediately. Over three days of work, eleven landforms were surveyed in this fashion. Ten marked anomalies were excavated, three of which were determined to be hearths (Fig. 19) and seven of which were false positives (associated with frost boils). Of the hearths, two produced dates consistent with other dated Sluiceway sites (Rasic, 2011). Both sites yielded diagnostic artifacts of the Sluiceway Complex, in close association with the hearth features. In one case, the Kelly River site, Sluiceway projectile points were contained within the hearth matrix and exhibited thermal (potlid) fractures that very directly link the artifacts to the hearth event and datable samples. The other Sluiceway hearth, at the

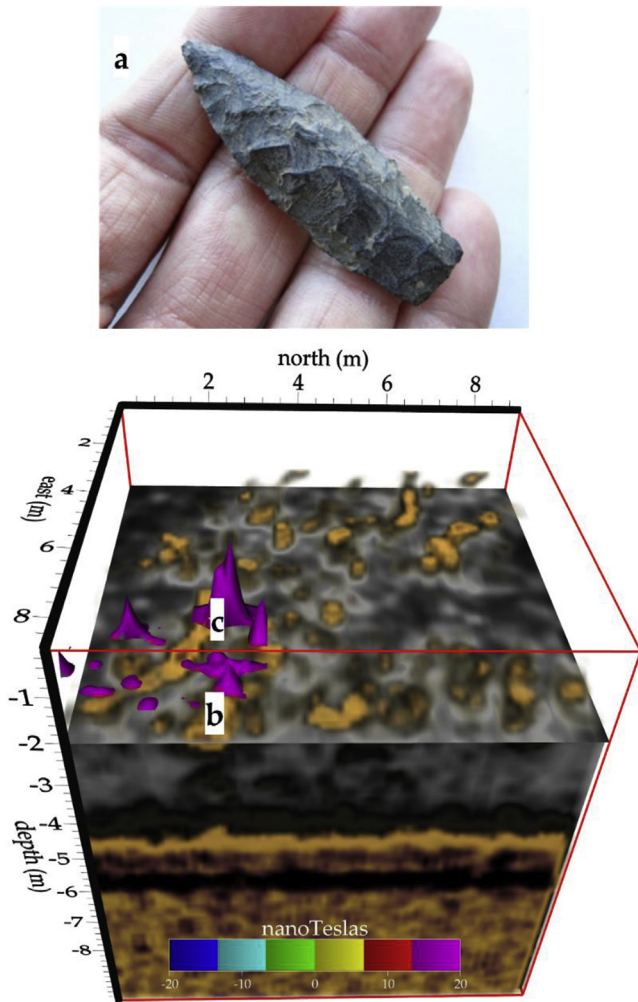


Fig. 18. A middle Holocene biface projectile point (a) was excavated in 2008 only 2 m from the location of the magnetic hearth anomaly found in 2014. A GPR survey of the area showed the deeply stratified river deposits, along with a number of embedded anomalies likely from stones (b), some of which exhibited clear magnetic anomalies (c). The magnetic anomaly cluster yielded charcoal dating to the Northern Archaic period, roughly contemporary with dates associated with the 2008 projectile point.

Miluk hilltop site, was located within a small (ca. 2 m) surface artifact cluster that contained multiple Sluiceway projectile points. Flaking debris recovered in the burned area also exhibited thermal fractures. A third hearth found at the Miluk site, was dated to the more recent Arctic Small Tool tradition.

In this example, the simplest use of the instrument for a rapid search mode survey, yielded both the oldest and rarest of the archaeological features discussed in this paper – features that would not likely have been found without magnetic surveying. Ground covered at each of the two sites consisted of multiple hectares, though the sought after features were only 0.5×0.5 m in area. Even more striking, these features were discovered with the instrument on search mode, and interpreted as features of interest from the live reading, then flagged and excavated the same day. No magnetic survey grid was ever set up and no data logged in the case of the Kelly River hearth, and the Miluk hearth was collected in a small grid (for presentation purposes) only after having first been flagged on search mode. This represents both the fastest and the simplest use of a magnetometer for hearth detection, yet still led to significant archaeological finds.

4. Discussion and conclusion

A reasonable comparison of detected magnetic anomalies associated with hearths is difficult given the number of variables that determine the character of the observed magnetic anomaly in each case. For example, factors that will affect the observed intensity and form of the anomaly include the firing temperature, fuel type, substrate type, burial depth (i.e. distance from the sensor), number and type of stones within the hearth deposit (i.e. fire-cracked rock), the overall size of the hearth, and geomagnetic location. For the magnetic anomalies described in this paper, an intensity range of less than ± 10 nT to greater than ± 50 nT was observed (Table 3).

4.1. Strong anomalies

The strongest magnetic anomalies were associated with sites at Katmai and Bering Land Bridge. In the case of Katmai, we believe that the relatively strong magnetic anomalies are the result of the substrate, which is very rich in magnetic tephra deposits. In the case of the Birnirk activity areas, the field strength may owe simply to the large size of burnt areas, possibly more intense heat, and certainly the dense concentrations of burnt or fire-cracked rock that have been observed at that site.

4.2. Weaker anomalies

In contrast, the fairly large hearths found at the Kobuk Valley Inupiat village (Fig. 20) are among the weaker observed magnetic anomalies, exhibiting intensities of less than ± 10 nT. This is likely to due to a combination of substrate type and burial depth. The much smaller hearths found in Noatak and Gates of the Arctic, for example, exhibited anomaly strength comparable to the Kobuk hearths. In contrast, however, these small hearths were all very shallow and therefore closer to the sensor. At Cape Krusenstern, small hearths associated with the Arctic Small Tool tradition (Fig. 20) varied in strength from less than ± 10 nT to ± 40 nT. Based on the numerous excavated anomalies at that location, it can be inferred that this disparity in strength corresponds with the amount fire-cracked rock present in a given hearth (more FCR = stronger anomaly).

4.3. Comparison to cases outside Alaska

Overall, the hearths detected in Alaska are broadly comparable with hearth anomalies detected in other parts of the world in terms of the intensity and form of the associated anomaly. Most manifest as a single dipoles or a cluster of several dipoles (with variable observed orientations), or simply as magnetic highs, with an observed intensity of greater than ± 5 nT but less than ± 100 nT. For comparison with magnetic anomalies associated with burnt features collected with cesium magnetometers elsewhere in the world, consider for example a large Early Bronze Age cooking area in Jordan documented by Urban et al. (2014) with an anomaly of comparable intensity to the strongest hearth anomalies described for the Alaska hearths (i.e. Bering Land Bridge and Katmai). Fassbinder (2017) describes a kiln site in Germany with a total field anomaly of ca. ± 20 nT, the mid-range intensity for the hearths observed in Alaska. Abbott and Frederick (1990) reported total field intensities with a proton-precession magnetometer for burned rock middens in Texas, also with comparable intensities for the mid-range Alaska hearth anomalies. Hearth anomalies have also been detected with vector magnetometers (e.g. fluxgate) in other parts of the world (e.g. Andreou et al., 2017), and these instruments, which are very common in archaeology, would likely be effective at

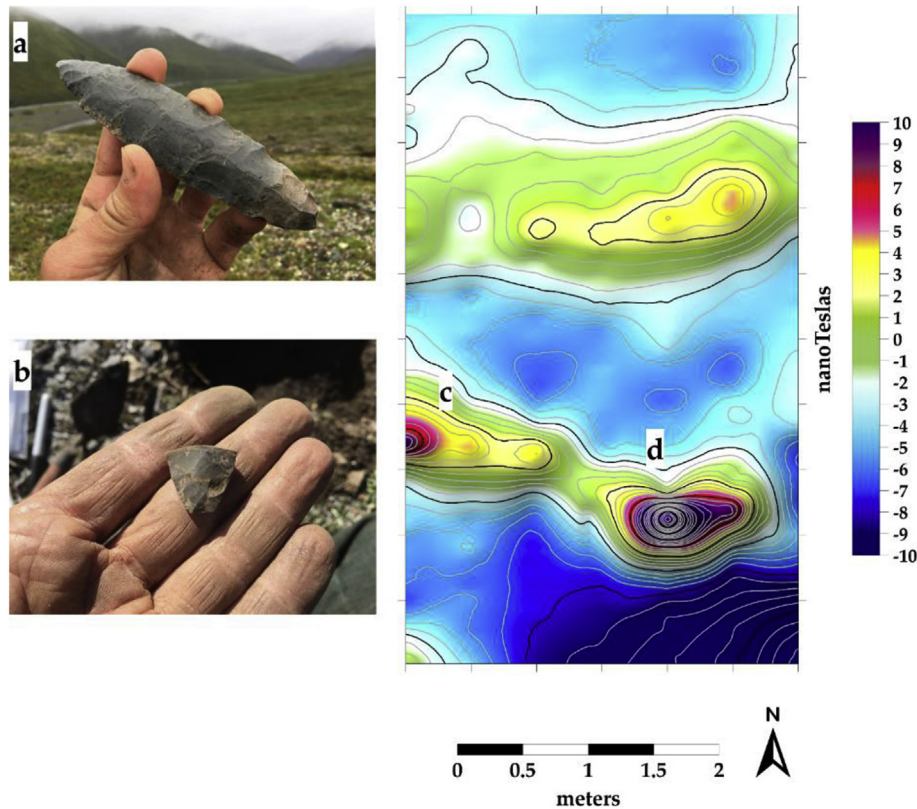


Fig. 19. (a) A Sluiceway projectile point at the Miluk site from Nuniviksak Creek in NOAT, which had both Sluiceway and Denbigh artifacts and produced dates consistent with both Sluiceway and Denbigh periods. (b) A Sluiceway projectile point fragment from DEL- 00391 (Kelly River). The artifact exhibits a potlid fracture and was recovered from within or adjacent to the hearth matrix. The hearth was found by the magnetometer on search mode, and contained charcoal, fire-cracked rock, and artifacts. (c, d) Two magnetic anomalies that were tested at the Miluk site featured no fire cracked rock, but such anomalies did yield dateable charcoal.

hearth detection in Alaska.

4.4. Active source magnetic detection

In addition to passive magnetometers such as those described above, it is also reasonable to suspect that active source instruments (e.g. field coils) used for magnetic susceptibility measurements could also play a role in detecting hearth deposits in Alaska. Such methods have shown success at detecting burnt soils in lower latitude in North America (e.g. [Dalan et al., 2017](#); [Dalan, 2008](#)), and have been the subject of recent tests in Alaska by R.

Bowman and J. Keeney (J. Keeney, pers. comm.). This might show particular promise at deeply stratified sites and cut bank sites where precise vertical measurements, either down a borehole or along an exposed scarp, could identify magnetized soils at depth.

4.5. The utility of magnetic hearth detection

We have outlined a number of cases where a magnetometer was used successfully for the detection of hearths in Eastern Beringia, including searches conducted within known sites or feature perimeters and broader searches for sites with minimal or no surface

Table 3
Hearth comparisons.

NPS Unit	Cultural tradition/site #	Surface/Substrate	Hearth depth	Number	Anomaly $\pm$	Tested
Noatak	Paleoarctic and Arctic Small Tool MIS - 00515	Thin top soil, rocky	Just below surface, < 0.2 m	2	<20 nT	Yes
Noatak	Paleoarctic DEL - 00391	Thin top soil, rocky	Just below surface, < 0.2 m	1	<20 nT	Yes
Yukon-Charley	Northern Archaic CHR - 00030	Deep river Sediments (silt, sand, gravel)	>1.0 m, < 2.0 m	1	20–30 nT	Yes
Gates of the Arctic	Northern Archaic XSP-00384	Thin top soil, rocky	Just below surface, < 0.2 m	1	<10 nT	Yes
Katmai	Ocean Bay XMK - 050	Deep river sediments, tephtras	>1.0 m, < 2.0 m	NA	>50 nT	No
C. Krusenstern	Arctic Small Tool NOA - 00XX	Tundra, beach ridge sand, gravel	Just below surface, < 0.2 m	17	<10–40 nT	Yes
Katmai	Norton XMK - 050	Forest top soil, tephtras	0.2–0.5 m	5	>30 nT <50 nT	Yes
Bering Land Bridge	Birnirk KTZ-304	Tundra, beach ridge sand	0.5–2.0 m	20+	>40 nT	Yes
Kobuk Valley	Inupiat XBM - 047	Forest top soil, River sediments (silt, sand)	>0.5 m, < 1.5 m	6	<10 nT	Yes

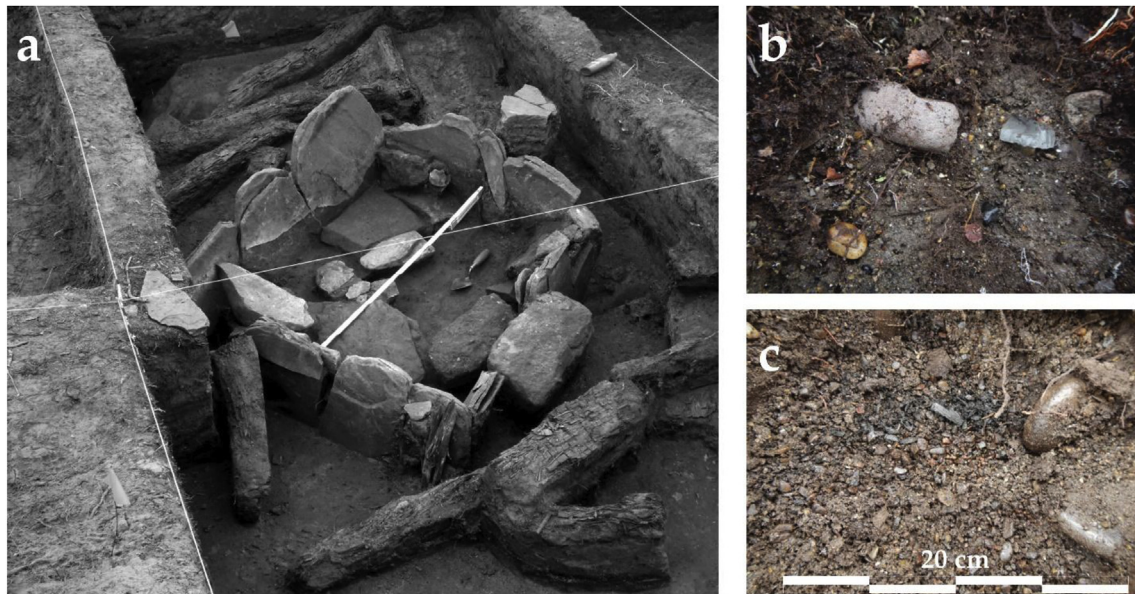


Fig. 20. Hearth types. (a) A large excavated house hearth at the Kobuk Valley Inupiat village site, Swift Water Place. (b, c) Small ASTt hearths from Cape Krusenstern just beneath the turf, with (b) showing a piece of FCR next to a chert artifact and (c) showing a charcoal deposit. Most tested hearth anomalies contained artifacts, charcoal, and FCR in varying quantities.

indicators. The method has proven effective in a range of depositional and environmental settings throughout the broader region, including such diverse settings as coastal tundra, boreal forest, and river terraces. Further, the method has proven effective for examples covering most of the occupational history of the region, ranging from terminal Pleistocene to early historic, a 12,000 year span. In terms of instrument use, we have described examples ranging from the rapid, minimalist “search mode” approach to more intensive multi-method approaches that incorporate other techniques such as GPR and EM induction. We have also demonstrated circumstances where false positives arise due to both natural and anthropogenic features that may present similar magnetic anomalies to those of hearths, thereby defining some difficulties that might be encountered with the method.

Beyond the obvious and far reaching implications for this method in conducting field investigations into the dispersal of humans in the Americas, magnetic survey methods (and other geophysical techniques applied to archaeology) can also be important resource management tools. All cases presented here are found on federally managed government lands. Magnetic survey offers an efficient means for resource managers of such lands to investigate potential sites on the basis of limited clues, or search for unknown sites where no clear clues are present, thus aiding in fulfilling policy mandates with respect to cultural resources, i.e. it is simply not possible to fully manage such resources until their presence is known. Such methods can also play a role in outreach to native communities, an important but sometimes overlooked aspect of archaeological work. In the most historically recent case presented here, Swift Water Place, the immediate descendants of people who occupied the archaeological site under investigation also participated in the fieldwork at that site. The magnetic results shown for that case study were collected with the aid of a community member from the nearby village of Kiana. Finally, a number of the sites investigated in this paper exist in precarious environmental conditions and could be under threat from environmental change—another important resource management consideration. The speed with which magnetic surveying has allowed us to locate dateable hearths at Cape Krusenstern, an area at risk of future

inundation from sea level rise as well as disruption from permafrost loss (Wolff and Urban, 2013), has allowed for the capturing of previously unknown archaeological information that could conceivably be lost in the not too distant future. Several of our Cape Krusenstern hearths were in fact found near the edge of an expanding thaw lake (a thermokarst landscape feature related to permafrost) with visible evidence of archaeological material eroding into the lake at its expanding perimeter. This indicates that some material has likely already been lost to such changes.

Overall, the broad overview of this work in Eastern Beringia demonstrates that magnetic surveying may be useful to some degree in all cases, even small searches within the boundaries of known archaeological structures, but most notably in the broader search for short-lived early camps such as demonstrated by the discovery of the Sluiceway camp fires. With the latter, finds are largely made by chance and guesswork, making the method particularly impactful. Magnetic methods, therefore, offer a very powerful tool in the ongoing search for the earliest sites in the region. Since so many archaeological sites in Alaska are small lithic scatters, usually (if not always) proximate to hearths (which themselves are rarely visible), the method presented here offers an unusually fruitful - if not unique - approach to identifying such sites. We believe that expanded use of magnetic survey methods in Eastern Beringia will continue to yield new insights into early human arrivals, as well as the emergence and dispersal of various cultural traditions at the gateway to North America.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.quascirev.2019.03.018>.

Akasofu, 1981; Alexeev et al., 1996; Bertheliet, 1976; Boller and Stolov, 1970; Bronk Ramsey, 2017

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