Magnetic prospection on prehistoric sites in Western Canada

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ABSTRACT

Prehistoric sites in Western Canada present unusual conditions for magnetic prospection. Archaeological features are few and difficult to discern using standard prospection procedures. However, by addressing specific types of features, particularly fire hearths and fired rock and pottery, useful information about the cultural content of an archaeological site can be obtained.

To secure comparative data, a number of replicative studies were conducted, with specific reference to determining a typical anomaly produced by the features. A small fire pit was kindled several times and repeatedly monitored with surveys using a single proton magnetometer. Fired rock received similar treatment. An in-situ collection of local aboriginal pottery was also assayed. The experimental results indicated that fired rock will produce a detectable magnetic field after one firing, but a hearth must be rekindled at least three times to produce a significant anomaly. Pottery fragments also generate a small magnetic field which requires that the material be very close to the site surface to be discerned. The experiments also suggested that interpretation is enhanced by obtaining two magnetic readings per sensor station and using their difference to minimize ambient field fluctuations and natural magnetic variation caused by subsurface geology.

The model data were used to interpret the results of a magnetic assessment of a large prehistoric campsite in Saskatchewan. Excavation results agreed well with the information provided by the predictive models. Two temporary dwelling remnants and two pottery vessels were exposed in areas determined to be magnetically significant. The magnetic assessment technique, when used to locate specific feature types, can be useful in prehistoric archaeological site assessment.

INTRODUCTION

Magnetometers have been used as prospection tools for archaeological site assessment in Manitoba, Saskatchewan, and Alberta for a number of years. The technique has been applied successfully to historic sites where shallowly buried remains are easily detected. Particularly, in Manitoba magnetic surveying has been used as an important tool to assess the archaeological content of protected sites for long-term resource management programs (Gibson, 1982; Hamilton, 1984; Hamilton and Hems, 1984).

Conversely, magnetic studies have rarely been implemented in the prairie provinces to assess prehistoric Indian archaeological sites. Because prehistoric prairie and forest inhabitants were nomadic, little material evidence of their existence remains apart from detritus, hearths, and pits. These hearths and pits are small and more difficult to detect than the cellars, wells, and foundations commonly found on historic sites. The cultural content and the extent of most of the prehistoric campsites in the region are poorly documented. Magnetic assessment requires resource expenditure for surveying of even small areas, and deciding where to place survey grids and how much area to cover is a difficult problem not commonly experienced in historic surveys. Also, prehistoric sites in the region are often situated in environmentally rugged, nearly inaccessible geographic areas. On the surface, vegetation and uneven terrain thwart data collection. Beneath the surface, complex bedrock geology, particularly in the shield areas of the boreal forest, complicates data interpretation. Consequently, it is difficult to establish the firmly founded survey parameters upon which successful magnetic prospection depends. Magnetometer survey strategies implemented on historic sites are usually inappropriate to prehistoric sites. However, when workable research strategies and survey techniques are implemented, magnetic prospection can be a very useful technique in prehistoric site assessment.
BASIS FOR MAGNETIC PROSPECTION ON PREHISTORIC SITES

Deriving models for prehistoric site assessment

Most prehistoric archaeological sites in Western Canada consist of cultural byproducts such as animal bone, flintknapping and boiling stone, pottery, and features such as hearths, storage pits, and graves. Site excavation strategies usually concentrate upon objectively recovering this debris so that patterns of human site occupation and use can be interpreted. Human activities—food preparation and consumption, tool making, general social interaction—usually produce nonregular distributions of artifacts and other remains. Durable features such as pits and hearths are generally associated with these clustered materials. Because animal bone and flintknapping debitage have insignificant magnetic properties, thus making them unsuitable as targets, the archaeologist must rely on site features to provide sources for magnetic prospection (Gibson 1982, 75). Even so, many classes of archaeological features would be of questionable reliability in most prospection surveys. Storage pits, for example, can be discerned only if the susceptibility of their fills is significantly different from that of the surrounding matrix. The same holds true for human internments, which have the added problem of being small in size and therefore correspondingly less discernible. Moreover, given the temporary nature of hunting and gathering residency, the presence of storage pits and burials on such sites would be exceptional.

The most reliable targets for magnetic prospection are fire hearths, fired rock, and pottery. These features produce significant magnetic fields in proportion to their bulk, and, at least in the case of hearths and fired rock, are found on virtually all archaeological sites. These sources are also important in archaeological interpretation. For example, a hearth is usually the focal point of numerous human activities; hence there exist localized artifact distributions. Excavation in the hearth vicinity often yields archaeological information in contexts from which a great deal of human behavior can be inferred. Pottery concentrations are less reliable as indicators of human site use. However, the intrinsic value of pottery as a diagnostic tool for inferring social behavior makes it an ideal artifact class to recover.

Fire hearths display magnetic fields because of the magnetic susceptibility of the heated soil remnants which exist after firing. Hearth magnetic anomalies vary depending upon the size of the fire, the composition of the soil on which the fire was built, and the number of times it was fired (Tite and Mullins, 1971, 216-217). Fired rock and pottery produce magnetic anomalies through thermoremanent magnetization. The anomalies produced by fired rock clusters are, like hearths, difficult to predict, being dependent not only upon the quantity of material available, but also on how the material has been moved after firing. Similarly, a single intact pot would be expected to produce a characteristically identifiable anomaly; however, because almost all pottery is found highly fragmented and only occasionally clustered, it may not be detectable at all.

These uncertainties are compounded by the lack of comparative data on archaeological features which can be used to isolate and identify magnetic anomalies on prehistoric sites in Western Canada. The solution I adopted was to conduct replicative experiments, thereby producing magnetic anomalies for each source type expected on prehistoric sites. The anomalies could serve as rough models for identifying features, and methods could be developed to enhance their detectability given the unpredictable magnetic conditions found during data collection.

Hearth magnetic model

Although the magnetic characteristics of hearths from northern plains village sites have been examined in detail by other researchers (Weymouth and Nickel, 1977), such information has limited application when nomadic sites of limited temporal occupation are investigated. Consequently, a hearth replication experiment was devised to represent a typical campfire associated with short-term nomadic settlement. A magnetically homogeneous, uncultivated plot of ground covered with grass and underlain by a gray, wooded soil was selected for the test. Figures 1 and 2 illustrate the relative magnetic relief of a 4 × 4 m grid within which a hole 60 cm in diameter and 10 cm deep was excavated. Magnetic measurements were obtained from each 50 cm station using a single proton magnetometer of 1 nT sensitivity, at sensor heights of 60 and 30 cm above the ground. Diurnal magnetic variation was controlled by exactly reoccupying a base station every 30 s and adjusting magnetic readings using linear interpolation. Figure 3 shows the vertical magnetic gradient for each station i.e., the difference between the upper and lower sensor readings. Apart from weak anomalies due to soil noise, particularly at the lower station position, the magnetic relief was not remarkable.

Three wood fires were then kindled in the pit over a period of several days. After each burn (which lasted an average of two hours and attained temperatures above 500°C), the grid

Fig. 1. Hearth relative magnetic relief, preburn, sensor at 60 cm above ground. Shaded circle represents pit position. Measurement interval is 0.5 m. Contour interval is 2 nT.
area was allowed to stand for 24 hours and then resurveyed in a manner similar to the unfired assessment.

Following the predictions of Tite and Mullins (1971), as a fire is kindled and then allowed to cool, magnetically susceptible soil will accumulate through chemical conversion, eventually in amounts sufficient to produce an anomalous magnetic field. Despite these predictions, readings retrieved from the test grid immediately after the first and second burn showed little difference in magnetic relief from those of the unburned grid. It is probable that the two burns did not produce enough susceptible material to be detected by the instrument. After the third firing, however, sufficient susceptible soil accumulated to generate a detectable magnetic anomaly.

The upper, lower, and vertical gradient results of the third burn are shown in Figures 4, 5, and 6. Although ambient field intensity on the periphery of the test grid varies insignificantly with that of the unfired trial, a 2 to 4 nT anomaly at the upper sensor position and an 8 nT anomaly on the lower position appear in the vicinity of the fired area. The differential or gradient data display a similar pattern, although the anomaly is somewhat more localized around the hearth.

This experiment demonstrates that weak, but detectable, magnetic anomalies are produced in soil within which a hearth has been rekindled several times. If repeated firing had taken place over a number of days, as would be expected of the cooking practices of hunters and gatherers, it is probable that a more powerful magnetic anomaly would have been produced by the burning area, and it should have been discernible at a distance even greater than 60 cm.

**Fired rock magnetic model**

After the third burn, 18 light and dark fist-sized, quartzite and granite cobbles were placed in the pit. Resurvey of the grid demonstrated they were nonmagnetic. A fire was then kindled above them. Temperature probes using a thermometer indicated that once the fire was firmly established, rock temperatures exceeded 700°C during most of the burn. The rocks were heated for several hours and then cooled over a 24-hour period. The grid was then reassayed magnetically.

Figures 7, 8, and 9 show the results of the resurvey. A significant anomaly appears in the vicinity of the hearth in both the 60 and 30 cm sensor heights, and in the gradient mode as well. Close inspection of the rocks using the magnetometer demonstrated that the light quartzite cobbles were...
very poorly magnetized but that the darker granitic rocks generated a significant anomaly.

Although the fourth fire probably contributed to the magnetization of the hearth area by enhancing soil susceptibility, thermoremanent magnetization of some of the rocks seems to have been the primary source of the strong anomaly produced in the grid. This suggests that fired rock, even after a single firing, may provide the most significant magnetic target for prospection on prehistoric sites. Consequently, bone boiling pits and rock-lined hearths should be magnetically detectable at much greater distances than hearths containing no rock.

However, if the rock is removed from the fire, as would be the case if it had been used for boiling water in skin-lined pits, the strength of the anomaly would depend upon the degree of rock dispersal. Nonetheless, the magnetic anomalies produced would not likely be as powerful as if the rock had been left in place after firing.

Pottery magnetic model

A similar experiment involving pottery was carried out on a ceramic-bearing archaeological site at Childs Lake in west-
central Manitoba (Badertscher, 1982; Gibson, 1982). On this site, located in heavily wooded terrain, a 3 m² excavation unit exposed a cluster of aboriginal pottery consisting of large and small sherds lying flat on the ground over a circular area about 40 cm in diameter. Unfortunately, because the pottery was found on the slope of a shallow gully, it was anticipated that the magnetic relief within the excavation would be so uneven that any anomaly produced by the pottery would be masked. Therefore the gradient method, first employed during the hearth experiments, was applied to this assessment as well. The excavation was gridded at 50 cm intervals and magnetic measurements were obtained at 50 and 30 cm for each sensor station. Contour maps (Figures 10 and 11) show the relative magnetic relief of the grid at these positions, demonstrating that, as expected, subsurface geologic noise was so prevalent the sherd cluster could not be discerned. However, the gradient transform eliminated the magnetic interference, revealing a 6 nT anomaly over the pottery (Figure 12).

The experiment indicates that pottery clusters do generate a detectable magnetic anomaly, but that, due to the dispersed and randomly aligned nature of the individual sherds, the magnetic field is small. This indicates that pottery not be buried deeply in the ground if it is to be discernible by standard magnetic detection techniques. Archaeological sites fre-
frequently are situated in areas where subsurface geology can badly distort magnetic relief. If such is the case, a survey might use accurate data recovery techniques but the ability actually to detect anomalies produced by pottery might be impaired. A practical remedy is to secure multiple readings at differing sensor heights for each station and employ the gradient method to enhance the effects of small, near-surface sources.

Summary

Based on the preceding experimental evidence, fire hearths are detectable, if fires have been rekindled several times, thus permitting susceptible soil to accumulate. Magnetic anomalies produced from such features are weak, so their depth of detection should not exceed a meter unless the hearths are large and well-used. Fired rock potentially produces a more powerful anomaly, depending upon the rock composition. Fired-rock features probably would be ideal targets for prospection, although the scattered material may introduce random anomalies which would interfere with lesser magnetic fields such as those produced by hearths. Fragmented pottery also produces a weak anomaly and is difficult to detect, is easily masked by uneven ambient field relief, and should not be buried greater than 30 to 50 cm from the sensor.

The models provided inadequate information on characteristic anomaly configurations for feature types. All evidence suggests that anomalies produced on prehistoric sites will be so weak that simple detection would be sufficient evidence to warrant more intensive investigation. Certain data collection procedures, in particular the gradient technique, are useful in emphasizing small, localized magnetic fields, which are most often associated with archaeological features. Unfortunately, small pieces of metal are particularly potent targets using the gradient for interpretation. A metal detector is useful in eliminating spurious surface metal when analyzing such data.

MAGNETIC PROSPECTION ON PREHISTORIC SITES: APPLYING THE MODELS

The test site

The hearth and pottery replication experiments demonstrated that those features could be reliably located on prehistoric archaeological sites, providing they were not deeply buried. An opportunity to test the models was afforded by a magnetic survey conducted on a late prehistoric campsite located beside the Saskatchewan River near the town of Nipawin, Saskatchewan. Bushfield West (FhNa-10) is a large (1.5 ha) prehistoric Cree campsite, characterized by dense accumulations of cultural debris clustering about well-used fire hearths. The cultural occupation rested on a single, thin organic horizon situated between 20 and 30 cm below the site's cultivated surface (Gibson, 1983). Bushfield West was to be inundated in the fall of 1984 by the Saskatchewan River at the completion of a hydroelectric project (Burley, 1982). Although shovel testing demonstrated that much of the site yielded little or no evidence of occupation, several areas within the site perimeter appeared to be quite productive. Standard assessment procedures involving random and regular test pit sampling were unsuccessful in intercepting artifact clusters associated with hearths believed to be the remnants of impermanent dwellings. Because the Bushfield West component was buried shallower, it was believed that magnetic prospection could be utilized to locate hearths and thus demarcate dwelling remains.

Site assessment procedure

A 10 x 20 m grid was installed over an area determined by shovel tests to harbor archaeological materials. The grid was surveyed at 1 m intervals, using a single magnetometer. Station readings were acquired at 60 and 20 cm above the ground. Diurnal variation was controlled by reoccupying a base reference every 1 to 2 minutes. Four hundred forty-one magnetic measurements were collected from the grid, with an estimated accuracy of ±2 nT. After the assessment, the data were analyzed and plotted using a personal field computer. Figures 13 and 14 show the grid magnetic relief at the upper and lower sensor positions. Figure 15 shows the gradient data (upper-lower sensor readings). Occupation depth averaged 30 cm beneath the ground. Consequently, the mean depth of detection for the lower and upper sensor was 50 and 90 cm.

Given the results of the replication experiments, the weak anomalies illustrated on the upper sensor plot (Figure 13) were not unexpected because 1 m was probably the maximum distance that most cultural features could be discerned on such a site. Indeed, the upper readings were to function as reference data for deriving the gradient, had ambient magnetic
relief masked the lower sensor readings. The gradient data were also used as a check against diurnal micropulsations, introducing spurious readings during data collection.

Based on lower sensor data (Figure 14) five principal anomalies were observed (marked A to E on Figures 13, 14, and 15). Referring to the gradient data (Figure 15), two anomalies, D and E, were deemphasized, and a sixth anomaly was prominently displayed and tagged F. The magnetic technique is most effective when additional assessment techniques, particularly probing or sweeping with a metal detector, are applied to assess anomalies further (Gibson, 1982, 119). Accordingly, the three most powerful anomalies on the lower data set, A, B, and C, were selected for more extensive assessment. Metal detector sweeps could not demonstrate the presence of metal in the plough zone near any of the anomalies.

Probing the anomalies with a 3 cm diameter soil coring device provided more information. Anomaly A was found to be a large magnetic rock situated just below ground surface in the plough zone. It was removed, and magnetic resurvey in the immediate area showed that the anomaly disappeared. Anomaly B was probed, and the soil core revealed a 6 cm thick layer of ash and orange-red soil located 24 to 30 cm below ground surface and at least 10 cm below the plough zone. This was interpreted to be a hearth. Upon probing anomaly C, an obstruction, believed to be rock, was encountered between 20 and 25 cm below ground surface, 5 to 10 cm below the plough zone. Subsequent probings encountered more obstacles, but no trace of firing. Since the rock was located beneath the plough zone, it was interpreted to be a fired-rock cluster, possibly associated with a nearby undetected hearth. The three other anomalies that remained unprobed were earmarked for more thorough investigation should excavation proceed in the block.

Assessment results

Based on the magnetic survey and test probings, the 200 m² grid was hypothesized to contain one and possibly two residence areas. This was sufficient justification to warrant detailed excavation of the target areas, with expansion to the entire block if possible. This excavation was undertaken the following year, and the results are shown in Figure 16. Because the occupation of the entire block was exposed, an excellent opportunity was afforded to compare targeted anomalies with actual sources responsible for them. Exposed features which did not produce anomalous readings could be documented as well, and reasons for their lack of detection could be determined.

Anomaly B was centered on a hearth. The feature was nearly 1 m in diameter and much of its content consisted of ash. The burned soil portion was little more than 50 cm in diameter, but it was nearly 10 cm thick at the center. A large, light-colored quartzite rock was found in association, but did not appear to be magnetic. The feature was the focal point of a residence remnant. Smashed bone, debitage clusters (the residue of stone tool manufacturing), stone tools, and dispersed pottery sherds were found in close association. Within this localized artifact scatter a dense concentration of smashed pottery was exposed, corresponding to anomaly F. The pottery cluster comprised the remains of two entire pottery vessels, which were later reconstructed in the laboratory (Figure 17).

A second, smaller residence was exposed in the vicinity of anomaly C. The major source was probably fired rock, the same material encountered by the probe the previous year, although a small hearth 30-40 cm in diameter and a few centimeters thick was exposed 0.75 m to the north. This residence contained some smashed bone and several debitage clusters, but no pottery. Near this residence was a shallow pit filled with loose soil (eventually determined to be a badger burrow). Anomaly D was caused by an elongated natural depression relating to the depositional process creating the landform on which the site rested. A small patch of burned soil and some bone fragments were recovered in the trench, indicating that it was perhaps utilized by the site's inhabitants as a refuse dump.

Assessment interpretation

The principal features exposed during the block excavation included two hearths, a dense pottery cluster, an accumulation of fired rock, a large rodent burrow, and half a dozen natural depressions. A few miscellaneous surface burn patches were also noted. The hearths and rock clusters were located before excavation using simple probing techniques. Because they could be intercepted and identified before excavation demon-

![FIG. 15. Gradient magnetic relief of assessment grid. Contour interval is 2 nT. Interval —2 suppressed for clarity.](image1)

![FIG. 16. Archaeological and natural features exposed after total excavation of assessment grid.](image2)
strates that these types of sources are viable targets for magnetic prospection. The hearth in the smaller residence was not as easily discerned magnetically, presumably because a collection of fired rock in its vicinity masked it. This rock was the chief target, prompting detailed assessment of the activity area. A similar quantity of fired rock was recovered from the larger residence, but its dispersion apparently precluded generation of a sufficiently powerful magnetic anomaly to afford detection.

The secondary anomaly within the larger residence, attributed to the large pottery cluster, was clearly demarcated only by examining the gradient data. This is consistent with the results of the Childs Lake experiment (Figure 12) and reaffirms the observation that clustered pottery sherds must be close to a magnetometer detector to be discerned. Therefore, during a pottery search, the sensor should be placed as close to the ground as possible without introducing magnetic noise because of natural susceptibility variation within the soil.

Gradient data are also useful in identifying bulky features containing fill, such as pits and burials, from more common hearth and rock cluster features. The anomaly of a localized source is most prominent in the lower and gradient data sets. The upper data usually show a wider, less powerful field reflecting the greater distance from source to sensor. Bulky features usually do not produce anomalies resembling those of point sources. The upper and lower sensor data do not vary significantly in intensity around such features, especially if their extent exceeds the distance between the upper and lower sensor. Consequently, the difference between the two sensor readings, the gradient, is negligible and is deemphasized in a contour plot. An example shown in anomaly E (Figures 13-16) was produced by the large in-filled badger burrow. Although the feature shows prominently in the lower data, it is imperceptible in the gradient information. Another example is anomaly D, where the broad anomaly caused by the natural depression in Figure 14 has been eliminated in Figure 15. This characteristic of gradient data is particularly useful in magnetic surveys of historic sites where buried pits and cellars are more commonly found (Gibson, 1982).

The minor surface burns shown in Figure 16 do not have definitive anomaly correlates, probably because of their minimal extent. Also, several anomalies in the block could not be associated with sources. These magnetic disturbances were minor and may be attributable to survey error during data collection.

CONCLUSION

Prehistoric sites in the prairie provinces present unique conditions for magnetic prospection which cannot be superficially addressed if useful results are desired. Culturally related magnetic targets on such sites are few and difficult to discern. A few of the most common source types—hearths and fired rock and pottery produce secondary magnetic fields of magnitudes sufficient for detection using a relatively simple survey methodology.

The example demonstrated the use of a “targeting” methodology, in which significant anomalies are located and then subjected to more intensive prospection techniques including probing, metal detector sweeping, and shovel testing. This methodological approach, though simple, will save substantial search time during site assessment. Certain methodological innovations, such as use of gradient data, permit simple survey techniques to be interpreted more effectively. Indeed, magnetic prospection is a viable tool for prehistoric site investigation and can profit the archaeologist who chooses to take advantage of it.

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