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The Use of Ground-Penetrating Radar on Small Prehistoric Sites in the Upper Midwestern United States

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Abstract

The use of ground-penetrating radar on prehistoric sites in the United States remains relatively uncommon because of its perceived expense and the assumption that radar works well only on large, complex sites. Recent studies at sites in the Upper Midwest indicate that these concerns are no longer completely valid. One such site is 21AN106, a 2,000 year old prehistoric camp located north of Minneapolis, Minnesota. In 1996, IMA Consulting conducted a radar study at this site as part of data recovery before disturbance of the site by a pipeline expansion project. Initial testing of the site suggested that it consisted of a series of thin loci of artifacts scattered across a relatively large area at the base of a sand dune. The radar study used a 450 MHz antenna over a 10 metre by 85 metre corridor across the site and successfully identified a series of very small clusters of artifacts. This information allowed excavation at the site to be tightly focused, reducing overall project costs. Further, residues from ceramics within the artifact clusters provided evidence that corn was used at the site between AD 200-300, seven centuries earlier than had been previously documented in the Upper Midwest.

1 Introduction

Geophysical survey methods — particularly ground-penetrating radar — are still only episodically used on archaeological projects in the Midwestern United States. These methods are sometimes viewed with scepticism by regulators and clients because of the perceived expense of such studies and the notion that such methods 'don't work' on many of the archaeological properties found in this portion of the world. Our experience in recent years, however, suggests that the expense of geophysical surveys is often far outweighed by the fine-scale data they provide for the analysis, interpretation, and excavation of archaeological sites.

Geophysical survey data becomes particularly important when sites are to be disturbed by construction projects and require data recovery ('rescue archaeology') before construction may begin. The costs of archaeological data recovery may be quite high and project sponsors are justifiably concerned about containing costs. However, when construction is delayed because archaeological sites were inadequately evaluated or characterised, the *total* costs to the project in down time, delayed schedules, or missed delivery dates can rapidly become quite large. The actual costs of geophysical survey, when considered in this context, are relatively small.

During the last several years, IMA Consulting (IMAC) staff have been integrating geophysical methods into our cultural resource management tool-kit. Although our primary focus has been to develop practical systems and applications for geophysical studies within the context of cultural resource management, an equally important concern has been to integrate geophysical studies into broader theoretical issues in archaeology, particularly intra-site analysis and interpretation.

In this paper, we review one example of this approach: the integration of ground-penetrating radar into a data recovery project at site 21AN106 in the north-central United States.

2 21AN106: site and project description

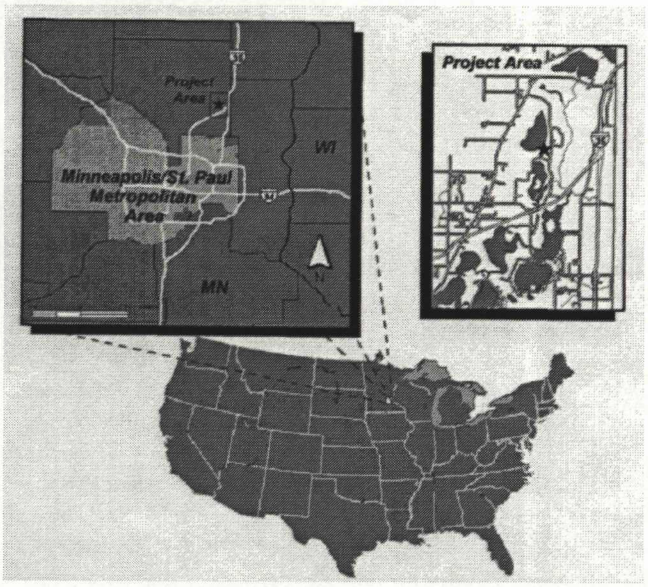

Figure 1. Map of the study area

21AN106 is small archaeological site situated on a small dune between Crossways and Rondeau lakes in the Anoka Sand Plain a few tens of miles north of the cities of Minneapolis and St. Paul, Minnesota (see Fig. 1). Initial testing of the site in 1995 indicated it contained a series of thin artifact and rock concentrations scattered discontinuously both horizontally and vertically across the dune. Ceramics from the site suggested that it fell broadly within the Middle and Late-Middle Woodland periods, ca. 1,500 to 2,200 years ago. Ploughing, erosion, and animal burrowing had substantially disturbed the upper 50 centimetres of the site.

2.1 Physical setting

The Anoka Sand Plain is a particularly distinctive geomorphic region within Minnesota. The Sand Plain was initially formed by glacial outwash at the end of the last Wisconsin glaciation and covers an area of approximately 2,200 km^2 in east-central Minnesota (Wright 1972:535-536). Since glaciation, the topography of the Anoka Sand Plain has been modified by a number of processes. Ice-block depressions have filled with water to form small kettle lakes and wetlands. Streams have formed shallow valleys and terraces. Finally, aeolian activity during warm and dry climatic episodes when vegetation was sparse formed numerous sand dunes that are still prominent on the landscape.

The age of the aeolian activity is uncertain. Keen and Shane (1990:863) suggest that the main period of dune formation was during the mid-Holocene dry period about 7,500-6,000 years BP. However, other studies suggest both earlier and later periods of aeolian activity occurred as well. A peat deposit, buried by some 24 feet of dune sand, at a nearby location yielded a radiocarbon date of 9,210 +/- 90 years BP (Donohue and Associates 1990). A recent investigation (Ketz et al. 1996) at a site located to the southwest of 21AN106 encountered a buried soil beneath about 2 metres of aeolian sand. A radiocarbon date of ~2,500 years BP was obtained on disseminated organic carbon associated with the A-horizon of the buried soil. Moreover, historic accounts of dune activity exist (Winchell and Upham 1888:418), and this geomorphic process can be observed in specific locations even today (Keen 1985:8). It is likely therefore that the aeolian history is complicated, and that several periods of landscape instability are recorded in the aeolian sediments and landforms.

The lakes along the Rice Creek drainage are predominantly shallow. A topographic map (United States Geological Survey 1993[1967]) of the area indicates that most of the lakes—including Crossways and Rondeau lakes—are no deeper than 5 feet. Only Peltier and Centreville lakes, located 2 to 5 miles to the south, are deeper than 15 feet. Shallower lakes in this region would have been particularly sensitive to changes in the amounts of precipitation, surface runoff, and groundwater. Lake levels may have fluctuated frequently, and area lakes may have dried completely. Changes in available water would have affected communities of plant and animals living in and around the lakes, thereby influencing the subsistence and settlement practices of human inhabitants relying upon those resources as well.

A model of Holocene vegetation and climate history for the Anoka Sand Plain has been constructed based on pollen analysis of lake sediment cores taken at Lake Ann in Sherburne County, Minnesota (Keen and Shane 1990). The patterns observed at Lake Ann compare favourably with other regional vegetation and climate histories (Bradbury et al. 1993; Webb III et al. 1993), with allowances made for local variations.

During the Holocene, the Anoka Sand Plain experienced a succession of changes in climate and vegetation (Keen and Shane 1990). In the Early Holocene, immediately following deglaciation, pollen records at Lake Ann indicate that spruce parkland became dominant by about 11,000 years BP. Between 10,000-9,100 years BP, a warming trend is indicated. Spruce parkland was replaced by a mixed conifer-hardwood forest.

The Mid-Holocene (9,100-4,000 years BP) brought severe changes in climate, which Keen and Shane (1990) divide into three major episodes: 9,100-6,500; 6,500-5,100; and 5,100-4,000 years BP. Each of these episodes is characterised by a sequence of drought and reduced vegetation cover, increased flux of aeolian sediment, a return to higher precipitation and greater vegetation cover, and a slow decline in aeolian flux (Keen and Shane 1990,1653).

Decreases in precipitation and increases in temperature led to the development of prairie vegetation. Lake levels were substantially lower during these periods of lower precipitation and higher evapotranspiration (Bradbury et al. 1993; Keen and Shane 1990). The combination of open vegetation conditions and lower water tables allowed the sediments of the Anoka Sand Plain to be eroded, transported, and redeposited by strong northwesterly winds, resulting in significant dune formation (Keen 1985). The pollen record reflects these episodes of dune formation by an increase in sage and ragweed pollen, plant types that colonise disturbed ground. Increases in precipitation and decreases in temperature produced increases in forest vegetation. Aeolian activity decreased correspondingly.

The Late Holocene (4,000 years BP to present) is characterised by a general trend toward modern climatic conditions (Bradbury et al. 1993; Keen and Shane 1990). In the Anoka Sand Plain, prairie vegetation decreased while forest vegetation (pine and oak) increased. Lake levels appear to have reached their maximum extent between 3,500 and 4,000 years ago (cf. Bradbury et. al. 1993; Abbott, Binford, Brenner, and Kelts 1997). Although evidence for short term fluctuations in climate during historic times (e.g. the Medieval Warm Period and the Little Ice Age) has been found elsewhere (Bradbury et al. 1993; Grimm 1981), no evidence was observed at Lake Ann (Keen and Shane 1990). Nevertheless, development of hardwood vegetation in the Big Woods south of the Anoka Sand Plain about 300 years BP corresponds to the cooler climate of the Little Ice Age (Grimm 1981).

At the time of initial Euro-American settlement, areas of good drainage in the Anoka Sand Plain were dominated by open oak groves interspersed with tall grass prairie, whereas areas of poor drainage were marked by mixed hardwoods, sedges, marsh grass, and tamarack (Agricultural Experimental Station 1980). In 1847, the earliest land surveyors characterised the Rice Creek drainage as an area of "tamarac [sic] swamp and floating marses [sic] with spots of timbered highland" (United States Bureau of Land Management 1850-1963?). The shallow lakes and drainage ways along Rice Creek may have fostered stands of wild rice (Jenks 1901:1122-1123). Where urbanisation has not altered the landscape, this basic vegetation pattern still remains today.

In summary, the Sand Plain is a complex network of small streams, lakes, and wetlands interspersed with dunes, small stream terraces, and small upland areas composed of glacial till. Each of these features contains distinctive suites of plant and animal resources ranging from fish, turtles, small mammals and wild rice along the streams and lakes to patches of mixed forest containing maple and oak in the uplands. This mosaic of seasonally available resources made the Sand Plain a particularly attractive location for prehistoric people during certain periods in the past. At the same time, the landforms and vegetation of the Sand Plain are particularly susceptible to relatively minor shifts in temperature and precipitation. Thus, the Sand Plain is an ideal venue for fine-scale analysis of the interaction between culture and environment.

2.2 Cultural setting

There is evidence that all of the major cultural traditions in Minnesota were present on the Anoka Sand Plain at one time or another during the last 11,000 years. However, a dramatic increase in human activity occurred approximately 500 BC, with the beginning of the Woodland period, and continued until about AD 700-800. The most striking aspect of this period is the presence of numerous sites containing Middle Woodland materials related to the Havana Hopewell complex of Illinois, some 500 miles to the south.

The term 'Middle Woodland' subsumes the complex cultures that developed along the Ohio, Illinois, and Mississippi River valley's between roughly 2,200 and 1,800 years ago. These cultures are distinctive and are best known for the appearance of complex and sophisticated mound and mortuary centres, long-distance trade in exotic raw materials (e.g. copper, marine shell, obsidian), increased population density, and the first use of corn as a cultigen in eastern North America. The major Middle Woodland centres are in Ohio and Illinois, although Middle Woodland influence is seen at many sites throughout the midcontinental region. Although the appropriate interpretation of Middle Woodland culture and interaction remains a matter of debate, it is clear the this culture represents a major florescence of Native American culture some 2,000 years ago.

The Anoka Sand Plain contains the most northerly Middle Woodland centre, which is represented by the Howard Lake phase. Although there are no radiocarbon dates from Howard Lake sites, the chronological position of this phase is estimated to be 800 BC to AD 200 (Johnson 1971). The large number of Middle Woodland sites in the Anoka Sand Plain indicate that it was an important population centre (Dobbs et al. 1990; Harrison 1978; Wendt 1986, 1987a, 1987b, 1988) and several large conical Middle Woodland mounds are present in the area. Howard Lake ceramics are quite similar to the Havana Hopewell materials of Illinois and artifacts made of exotic raw materials, particularly copper, have been found in this area.

The Howard Lake Phase appears to parallel the rise and subsequent decline of Middle Woodland farther to the south. There are several subsequent Woodland phases on the Sand Plain, and sporadic use of the region continued until the time of European contact. However, the most intense period of Woodland use of the region appears to encompass about eight centuries from ca. 2,200 years ago until around 1,400 years ago and is documented by over 300 sites within several miles of 21AN106.

There appears to be a distinct site hierarchy within the Middle and later Woodland sites in this region. Several large sites, most commonly associated with mounds, appear to have been used over extended periods of time. Many other sites are smaller in scale and may or may not be associated with mounds. Finally, there are a number of small sites that appear to have been used on an occasional basis for specific tasks. Although these sites tend to have low artifact density and few, if any, cultural features, analysis of their function and position within the landscape may provide important clues to the natural and/or cultural aspects of the Middle and Middle-to-Late Woodland florescence on the Anoka Sand Plain. 21AN106 is of one these small, ephemeral sites and research at the site was directed toward determining its function and role within the larger Woodland settlement system.

2.3 21AN106 project description

Northern Natural Gas Company (Northern) owns and operates an interstate natural gas pipeline system that transports gas throughout the midwestern United States. As part of an expansion project of its system in 1996, Northern proposed to construct an additional pipeline segment (known as a loopline) 25 feet north of its existing natural gas pipeline in Anoka County, Minnesota. To comply with federal environmental regulations, Northern commissioned a number of studies to evaluate the effect that its proposed project would have on the environment. One of these studies was designed to locate and evaluate any cultural properties that would be affected by the project.

A file search and Phase I cultural resource survey of the pipeline route revealed that the proposed loopline would cross archaeological site 21AN106 (Breakey 1995). Subsequent evaluation of this site (Dobbs and Breakey 1995) demonstrated that the site contained clusters of fire-cracked rock (FCR), ceramics, and other artifacts scattered within the dune from the ground surface to roughly 80 centimetres below surface. The ceramics appeared to be Middle and/or Middle-Late Woodland in age. The physical setting of the site adjacent to two lakes and within a larger cluster of archaeological sites suggested that a careful study of both the artifacts from the site and its internal settlement pattern could provide important information about the evolution of Middle Woodland settlement patterns and systems within the Anoka Sand Plain. Based on this information, regulatory agencies concluded the site was eligible for listing on the National Register of Historic Places and that excavation of the portion of the site to be affected by pipeline construction would be required if the site could not be avoided. An analysis of the pipeline route and the various environmental constraints at this particular site demonstrated that the site could not be avoided, and data recovery was selected as the most suitable treatment option for the site.

Developing an excavation plan for the site posed several key problems. Some of the most important information that the site might yield was in the structure and patterning of the deposits within the site itself. However, the area to be disturbed by construction was roughly 3 metres wide, extended 85 metres across the length of the site, and cultural materials were buried to a depth of up to 80 centimetres. A complete excavation of this large area was well outside both the scope of the budget for the entire project and beyond what could be justified by the information present at the site. Mechanical stripping of the entire area was also considered. However, the sandy soils of the dune were prone to collapse, and damage to the site surface in these types of conditions would have been very difficult to prevent. Moreover, the concentrations of materials at the site were relatively small and subtle to identify. Mechanical stripping could have easily destroyed such concentrations before the were recognised.

Various sampling approaches to the site were also considered but were rejected for several reasons. A systematic sampling design had been used during initial testing of the site and this approach had provided a reasonable picture of the variability of materials within the site. However, what was particularly important was an understanding of the *patterning* of cultural debris across the site, the internal consistency of this patterning, and its relationship to the immediately adjacent lake and wetland margins. While only a sample of artifact concentrations within the site were to be excavated, it was essential that the totality of the patterning of these concentrations and any other features present be understood. Finally, both Northern and the regulatory agencies were concerned that the sandy soils of the area might create conditions that could require a larger working area during construction than would be excavated by the archaeologists.

3 Radar study at 21AN106

Geophysical survey of the entire construction corridor seemed a reasonable way to identify patterning of cultural materials, and several different geophysical methods were evaluated. Soil resistance was immediately eliminated since it could not identify the types of subtle patterning present at the site. Magnetic survey using a fluxgate gradiometer was considered but quickly eliminated when it became clear that the background signal from the existing buried pipeline would overwhelm any magnetic signals created by cultural material.

Finally, ground-penetrating radar (GPR) was evaluated. Our evaluation concluded that radar would not be affected by the proximity of the existing pipeline and could provide information on both the depth and horizontal distribution of cultural materials. The sandy sediments at the site provided an ideal medium for radar survey and, because the site was within a dune, the only natural sediments present should be wind-blown sands. Any rock within the site would therefore have to be of cultural origin. Finally, individual pieces of FCR and concentrations of FCR and artifacts identified during the initial testing were six inches or greater in diameter. Initial calculations demonstrated that targets of this size could be resolved and identified by radar using a 450 MHz antenna.

Based on these considerations, we concluded that the use of GPR at 21AN106 had a reasonable chance of identifying the types of cultural information we wanted to recover, and a radar survey was included as the first step in the excavation process (Maki and Forsberg 1996).

3.1 Basic principals of GPR

GPR sends high frequency radio waves into the ground with a transmitter antenna. Some of these waves are reflected back to the surface, while of the rest of this wave energy either continues to penetrate the soil or is scattered and/or absorbed (called attenuation). The energy that is reflected back to the surface is picked up by a receiver antenna. The time it takes the wave to travel from the transmitter to the subsurface feature and back to the receiver, is the *two way travel time*. The transmitter and receiver are dragged across the ground surface at a fixed interval (see Fig. 2), creating a two dimensional plot of distance versus travel time.

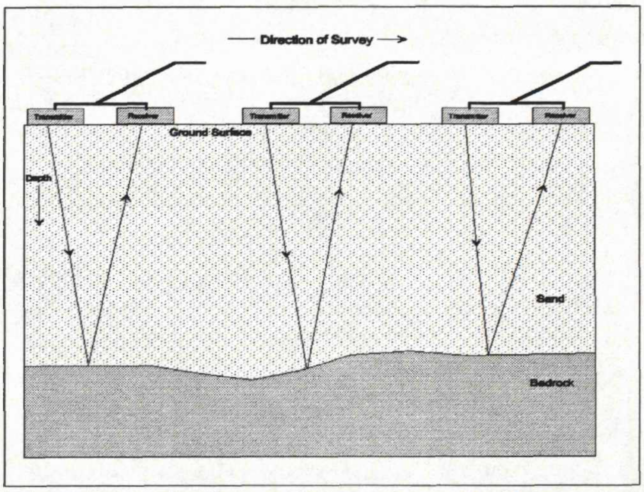

Figure 2. Fixed offset continuous data collection mode

The response plotted is dependent upon the geometry of the subsurface target. A planar feature beneath the surface (such as a change in soil stratigraphy or water content) will appear as a planar anomaly, roughly proportional to the actual subsurface feature. A subsurface object will appear as an inverted hyperbolic shape. This is due to the cone shaped geometry of the radar pulse as it travels beneath the surface (see Fig. 3). The forward edge of the cone encounters the object first and a two way travel time is plotted. As the cone moves over the object this travel time approaches a minimum. The top of the hyperbola corresponds to the true horizontal location and estimated depth of the object.

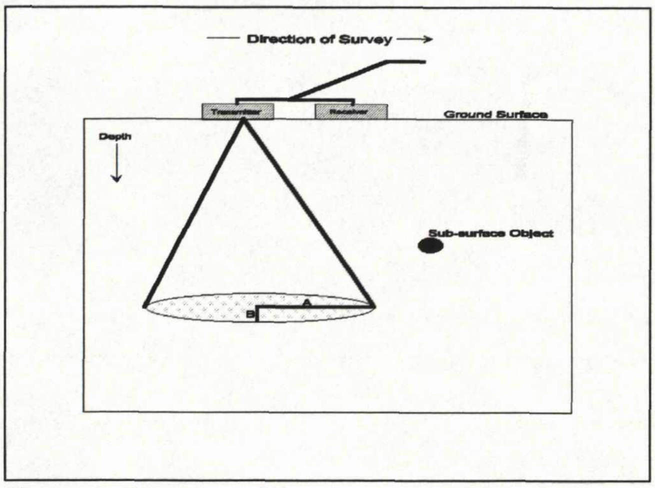

Figure 3. Geometry of the electromagnetic pulse beneath the ground surface

The velocity which the wave travels through the soil varies with soil type. Knowing the soil type at a particular site allows one to *estimate* this velocity. Knowing the travel time and estimated velocity of the wave, a depth to the subsurface reflector can be *estimated* by the following equation:

depth = velocity * (time/2)

The depth to which GPR can penetrate varies with soil type. The attenuation and dielectric properties of the soil change as a function of moisture content and density. Generally, depth of penetration is greater in dry sandy soils and is reduced in moist clayey soils.

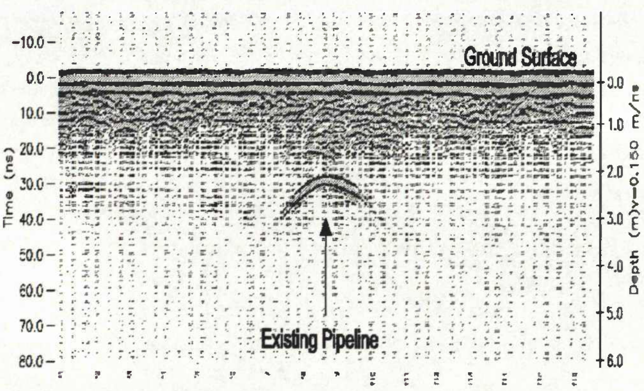

Figure 4. A typical GPR response from a subsurface target. The left axis is the two way travel time. The right axis is the estimated depth. The markers along the bottom of the plot indicate distance along the transect in meters.

The resolution of the radar data varies with the frequency of the wave. Higher frequencies have greater resolution but less depth of penetration. For example, a 450 MHz antenna penetrates from zero to four metres into the soil with the ability to detect objects on the order of centimetres. A 20 MHz antenna penetrates tens of metres into the earth with a resolution on the order of metres.

The aeolian dune topography at 21AN106 is nearly ideal for high resolution GPR data collection. The homogenous sands permit sufficient depth of penetration to allow the use of a high frequency antenna. For this reason the decision was made to use a high resolution 450 MHz antenna. The performance of this antenna was tested by collecting data over a known subsurface object (the existing Northern pipeline) at the onset of the survey (see Fig. 4). This test confirmed the depth of penetration and resolution of the antenna was sufficient for this soil type.

3.2 Radar survey design

Complete areal coverage of the loopline corridor at a depth of one metre below surface was the objective of the survey design process. The loopline corridor extended 6 metres to the north of the proposed pipeline and 4 metres to the south of the proposed line. The length of the project area was 85 metres.

GPR data was collected in 20 metre long transects. The spacing of these transects was based upon the GPR illumination equation. The equation is as follows (Annan and Cosway 1994):

$A = (\lambda / 4) + (\text{depth} / (k-1)^{0.5})$

where λ = wavelength = velocity/frequency

k = relative permittivity

$B = A / 2$

The following parameters were used in the above equation to arrive at the illumination radius given below:

At 450 MHz and an estimated velocity of 0.15 m/ns: λ = .333 metres, k was estimated at a value 4, depth used was one metre. The dimensions are.

A = 0.66 metres

B = 0.33 metres

These dimensions resulted in a choice of 0.5 metres as the transect interval for the survey. At a 0.5 metre transect interval there is an overlap of 0.16 metres between each transect, resulting in complete areal coverage of the corridor.

Calculations were next made to determine whether targets would be visible to the radar, and if so, what was the size of the smallest detectable target. There are two conservative rules of thumb to predict whether the target will be visible. First, a contrast in electrical properties of the surrounding soil matrix (host) and the target material is required. The power reflectivity expression (Annan and Cosway 1992) is a measure of this contrast. The expression is as follows:

$P_r = | (k_{host} - k_{target}) / (k_{host} + k_{target}) | ^2$

A value greater than 0.01 for P_r indicates the target will be visible. Assuming a host material of dry sand (k = 4) and a target of FCR/ceramic (k = 6) results in a power reflectivity of 0.0102 which is greater than 0.01. Therefore the power reflectivity should be sufficient to make targets visible to GPR. The second rule of thumb is a ratio of target depth to smallest target dimension of less than or equal to 10:1. This implies that at one metre below surface a target size of 10 centimetres should be visible.

The size of targets visible to the radar was estimated using the following equation (Annan and Cosway 1992):

frequency used = 150 / (x * K_{host}) where x = resolution required

At 450 MHz and in dry sand, solving for x results in a minimum target size of 8.3 centimetres.

In short, FCR/ceramic clusters should be visible to the GPR. The diameter of these detectable clusters should be on the order of 10 centimetres.

3.3 System settings

Data were collected using the pulseEKKO 1000 GPR in fixed offset reflection mode. The frequency used was 450 MHz with an antenna separation of 0.25 metres and a 100 ns time window. A stepsize of 0.05 metres with a stacks setting of 32 and a sampling interval of 200 ps was used (32 readings were taken every 5 centimetres and the result was averaged).

3.4 Field methods

The centrelines of the existing pipeline and proposed loopline were surveyed and marked by Northern Natural surveyors. The loopline right-of-way was surveyed by IMAC at the onset of the project. A grid system was then established over the site for later use during the excavation phase of the project (see Fig. 5).

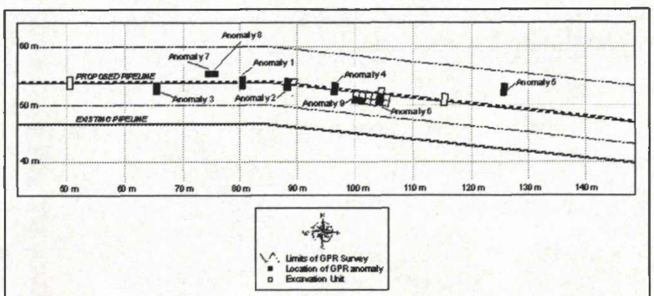

Figure 5. Location of radar anomalies and excavation units at site 21AN106

GPR data was then collected in 20 metre transects spaced at 0.5 metre intervals throughout the 85 metre construction corridor. Each 20 metre segment of GPR data was saved as a computer file to be processed and analysed in the lab at a later date.

3.5 Data processing and analysis

The analysis of the GPR data was carried out by processing the data using different gains and filtering techniques. *Gain* is a scalar with which the raw data is multiplied to enhance the presentation of the data. *Filtering* is the use of mathematical averaging techniques to "clean" noise from the data and/or enhance certain characteristics of the data.

Constant gain and SEC (Spreading and Exponential Compensation) gain were used. *Constant gain* is simply a constant by which the raw data is multiplied. *SEC gain* is a function by which the raw data is multiplied. The function is as follows:

$$SEC = C + (1 + \tau / \tau_w) * e \wedge (\beta * \tau)$$

where: C = constant

$\tau = (t - (\tau_w + t_o))$

τ_w = pulse width

t_o = time zero

β = attenuation * velocity / 8.69

velocity = 0.1 m/ns

attenuation = 0.5 dB/m

This gain function was selected in the hope of preserving stratigraphic detail near the ground surface where the reflection strength is high, while enhancing details at depth (the exponential part of the function).

The filtering used was down-the-trace (temporal) averaging and trace-to-trace (spatial low pass filtering) averaging. Down-the-trace averaging was used to reduce the random noise in the data. Trace-to-trace averaging was used to enhance stratigraphic detail in the data.

Each transect of data from 21AN106 was processed and plotted using the following three processing options.

1. Constant Gain = 150 , no filter.
2. SEC Gain with Attenuation = 1 and Constant = 150, down-the-trace averaging with a window of 3 points.
3. SEC Gain with Attenuation = 1 and Constant = 150, down-the-trace averaging with a window of 3 points and trace-to-trace averaging with a window of five points.

All data was initially processed using an estimated wave propagation velocity of 0.15 m/ns. This estimated velocity was later recalibrated after excavation revealed the true depth of subsurface objects. The recalibrated velocity was calculated by solving the depth equation (see GPR Basics) for velocity, using known values for depth and travel time. Recalibration revealed the true velocity to be closer to 0.10 m/ns. The data files were then plotted again using this new velocity estimate. However, it should be noted that this value is still an approximation. An absolute value could be calculated only if the soil were *completely* homogenous.

3.6 Results

Processing and analysis of the GPR data from 21AN106 revealed three main types of radar signatures. These were:

1. A planar response, due to changes in soil stratigraphy and moisture content. This signature was present in nearly all radar profiles at 0.8 - 0.9. metres below surface and again at 1.5 - 2.0 metres below surface. Examination of soil profiles indicates that the upper planar response is due to a change in moisture content whereas the lower planar response marks a change from loosely-packed fine aeolian sand to dense clayey lacustrine deposits.
2. A point target or object response, exhibiting an inverted hyperbolic shape. These anomalies were likely due to subsurface objects (possible artifacts).
3. Vertical and horizontal areas of disturbed soil. These anomalies are were likely due to areas of disturbed soil,

possibly of a cultural origin (post-holes, fence-posts storage pits).

A total of nine GPR anomalies were excavated. For the location of excavation units which were placed to investigate these anomalies see figure 5. A description of each anomaly and the results of excavation follow.

Anomaly 1: A vertical soil disturbance.

Associated Excavation Units: 1 and 2.

Description: Anomaly 1 appeared as a vertical disturbance at a depth of 30-180 centimetres below surface (see Fig. 6). The anomaly was interpreted as a possible fence-post-hole, rodent burrow, or shovel test from the Phase II site evaluation. During excavation, cultural material was recovered from 50 to 150 centimetres below surface, however, no features were discovered that suggested a cultural origin for the anomaly. An extensive (both vertical and horizontal) system of rodent burrows were mapped. These burrows are the probable cause of the GPR anomaly. The burrows were easily distinguished because the soil which had filled them was darker (10YR3/2), texturally different (loamy fine sand), and richer in organic material than the surrounding matrix (10YR5/3 fine sand). Presumably, this material represents topsoil that filled the rodent burrows subsequent to their abandonment. The difference in the dielectric properties between the burrow fill and surrounding matrix likely produced the reflection in the radar profile.

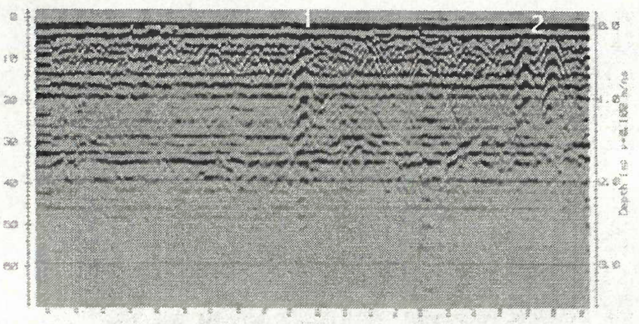

Figure 6. Anomaly 1: Vertical disturbance at f10.5. Anomaly 2: Two vertical disturbances at f19 anf f20. Note planar responses at 0.8 to 0.9 meters and 1.5 to 2.0 meters. The upper response results from changes in soil moisture content due to capillary action from the water table below. The lower response marks a change from loose fine sand to dense clayey sand observed at about 1.5 meters below surface in excavation profiles.

Anomaly 2: A vertical soil disturbance.

Associated Excavation Units: 3 and 4.

Description: Anomaly 2 registered as two adjacent vertical disturbances between 20-100 centimetres below surface (see Fig. 6). The anomaly was interpreted as possible fence-post-holes, rodent burrows, or shovel tests from the Phase II site evaluation. During excavation, cultural material was recovered from 50 to 150 centimetres below surface, however, no cultural features were discovered that suggested a cultural origin for the anomaly. An extensive (both vertical and horizontal) system of rodent burrows were mapped. These burrows are the probable cause of the GPR anomaly. The burrows were easily distinguished because the soil which had filled them was darker (10YR3/2), texturally different (loamy fine sand), and richer in organic material than the surrounding matrix (10YR5/3 fine sand). Presumably, this material represents topsoil that filled in the rodent burrows subsequent to their abandonment. The difference in the dielectric properties between the burrow fill and surrounding matrix likely produced the reflection in the radar profile.

Anomaly 3: Point target.

Associated Excavation Units: 5 and 6.

Description: Anomaly 3 registered as a point target reflection at 60-80 centimetres below surface (see Fig. 7). During excavation, a small cluster (~10 centimetres in diameter) of cultural material (3 pieces of FCR and 2 ceramic sherds) was encountered between 73-75 centimetres below surface. Although other cultural material was recovered, no other clusters or large objects were encountered, suggesting that the cluster at 73-75 centimetres below surface was the cause of the reflection.

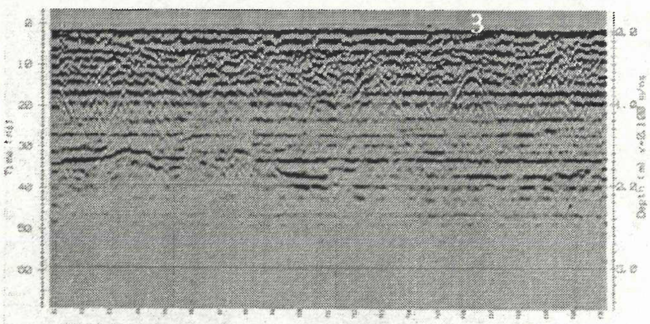

Figure 7. Anomaly 3: Point target response at f16.

Anomaly 4: Point target.

Associated Excavation Units: 9 and 10.

Description: Anomaly 4 registered as a point target 30-50 centimetres below surface. Several small (5-10 centimetres in diameter) clusters of FCR were identified between 40 and 90 centimetres below surface during excavation in unit 10. It is uncertain which of these clusters, if any, was the cause of the anomaly.

Anomaly 5: Point target.

Associated Excavation Units: 11 and 12.

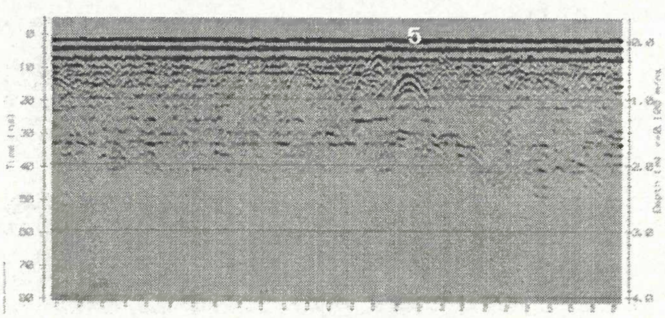

Figure 8. Anomaly 5: Strong point target response at f17

Description: Anomaly 5 registered as a very strong point target reflection 60 centimetres below surface (see Fig. 8). During excavation, a thin oblong piece of iron (later identified as a tine from a harrow rake dating to the 1940's) was recovered from between 60-64 centimetres below surface in unit 12. The depth at which this strong metal reflector was recovered was used in the recalibration of the radar data.

Anomaly 6: Point target.

Associated Excavation Units: 13 and 14.

Description: Anomaly 6 registered as a point target at a depth of 30-40 centimetres below surface. Several small (5-10 centimetre diameter) clusters or single cobble sized pieces of FCR were recovered between 40 and 90 centimetres below surface during excavation in unit 10. It is uncertain which of these features, if any, was the cause of the anomaly.

Anomalies 7 and 8: Point target and horizontal disturbance.

Associated Excavation Units: 15 and 16.

Description: These excavation units were placed to sample two adjoining anomalies. Anomaly 7 registered as a point target 60-70 centimetres below surface. Excavation revealed two clusters of FCR near the unit's centre at 55 centimetres below surface. One of these clusters may have produced the reflection.

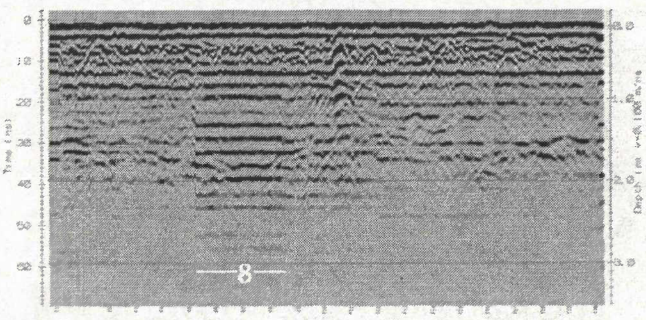

Figure 9 Anomaly 8: Unusual horizontal disturbances at f5-f8.5

Anomaly 8 consisted of a section of unusual horizontal disturbance of unknown origin present at 0.60 - 2.5 metres below surface (see Fig. 9). Excavation revealed a linear rodent burrow (5-10 centimetres in diameter) running approximately parallel to the centreline from the centre of unit 15 through unit 16 and continuing on to the east. The burrow was easily distinguished because the soil which had filled it was darker (10YR3/2), texturally different (loamy fine sand), and richer in organic material than the surrounding matrix (10YR4/3 fine sand). Presumably, this material represents topsoil that filled in the rodent burrow subsequent to its abandonment. The difference in dielectric properties between the burrow fill and the surrounding matrix may have produced the GPR anomaly. The orientation of the burrow (approximately parallel to the radar transect at 1.5 metres north of the centreline) may also have contributed to the unusual response seen in the radar profile.

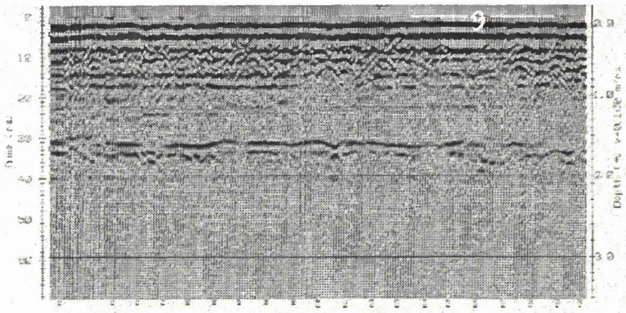

Figure 10 Anomaly 9: Area of weak scattered response at f10-f13

Anomaly 9: Area of scattered weak disturbance.

Associated Excavation Units: 20 and 21.

Description: Anomaly 9 was not particularly prominent in the radar profile. However, there was a subtle area of scattered response at 0.5 - 1.0 metres below surface, which, it was hoped, was caused by scattering due to a high concentration of small artifacts. While excavation revealed no single discrete feature which could account for the anomaly, a relatively high density of FCR was concentrated between 50-110 centimetres below surface in both units 20 and 21. The presence of these artifacts may have caused the scattering observed in the radar profile.

4 Discussion

Data recovery at 21AN106 consisted of two phases: first, a geophysical survey of the construction corridor using GPR to identify cultural materials or features (Maki and Forsberg 1996); second, the excavation of 30 1-x-1-m test units within the construction area (Forsberg and Dobbs 1997). The entire proposed pipeline corridor to be impacted by construction was surveyed using GPR, and a number of radar anomalies were identified. The anomalies thought most likely to have been created by cultural features were chosen for further investigation. Several other areas within the site were also excavated based on the results of the earlier testing.

The radar survey provided high resolution data on the presence/absence and location of subsurface features that proved to be accurate when tested by excavation. A total of nine GPR anomalies were investigated: two vertical soil disturbances, one horizontal soil disturbance, five point targets, and one area of scattered response. All of the disturbed soil anomalies investigated were the result of bioturbation (rodent burrows). Three of the five point targets investigated yielded objects which were the likely reflectors. Numerous objects were discovered associated with the remaining two point targets. It was unclear which if any of these objects were the source of the GPR anomaly. Finally, the area of scattered response did prove to have a higher concentration of artifacts than the surrounding soil matrix.

Controlled excavation resulted in the recovery of 2,456 artifacts. Major prehistoric artifact classes included chipped stone tools and chipping debris, ceramics (all grit tempered), and FCR. In addition, a single conical spear point fashioned from native copper was found. Small numbers of historic artifacts were recovered at depth. Finally, small quantities of charcoal, unidentifiable bone fragments, and other material of uncertain cultural origin were recovered.

Phytolith analysis of food residues from seven ceramic sherds provide direct evidence for use of wild rice and corn and possible use of an unidentified grass and cucurbits (gourd/squash) (Thompson 1996). Accelerator mass spectrometry (AMS) dating of these same residues yielded six radiocarbon dates [Beta-98075 (2030±60 BP); Beta-98076 (2040±50 BP); Beta-98077 (1700±60 BP); Beta-98078 (1680±50 BP); Beta-98079 (2040±50 BP); Beta-98080 (2130±50 BP)] which provide an age range for plant use (and occupation) at the site. AMS dates indicate that wild rice use occurred between 200 BC - AD 75, whereas use of corn occurred AD 200-500. This date for corn use is the earliest yet obtained in this northerly portion of the upper Midwest and the wild rice dates are also the earliest yet obtained along the southern margin of wild rice usage.

Evidence for a wide range of subsistence activities at the site (e.g. hunting, fishing) were lacking. Rather, 21AN106 appears to have functioned as a limited activity or resource extraction site. Its location overlooking Rondeau Lake, where extensive wild rice beds exist, suggests that wild rice attracted prehistoric humans to the area. The artifact assemblage suggests that 21AN106 was a processing site, with FCR and ceramics dominating the assemblage. The presence of FCR (associated with stone boiling) and certain ceramic types (e.g. St. Croix/Onamia at 21AN106) often associated with intensified wild rice use has been interpreted as evidence for wild rice processing at other sites (e.g. Mooers and Dobbs 1993). Direct evidence for wild rice use is provided by wild rice chaff phytoliths identified in food residues from three ceramic sherds. AMS dating of the food residues indicates that wild rice use occurred between ca. 200 BC - AD 75. Phytolith analysis indicates that use of an unidentified wild grass and possibly cucurbit (squash or gourd) co-occurs with wild rice use. Phytolith analysis also provides direct evidence for corn use between AD 200 - 500. While the use of corn by Middle Woodland groups to the south is reasonably well documented, these dates represent a significantly earlier use of corn along the northern frontier of the Middle Woodland world than might be expected.

5 Conclusions

The radar survey provides us with a reasonably clear picture of the internal site plan of 21AN106. This information, when coupled with the excavated data and other paleoecological information, makes it possible to develop a hypothesis which may explain the florescence of Middle and Middle-to-Late Woodland culture on the Anoka Sand Plain.

At least two dynamic geomorphic processes influenced the evolution of the Sand Plain landscape and, therefore, prehistoric settlement activity upon this landscape. These forces are the creation and modification of sand dunes by wind, and changes in lake levels.

Models for dune activity on the Anoka Sand Plain indicate that major episodes of dune formation occurred in the Mid-Holocene between 9,100-4,000 years BP (Keen 1985; Keen and Shane 1990). These episodes correspond to periods of lower precipitation, higher temperatures, reduced vegetation cover, and lower lake and groundwater levels. The shallow lakes along Rice Creek—including Crossways and Rondeau lakes—would have been particularly responsive to decreases in precipitation and groundwater and probably dried up altogether. Thus, sediment in these lakes and the surrounding shallow marshes was exposed to erosion and transport by wind.

Direct evidence for changes in lakes levels in the Rice Creek area is not yet available. However, given regional models (Webb III et al. 1993; Winkler et al. 1986) for lake level fluctuations it is likely that lake levels dropped substantially during the Mid-Holocene, rose during the early Late Holocene to levels higher than at present, and subsequently dropped to about modern levels. There is increasing evidence that this phenomenon occurred throughout the western hemisphere (Abbott et al. 1997).

During the warm and dry Mid-Holocene, when lake levels were low, vegetation cover reduced, and sand dune activity widespread on the Anoka Sand Plain, the area must have been relatively inhospitable. However, as climatic conditions ameliorated after 4,000 years BP, lake levels rose and the landscape stabilised. Thus, although conditions for human settlement were poor throughout most of the Archaic Period, by Late Archaic times, roughly 4,000 years ago, the Rice Creek area would have offered a relative wealth of resources such as wild rice, waterfowl, and fish.

We hypothesise that the expanded use of the Anoka Sand Plain by Middle Woodland groups — and the specific location of 21AN106 — is the result of complex interaction between changes in the physical environment of the Sand Plain, the emergence of the Woodland Tradition throughout the upper Midwestern United States, and interaction with sophisticated Middle Woodland groups farther to the south, similar to other situations documented in both Minnesota and other parts of the New World (e.g. Mooers and Dobbs 1993; Binford et al. 1997). As lake levels dropped from their maximum levels, a variety of new areas appeared that were optimal for wild rice growth. Almost simultaneously, around 2,500 years ago, new ideas about how to process and use 'wild' grains — most notably wild rice and corn — emerged. Whether these ideas and their associated technology are local developments or were adopted from more southerly groups remains unclear. However, it is apparent that the relationship between changes in the Sand Plain landscape which were conducive to wild rice production and procurement, and the Woodland florescence in this same area, are more than coincidental.

By roughly 1,500 years ago, the Sand Plain was no longer the focus of intensive Woodland settlement and use. While several different factors may have contributed to this change, certainly the continued drop in lake levels may have been a key factor. At 21AN106, even modest changes in lake levels of a few feet would have significantly changed the relationship of the nearby rice beds to the site itself. Such minor fluctuations in lake levels would have had little effect on the larger, central sites in the Woodland settlement system which were adjacent to deeper lakes. However, they seemingly had a very significant effect on the location and character of smaller, processing and procurement sites like 21AN106.

Obviously, ground-penetrating radar was only one in a variety of tools used in the investigation and interpretation of 21AN106. However, radar facilitated a comprehensive examination of the entire portion of the site and provided important information on the patterning of cultural materials within the site itself. This information allowed us to structure the site excavation in a way that maximised the information we recovered while maintaining careful control over archaeological costs. While the same information could have been recovered without the radar survey, a significantly larger area would have had to have been dug — and we would have been left with continued nagging doubts about what we might have missed and what really lay in the unexplored areas between our excavation units.

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