RESEARCH/REVIEW ARTICLE

Geophysical analysis at the Old Whaling site, Cape Krusenstern, Alaska, reveals the possible impact of permafrost loss on archaeological interpretation

Christopher B. Wolff[1] & Thomas M. Urban[2]

[1] Department of Anthropology, State University of New York–Plattsburgh, 101 Broad St., Plattsburgh, NY 12901, USA
[2] Research Laboratory for Archaeology and the History of Art, Dyson Perrins Building, University of Oxford, South Parks Road, Oxford OX1 3QY, UK

Keywords
Cape Krusenstern; Old Whaling culture; geophysics; cryoturbation; archaeology; Alaska.

Correspondence
Christopher B. Wolff, Department of Anthropology, State University of New York –Plattsburgh, 101 Broad St., Plattsburgh, NY 12901, USA. E-mail: christopher.wolff@plattsburgh.edu

Abstract

The Old Whaling site at Cape Krusenstern, Alaska, has been the subject of contested interpretations stemming from an original theory proposed by J. Louis Giddings more than half a century ago. In an attempt to address recent suggestions that the occupational history is more complex than originally believed, the site was the subject of a non-invasive geophysical survey conducted by our team in 2011. The project served as a starting point for assessing the potential for archaeological remains at the site that had not been detected with previous investigations, and to gain a better understanding of site morphology. The investigation was implemented with two well-established geophysical methods, ground-penetrating radar (GPR) and magnetic gradiometry. The survey revealed no unequivocal evidence of additional occupations as has been recently suggested, but did reveal a dynamic site morphology that may have implications for archaeological interpretation.

In 1958, William Simmons, under the direction of J. Louis Giddings, discovered two discrete groups of 3000-year-old prehistoric house pits located on the ancient beach ridges presently known as Cape Krusenstern National Monument in north-western Alaska. Giddings (1967: 223) termed the culture "Old Whaling" because he believed that the presence of whalebone and the nature of the artefact assemblage found at the site provided evidence of the earliest active whale hunting by a human group in the region. Based on the different construction techniques between two discrete clusters of residences present on the site, he believed that there was evidence of both a winter and a summer occupation, and that together these seasonal occupations represented the same cultural group (Giddings 1967; Giddings & Anderson 1986). Giddings further suggested that this group's material culture was unlike any other known prehistoric culture of the Bering Strait region. This distinction was characterized primarily by the morphology of the house structures and the unique stone tool assemblage, particularly the presence of large projectile points that Giddings believed to be similar in form and function to more recent cultures known to have actively hunted whales.

Giddings' interpretation has since been scrutinized, with some scholars suggesting that the Old Whaling artefact assemblage resembles materials of the Northern Archaic people of north-western Alaska (Collins 1967; Mason & Gerlach 1995). Others (Ackerman 1988) saw similarities between the Old Whaling assemblage and the Devil's Gorge (Chertov Ovrag) site on Wrangel Island (Dikov 1988). Various people have also noted similarities with artefacts found along the Noatak River and petrographic studies have demonstrated that some stone from which the Old Whaling tools were made originates from the Wrench Creek source in the Noatak Drainage (Darwent & Darwent 2005). However, since Giddings' original excavation in the early 1960s, there has been little systematic research conducted at the Old Whaling site to address these issues until a recent investigation by Christyann and John Darwent (Darwent & Darwent 2005; Darwent 2006). Their findings, based on a series of systematic auger testing and a small-scale excavation,

Citation: *Polar Research* 2013, *32*, 19888, http://dx.doi.org/10.3402/polar.v32i0.19888

suggested that the Old Whaling site's occupational history might have been more complex than previously thought.

The Darwents found that the stratigraphy of the site represent a series of depositional regimes that resulted in at least six "zones," or stratigraphic sequences (Darwent & Darwent 2005:137). Cultural material was only securely associated with the upper two zones (ca. 60 cm average depth) in the summer and winter settlements. Proximate to the summer settlement they found a possible house floor based on poorly preserved wood fragments that appeared to be similar to Giddings & Anderson's description of house floors in the winter settlement. They also found a "deeply buried dwelling structure" approximately 60 cm below surface near the summer settlement identified from a collection of 61 pieces of fire-cracked rock, 18 bone specimens, 14 pieces of chert debitage and a few stone tools they found "sandwiched" between wood timbers (Darwent & Darwent 2005:139). In the winter settlement they also found cultural material in several auger tests deeper than the documented house strata, which they believed may have been "marine deposited" from cultural features elsewhere at the site (Darwent & Darwent 2005:147). They also documented possible tent pad features on the beach ridge between the two settlements that could relate to another culture, possibly the subsequent Choris people (Darwent & Darwent 2005).

Our paper presents new findings from a recent geophysical survey of the Old Whaling site conducted in the summer of 2011, with a focus on investigating both natural and anthropogenic site complexity. In particular, our project aimed to assess whether additional subsurface cultural deposits existed as suggested by recent research (Darwent & Darwent 2005; Darwent 2006), and if so, if these were detectable with non-invasive methods. Additionally, we sought to learn more about taphonomic processes that could influence the interpretation of the site. It is worth noting that the first attempt to use geophysical methods at archaeological sites in the western Arctic is attributed to J. Louis Giddings, the original investigator of the Old Whaling site, more than half a century ago in this very region (Urban 2012), and that remarkably little has been attempted since in the region

Site description

Cape Krusenstern lies just north of the Arctic Circle and within the continuous permafrost zone (Fig. 1). The area is comprised of a series of more than 100 ancient beach ridges divided by low-lying swales that are often marshy and inundated with standing water in the warmer months (Fig. 2). The cape extends westerly into the Chuckchi Sea. The beach ridges are the result of the changing position of the coastline, with the more ancient ridges lying successively further inland. The Old Whaling site is situated on one of these beach ridges (No. 53), roughly 1.3 km from the coast. A 100 m stretch of open space along the long axis of the ridge separates two discrete clusters of earthen houses that have been interpreted as summer and winter settlements (Giddings & Anderson 1986). Though ridge No. 53 is moderately

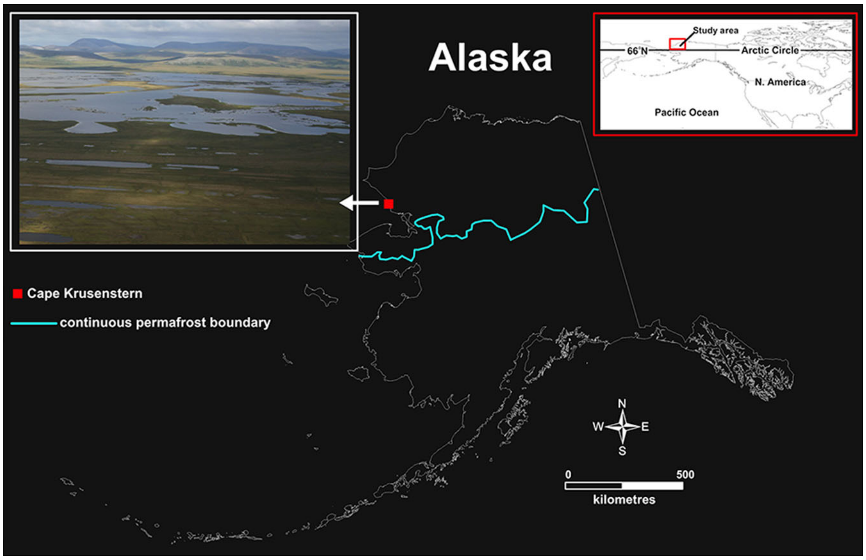

Fig. 1 Location of Cape Krusenstern National Monument. The study area lies just north of the Arctic Circle, and within the continuous permafrost zone (permafrost boundary after Jorgenson et al. 2008).

Fig. 2 Cape Krusenstern beach ridges and site location.

well drained, low-lying areas running parallel to the ridge contain standing water with marshy vegetation. The tundra-like setting of the site offered a relatively easy survey environment as an open, mostly flat space exhibiting very few obstructions with the exceptions of the Old Whaling houses themselves (Fig. 3).

Methods

The geophysical investigation at the Old Whaling site was undertaken over the course of a single week in August 2011. The project included three personnel: archaeologist and Principal Investigator (PI) Christopher Wolff, geophysicist Thomas Urban and field assistant Luke Brown. Geophysical data collection and processing were conducted by Urban. Assistance with the geophysical data collection was provided by Wolff and Brown, who also conducted small-scale test excavations (two 1 × 1 m units and three 50 × 50 cm units). Interpretation of geophysical results was undertaken collaboratively by Wolff and Urban. Transport of personnel and field equipment to the site required three trips with a float-plane as only waterborne landings were possible and the plane's capacity was limited. A small camp was set up

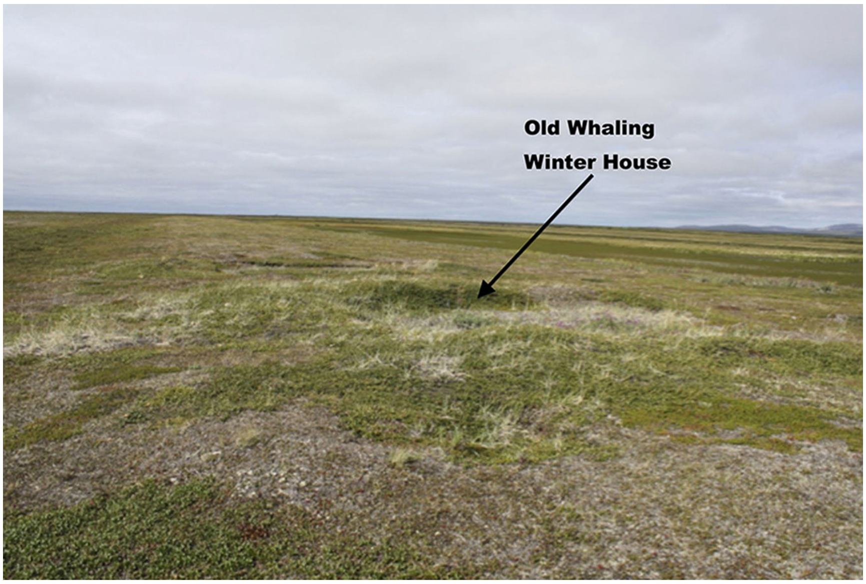

Fig. 3 Looking north towards a house pit in Giddings' winter settlement. (Photo by Christopher Wolff.)

several hundred metres from the site. Maintaining geophysical and other electronic equipment (total station, field computers) on site required an additional equipment tent. A small generator was also necessary to recharge batteries for survey equipment and field computers, with the latter used to download, back-up and conduct initial data-processing in the field. Geophysical data collection was only possible intermittently due to bouts of severe weather that included high winds and heavy rain. The data collection time totalled approximately 14 hours. Downtime was used to process collected data and examine preliminary results.

Due to surface conditions at the site and an equipment malfunction, broader coverage was possible with magnetic gradiometry than with ground-penetrating radar (GPR). With GPR, a broad section of the beach ridge lying between the summer and winter settlements was surveyed. The grid size was 95 × 20 m. With magnetic gradiometry, this same grid was extended an additional 12 m on the narrower axis of the beach ridge into a marshy area, with a new grid size of 95 × 32 m. This was possible because the magnetic instrument could be operated in an area toward the edge of the beach ridge that presented thicker vegetation and some standing water, thus limiting reasonable access with GPR because the latter entails movement along the survey surface while the former is carried above the surface. A separate gradiometry survey of the summer settlement was also undertaken with a 27 × 32 m grid. GPR, however, was not used in this area because of a damaged cable that rendered the instrument inoperable.

Ground-penetrating radar

GPR was used to assess the potential for subsurface features of archaeological and morphological interest occurring in the 100 m stretch of open space in between the summer and winter settlements (Fig. 4). GPR relies on reflected energy from the propagation of electromagnetic pulses generated at the surface. In air, the velocity of a radar wave approaches the speed of light in a vacuum. In the ground, however, this velocity is greatly reduced and the wave propagates at velocities governed by the electrical properties of the medium, with the primary controlling properties being electrical conductivity and relative permittivity (dielectric constant; Davis & Annan 1989; Conyers 2004; Daniels 2004; Jol 2009). At interfaces where electrical properties vary, a backscattering of reflected energy will occur. This reflected energy is the primary information sought with a GPR survey. The two-way travel time of the observed signal can then be used to estimate the depth to an embedded object or interface in the ground (Davis & Annan 1989). Due to the very short wavelengths involved, GPR is capable of resolving finer detail than most other geophysical methods, though it may not work well where the ground is very conductive or insufficient contrast exists between the electrical properties of the target and the host medium (Conyers 2004). With appropriate processing, GPR data can be presented as profiles, planar images (time-depth slices), three-dimensional volumes or combinations thereof.

Fig. 4 The site presented a flat surface free of obstructions, making the deployment of geophysical instruments very easy. Shown here, Thomas Urban with Noggin ground-penetrating radar system. (Photo by Christopher Wolff.)

Citation: *Polar Research* 2013, *32*, 19888, http://dx.doi.org/10.3402/polar.v32i0.19888

The GPR survey was undertaken using the Noggin GPR system (Sensors and Software, Mississauga, ON, Canada), with a 250 MHz centre-frequency antenna. The instrument was deployed on a sled configuration that glided smoothly across the lichen and moss covered ground. In this setting, such a mode of GPR deployment may be preferable to the more typical cart set-ups due to reduced packing space, an issue for small float planes, and to ease of manoeuvrability: a sled moves more easily across this type of surface that a wheeled cart likely would. Transects were spaced at 0.25 m and in-line distances were recorded with both a survey tape and an instrument odometer. The subsurface environment offered minimal attenuation of the radar signal, with only a weak gain being necessary to view the data in real time. While this may seem surprising for a once saline environment, it was clear that hydrologic processes have acted to remove any remnant salts, which would have increased the electrical conductivity, thereby attenuating the GPR signal.

A number of typical signal processing protocols were applied to the radar data to enhance desired features. The most common procedure where radar data are concerned is the application of a gain to amplify a signal as it weakens with depth. This was achieved by implementing a moderate spherical and exponential compensation gain. Subsurface velocities were determined with a hyperbola fitting procedure during post-processing, and average velocity was shown to be 0.1 m/ns. A signal-saturation removal procedure (dewow) was implemented as a high-pass filter to remove unwanted low frequency trends from shallow induction currents (generated by the instrument itself or other sources), along with a background removal filter which subtracted the average value of all traces in the collected grid for an additional high-pass effect. To eliminate the unwanted tails of diffraction hyperbolas, a common GPR data artefact, a velocity migration procedure was implemented using the velocity previously determined with hyperbola fitting. This procedure resulted in a more spatially accurate rendering of embedded features. Finally, an enveloping procedure was applied to eliminate the oscillatory nature of radar traces so that similar reflections in close spatial proximity could be packaged across multiple traces for more accurate spatial rendering. Two-way travel times were converted to depths using the previously determined velocity, and individual profiles were grouped for time-slicing and three-dimensional rendering. A more detailed discussion of the processing techniques described here can be found in Annan (2004), Conyers (2004), Daniels (2004) and Jol (2009).

Magnetic gradiometry

In addition to GPR, magnetic gradiometry was used to obtain information about subsurface features on the site and to supplement the GPR results. Magnetometers are sensitive to remnant magnetization (permanent magnetization locked into the structure of a material) and induced magnetization (caused by Earth's magnetic field), both of which vary significantly across material types. Since the instrument used for this survey measures the total-field response (total flux density without a directional component), it is difficult to differentiate between induced and remnant contributions, though this can be possible through comparison with electromagnetic in-phase data (Won & Huang 2004).

In this setting, a vertical magnetic gradient was preferable to a total field survey. While Earth's magnetic field fluctuates temporally throughout the course of the survey, the differential measurement between two sensors of varying elevations (vertical gradient) is often used as a relative measurement of variations in the local magnetic environment, eliminating the need for additional diurnal corrections to the data. This also enhances the response from shallow magnetic features by minimizing low frequency trends, acting as a type of high-pass filter (Silliman et al. 2000). Use of the vertical gradient is especially beneficial in northern latitudes, such as Cape Krusenstern, that experience more rapid and intense fluctuation in the magnetosphere throughout the day, thus making diurnal corrections impractical. This is especially true in the auroral zone during the summer months (Urban et al. 2012), the effects of which were responsible for the failure of J. Louis Giddings' early attempt at magnetic surveying in this region (Urban 2012).

A G-858 cesium vapour magnetometer (Geometrics, San Jose, CA, USA) deployed in gradiometry configuration (vertical gradient survey) was used for this project. With the sensors positioned at 0.25 and 1.25 m above grade, transects were collected with a 0.50 m interval. In-line distance was recorded with a survey tape. Limiting factors to the magnetic survey included the presence of modern ferrous metals on the surface and the natural effects of the northern magnetosphere. With the former issue, little could be done to mitigate the problem. The offending objects included a permanent steel datum set by the National Park Service (NPS), as well as steel cans and stakes left behind from previous archaeological work that were well hidden by surface vegetation. The latter issue of Arctic diurnal effects was mitigated by using the relative measurement of vertical gradient only rather than attempting diurnal corrections, which would have required a continuous base station, as noted by previous studies in the region (Urban et al. 2012).

Processing of the magnetic data required a standard set of procedures including despiking, drop-out removal and gridding with the Kriging interpolation algorithm. Some less routine procedures were also applied. For example, in order to enhance certain subsurface features an upward continuation was implemented. The upward continuation is a potential field transformation procedure that develops synthetic magnetic observations for a specified plane above the actual sensor (Blakely 1995). By simulating a magnetic surface at a higher elevation in this fashion, a pseudo-gradient was developed with the originally observed magnetic data and the upward continued data. This procedure was implemented as a noise reduction strategy that acted to suppress local noise at the survey surface—in essence acting as a low-pass filter—resulting in a smoother image. This was done specifically to reduce noise generated at the low sensor by the shallow ferrous debris previously described. Though the continuation was over a short distance (50 cm), it was effective in enhancing general trends that were obscured by the debris, and without sacrificing significant detail where such trends occurred.

Results

Area in between settlements

GPR revealed a complex dendritic morphology of the Old Whaling beach ridge's subsurface (Fig. 5). This morphology between the two known settlements (summer and winter) appears to be the result of natural morphologic processes rather than tent pads as the Darwents hypothesized (Darwent & Darwent 2005:151), and offers a glimpse into the past drainage and cryogenic processes of the site area. Most of the anomalous patterns detected with GPR are likely the perimeters of buried permafrost polygons and associated shallow ponds generated by the seasonal freeze–thaw cycle. Similar features are visible on the modern surface near the coast. Those detected in the GPR results may have been surficial features when the coast was closer to the Old Whaling beach ridge.

To further evaluate if these were natural features, several test excavations were conducted to investigate if the slight depressions were possible cultural features since many are roughly the same size and shape as prehistoric house features from the region. This could also explain the Darwents' interpretation, although they noted fire-cracked rock and debitage on the surface at one of these locations. A 50 × 50 cm test excavation at that same location revealed only eight pieces of chert debitage at or near the surface, as well as infilling episodes related to natural processes (Fig. 6). No indication of an interior hearth feature is present in the area and our magnetic survey revealed no buried external hearth features. Depth estimates of a similar feature derived from GPR and test excavations support the argument that the feature was a pond generated by a low-centred frost polygon that appears to be contemporaneous to the documented settlements (based on depth of the feature). In addition to the dendritic patterning of the frost polygons, a relatively deep channel cutting through the middle of the survey area appears in the GPR survey results. This represents a present topographic feature related to site drainage rather than a subsurface feature. This feature appears to bisect several of the deeper subsurface features.

In areas between the two settlements, the drainage patterns detected with GPR were also evident with gradiometry (Fig. 7). These manifested more prominently in the west, toward the summer settlement, and are not nearly as well defined as with the GPR results; however, the perimeters of frost-polygons are apparent. Some of these appear as magnetic lows, while others appear as magnetic highs. There are a number of possible

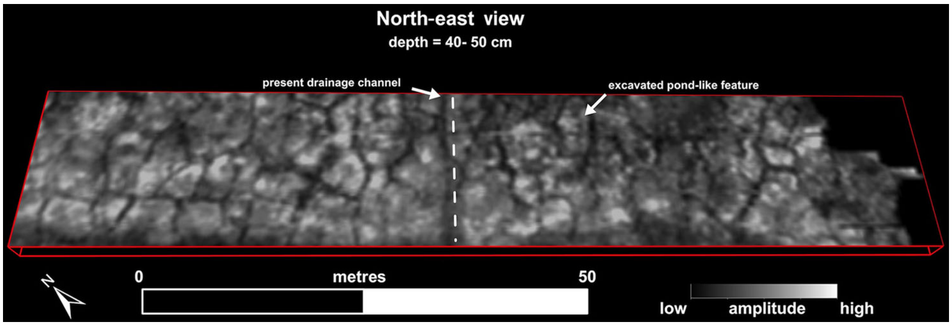

Fig. 5 Amplitude-slice image of ground-penetrating radar results revealing complex dendritic patchwork related to a combination of hydrologic and cryogenic processes in the active layer (i.e., above the permafrost layer).

Fig. 6 Test excavation of the edge of sunken surface feature revealing fine sandy deposits (under north arrow) that naturally infilled a permafrost fissure.

explanations for this, including magnetization and demagnetization of sediments from hydrologic processes, variations in the density of the sediments (i.e., these may be fissures infilled with various material including sediment, water and organics), and variations in respiration with associated changes in microbial activity. These observed disparities are likely related to whether a given polygon is low-centred or high-centred as the fore fosters the accumulation of water (i.e., pooling) while the latter fosters draining. With the magnetic results alone, several of these features could easily be mistaken for house sites on the basis of scale and layout. However, when compared with the radar results, it is clear that these are part of the broader dendritic pattern across the site. That is not to say that all of these features are without cultural relevance. Indeed, some of these may have served as good locations for tent pads or other features as the Darwents suggested. It is evident, however, that houses of the type and scale seen in the summer and winter settlements are not apparent across the rest of the site.

The underlying foundational structure of the beach ridge is also evident with both survey methods (Fig. 8).

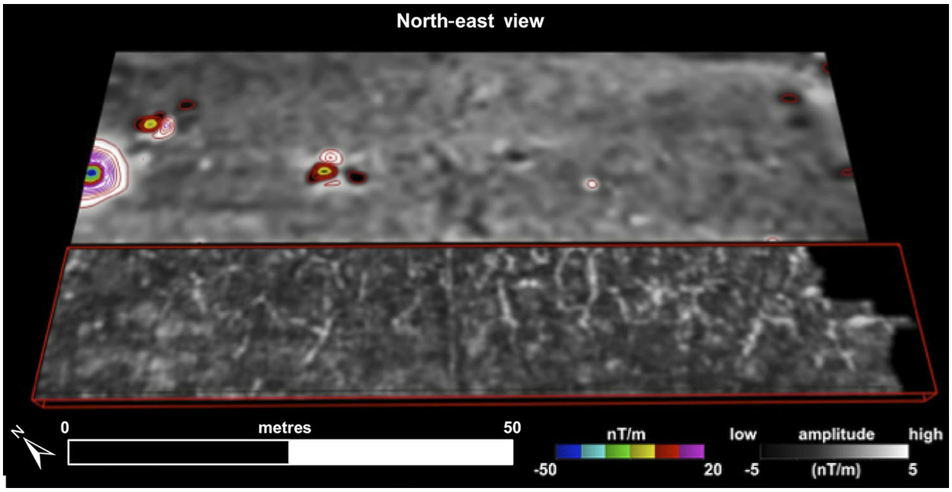

Fig. 7 In this comparison of magnetic and ground-penetrating radar results, the ground-penetrating radar image (lower) has undergone a spherical averaging filter to reduce clutter and emphasize strong trends. This is a true three-dimensional rendering with the upper 50 cm removed to reveal underlying features. The magnetic image (upper) incorporates a grey-scale rendering of the upward continued pseudo-gradient with a colour-contour map. The contour map uses the full range of magnetic data to indicate the locations of metal (contour interval =3 nT/m) and demonstrate that features of interest are represented in only a very narrow range of the data.

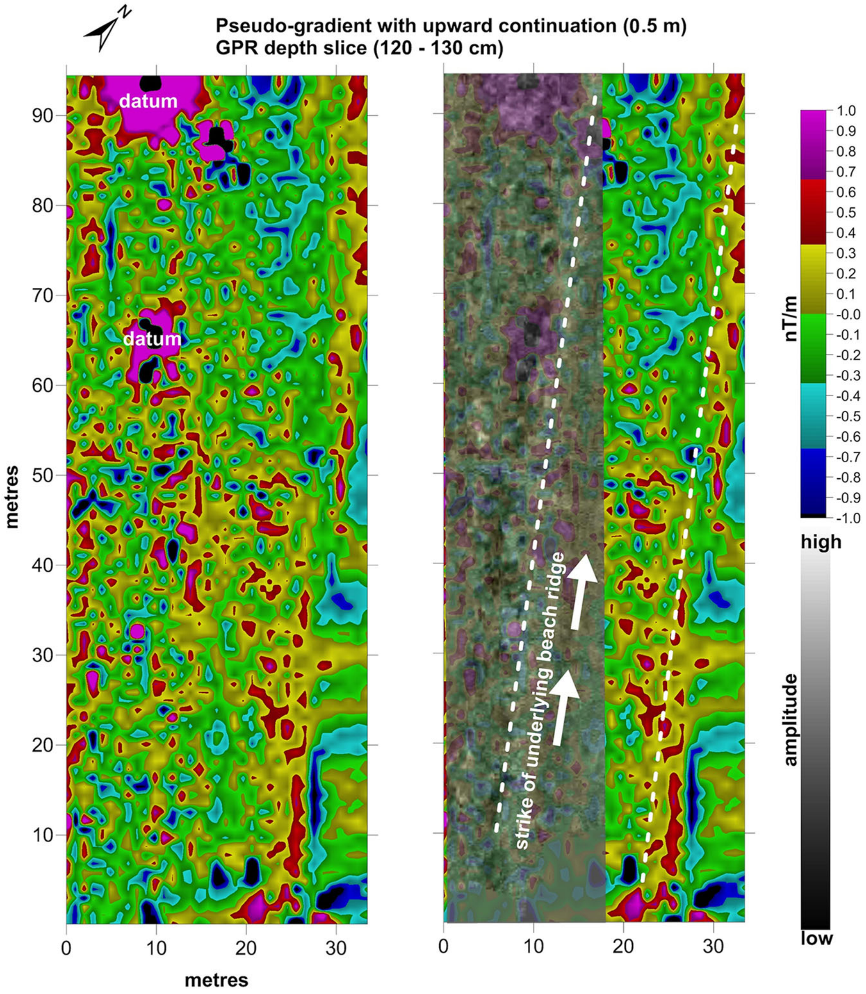

Fig. 8 Overlays of magnetic and ground-penetrating radar (GPR) results along entire survey area indicated a deeper trend from the underlying beach ridge.

Comparison of upward continued magnetic data with some of the deeper GPR time-slices reveal a consistent, underlying trend striking across the full length of the site. This may be related to the early formation of the beach ridge.

Summer settlement

The footprints of the previously excavated houses in the summer settlement were easily visible in the magnetic results, which are likely a result not only of the features themselves, but also of topographic variations, disturbance from previous excavation, and additional anomalies clearly related to modern ferrous trash, such as cans and stakes (Fig. 9). A metal rebar datum placed at the site by the NPS (which we were unable to remove) also generated a prominent anomaly. The additional deeply buried structure identified by the Darwents (Darwent & Darwent 2005) was not detected with gradiometry. Weak randomly distributed dipoles were visible throughout the settlement area, which could be the result of heat-exposed rocks. Interestingly excavation in the area of the possible buried structure (Fig. 10), revealed a small amount of animal bone (marine, terrestrial and possibly bird), wood fragments, a projectile point base fragment, and a few pieces of chert debitage at a depth of approximately 47–51 cm below surface, slightly above where the Darwents identified possible house timbers. None of these artefacts are diagnostic so there affiliation remains undetermined. They may relate to the nearby house structure (House 204) excavated by Giddings & Anderson (1986) and possible midden deposits.

Discussion

The types of geophysical disturbances expected by the presence of prehistoric semi-subterranean houses were not obvious in the survey area, with the exception of the

Citation: *Polar Research* 2013, *32*, 19888, http://dx.doi.org/10.3402/polar.v32i0.19888

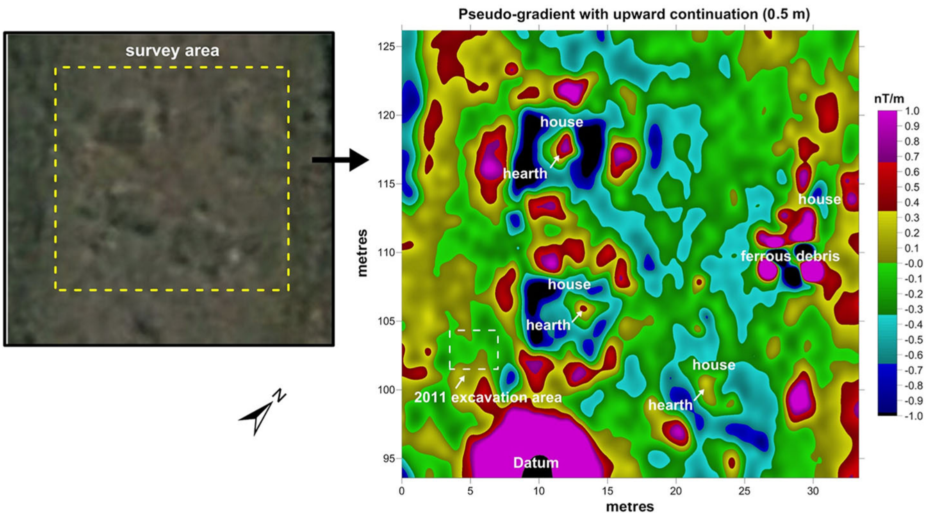

Fig. 9 The magnetic survey of the summer settlement revealed strong signals from the known houses and from various ferrous debris. The additional house documented by Darwent & Darwent (2005) was not evident.

previously recorded houses in the summer settlement. Most prominent beyond the known house sites were disturbances generated by previous archaeological work (i.e., test pits, metal) and patterns created by natural hydrology and cryogenic processes in the active layer. It must be recognized, however, that the latter processes produce geometric patterns that could in some cases be difficult to discern from cultural activity. As noted by Wood & Johnson (1978), patterned ground generated by freeze–thaw processes can easily be mistaken for cultural features.

While some discrete magnetic responses were apparently generated by the presence of fired rock later confirmed with test excavation, these materials appear to be widespread around the summer settlement, and in many instances may be heavily obscured by the presence of modern metal (which elicits a response several orders of magnitude greater than the archaeological material). Many of these stones are scattered on the site surface, and some were tested in real-time with the magnetometer to confirm the suspected response. The areas surrounding the known houses in the summer settlement may also contain unrecognizable features and materials of archaeological interest (e.g., midden deposits), some of which may be only weakly visible in the magnetic survey results.

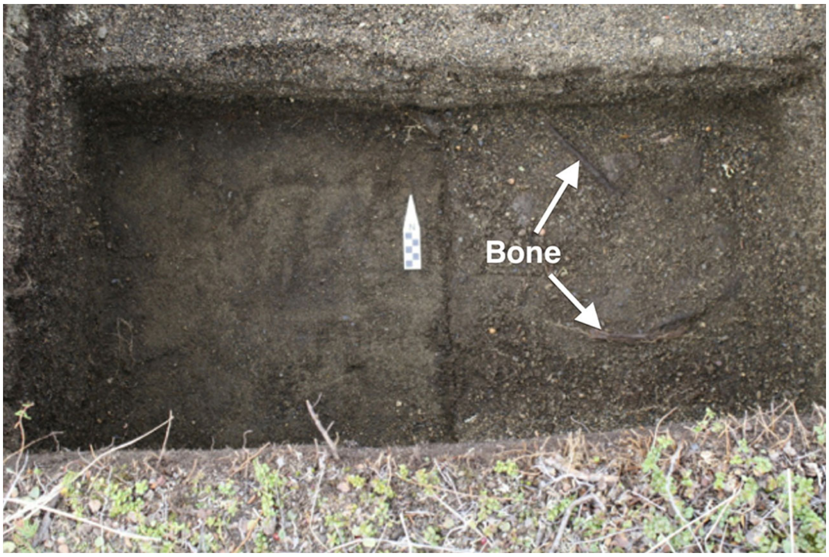

Fig. 10 Test excavation near winter house revealing probable midden deposits.

The magnetic responses from hearths in the known houses of the summer settlement are readily apparent in the magnetic survey results. These anomalies appear as magnetic highs concentrated in the house centres, despite disturbance from previous excavation and subsequent removal of the hearth stones as described by one the original excavators, Douglas Anderson (pers. comm., 2012). This is likely due to both remnant magnetization and enhanced magnetic susceptibility cause by heating of the soil where the hearths were located, as well documented process (e.g., Le borgne 1960; Tabbagh 1984). We expect that intact (not disturbed by excavation) hearth deposits from earlier houses would be easily detectable with magnetic methods and generate an even stronger response than the disturbed deposits of the known houses owing to the presence of magnetized hearth stones. Anomalies from additional hearths from unknown houses, perhaps more deeply buried as the Darwents suggest (Darwent & Darwent 2005; Darwent 2006), were, however, not apparent in the magnetic results from the area surrounding and including the summer settlement. Given the relatively shallow deposits at Cape Krusenstern, hearth locations from previous occupations should have been readily detectable with the magnetic survey. Findings at another site in the region, for example, showed that hearth locations were very easily detectable as deep as 2 m below the surface (Urban et al. 2012), more than triple the depth observed by the Darwents for the evidence of earlier occupation. While this does not mean the Darwents' interpretation is incorrect, the slightly deeper provenience of the artefacts that led to their conclusions could also be explained by natural processes. In particular, cryoturbation relating to permafrost changes and active layer dynamics could have shifted embedded material, and/or they may have been originally deposited or redeposited on a lower elevation surface during occupation of the site. Further excavation is needed to determine if these deposits are in a primary or secondary context.

Perhaps the most significant finding of the geophysical survey was the documentation of the effects of the freeze–thaw cycle on the subsurface environment. In particular, observations suggest an increase in the thickness of the active layer since the time of Giddings' original investigation. The two previous archaeological investigations of the Old Whaling site have reported permafrost depths that were revealed during archaeological excavation. Both studies were conducted in the summer months. The earlier study, headed by Giddings in 1958, noted that the permafrost table was encountered at approximately 60 cm (Giddings 1967; Giddings & Anderson 1986), while the later 2003 investigation by the Darwents noted the permafrost at 100–140 cm (Darwent & Darwent 2005). One of our test excavations encountered the water table at 110 cm below surface near the peak of the beach ridge. This excavation did not encounter the permafrost table, however, and was abandoned after water flooded the excavation unit. This does support the Darwents' observation that the permafrost table was significantly deeper than when Giddings first investigated the site, suggesting an effect of increasing Arctic mean temperature.

A number of recent reconstructions of historical temperature trends (pre-instrumental) derived from various proxy records, such as tree rings, have suggested a general millennial-scale cooling trend in the Northern Hemisphere (Mann et al. 1999; Esper et al. 2002; Moberg et al. 2005; Hegerl et al. 2007; Mann et al. 2008; Kaufman et al. 2009; Ljungqvist 2010; Esper et al. 2012). Though this trend has been estimated and reported with various magnitudes for the pre-industrial era, these studies have consistently pointed to long-term cooling of the Northern Hemispheric mean temperature for the 2000 years prior to widespread, modern industrialization. Such a cooling trend suggests the general stability and possible on-going expansion of Arctic permafrost for the past 2000 years, with some intermittent variability during warming periods. These same studies, however, also demonstrate a more recent reversal of the long-term cooling in the wake of industrialization. Arctic warming has obvious implications for permafrost. Reduction in permafrost, and by default expansion of the active layer, may have significant implications for archaeological sites falling within the continuous permafrost zone. It has been previously reported that the freeze–thaw cycle of the active layer through cryoturbation may grossly distort physical associations in the archaeological record (Ashton et al. 1992; Waters 1992), and embedded materials may be displaced both vertically and horizontally (Dincauze 2000). The geophysical results reported here suggest that this may be the case for the Old Whaling site. Further, with Arctic temperatures on the rise as suggested by the aforementioned studies, cryoturbation at this site may have been exacerbated since the time of Giddings' original investigation, perhaps contributing to the disparity between the original interpretation and that proposed by the Darwents half a century later.

Conclusions

Our use of geophysical techniques clearly documented the known houses of the Old Whaling summer settlement, but they did not provide evidence of additional

Citation: *Polar Research* 2013, *32*, 19888, http://dx.doi.org/10.3402/polar.v32i0.19888

occupations of the beach ridge as suggested by earlier research. While some weak magnetic responses appear to have been generated by the presence of fire-cracked rock, these materials are generally confined to the vicinity of the summer settlement houses and, in some instances, may be heavily obscured by the presence of modern metal debris. Some of the strongest broad patterns detected are likely the result of disturbances generated from previous archaeological work and features created by site hydrology and cryogenic processes. The latter processes produce fissures across the site in variable geometric patterns, some of which are quite deep. In some instances, the patterns could be difficult to discern from cultural features, such as single-family house pits that may exhibit comparable scale and shape to some frost polygon perimeters. These features could also foster vertical transport of artefacts into deeper contexts, particularly if some of these features once contained flowing water or expanding and contracting ice. It is still possible that the area surrounding the summer settlement has underlying cultural deposits that would only create weak geophysical anomalies, such as the observed midden deposit, and would not necessarily be easily detected by geophysical methods. We believe, however, that any future excavation would need to include a systematic examination of the site morphology to identify any taphonomic processes that could significantly affect interpretation of the site.

Acknowledgements

This research was supported by the National Science Foundation (grant no. 1048194), the National Park Service (NPS) Shared Beringian Heritage Program, the Haffenreffer Museum of Anthropology at Brown University, State University of New York – Plattsburgh and the Weidenfeld Research Fellowship. We thank CH2M Hill Polar Field Services for logistical support, and NPS staff in Kotzebue, AK, for logistic support and housing, especially Robert Gal. We thank Luke Brown for field assistance, and also thank Daniel Odess, Jeff Rasic, Douglas D. Anderson, Christyanne Darwent and John F. Hermance for advice and support. We thank James Savelle and one anonymous reviewer for thoughtful comments on this manuscript. Finally, we thank our families for their on-going support.

References

Ackerman R.E. 1988. Settlements and sea mammal hunting in the Bering–Chukchi Sea region. *Arctic Anthropology 25*, 52–79.

Annan J.P. 2004. *Ground penetrating radar: principles, procedures and applications*. Mississauga, ON: Sensors and Software Inc.

Ashton N.M., Cook J., Lewis S.G. & Rose J. 1992. *High Lodge: excavation by G. de G. Sieveking 1962–1968 and J. Cook 1988*. London: British Museum.

Blakely R.J. 1995. *Potential theory in gravity and magnetic applications*. New York: Cambridge University Press.

Collins H.B. 1967. *Introduction to J. Louis Giddings' ancient men of the Arctic*. New York: Alfred A. Knopf.

Conyers L.B. 2004. *Ground-penetrating radar for archaeology.* Walnut Creek, CA: Altamira Press.

Daniels D.J. 2004. *Ground penetrating radar.* 2nd edn. London: Institute of Electrical Engineers.

Darwent C.M. 2006. Reassessing the Old Whaling locality at Cape Krusenstern, Alaska. In J. Arneborg & B. Grønnow (eds.): *Dynamics of northern societies: proceedings of the SILA/NABO Conference on Arctic and North Atlantic Archaeology, Copenhagen. May 10th–14th, 2004*. Pp. 95–102. Copenhagen: National Museum of Denmark.

Darwent J. & Darwent C.M. 2005. The occupational history of the Old Whaling site at Cape Krusenstern. *Alaska Journal of Anthropology 3*, 135–153.

Davis J.L. & Annan J.P. 1989. Ground penetrating radar for high resolution mapping of soil and rock stratigraphy. *Geophysical Prospecting 37*, 531–551.

Dikov N.N. 1988. The oldest sea mammal hunters of Wrangel Island. *Arctic Anthropology 25*, 80–93.

Dincauze D.F. 2000. *Environmental archaeology: principles and practice*. Cambridge, UK: Cambridge University Press.

Esper J., Cook E. & Schweingruber F. 2002. Low-frequency signals in long tree-ring chronologies for reconstructing past temperature variability. *Science 295*, 2250–2253.

Esper J., Frank D., Timonen M., Zorita E., Wilson R. & Luterbacher J. 2012. Orbital forcing of tree-ring data. *Nature Climate Change 2*, 862–866.

Giddings J.L. 1967. *Ancient men of the Arctic*. New York: Alfred A. Knopf.

Giddings J.L. & Anderson D.D. 1986. *Beach ridge archeology of Cape Krusenstern*. Washington, DC: National Park Service.

Hegerl G.C., Crowley T.J., Allen M., Hyde W.T., Pollack H.N., Smerdon J. & Zorita E. 2007. Detection of human influence on a new, validated 1500-year temperature reconstruction. *Journal of Climate 20*, 650–666.

Jol H.M. (ed.) 2009. *Ground penetrating radar (GPR) theory and applications*. Amsterdam: Elsevier.

Jorgenson T., Yoshikawa K., Kanevskiy M., Shur Y., Romanovsky V., Marchenko S., Grosse G., Brown J. & Jones B. 2008. *Permafrost characteristics of Alaska*. (December 2008 update to July NICOP map.) Fairbanks: Institute of Northern Engineering, University of Alaska.

Kaufman D.S., Schneider D.P., McKay N.P., Ammann C.M., Bradley R.S., Briffa K.R., Miller G.H., Otto-Bliesner B.L., Overpeck J.T., Vinther B.M. & Arctic Lakes 2K Project Members 2009. Recent warming reverses long-term Arctic cooling, *Science 325*, 1236–1339.

Le Borgne E. 1960. Influence de feu sur les properties magnetiques du sol et du granite. (Influence of fire on the magnetic properties of soil and granite.) *Annales de Geophysique 16*, 159–195.

Ljungqvist F.C. 2010. A new reconstruction of temperature variability in the extra-tropical Northern Hemisphere during the last two millennia. *Geografiska Annaler 92A*, 339–351.

Mann M.E., Bradley R.S. & Hughes M.K. 1999. Northern Hemisphere temperatures during the past millennium: Inferences, uncertainties, and limitations. *Geophysical Research Letters 26*, 759–762.

Mann M.E., Zhang Z., Hughes M.K., Bradley R.S., Miller S.K., Rutherford S. & Ni F. 2008. Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia. *Proceedings of the National Academy of Sciences of the United States of America 105*, 13252–13257.

Mason O.K. & Gerlach S.C. 1995. The archaeological imagination, zooarchaeological data, the origins of whaling in the western Arctic, and "Old Whaling" and Choris cultures. In A.P. McCartney (ed.): *Hunting the largest animals: native whaling in the western Arctic and Subarctic*. *Studies in Whaling 3*. Pp. 1–32. Edmonton: Canadian Circumpolar Institute.

Moberg A., Sonechkin D.M., Holmgren K., Datsenko N.M. & Karlen W. 2005. Highly variable Northern Hemisphere temperatures reconstructed from low- and high-resolution proxy data. *Nature 433*, 613–617.

Silliman S.W., Farnsworth P. & Lightfoot K.G. 2000. Magnetometer prospecting in historical archaeology: evaluating survey options at a 19th century Rancho site in California. *Historical Archaeology 34(2)*, 89–109.

Tabbagh A. 1984. On the comparison between magnetic and electromagnetic prospection methods for magnetic feature detection. *Archaeometry 26*, 171–182.

Urban T.M. 2012. In the footsteps of J. Louis Giddings (1912–1964): archaeological geophysics in Arctic Alaska. *Antiquity 86(332)*.

Urban T.M., Anderson D.D. & Anderson W.W. 2012. Multimethod geophysical investigations at an Inupiaq village site in Kobuk Valley, Alaska. *The Leading Edge 31*, 950–956.

Waters M.R. 1992. *Principles of geoarchaeology*. Tucson: University of Arizona Press.

Won I.J. & Huang H. 2004. Magnetometers and electromagnetometers. *The Leading Edge 23*, 448–451.

Wood W.R. & Johnson D.L. 1978. A survey of disturbance processes in archaeological site formation. In M.B. Schiffer (ed.): *Advances in archaeological method and theory. Vol. 1*. Pp. 315–381. New York: Academic Press.

Citation: *Polar Research* 2013, *32*, 19888, http://dx.doi.org/10.3402/polar.v32i0.19888