Archaeological magnetometry in an Arctic setting: a case study from Maguse Lake, Nunavut

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ARTICLE INFO

Article history:
Received 9 September 2010
Received in revised form 3 March 2011
Accepted 4 March 2011

Keywords:
Magnetometry
Arctic
Keewatin district
Frost features
Glacial erratics

ABSTRACT

Magnetometry has been little used on Arctic archaeological sites, but has great potential to help us understand site structure by identifying buried features and providing additional detail about the construction and use of visible surface features. In the Arctic environment, magnetometer surveys have to deal with the effects of permafrost activity on soils and the potential influence of glacial erratics of varying geological composition. Here, we present the results of magnetometer surveys of a non-cultural site with periglacial features and two archaeological sites located in the Canadian low Arctic. Despite considerable “noise” apparently caused by igneous erratics, the surveys successfully identified several frost features and a range of archaeological feature types. They also appear to have located buried archaeological features and identified activity areas within some dwellings. These preliminary results suggest that the technique is worth pursuing on northern sites.

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1. Introduction

Because of slow and very limited soil development in the Arctic, most archaeological sites are highly visible on the landscape in the form of surface artifacts, surface features made of stone, whale bone and/or turf, and areas where organic waste has resulted in enhanced vegetation cover. Archaeological investigations on Arctic sites have traditionally focused on visible surface features, in particular dwellings and their associated middens, which are the target of excavations (McGhee, 1984:1; e.g. Desrosiers and Rahmani, 2003; Harp, 1976; Morrison, 1983:49). We believe that magnetometry can help enhance our understanding of Arctic sites by adding an important layer of information to the visible remains. While restricted in northern latitudes, soil development can be sufficient to cover some of the archaeological features and artifacts (e.g. Arnold, 1981:30; Maxwell, 1973:8). Magnetometer survey has the potential to locate buried features, identifying areas of interest that would be overlooked using a more traditional approach. It may also be able to provide additional information about visible features, potentially detecting traces of their construction and use that are not obvious based solely on surface mapping or excavation.

Here, we present the results of magnetometer surveys conducted around Maguse Lake, in the southern Keewatin district of Nunavut, Canada (Fig. 1). Our use of magnetometer survey in the region is part of a recent trend in arctic archaeology to experiment with innovative techniques for investigating site structure in greater detail. These studies include micro-debitage analysis to confirm the existence of dismantled tent rings (Milne, 2003:80) and geochemical analysis to investigate site structure and identify activity areas between visible dwellings (Butler, 2010).

The utility of geophysical survey for the identification and mapping of archaeological sites is well documented (Aitken, 1961; Clark, 1990; Gaffney and Gater, 2003; Johnson, 2006; Scollar et al., 1990). Geophysical techniques are widely used in European archaeology and are increasingly important in the United States (Johnson, 2006; Kvamme, 2003). In Europe, these techniques are most widely used on sites occupied by settled farming groups, since they tend to produce substantial archaeological features including numerous burnt features and rubbish deposits that lend themselves to geophysical prospection (Gaffney and Gater, 2003:23). The same is true in the US and Canada, where geophysical survey has concentrated primarily on large pre-contact villages and historic European sites (Kvamme, 2003; Gibson, 1982; Nobles, 1994). While the small and unstructured remains left by mobile hunter-gatherers are harder to detect (Johnson, 2006:3; Gaffney and Gater, 2003:120), improvements in instrumentation and computer processing now allow many of these ephemeral sites to be mapped with a variety of geophysical instrumentation (Jones and Munson, 2005:43; Kvamme, 2003:436–437).
The potential of magnetometry on arctic sites

Magnetometer survey records spatial variations in the earth's magnetic field, which occur as a result of local changes in magnetization. In archaeological applications, we are obviously concerned with the magnetic anomalies caused by human activity. People can create these anomalies in a number of ways, for example by depositing ferrous metal artifacts on a site, and through extreme heating, such as firing a kiln or oven, which produces thermoremanent magnetism (Linford, 2006: 2223). In such cases the magnetic minerals in soils are heated past their Curie point and align themselves along the direction of the earth's magnetic field. This new direction of magnetization becomes fixed as the object cools (Clark, 1990: 65). More importantly for our case study, a range of human and natural factors can lead to enhanced magnetic susceptibility in topsoil in comparison to the underlying subsoil (Aspinall et al., 2008: 22–28). These include heating and burning, through which weakly magnetic hematite, a common naturally occurring iron oxide in soils, is converted into a strongly magnetic form, maghemite (via magnetite). Deposition of organic waste can also lead to magnetic enhancement since the bacteria associated with midden deposits can, like heating and cooling, create the appropriate reducing and oxidizing conditions to convert magnetic minerals into more magnetic forms. In addition, magnetotactic bacteria, which are often found in large quantities in decayed wooden posts, are capable of producing magnetite crystals from iron oxides that occur within soils (Fassbinder et al., 1990; Fassbinder and Stanjek, 1993). Finally, natural soil formation (pedogenesis) can produce magnetite in soils (Maher and Taylor, 1988). When people disturb this “magnetization,” for example by digging a house pit or backfilling a post hole, they can therefore create weak, but detectable, magnetic anomalies (Linford, 2006: 2223).

Magnetometry and other geophysical techniques have been little used on Arctic archaeological sites. The few surveys that have been carried out have concentrated on locating sites associated with 19th century European exploration, through the identification of iron artifacts (Arnold, 1982; Gibson, 1982). However, we believe that the technique’s potential in an Arctic context lies not in locating sites, but in better understanding individual sites. Because geophysical techniques allow the rapid investigation of large areas, they facilitate the study of site structure, content and organization (Kvamme, 2006:228). Given the short field seasons and high costs of arctic fieldwork, they have the potential to make a substantial contribution, allowing relatively large areas to be rapidly surveyed and helping to target areas for further investigation.

One of the potential limiting factors for magnetometer survey in the Arctic is the thin soils that are present in many regions. The ground surface of large areas of the High Arctic, and intermittent patches at lower latitudes, consists of exposed glacial till with no soil cover. As outlined above, the quantity and physical properties of topsoil are particularly relevant to the potential success of magnetometer survey because topsoil typically has higher magnetic susceptibility than the underlying subsoil (Clark, 1990:65; Dalan, 2006:162). Areas where there is little or no topsoil development present, such as some regions of the American South West, have been shown to respond poorly to magnetic prospection (Kvamme, 2006:222). It is therefore unlikely that sites in the High Arctic, where soils are thinnest, will respond well to magnetic prospection. However, there is good potential for the technique at lower latitudes, which exhibit better soil formation as attested by the degree to which arctic peoples used sod in the construction of their dwellings.

Another potential challenge for arctic magnetic survey is the periglacial environment. As a recently deglaciated landscape, the Arctic abounds with glacial tills composed of gravel and larger erratics of varying geological composition. Permafrost also has a major impact on Arctic geomorphology. Seasonal melting and freezing in the active upper layer of permafrost results in cryoturbation, which moves soils both vertically and horizontally, and can result in size sorting of sediments as larger clasts migrate to the surface (French, 2007:144; Hallet and Waddington, 1992:252; Williams and Smith, 1989: 42). Frost action also causes cracking, and repeated freeze and thaw cycles lead to the formation of ice wedges in these cracks. Common frost features include patterned ground (when ice wedges occur in geometric forms), hummocks (small regular mounds) and involutions (convolutions of layers of ground). Unfortunately there has been no systematic research on the effects of these processes on near-surface magnetometer survey, though a preliminary assessment of their influence in archaeology suggests that their presence complicates the interpretation of results (Horsley and Dockrill, 2002:3). The moving and sorting of soils certainly has the potential to create magnetic signatures in the same way that human activity can.

Study area

Maguse Lake is situated approximately 50 km northwest of the Inuit Community of Arviat, Nunavut near the southwestern coast of Hudson Bay (Fig. 1) and falls within the Maguse Upland ecoregion. Geologically, this region is part of the Canadian Shield and is characterized by scattered bedrock outcrops covered with discontinuous sandy and granitic tills (Marshall and Schutt, 1999).
Maguse Lake and environs are underlain by a mafic-dominated volcanic belt and narrow strings of banded iron formations in metaturbiditic sedimentary rocks, all of Archean age (Tella et al., 2007). The overlying tills are quaternary deposits dominated by the expanse of Archean mafic belt at the north end of Maguse lake shedding smaller material, mixed with larger boulders of Proterozoic sedimentary rocks and Archean granites from further inland.

Historically, the area has been occupied by both the Chipewyan Dene and Caribou Inuit who trace their ancestry through several familial lineages (Gordon, 1996). While there is some evidence of Dene and Caribou Inuit who trace their ancestry through several familial lineages (Gordon, 1996). While there is some evidence of chipewyan descendants who were much more mobile, and who restricted their use of the tundra to the warm season (Gordon, 1975; Noble, 1971; Wright, 1976). They are followed by sites of the Shield Archaic, Northern Plano (8000-7000 B.P.) (Gordon, 1996; Noble, 1971; Wright, 1976). The overlying tills are quaternary deposits dominated by mixed material from the outer part of the depression into the central mound. A survey consisting of three 10 m grids were conducted with a Geoscan FM256 Fluxgate Gradiometer within 10 m or 20 m grids, depending on site size. Traverses were aligned east to west at Suluk 1 and Kuuvik 1, and northwest to southeast at Ikirahak 1. Readings were logged at 6.25 cm intervals along parallel traverses spaced 25 cm apart. We employed this very fine-grained approach to our survey in order to maximize the chance of recording anomalies produced by small, ephemeral archaeological features, which are so often created by hunter-gatherer groups. The raw data from the survey were downloaded into Geoplot 3.00t where they were processed and converted into grayscale plots for display. The data were very clean and required little processing. We clipped the plotting parameters to increase the visibility of weaker anomalies. At Kuuvik 1 we also de-spiked the results to reduce the influence on the data of modern iron artifacts on the ground surface. The grid and all the visible surface features at each site were surveyed using a Topcon Hyperlute differential GPS. The topographic data were then imported into ArcGIS and overlaid on the magnetometer plots to establish the relationship between anomalies identified in the gradiometer survey and the visible topographic and cultural features.

3. Results

3.1. Suluk 1

In order to better understand the magnetic anomalies produced by periglacial features in the study area, we conducted a small gradiometer survey on a series of known frost features on the south eastern shore of Maguse Lake (Fig. 1) adjacent to the cabin of Luke Suluk, a resident of the Hamlet of Arviat and co-director of the 2008 survey. Suluk 1 is located on gently sloping ground approximately 3 m above Maguse Lake. The surrounding area consists of numerous circular depressions and linear cracks. The depressions are of similar size and shape to the dwellings noted at the archaeological sites, but unlike the dwellings they are slightly mound ed in their centre. A survey consisting of three 10 m grids was conducted over four of the frost depressions and a single frost crack that ran from east to west across the area (Fig. 2).

The magnetometer survey at Suluk 1 identified all of the visible frost features as magnetic anomalies (Fig. 2). The frost depressions appear as weaker circular negative anomalies (−5 to −30 nT) with a pronounced high in the centre (30 to 37 nT). We believe the frost action moving sediments from the outer edges of these features into their centre is enhancing the magnetism in the mound ed centre of these features, and reducing it at their outer margins. The largest of the mounds produced a particularly strong circular magnetic low surrounding a very large irregular positive anomaly, slightly offset from the centre of the feature. The strength of this anomaly likely relates to the movement of a larger volume of material from the outer part of the depression into the central mound. The survey also identified the frost crack which appears as a strong linear magnetic low (−22 to −30 nT). A second, somewhat weaker linear negative anomaly runs south-eastward from the first, suggesting that either a remnant frost crack or a newly forming one lies unseen below the surface. The Suluk 1 survey also identified numerous small circular positive anomalies that had no surface

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<th>C13/C12 Ratio</th>
<th>Conventional Radiocarbon Age</th>
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<td>1340 +/- 40 BP</td>
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*a All dates are on caribou bone.*
trace. These magnetic highs are difficult to interpret at this stage, but likely represent igneous glacial erratics (see sections 3.2 and 3.3). Alternatively, they could be caused by periglacial geomorphological processes, perhaps representing early stages in the development of depressions like those observed on the surface.

3.2. Kuuvik 1

Kuuvik 1 is located on a southwestern slope on the northern shore of Maguse Lake, approximately 10 m above the modern shoreline (Fig. 1). The site consists of six well-defined house depressions (Fig. 3: 1–6) as well as an ill-defined hollow that may be an additional house (Fig. 3: 7). The area is littered with large rounded rocks, many of which have been used to construct features including tent rings, caches and hearths. The most obvious of these rock features is a tent ring consisting of an inner tent circle as well as an outer ring of stones that was likely used to weigh down guy ropes (Fig. 3: 8). A cache (Fig. 3: 9) and two small hearths (Fig. 3: 10, 11) are also clearly visible. Not all of these features are contemporaneous. The artifact assemblage indicates that the site was occupied by at least three cultural groups: the Northern Plano, Taltheilei and Caribou Inuit. Based on the distribution of artifacts and the degree of weathering on the features it appears that the depressions relate to the Taltheilei occupation while the tent ring, cache and hearths are from subsequent Caribou Inuit use of the site. The site has experienced considerable subsidence, with at least two of the house depressions (Fig. 3: 1, 2) now located down a steep slope where the ground has begun to collapse into the lake.

We surveyed four 20 m x 20 m grids at Kuuvik 1 (Fig. 3). Four of the confirmed house depressions as well as all of the stone features were included in the survey area. The clearest anomalies resulting from known archaeological features at the site are those associated...
with house depressions. Three of the four depressions show as round, negative anomalies surrounded by ring-shaped positive anomalies (Fig. 3: A–C). The negative anomalies range from −10 to −14 nT and the positive ones from 0.5 to 5 nT. These values are weaker than those associated with the frost features at Suluk 1. There appears to be a correlation between the size and depth of the depression and the strength of the magnetic anomaly. House depression 4 (Fig. 3: D), the smallest and most poorly defined depression at the site, is less easily discernable in the survey results and might not have been recognized if its location were unknown. Of the more recent archaeological features, the survey identified the cache immediately north of depression 6 (Fig. 3: E) and possibly the hearth to the north of depression 5 (Fig. 3: F). However, it did not pick up the second hearth adjacent to the tent ring. There is some indication that the survey identified the tent ring which appears as a circular arrangement of small round positive anomalies (Fig. 3: G). A small dipolar anomaly (Fig. 3: H) within this ring may indicate the presence of a hearth, however no hearth architecture or visible trace of burning was noted on the ground surface.

In addition to the anomalies that appear archaeological in origin, there are numerous small round positive and dipolar anomalies across the site, particularly in the western half of the survey area. These anomalies all measure at least ±30 nT and most have considerably higher or lower values, making them much stronger than the anomalies associated with archaeological features at the site (which range from +5 to −14 nT). We suspect that many of these stronger anomalies are produced by the small erratics that litter the site's surface and are buried within the gravel substrate. The tills around Maguse Lake include a mix of sedimentary and igneous rocks from a range of sources, the latter including both mafic rocks and granites. Formed from molten magma or silicate liquid, igneous rocks develop remanent magnetization in the direction of the earth’s magnetic field as they cool through their Curie temperatures. This ferromagnetism is generally stronger in basalts and other mafic rocks than in granites (Aspinall et al., 2008: 174), which would explain some of the observed variability in signal strength. For a particular erratic, the response will also vary with its depth below surface relative to the length of its dipole, and its polarity orientation (Aspinall, 2006: 30). Depending on the orientation of its magnetic axis, the same stone could produce either a positive or a dipolar anomaly. The random orientation of the magnetic axes of stones deposited through glacial action (Clark, 1990: 94) would produce exactly the sort of varied “noisy” responses observed in the Kuuvik data.

The most striking feature in the Kuuvik 1 survey is a strong radial dipolar anomaly running roughly north-south on the western side of the survey area (Fig. 3: I). The observed magnetic gradient for this feature was extremely high and beyond the range of the instrument (±204.7 nT). While similar anomalies have been identified elsewhere as the result of lightning strikes (Jones and Maki, 2005), this anomaly corresponds perfectly with the break of slope and may relate to an intrusion in the underlying geology.

The Kuuvik 1 survey also identified other natural features that likely result either from the periglacial environment or the geological composition of the substrate. Some appear as thin linear negative anomalies that criss-cross the site, particularly in the eastern part of the survey area (Fig. 3: J). Although no surface frost features were identified at the site, these anomalies are remarkably

![Diagram](image-url)
similar to that produced by the frost crack at Suluk 1. In addition, a large positive anomaly (Fig. 3: K) similar to those produced by the frost depressions at Suluk 1 may also be the result of frost action. At first we believed this anomaly might result from a midden associated with Dwelling 3, since middens are commonly found in the proximity of Arctic dwellings (e.g. Graham et al., 1982; Morrison, 1983; Newell, 1988). However, a test pit dug into the centre of the feature revealed no artifacts or evidence of burning.

3.3. Ikirahak 1

Ikirahak 1 is located on a small island in the narrows of Maguse Lake (Fig. 1). The site consists of eleven semi-subterranean house depressions (Fig. 4: 1–10, the eleventh dwelling is situated 20m to the south of the main group) and two sub-circular rock alignments (Fig. 4: 11–12) regularly distributed along a gently sloping grassy terrace approximately 10m above the modern lakeshore. Like Kuuvik, the site is littered with erratics, particularly along its western and northern edges (Fig. 4).

The survey was conducted within four complete and three partial 20 × 20 m grids positioned to include all but the most southerly house depression (for a total surveyed area of 1760 m²). The results from Ikirahak are very similar to those obtained from Kuuvik, with nine of the ten depressions within the survey area clearly visible as circular positive anomalies surrounding a magnetic low (Fig. 4: A–I). The northernmost dwelling (Fig. 4: 1) was not detected, likely because of the magnetic “noise” created by the numerous erratics in the area. Interestingly, the magnetic response for each of the dwellings differs from the others in shape, size and magnetic intensity. Dwelling 9 is the most unique, appearing as a strong, square positive anomaly surrounding a strong negative anomaly (Fig. 4: H), in contrast to the other dwellings which produce weaker oval or round anomalies. This distinction may indicate functional or seasonal differences between dwelling 9 and the others.

The survey also produced several anomalies of interest that were not associated with visible surface features. An anomaly (Fig. 4: J) immediately north of House 4 looks very similar to those produced by Houses 2, 4 and 5 (Fig. 4: A, C, D). A second anomaly in the south of the survey area (Fig. 4: K) looks like a smaller version of Houses 3, 6 and 7 (Fig. 4: B, E, F). Both of these anomalies warrant further investigation through excavation, but unfortunately due to time constraints in the field, we have not yet been able to examine them further in order to ascertain whether they are caused by sub-surface archaeological features or are natural in origin. There is also a linear magnetic low that runs east-west just south of House 7. This anomaly (Fig. 4: L) is similar to that produced by the frost crack at Suluk 1, and likely has the same cause.

As at Kuuvik 1, there are numerous small anomalies, both positive and dipolar, scattered liberally across the survey area around a “quiet” area in the centre. Again, we suspect glacial erratics as the cause and indeed, many are associated with surface erratics. Fig. 5 shows the trace plot of a subset of the survey data from Ikirahak. As discussed earlier, the shape of the anomalies is partially determined by the orientation of the magnetic axis of individual rocks. The trace plot clearly illustrates the varied magnetic responses produced by the surface erratics along the site’s western edge. While very few erratics were visible on the surface along the eastern edge of the survey area, the similar cluster of anomalies was likely produced by buried erratics and is labeled accordingly. The trace plot also shows that the pit house anomalies are weaker than those produced by the erratics, but more consistent in their form. We placed 50 × 50 × 30 cm test pits in the location of a number of the small anomalies that were not associated with surface erratics in an attempt to determine whether they might have a cultural origin. In only one case was there any indication of human activity in the area, in the form of a large core. We were also unable to locate any buried erratics that might be producing the anomalies. Thus, the relationship between erratics and these small, strong anomalies cannot be conclusively demonstrated in all cases. Some of the anomalies that do not correspond with surface erratics may have been caused by rocks buried more than 30 cm below the ground surface. In other cases, they may be produced by factors other than the geological composition of the substrate, perhaps frost action that leaves no obvious near-surface trace.

Excavation of two of the dwelling features at Ikirahak 1 helps to explain the observed magnetic anomalies associated with all of the dwellings at both this site and Kuuvik 1. The two excavated features were constructed by digging a roughly circular depression and piling the excavated material up around the outside to form a berm, which we interpret as a sitting platform inside the skin superstructure of these tents. Comparing the plans of the

Fig. 5. Trace plot of the central portion of the Ikirahak 1 survey area. Visible pit houses are labeled B, E and F in Fig. 4.
excavated dwellings with the survey results (Fig. 6) it is clear that the central depressions are indicated by round negative anomalies, and the berms correspond with the surrounding ring-shaped positive anomalies. The magnetometer data therefore appear to reflect a disruption in the magneto-stratigraphy of the site (Linford, 2006), created when people removed magnetically enhanced topsoil from the centre of the dwellings and added it to their perimeter. This pattern is the inverse of the process observed in the frost depressions at Suluk 1, where material was being moved from the perimeter into the low mounds in the centre of the depressions, creating a positive anomaly surrounded by a negative one.

For both of the excavated dwellings at Ikirahak, the presence of some of the small circular positive and dipolar anomalies described above complicates the picture and partially obscures the magnetic signature of the archaeological features. Nonetheless, in both cases, it is clear that the magnetic signature of the berms varies in strength around their circumference and that there is no direct correlation between the width of the berm and the strength of the magnetic signal. Some of this variability may relate to differential use of space within the dwelling. Burning, for example, can enhance the magnetic susceptibility of the underlying soils, although the charcoal concentrations within both dwellings (Fig. 6) do not correspond with positive anomalies on the magnetometer survey. We might also expect the entranceway to have a different magnetic signature from the rest of the berm (cf. Eastaugh and Taylor, 2005).

4. Discussion

Our surveys had mixed success, but overall the results are promising. Somewhat unexpectedly, the magnetometer data did not clearly identify the hearths at Kuuvik 1 or Ikirahak 1. At Kuuvik, it is difficult to know whether the small circular positive anomalies

Fig. 6. Detail of Ikirahak 1 magnetometer results showing excavated dwellings alongside their associated anomalies.
in the same locations as the hearths are produced by those features or by buried erratics which appear to be causing similar anomalies across the site. The lack of magnetometer response to the possible hearth features at Ikirahak 1 may be attributable to the sandy soils and the relatively low temperatures that would be reached in the small open hearths at the site. Weston (2004) has demonstrated experimentally that the enhancement of magnetic susceptibility values that generally occurs as a result of heating is suppressed in sandy soils and takes place at higher temperatures relative to finer-grained soils (clays) and those with higher amounts of organic matter. Alternatively, the concentrations of charcoal within the dwellings may not represent hearths but merely re-deposited material from fires elsewhere.

Other difficulties were encountered because of the presence of the many erratics across the sites. This is a region-specific problem, which is not restricted to the Arctic and will not affect all areas of the Arctic. Unfortunately, we did not observe a perfect correlation between the surface erratics and small circular magnetic anomalies. We can only assume at this stage that the geological composition of the erratics varies and that igneous erratics buried in the gravel substrate are also being picked up by the magnetometer. These disappointments are outweighed by the positive results of the surveys. First, we were able to clearly distinguish between frost depressions and house depressions based on their magnetic signatures. The former consist of a negative ring-shaped anomaly around a strong positive centre, while the latter appear as a positive ring around a negative centre. Second, the magnetometer identified a series of negative linear features at both Kuvvik 1 and Ikirahak 1. We interpret these as frost cracks similar to those at Suluk 1, though in this case they are completely buried with no visible signs on the surface of either archaeological site. The survey may also have succeeded in locating several buried archaeological features. Perhaps the most promising of these are the two possible house features at Ikirahak, which we hope to excavate in a future field season. As mentioned previously, the use of house pits suggests lower levels of anticipated residential mobility than has previously been reported for Taltheilei groups. Interestingly, storage features (boulder caches) are noticeably absent at these sites. It is possible that snow caches may have been used in their place, leaving no obvious visible signs on the surface of the site. At least a few of the anomalies identified may reflect such storage practices. Geochemical research using soil cores extracted from the site is currently being undertaken and may shed further light on this possibility (Butler, 2010).

The magnetometer results also have interesting implications for the interpretation of the dwellings. They show variability in the shape and intensity of the dwelling anomalies at Ikirahak that warrant further investigation through excavation, as they may indicate differences in the function or seasonal use of the dwellings. They further show variability in the magnetic signature of the berm surrounding each dwelling, which may potentially reflect different activity areas within the dwellings. We plan to investigate this possibility by examining the distribution of micro-debitage from these features and conducting soil chemistry analysis.

5. Conclusion

Overall, this preliminary study reveals excellent potential for magnetometer survey in Arctic archaeology. More work is required to ground-truth some of our results in order to determine whether we have successfully located buried archaeological features and identified activity areas within the dwellings. We would also like to employ different geophysical modalities in order to compare the results from different instruments with our magnetometer data. In particular, closely spaced magnetic susceptibility measurements would help to resolve whether the lack of magnetometer response to the hearth features is because heating of the sandy soils did not result in enhanced magnetic susceptibility values, or whether they were simply not heated at all, in which case we would have to rethink our interpretation of these features as hearths. Close interval magnetic susceptibility survey would also provide information about the presence of middens and complement the intra-site mapping based on the magnetometer survey. The magnetometer data have certainly done what we hoped they would: helped us to identify areas of high potential for excavation, and helped us to interpret site structure. This will allow us to make more effective use of our future field time.

Our study also has important implications for archaeological site management in this era of climate change and increased rates of erosion on Arctic sites. The identification of sub-surface frost cracks through magnetometry may be useful in assessing the stability of sites and their level of threat through erosion. Our work has shown that these features can exist below ground before any surface evidence appears. Knowing of their existence and location relative to other geological features such as slopes and shorelines could help in flagging sites that may be more prone to damage through erosion than sites without such sub-surface features. Ground-penetrating radar, while perhaps less informative than magnetometry or magnetic susceptibility about the archaeological features on Arctic hunter-gatherer sites, would provide a very effective means to map the permafrost features that underlie them (cf. Hinkel et al., 2001; Moorman et al., 2003), and could represent another productive direction for future work aimed at assessing the threat to sites due to permafrost melt.

Acknowledgments

We are grateful to Lewis Somers for his helpful discussions of our data and for his comments on an earlier draft of this paper. Also to Mike Beauregard who helped us to understand the local geology around Maguse Lake. Thanks to two anonymous reviewers for their constructive feedback and to the field crews who assisted with the project: Luke Suluk, Don Butler, Howard Cyr, Calla McNamee, Sean Pickering and Matt Wells. We also thank the Government of Canada International Polar Year Grants and the Agnes Cole Dark Fund, Faculty of Social Science, University of Western Ontario for helping fund the fieldwork. Equipment was provided through the UWO Academic Development Fund.

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