A Geophysical Investigation Searching for Archaeological Features at Sunwatch Indian Village

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A GEOPHYSICAL INVESTIGATION SEARCHING FOR ARCHAEOLOGICAL FEATURES AT SUNWATCH INDIAN VILLAGE

A thesis submitted in partial fulfillment
Of the requirements for a degree of
Master of Science

By

Danielle Torridi
B.S., Salem State College 2010

2012
Wright State University
WRIGHT STATE UNIVERSITY
GRADUATE SCHOOL

June, 8 2012

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY
SUPERVISION BY Danielle Torridi ENTITLED A Geophysical Investigation Searching for
Archaeological Features at SunWatch Village BE ACCEPTED IN PARTIAL FULFILLMENT
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Abstract

Torridi, Danielle D., M.S. Department of Earth and Environmental Sciences, Wright State University, 2012, A geophysical investigation searching for archaeological features at SunWatch Indian Village.

A near-surface geophysical survey was conducted at SunWatch Indian Village in Dayton, Ohio. The main motivations for this investigation were to evaluate geophysical methods to locate, map, and identify features associated with the SunWatch Indian Village archaeological site and to expand the area surveyed. Previous studies (Houston, 2002; Miller, 2004) have determined that burials covered with limestone slabs are relatively easy to detect and map geophysically with GPR and electrical resistivity. This was reconfirmed in this study by collecting 3D GPR data over a ‘control’ location previously surveyed by Houston (2002) and Miller (2004). However, similar anomalies were not observed in the other areas surveyed in this study suggesting that they are absent there. The GPR data were collected at 6 inch line spacing for 3D surveys. A comparison of 3D GPR analysis of 6 inch line spacing and 12 inch line spacing (by removing alternate lines) indicates that a 6 inch line spacing was better at defining the subtleties of limestone slabs but that the 12 inch line spacing was adequate for mapping the slab-covered burial site. Electromagnetic (EM) surveys were also conducted across the control as well as new areas but the EM did not show an anomaly at the known limestone slab-covered burial in the control area. This suggests that EM is not able to detect small, thin, resistive bodies (limestone slabs) in these conductive soils. On the other hand electrical resistivity is useful in detecting limestone slabs (Houston, 2002; Miller, 2004) but may be unable to detect more subtle conductivity contrasts likely associated with storage/ trash pits. The magnetic gradiometer surveys were successful in identifying local magnetic anomalies that correlated with an EM
inphase anomaly. An interesting find was that the EM unit was able to detect in several unexcavated areas anomalies of high conductivity and low magnetic susceptibility that are believed to be associated with clusters of storage/trash pits. Another interesting find was that the EM instrument was able to detect the presence of an area of high magnetic susceptibility and low conductivity possibly indicating the location of a fire hearth or pottery kiln. Based on the results of this survey there are no new limestone slab covered burials located at SunWatch Indian Village in the areas surveyed but there is a possibility of clusters of storage/trash pits based on the EM signature. Before this study was conducted there was no definitive geophysical method of locating storage/trash pit at SunWatch Indian Village, however, this study suggests there may be a way to locate clusters of storage/trash pits using electromagnetics.
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Chapter 1: Introduction

Site Description and History

SunWatch Indian Village is an archaeological site/park located southwest of Dayton, Ohio, on the floodplain of the Great Miami River (Figure 1.1). The land was originally farmland owned by the Vance Family (1853-1941) that in the 1940s became the property of the City of Dayton. Relics had been found on the site since the 1930s but large-scale excavation by amateur archaeologists John Allman and Charles J (Chuck) Smith did not occur on the site until 1964 (Heilman, Lileas, & Turnbow, 1988).

Figure 1. 1 Shows the location of SunWatch Indian Village relative to the Dayton, Ohio. These images are from Google Earth.

Archaeological excavations that took place on site in the early years were not exhaustive and not every artifact was well documented or accounted for. When the site was proposed by the City of Dayton to be the location of a wastewater treatment plant a great deal of the site was excavated quickly. As a result of the richness of the artifacts discovered, the site was designated a National Historic Landmark in 1974 (Heilman, Lileas, & Turnbow, 1988).
Based on the artifacts, SunWatch Indian Village has been dated to 1200 CE (800 years ago) and of the Fort Ancient Culture. The village consists of a series of rings with each ring exhibiting a different purpose (Heilman, Lileas, & Turnbow, 1988).

The outermost ring consisted of a series of closely spaced postholes suggesting a stockade. The ring just inside the stockade consisted of different patterns of postholes, many rectangular, which were later determined to be houses. Associated with the houses were over 400 storage/trash pits. This transitioned to the next inner ring which contained many burial sites. Many of the burial sites were covered by limestone slabs, which usually indicated someone of importance. However, several burials were also found within this ring that were not marked by limestone slabs. The innermost ring was believed to have been a central courtyard, largely devoid of artifacts except for a series of postholes. Reconstructions indicate that the posts of the courtyard when viewed from the doorways/hearths of some of the important houses aligned with the sunrise during the solstices, indicating the times to harvest or plant crops (Heilman, Lileas, & Turnbow, 1988). Figure 1.2 is photograph of a model reconstruction at the SunWatch museum with each ring outlined.
Figure 1.2. A scale model of how the village may have appeared 800 years ago. (A) The outermost ring consisted of the stockade. (B) The ring that consisted of the building structures were storage/trash pits are also found. (C) The location where majority of the burials were located, many were covered with limestone slabs. (D) The inner-most area was largely devoid of artifacts other than a series of postholes indicating important alignments.

Many artifacts and structures have been located on site (Figure 1.3). The storage/trash pits were extremely valuable to archaeologists because they contain many discarded artifacts of daily life, giving valuable insight into the Fort Ancient Culture. Over 400 pits have been excavated at the site and it was likely that many more are present in unexcavated areas. Even though a great number of storage/trash pits were excavated they are not easily detectable with geophysical techniques.

Another, valuable find has been the burial sites covered by limestone slabs. The archaeologists on site were interested in knowing where they were located to avoid accidental excavation of burials. However, since excavation has been largely suspended here, geophysical mapping of the slabs is valuable to the archaeologists by mapping their distribution. The limestone slabs have been detected with geophysical techniques in previous work done at this site (Houston, 2002).
Site Geology

The geology of the site consisted of fine-grained flood deposits consisting of clays and silts known as Wea Soil. The Wea Soil was underlain by glacial deposits. The bedrock consisted of Ordovician limestone with interbeds of shale. The archaeological level was at a depth of about 1 - 1.7 feet below present ground surface. The flood plain sediment deposited after the site was abandoned has preserved the archaeological level (Heilman, Lileas, & Turnbow, 1988). When walking around the site the unexcavated areas were easily recognized because they were elevated relative to the original, excavated village level (Figure 1.4).
Figure 1.4 The above image is of Dr. Ernest Hauser and Danielle Torridi working with the EM unit within Area D. This image shows how the unexcavated areas are a series of platforms. Torridi is standing on top of the platform (unexcavated area) while Hauser is standing on the excavated surface. This image was taken by a volunteer from SunWatch Indian Village.

Previous Research

In 2002, Steven Houston, a graduate student from Wright State University, focused on geophysical surveys at the SunWatch archaeological site (Houston, 2002), in two locations A and B (Figure 1.5). Houston conducted ground penetrating radar (GPR), resistivity and magnetic surveys. His GPR surveys consisted of a series of 2D GPR lines with 80, 300 and 500 MHz antennas. Houston’s resistivity surveys were 2D profiles at 2-foot spacing used a 56-electrode dipole-dipole configuration. Houston also conducted a magnetic survey with a proton precession magnetometer and a base station. He was able to locate with both the GPR and the resistivity surveys, several anomalies suggesting presence of limestone slabs over burials. The anomalies have very distinctive GPR signatures (Figure 1.6). Probing with a metal soil probe confirmed the presence of rock at these sites. Houston (2002) also suggested the locations of several storage/trash pits using 500 MHz GPR but these features have not been confirmed by excavations. The magnetic survey Houston conducted was not entirely successful in finding distinctive anomalies except for a possible fire hearth in Area B, which later turned out to be
caused by metal coat hangers buried in the shallow soil, perhaps left there during earlier excavation.

Figure 1.5 Site map showing the unexcavated areas in white. Houston (2002) surveyed areas A and B; Miller (2004) surveyed Area A. This study will focus on Areas A, C, D, E and F.

Figure 1.6 Examples of the GPR profiles of Houston (2002). Rectangles highlight high amplitude anomaly that can be traced across several adjacent lines. Houston believed that this anomaly is associated with a limestone-covered burial.

In 2004, Kurtz Miller, another student from Wright State University, also focused on geophysical surveys at the SunWatch archaeological site (Miller, 2004). His study was limited to
Area A (Figure 1.5) using GPR and electrical resistivity. His GPR surveys were much higher resolution, collected in a point mode at a 10 centimeter spacing using both 500 and 900 MHz antennas with the GSSI Sir2. The detailed GPR grid was centered on the limestone slab location that Houston (2002) had discovered and was used to produce a 3D image (Figure 1.7). The electrical resistivity survey used the Sting/Swift system and consisted of 50 smart electrodes deployed in a grid over the location of the known limestone slab-covered burial. Miller used a pole-pole array with one fixed current electrode about 150 feet to the south and one potential electrode about 150 feet to the north of Area A (Figure 1.8). The limestone slab-covered burial was confirmed with both the higher resolution GPR and the resistivity surveys. Miller (2004) also took the earlier 2D resistivity profile results of Houston’s survey and concatenated them into 3D images (Figure 1.8).

![Figure 1.7 The 3D GPR results from Area A (Miller, 2004), showing multiple limestone-covered burials and multiple slabs indicated by the arrows.](image)
Figure 1.8 (A) High resolution (1.5 feet between electrodes) pole-dipole 3D resistivity map within Area A (Miller, 2004). The limestone slab-covered burial appears as a resistivity anomaly at a depth of 2.3 feet. (B) Concatenated 3D map at a depth of 1.8 feet by Miller (2004) using the 2D resistivity results of Houston’s (2002) showing high resistivity anomaly interpreted as limestone slab-covered burial.

Motivation for Research

The main motivation for this investigation was to evaluate geophysical methods to locate, map, and identify features that were associated with the SunWatch Indian Village archaeological site. Previous studies (Houston, 2002; Miller, 2004) have determined that burials covered with limestone slabs (Figure 1.3) are relatively easy to detect and map geophysically. In this study I planned to continue to identify and map limestone-covered burial sites in unsurveyed areas and attempted to identify the geophysical signature for trash/storage pits. The geophysical techniques used in this investigation were GPR, electromagnetic (EM), electrical resistivity, and a magnetic. Overall, the goal was to expand on previous work conducted at the site and to give the archaeologist a better understanding of the location and nature of unexcavated features below the present-day surface.
The four geophysical techniques (GPR, EM, electrical resistivity and magnetics) were used in different areas of the SunWatch Village archaeological site (Figure 1.5). Area A was previously surveyed by both Houston (2002) and Miller (2004) in their MS theses. Area A contains a known location of a limestone slab-covered burial that was located using GPR and electrical resistivity. The limestone slab-covered burials have a distinct geophysical character and were resurveyed to be compared to anomalies in other areas, making Area A the control area. The other areas of interest were Areas C, D, E and F which have not previously been surveyed. Each area was surveyed, however, not all techniques were applied to all of the areas of interest.

The results from each of the techniques were compared to develop a better understanding of the nature of geophysical anomalies and to interpret what each anomaly represents. The techniques previously used were modified slightly in the attempt to improve resolution. For example, the ground-penetrating radar surveys were conducted on a finer grid for control Area A (6 inch spacing) than that previously used. This permits examination of the impact of line spacing on the quality and detail of GPR surveys.
Chapter 2: GPR, EM, Resistivity and Magnetics

Theory of GPR

Ground Penetrating Radar is a geophysical technique that transmits electromagnetic energy in the form of radio waves into the subsurface where they can reflect from boundaries and return to the surface and be detected. A reflection results at a boundary between materials with different relative dielectric constant ($\varepsilon_r$) (Figure 2.1). The relative dielectric constant for a low loss material is the ratio of the speed of electrometric waves in a vacuum squared ($c^2$) divided by the speed of electromagnetic waves in a material squared ($V_m^2$) (Equation 2.1) (Reynolds, 1997).

![Figure 2.1](image)

Figure 2.1 The above diagram is a “simplified diagram of (A) the components of a GPR system with (B) the interpreted section of (C) the radargram display” (Reynolds, 1997; Butler et al., 1991; and Daniels et al., 1988).
Equation 2.1

\[ \varepsilon_r = \frac{c^2}{V_m^2} \]

The reflection coefficient at a boundary is related to the difference in radar velocity of the materials above and below the boundary (Equation 2.2). Therefore, the reflection coefficient is a relationship between dielectric constant of the materials above and below the boundary (Equation 2.2). The larger the difference in dielectric constant the larger the amplitude of the reflection (Reynolds, 1997).

Equation 2.2

\[ R = \frac{(V_1 - V_2)}{(V_1 + V_2)} \text{ or } R = \frac{\sqrt{\varepsilon_2} - \sqrt{\varepsilon_1}}{\sqrt{\varepsilon_2} + \sqrt{\varepsilon_1}} ; V_1 < V_2 \]

Theory of EM

 Electromagnetic (EM) induction is the process of propagating electromagnetic energy into the subsurface and as a result the conductivity can be measured and mapped. “The waves are made up of two orthogonal vector components, an electrical intensity (E) and a magnetic force (H) that are in a plane perpendicular to the direction of travel” (Reynolds, 1997). This can be seen in Figure 2.2. The primary electromagnetic field created propagates into the subsurface where it generates electric eddy currents in conductive materials. These secondary electric currents then produce a secondary out-of-phase magnetic field which can be observed together with the primary field at a receiving coil in the instrument (Figure 2.3) (Reynolds, 1997).
Figure 2.2 Schematic diagram of an electromagnetic wave showing the two main components that make up the wave. The components are an electrical (E) and magnetic (H) component (Reynolds, 1997; Beck, 1981).

Figure 2.3 Diagram illustrating how electromagnetic energy travels through the subsurface. The primary magnetic field that is created by the transmitter coil will induce eddy currents to form in the conducting body. The eddy currents then induce a second alternating magnetic field that will induce a current in the receiver coil. This induced current in the receiver coil will be recorded by the EM unit (Reynolds 1997; Grant and West 1965).

The electromagnetic induction survey unit used for this survey was a Geophysical Survey System Inc (GSSI) Profiler EMP-400 (Figure 2.4). The unit consisted of two coils of wire, one that transmits electromagnetic energy and one that receives electromagnetic energy. The unit was
able to transmit three frequencies, which in this study were 15,000 Hz, 11,000 Hz, and 7,000 Hz. Each of the frequencies is able to penetrate the subsurface to different depths relative to the skin depth of each frequency (Reynolds, 1997). Therefore, the lower frequency electromagnetic waves penetrate more deeply and are able to map variations in conductivity at greater depths whereas higher frequencies penetrate less deeply and map variations shallower in the subsurface.

![Figure 2.4 Image of GSSI's Profiler EMP-400. This image is from the GSSI website http://www.geophysical.com/profiler.htm](image)

The raw data from the EM surveys contain measurements of quadrature (i.e., conductivity) and inphase (i.e., magnetic susceptibility) at each frequency. Maps of quadrature (90° out of phase) and inphase at different frequencies can show variation in conductivity and magnetic susceptibility (i.e., how susceptible a material is to becoming magnetized) (Reynolds, 1997) at different depth ranges. Conductivity variations associated with limestone slabs and possibly storage/trash pits were targeted in this study.
Theory of Electrical Resistivity

Resistivity is a material property. Different materials have different resistivity values. An earth material and mixtures can have a range of resistivity values but also vary in relation to the presence or absence of water (Reynolds 1997).

The electrical resistivity method involves the injection of a known current (direct current or low frequency alternating current) into the ground between a pair of electrodes (current electrodes) and measuring the voltage difference (potential difference) between another pair of electrodes (potential electrodes). The potential difference is a result of the injected current passing through the subsurface measured at specific locations between the two current electrodes (Figure 2.5). Variations in the resistivity of materials in the subsurface affect the flow of current which affects the voltage difference observed at the potential electrodes on the surface (Reynolds, 1997; Burger, 1992).
Figure 2.5 Diagram showing current and equipotential lines produced by a current source (S1) and a current sink (S2). Note that this is with a prefect insulator (from Reynolds 1997; van Nostrand and Cook 1966).

Resistivity is defined by Ohm’s Law (Equation 2.3). Resistance (R) is the ratio of the voltage (V) measured at the potential electrodes and the current (I) injected into the material times a geometric constant (Reynolds, 1997).

**Equation 2.3**

\[ R = \frac{\Delta V}{I} \ (\Omega) \]

Resistivity (\( \rho \)) is a material property. Resistivity is a resistance (Equation 2.3) across a cross sectional area (A) over a distance (L) and is expressed in units of Ohm-meters (Equation2.4) (Reynolds, 1997).
Equation 2.4

\[ V = \frac{\rho l I}{A} (V) \text{ or } \rho = \frac{VA}{LI} (\Omega m) \]

A resistivity survey in its most basic form uses four electrodes, two current and two potential (Figure 2.6). A current is injected into the ground between the pair of current electrodes (C₁ and C₂ of Figure 2.6) and the resulting voltage difference is measured between an independent pair of potential electrodes (P₁ and P₂ of Figure 2.6). The relative distribution and geometry of the current and potential electrodes for a particular array type defines a unique geometric factor (K) (Equation 2.5) which for the dipole-dipole array used in this study is shown in Figure 2.7. The apparent resistivity (ρₐ) for a measurement using a dipole-dipole array is show in Equation 2.6 (Reynolds, 1997).

![Diagram](image)

**Figure 2.6** The above diagram is a generalized form of an electrode configuration. “C₁” and “C₂” are current electrodes. “P₁” and “P₂” are the potential electrodes (from Reynolds, 1997).

Equation 2.5

\[ K = 2\pi \left[ \frac{1}{AM} - \frac{1}{MB} - \frac{1}{AN} + \frac{1}{NB} \right]^{-1} \]
Figure 2.7 The dipole-dipole electrode configuration used in this electrical resistivity survey. The dipole-dipole array was used in this data collection (Reynolds, 1997).

Equation 2.6

\[ \rho_a = KR \, (\Omega \, m) \, (\text{general}) \]

\[ \rho_a = \pi n(n + 1)aR \, (\text{dipole-dipole}) \]

The resistivity survey conducted at SunWatch Indian Village used a dipole-dipole array which is sensitive to lateral variation within the subsurface. In this study multiple resistivity parallel profiles were collected and used to create a 3D apparent resistivity map of the subsurface.

Theory of Magnetics

When trying to understand the theory of magnetics one first needs to visualize the earth’s magnetic field which is a dipole and approximated by a large bar magnet within the earth orientated parallel to the axis. Magnetic lines of flux (vectors) enter and exit the earth’s poles. Magnetic North is where compass needles currently point and where lines of flux enter the earth and they exit the earth through the South Pole (Figure2.8). These lines of flux have both magnitude and direction (vectors). The strength of which is greatest were the lines of flux are closest together (Reynolds, 1997; Burger, 1992).
Figure 2.8 The above diagram shows the present day magnetic field of the earth which is like that produced by an imaginary bar magnetite in the interior if the earth. This diagram is from http://hyperphysics.phy-astr.gsu.edu/hbase/magnetic/magearth.html

The earth’s magnetic field varies both spatially and temporally. The magnetic lines of force can be deflected by a buried metallic object and the magnetic field can vary in relation to magnetic storms (solar winds). Anomalies created by metallic objects can have two different types of magnetic fields associated with them: (A) a permanent magnetic field that can be a different orientation than the earth’s magnetic field and or (B) an induced magnetic field caused by the earth’s magnetic field. In the latter case the induced magnetic field will be the same orientation as the current day magnetic field. Since magnetic metallic objects are not among the archaeological artifacts at this 800 year old site then induced magnetic anomalies are the focus of this survey (Reynolds, 1997; Burger, 1992).

For this project a gradiometer was used to measure the vertical gradient in the earth’s magnetic field. A gradiometer survey measures the gradient of the earth’s magnetic field on a local scale by using a pair of magnetometers separated by a fixed distance and measures the earth’s magnetic field at the same time. The readings from the sensor pair are subtracted to find the vertical difference or gradient of the local magnetic field. In this survey the gradiometer consisted of two vertically mounted proton precession magnetometers separated by 2 feet 8 inches.
A proton precession magnetometer consists of a cylindrical container filled with a proton (hydrogen atoms) rich fluid (kerosene) surrounded by a coil of wire. Initially the protons are aligned with earth’s magnetic field, but when a current is induced in the surrounding coil it creates a magnetic field to which the protons (tiny bar magnets) align themselves. When the current is switched off the protons process or rotate like a top around the earth magnetic field before they realign with the earth’s magnetic field (Figure 2.9). The rate of precession depends on the strength of the earth’s magnetic field. The precession back to the earth’s magnetic field induces a small alternating current in the coil at the precession frequency. “The frequency of precession is proportional to the strength of the total magnetic field because of the constant of proportionality know as gyromagnetic ratio of the proton” (Burger, 1992).

Figure 2.9 A diagram of how the protons in a proton precession magnetometer react when a current is induced in the coil of wire. (A) The arrows represents the position of the protons aligned with the ambient field (F) before the current is induced in the wire. (B) When current is induced in the wire the protons (arrows) will align with the induced magnetic field (\(F_a\)) created by the current. (C) When the current is turned off abruptly the protons precess as they align with ambient field (F) (Reynolds, 1997)

As the gradiometer approaches an induced magnetic field associated with a subsurface feature the two sensors will measure different values representing the sum of the induced field and the ambient field. The top sensor being farther from the source of the induced field will be affected less than the bottom sensor. Figure 2.10 is a simple schematic diagram showing how the two sensors respond differently to a total magnetic anomaly. Note that ambient and local induced field constructively add and destructively add up to total field anomaly.
Figure 2.10 A schematic diagram showing how the two sensors of a gradiometer respond differently to an induced magnetic field. The square represents a magnetic feature having an induced magnetic field parallel to the ambient field. The green arrows represent the ambient magnetic field of the earth. The blue and purple curves represent the magnetic anomalies measured by the bottom and top magnetometers respectively. The bottom magnetometer is being more affected by the local field produced by the magnetic anomaly.

In the case of this study the readings recorded by the bottom sensor were subtracted from the top sensor, resulting in a coupled pair of anomalies of opposite sign. The magnetic producing body will be located between this positive negative pair of anomalies. If magnetic anomalies are induced by the present day magnetic field their coupled positive and negative parts will be aligned with the ambient field (Reynolds, 1997).
Chapter 3: Methodology

The geophysical techniques used in this study were GPR (400 MHz antenna), EM, electrical resistivity and magnetics. However, not all the techniques were used in all areas. Each of the areas were surveyed for different reasons. The reasons will be discussed before going into detail about the design of the survey grid for each area.

GPR

The GPR unit used for each of the individual surveys was a GSSI SIR 3000 with a shielded 400 MHz bistatic antenna. The type of survey conducted was what GSSI refers to as Utility Scan i.e. 512 samples/scan, 16 bits/sample, 100 scans/second, 24 scans/foot, 4 feet/mark, and a dielectric constant of 8. Each of the GPR surveys used a 6 inch spacing between lines in both north-south and east-west directions (Figure 3.1) which facilitates 3D interpretation of the data. All the lines for one direction begin from the same reference baseline. The only area that did not have 6 inch spacing was Area F with 4 inch spacing between radar profiles.

Figure 3.1 Schematic diagram (not to scale) of the GPR profiles across Area A designed for 3D analysis. N-S Profiles were collected starting at the southern baseline (red) with a line separation of 6 inches. Then a series of E-W profiles were collected starting at the western baseline (blue) with a line separation of 6 inches. This pattern results in an overlapping grid for 3D analysis. A similar GPR acquisition plan was used for Area C, D, E and F
EM

The EM unit used for each of the individual surveys was a GSSI Profiler EMP-400. Each survey was collected in a point mode fashion with 2 feet between each data point and 2 feet between each line. Three different frequencies that used for each survey 15,000 Hz, 11,000 Hz and 7,000 Hz.

Resistivity

The electrical resistivity unit used in this project was an AGI (Advanced Geosciences, Inc.) Sting Swift automated resistivity meter with 28 smart electrodes in a dipole-dipole array. A series of 2D resistivity profiles were conducted over each of the study areas at a line spacing of 2 feet. Areas C and D were conducted with a 2.5 foot electrode spacing, whereas Area E used a 2 foot electrode spacing.

Magnetics

The magnetic surveys were conducted with a Geometrics proton precession gradiometer. Magnetic surveys Areas A and C were conducted during two field methods classes. The magnetics data were collected at a 2 foot grid spacing. Both magnetic surveys started in the southwest corner of the grid with next data point 2 feet towards the north. The next line in the sequence was 2 feet west of the previous line.

Area A

Area A was surveyed as a control in this study since it has a known location of a limestone-covered burial that had been previously detected with both GPR and resistivity (Houston, 2002; Miller, 2004). The limestone slab-covered burial has a distinct geophysical
signature that can be compared to geophysical to anomalies in other areas. The techniques
applied to Area A were GPR, EM and Magnetics (Table 3.1). Using a grid of dimensions of 34
feet by 50 feet (Figure 3.2).

![Figure 3.2 Schematic diagram of the grid layout of Area A. The grid was located on top of the
platform and encompassed most of the platform. The areas that were not added were the cutouts of
the platform towards the east where previous excavations took place. The red box in the southwest corner
indicates the start location of all three surveys. The orange lines represent the baselines that were used for the
GPR collection. The southern baseline was also used in the EM and magnetic survey. Note that this figure is
not to scale.]

<table>
<thead>
<tr>
<th>Table 3.1 Area A</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GPR July 30, 2010</strong></td>
</tr>
<tr>
<td><strong>First Dataset</strong></td>
</tr>
<tr>
<td>Origin</td>
</tr>
<tr>
<td>SW Corner</td>
</tr>
<tr>
<td><strong>Second Dataset</strong></td>
</tr>
<tr>
<td>Origin</td>
</tr>
<tr>
<td>SW Corner</td>
</tr>
</tbody>
</table>

| **EM June 25, 2011and Magnetics August 17, 2010** |
| Origin | Data Collection | Point Spacing | Point Progression | Line Spacing | Next Line in Sequence |
| SW Corner | Point Mode | 2 feet | Northward | 2 feet | East |
Area C

The position of Area C in the ring pattern of the village suggests a high probability of finding limestone slab-covered burials, a notion reinforced by the presence of four previously excavated limestone-covered burials immediately adjacent (Figure 3.3). No record of any previous excavation exists within Area C.

Figure 3.3 The above image is from Google Earth, of Areas A, C, and D respectively labeled. The red circles are the location of excavated limestone slabs. Three limestone slab-covered burials are located adjacent to the southwest corner of Area C. A number of the geophysical surveys were conducted directly over these slabs. Note that there are also three limestone-covered burials located between Areas A and D.

The grid constructed for Area C was not rectangular but was more asymmetrical due to the shape of the platform (Figure 3.4). The longest lines making up the grid were 60 feet long with the shortest lines roughly 26 feet long. A metal chain link fence lies along the eastern edge of this grid and had to be considered when analyzing the EM and resistivity data. A great deal of also honeysuckle lined the fence making data acquisition difficult. The geophysical techniques applied to Area C were GPR, EM and resistivity. The parameters for the GPR survey can be found within Table 3.2.
Figure 3.4 The above figure is a layout of the Area C grid. The black ovals represent the excavated limestone-covered burials located on the archaeological level. The green circle represents a large tree within the grid. The tree roots could possibly affect the geophysical results. The green shaded area represents the tree line along the chain link fence. The yellow lines represent the western and northern baselines that were used for data collection. The red square represents the origin point of the GPR and EM datasets. Note this image is not to scale.

<table>
<thead>
<tr>
<th>Table 3.2 Area C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GPR July, 2010</strong></td>
</tr>
<tr>
<td><strong>First Dataset</strong></td>
</tr>
<tr>
<td>Origin</td>
</tr>
<tr>
<td>NW Corner</td>
</tr>
<tr>
<td><strong>Second Dataset</strong></td>
</tr>
<tr>
<td>Origin</td>
</tr>
<tr>
<td>NW Corner</td>
</tr>
</tbody>
</table>

As previously stated the EM data was collected in point mode (individual data points).

The EM survey started in the northwest corner of the grid with the next point 2 feet towards the east. Each line consisted of 31 data points (60 foot line), however, due to the irregular shape of the grid many of the lines had token data points inserted at the end of the line to simulate a rectangular grid. These token data points were replaced with a dataset average value when later
interpolating the dataset. The entire grid consisted of a total of 31 lines of data. Only one operator was used to ensure consistency. The entire dataset was collected on October 23, 2011.

A series of 2D resistivity profiles were collected over several days in July, 2011. The type of array used was a dipole-dipole array with 28 electrodes with an “a” spacing of 2.5 feet between each electrode. The first electrode was placed 5 feet north of the northwest corner of the grid with the line of electrodes stretching roughly 70 feet due south of the first electrode. The first resistivity dataset was collected along the western baseline with subsequent 2D profiles being 2 feet east of the previous one.

Due to the non-uniform shape to the platform not all of the electrodes were initially on the platform. Several electrodes towards the southern end of each profile were actually on the archaeological level. As the 2D profiles marched towards the east more electrodes covered the top of the platform. The first 16 profiles consisted of all 28 electrodes. After profile 16 not all of the electrodes were used due to the irregular shape of the platform, the fence, and the tree line. The last 2D profile (profile 30) only consisted of the first 11 electrodes. Each of the profiles started with the first electrode being 5 feet north of the northern baseline.

**Area D**

Area D is located 14 feet east of Area A (Figure 3.5). Area D was chosen for this survey due to its location and there being a high probability of locating a limestone-covered burial (Figure 3.3). The excavated strip of land between Areas A and D has several excavated limestone-covered burial slabs (Figure 3.3). Since a known limestone-covered burial slab is located within Area A and limestone-covered burials slabs have been excavated between Area A and Area D it seems likely that a burial might be found within Area D. The geophysical
techniques conducted in Area D were GPR, EM and resistivity. The GPR parameters can are located within Table 3.3

![Figure 3.5](image)

Figure 3.5 The above figure shows the relationship of Areas A and D. The excavated zone between the two platforms is 14 feet and contains three limestone-covered burials. This suggests some likelihood of finding a limestone burial within Area D. Note that the southern baseline of the two grids are aligned with one another. The red squares represent the starting location of the GPR surveys. The orange lines represent the baselines. This image is not to scale.

<table>
<thead>
<tr>
<th>Table 3.3 Area D</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GPR July, 2011</strong></td>
</tr>
<tr>
<td><strong>First Dataset</strong></td>
</tr>
<tr>
<td>Origin</td>
</tr>
<tr>
<td>NW Corner</td>
</tr>
</tbody>
</table>

| **Second Dataset** |
| Origin | Profile Progression | Next Profile in Sequence | Profile Spacing | Profile Length (1st 21 profiles) | Profile Length (Remaining Profiles) |
| NW Corner | Southward | East | 6 inches | 58 feet | 18 feet |

The EM data was collected in a point mode (single measurement at grid points) starting in the southwest corner of the grid with the next point in sequence being 2 feet towards the north. The next line in the sequence was 2 feet east of the previous line. Each line consisted of 30 data points (58 feet) however due to the odd shape of the grid many of the lines had token data points at the beginning of the line to hold place. These data points were replaced with average...
background values when analyzing the data. Only one operator collected these data to ensure consistency. These data were collected in the winter of 2012.

The resistivity survey was collected over several days due to time constraints. The type of array used was a dipole-dipole array with 2.5 foot spacing between electrodes. Due to the shape of the platform two rectangular datasets were collected. The first dataset consisted of 14 electrodes. The first resistivity profile was conducted along the eastern baseline with the next profile 2 feet towards the west. The first electrode in each profile was placed 5 feet north of the northern base line. The last electrode was 32 feet due south of the first electrode. Not all of the electrodes were not on the platform due to the shape of the platform but the last electrode on top of the platform was the tenth electrode. The rest of the electrodes were on archaeological level. The first dataset consisted of 5 resistivity lines.

The second survey consisted of all 28 electrodes in a dipole-dipole array with 2.5 foot spacing between electrodes. The first profile of the second dataset was located 2 feet west of the Profile 5 of previous dataset. As before, the first electrode in each profile was placed 5 feet north of the northern baseline. The last electrode was placed roughly 5 feet south of the southern baseline. The second survey consisted of 6 resistivity profiles with the last profile located along the western baseline of grid.

**Area E**

Area E was located northeast of the village just outside the stockade. These dataset were initially acquired during a field class during the summer of 2011. The reason this location was originally chosen was to explore for possible locations of a pottery kiln. A great deal of pottery has been found at site but no kilns have been located. The location of Area E is not far from the
Great Miami River and a possible source of clay, water, and firewood. The area was also chosen based on an initial walkover GPR recon that seemed to show features of interest.

Area E was located 58 feet south of the paved driveway, paralleling the south side of the museum. The eastern edge of the grid runs along the N-S tree line. The grid dimensions were 40 feet by 56 feet. Located roughly in northeast corner of the grid is a drainage pipe (Figure 3.6). The opening to the pipe is 3 feet north of the northern baseline. The techniques used within Area E were GPR, EM, resistivity and magnetics. Table 3.4 has the parameters of the GPR EM and magnetic surveys.

Figure 3.6 The above figure is the layout of Area E. The grid was located outside of the stockade 58 feet south of the driveway located at the back of the museum. The red line within the grid represents the location of a drainage pipe. The pipe intersects the northern baseline at roughly 23 feet from the western edge of the grid. The pipe exits the grid along the eastern baseline at about 7 feet south of the northern baseline. The orange lines represent the baselines used for the radar collection. Note this figure is not scale.

The resistivity survey was collected over several days using a dipole-dipole array with 28 electrodes at a spacing of 2.0 feet between electrodes. The first electrode was placed on the southwest corner of the grid with the next electrode placed 2 feet east. The last electrode was placed roughly 54 feet east of the western baseline 2 feet from the eastern base line. The next line in the sequence was 2 feet north of the previous.
Two GPR surveys were conducted over Area E, one on August 23, 2011, a second on September 17, 2011. The second survey was conducted to try to get a better quality dataset for the 3D analysis of the data. Note that the repeated survey N-S dataset has an incorrect number of radar profiles indicating one was not collected, however another repeat was not conducted due to time constraints.

<table>
<thead>
<tr>
<th><strong>Table 3.4 Area E</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1st GRP Survey August 23, 2011</strong></td>
</tr>
<tr>
<td><strong>First Dataset</strong></td>
</tr>
<tr>
<td>Origin</td>
</tr>
<tr>
<td>SW Corner</td>
</tr>
<tr>
<td><strong>Second Dataset</strong></td>
</tr>
<tr>
<td>Origin</td>
</tr>
<tr>
<td>SW Corner</td>
</tr>
<tr>
<td><strong>2nd GRP Survey September 17, 2011</strong></td>
</tr>
<tr>
<td><strong>First Dataset</strong></td>
</tr>
<tr>
<td>Origin</td>
</tr>
<tr>
<td>SW Corner</td>
</tr>
<tr>
<td><strong>Second Dataset</strong></td>
</tr>
<tr>
<td>Origin</td>
</tr>
<tr>
<td>NW Corner</td>
</tr>
<tr>
<td><strong>EM Fall 2011</strong></td>
</tr>
<tr>
<td>Origin</td>
</tr>
<tr>
<td>NW Corner</td>
</tr>
<tr>
<td><strong>Magnetics August 2011</strong></td>
</tr>
<tr>
<td>Origin</td>
</tr>
<tr>
<td>SW Corner</td>
</tr>
</tbody>
</table>
Area F

The location of Area F (Figure 3.6) was chosen as part of a field methods class to seek possible evidence of stockade postholes. The excavated position of the stockade was nearby and projected across this area. If stones or broken pottery (“clinking stones”) had been used to reinforce the post, GPR may be able to detect and map the posthole pattern. The projected location of the stockade fence was the most predictable location of likely post in unexcavated areas. The GPR parameters can be found in Table 3.5.

Figure 3.7 The above figure is the layout of Area F. The grid was 12 feet by 12 feet with 4 inch spacing between radar profiles. Boards there were placed along the edges of the grid to align and measure along profiles. The orange lines indicate the baselines used in acquiring the GPR data. The green line represents the approximate location of the reconstructed stockade. It is believe that the stockade should continue through Area F. The black dashed rectangle represents the area were anomalies associated with the stockade would be expected to be observed. Note this figure is not to scale.
## Table 3.5 Area F

**GRP August 2011**

<table>
<thead>
<tr>
<th>Origin</th>
<th>Profile Progression</th>
<th>Next Profile in Sequence</th>
<th>Profile Spacing</th>
<th>Profile Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW Corner</td>
<td>Northward</td>
<td>East</td>
<td>4 inches</td>
<td>12 feet</td>
</tr>
</tbody>
</table>

**Second Dataset**

<table>
<thead>
<tr>
<th>Origin</th>
<th>Profile Progression</th>
<th>Next Profile in Sequence</th>
<th>Profile Spacing</th>
<th>Profile Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW Corner</td>
<td>Eastward</td>
<td>North</td>
<td>4 inches</td>
<td>12 feet</td>
</tr>
</tbody>
</table>
Chapter 4: Data Processing

GPR Processing

The GPR data of this study was processed using RADAN v.6.6. The processing for each of the GPR surveys began by reviewing at random individual radar profiles. Analysis of the random radar records tested a series of processing steps to determine a template for batch processing to be applied to the entire dataset for construction of a 3D dataset.

The first processing step was to shift times to a t=0 for the true ground surface on the radar record. The t=0 for the original records was the antenna self excitation at the initiation of the radar pulse. Shifting the data in time such that t=0 was at the ground surface reflections resulted in more accurate time to depth conversion of the data (Figure 4.1).

![Figure 4.1](image.jpg)

Figure 4.1: The above figure is of the same radar record from Area F that has had the position corrected for with RADAN 6.6. The radar record on left is the original record without any processing. The radar record on the right has had the data shifted to a time zero representing the ground surface reflections. The change in time in this example is 4.05 ns. During this process the header file is also updated with true time zero position.

The second GPR processing step applied was an FIR Filter for background removal using 81 scans. This process removes the high-amplitude horizontal banding which is caused by radar
multiples between the ground surface and the radar antenna. FIR filtering effectively removes the average trace determined by summing 81 traces. This process does not remove the low amplitude signal of less than 81 trace continuity or with dips which are modulated on and obscured by the surface multiple (Figure 4.2).

![Image](image.png)

**Figure 4.2** The above figure is of the same radar record form Area F that has had an FIR Filter for background removal applied using 81 scans. The radar record on the left is before the FIR Filter application, the radar record on the right has had the FIR Filter applied. The horizontal bands associated with surface multiples has been removed leaving behind low amplitude signals.

The third processing step applied to the GPR datasets was a linear range gain function to boost the weak signals remaining after the surface multiple removal (Figure 4.3). The linear function applied divided the radar trace into 6 equal sections bounded by nodes. The individual nodes were adjusted to increase the gain of the signal with the gain function linearly interpolated between nodes.
Figure 4.3 The above figure is of the same radar record from Area F showing the result of a linear range gain function. The radar record on the left is pre gain function. The radar record on the right has had the linear range gain function applied to make the signals viable.

Once the batch processing parameters were determined, a 3D dataset was generated using RADAN software. The resulting 3D cube of data was then analyzed by examining both vertical sections and time slices throughout the dataset to identify patterns and/or distinctive features. Table 4.1 is of the individual batch processing parameters used for the 3D datasets. Note for Areas D and E the individual radar profiles had their own time correction.

<table>
<thead>
<tr>
<th>Table 4.1 GPR Batch Processing Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Area</strong></td>
</tr>
<tr>
<td><strong>Time Correction</strong></td>
</tr>
<tr>
<td><strong>FIR Background Removal</strong></td>
</tr>
<tr>
<td><strong>Linear Range Gain Function</strong></td>
</tr>
<tr>
<td><strong>Node 1</strong></td>
</tr>
<tr>
<td><strong>Node 2</strong></td>
</tr>
<tr>
<td><strong>Node 3</strong></td>
</tr>
<tr>
<td><strong>Node 4</strong></td>
</tr>
<tr>
<td><strong>Node 5</strong></td>
</tr>
<tr>
<td><strong>Node 6</strong></td>
</tr>
</tbody>
</table>
EM Processing

The EM data was downloaded from the EMP-400 Profiler as three data files with extensions a .DZB, .GPS, and .EMI. The .GPS file contained GPS information. The .DZB file is a data file that can be read into RADAN Software to display the data. The .EMI file is an ASCII data file read directly by SURFER8 for analysis.

For each EM survey the data were brought in to SURFER8 and each of the individual frequencies were analyzed looking particularly at the measurements of inphase and quadrature. Using SURFER8 a series of contour maps of the data were created for both the inphase and quadrature components for each frequency. In SURFER8 the x, y parameters were the grid coordinates of each data point and the z parameter was one of the four different measurements to be mapped. The method used for gridding was Kriging.

Once the gridding of the data was completed contour maps of the data were created. In some cases extreme outlier data values were removed because they skewed the gridding process. In many cases multiple revisions or data edits were performed to produce a usable map image. After each contour map was created they were analyzed for any patterns or particular features of interest. The maps were compared to the results of other geophysical techniques to seek any correlation of anomalies between the datasets.

Resistivity Processing

The resistivity data was downloaded from the Sting unit as an ASCII file in AGI format and was converted to a .DAT file which contained all the surveys in one file. The software used to invert these resistivity data was RES2DINV version 3.57 by Geotomo. Before the .DAT files
were read into RES2DINV the individual survey lines were separated using the computer program Notepad, in which negative data points were also removed.

Each individual 2D resistivity profile was processed using RES2DINV. The first step was to “Exterminate Bad Datum Point” in which one can remove any outlier data point that might differ significantly from the adjacent values (Figure 4.4). The resulting edited data were then saved as a new .DAT file that was reread into RES2DINV for processing using Least Square Inversion (Equation 4.1).

![Figure 4.4](image)

*Figure 4.4 The above image is of the data points making up a resistivity line in Area D in the Exterminate Bad Datum Point mode. The red circles identify outlier data points that were removed.*

**Equation 4.1**

\[ (f^T J = \lambda F) d = f^T g \quad \text{where} \quad F = f_x f_x^T + f_z f_z^T \]

- \( J \) = matrix of partial derivatives
- \( \lambda \) = damping factor
- \( d \) = model perturbation vector
- \( g \) = discrepancy vector
- \( f_x \) = horizontal flatness filter
- \( f_z \) = vertical flatness filter
The least square inversion process produces a resistivity model and a RMS (root mean square) error percentage (Figure 4.5). For cases having a high RMS the data points were reexamined and reedited and the least square inversion was recalculated. This was done until the RMS was a reasonably low value (less than 10% error).

Figure 4.5 The above image shows the results of a least square inversion of Line 3 in Area D using RES2SDINV. The top cross sectional model is of the measured apparent resistivity. The middle cross sectional model is of the calculated apparent resistivity from the new model. The bottom cross section is of the results of the least square inversion or a cross sectional view of the resistivity along the profile. Note that units are in ohm-m.

Once the individual 2D resistivity lines were processed they were combined or concatenated into a 3D volume using the resistivity software RES3DINV by Geotomo Software. After each 3D volume was created it was carefully analyzed for any patterns or particulate futures of interest. Anomalies within the 3D volume were also compared to the results of other geophysical techniques to examine any correlation between the datasets.
Magnetic Processing

The gradiometer produces two raw data files one from the top magnetometer and one from the bottom magnetometer. These files are text files with the filename extension .DAT and can be opened in Microsoft Excel. In Microsoft Excel the values of corresponding data points for the pair of magnetometers were subtracted to give the difference or gradient of the vertical component of the magnetic field. The gradient value was also assigned to the correct x and y position in the Excel spreadsheet.

The combination data file was then bought into the SURFER8 (Golden Software Inc.) where the gradient data was gridded. The method used for gridding the data was Kriging. The gridding process included tests of the grid spacing. Initially 2 foot spacing was used, but eventually the spacing was decreased to 0.5 foot permit smoother interpolation (Figure 4.6).

From the gridded data contour maps of the data were created to examine the extent of any anomalies present. Outlier data values were removed because they were dominating the gridding process. In many cases multiple revisions had to be made to the original combination file to
produce a usable image. After each contour map was created they were carefully analyzed for any patterns or particular features of interest. The maps were also compared to the results of other geophysical techniques to examine any correlation between the dataset.
Chapter 5: Interpretation and Discussion

Area A

GPR Interpretation

Figure 5.1 The above figure is of the 3D processed results of Area A’s GPR survey. This image is at a depth of 0 feet. The red indicates the high amplitude positive values and the blue represents the high amplitude negative values.

Figure 5.2 The above image is of the results of the 3D processing of the GPR data from Area A. This image shows the 3D GPR results at a depth of 0.86 feet, which is above the archaeological level of interest. The black circles represent a series of high amplitude anomalies in a linear pattern. This pattern lies within the plow zone and post village sediments and cannot represent features associated with SunWatch.
Figure 5.3 The above figure is of the 3D processed results of Area A’s GPR survey. This image is at depth 1.88 feet. The black rectangle highlights a high amplitude anomaly that is associated with a limestone-covered burial (Houston 2002).

Figure 5.4 The above 3D images are of the GPR results of Area A for a depth of 1.45 ft. The left image includes data from all profiles at 6 inch spacing. The right image is constructed from only alternate profiles and represents a 12 inch profile spacing. Although the full dataset at 6 inch spacing shows more detail, the degraded results at 12 inch spacing are nearly equivalent and would have easily identified the burial site.
**EM Interpretation**

The raw EM data for Area A was brought into SURFER8 and the inphase and quadrature components of each of the individual frequencies were mapped as a series of contour maps. The gridding method used in SURFER8 was Kriging (Figures 5.5-5.7). Due the high-quality of the data there was no additional processing necessary.

![Contour Maps](image)

**Figure 5.5** The above contour maps are EM quadrature (top) and inphase (bottom) survey results at three different frequencies for Area A. From left to right (15,000 Hz, 11,000 Hz, and 7,000 Hz) each image represents deeper layers in the subsurface as a result of skin depth. The black polygon represents the known location of a limestone slab-covered burial found by Houston (2002). Note that there is a north south grain to the data that is parallel to the acquisition direction which is therefore likely an artifact.
Figure 5.6 The above contour map is of the EM quadrature 11,000 Hz result for Area A. The black polygon outlines the known location of a resistive limestone slab-covered burial found by Houston (2002). The white circle represents an area of low conductivity and corresponds to a location with a magnetic gradiometer anomaly.

The known location of a limestone slab within Area A was expected be imaged on the EM dataset as an area of low conductivity (resistive). The reason being was that both Houston (2002) and Miller (2004) were able to detect the limestone slab-covered burial as an area of higher resistivity (conductivity low). However, the EM data (Figure 5.6) indicates an area of higher conductivity at this location despite clear evidence of limestone slabs from GPR and resistivity surveys. This can be explained by the fact that limestone is not a conductive material and will not produce eddy currents associated with EM field mapping. Therefore, the slabs were not being detected but the surrounding conductive clay rich soil was producing the area of higher conductivity.
Figure 5.7 The above contour maps are of the EM 7,000 Hz quadrature (left) and inphase (right) result for Area A. The black polygon outlines the known location of a limestone slab-covered burial found by Houston (2002). The white circle represents an area of low conductivity and low magnetic susceptibility. This location also corresponds to an anomaly detected with the magnetic gradiometer. The black rectangles outline areas of high apparent conductivity and low magnetic susceptibility.

**Magnetic Interpretation**

The magnetic data was initially gridded using SURFER8 using the Kriging method of gridding with 2 feet spacing between the contours. This resulted in angular contours. The magnetic data were then gridded with 0.5 foot spacing rather than 2 foot spacing. This resulted in a map with smoother contours (Figure 5.8). The data were then displayed using a contour map with colored contours.
Figure 5.8 The left image above is a contour map of the magnetic survey of Area A using the Kriging method of gridding the data. The spacing that was 0.5 feet which results in contour lines more smooth in appearance. The image on the right is a 3D surface representation of the data.

Along the western edge of the grid were a series of high magnitude values an artifact likely of the way the data were collected. These anomalies were in a north-south linear trend parallel to the direction the data was collected. As a result these stations (lines 0-6) were removed from the dataset to show more variation between the contours within the middle of the grid (Figure 5.9). Another apparent edge effect occurring along the southern edge of the grid and was present for the first two data point in each of the lines. This most likely was related to a variation of the instrument and operators position along the side of the platform. As a result the first two data points were removed from the beginning each of the lines (Figure 5.9).
Area A Discussion

After reviewing all of the results from Area A the data confirm the presence of limestone-covered burial within Area A (Houston, 2002) (Figures 5.3 and 5.4). The limestone slabs were well defined using the 6 inch spacing between GPR transects, however the test using 12 inch spacing was found to be sufficient.

When analyzing the EM quadrature data for Area A the results were puzzling. The reason being is that the limestone slab-covered burial was not detected as a resistive anomaly (Houston, 2002; Miller, 2004) but as a conductive anomaly. This can be explained by the fact that limestone is a resistive material and it will not produce eddy currents associated with EM field mapping. However, it is possible the rich soil (Wea Soil) within which the slabs are embedded was conductive enough to mask the presence of local rock slabs.
An explanation for the areas of higher conductivity and low magnetic susceptibility (Figure 5.7) could possibly represent clusters of storage/trash pits. The higher conductivity could be associated with the organic rich material present within storage/trash pits. The source of the higher organic material could possibly be the result of the decayed food that would have been present in the trash pits.

Along the eastern edge of Area A, was distinctive anomaly at roughly coordinate (28, 25) that has an extremely low quadrature value (low conductivity). This anomaly appeared on the inphase (7,000 Hz) EM survey as a magnetic low. This area of low conductivity and low magnetic susceptibility was also detected with the magnetic gradiometer as an area of low magnetic susceptibility. Figure 5.10 shows this distinctive anomaly detected using the three different geophysical methods. It is not clear what, if any, archaeological feature this anomaly may represent.
Figure 5.10 The top left plot is the map of the EM 7,000 Hz quadrature survey, showing an area of extreme low conductivity (circle). The top right is the map of the EM 7,000 Hz, inphase survey with an area of low magnetic susceptibility outlined (circle). The bottom map is of the results of the gradiometer survey, showing an area of low magnetic susceptibility (circle) at the same location as the anomalies associated with the EM surveys.

The gradiometer survey also showed a distinctive pair of +/- anomalies located at roughly coordinate (27, 10). This pair of anomalies stands out because the extreme variation in reading over as short distance (3 feet) This may suggest a feature that is permanently magnetized based on it orientation. What was puzzling about this pair of anomalies was that there were no associated pairs located on the EM inphase results possibly indicating that this feature may have been extremely shallow and was not detected by the shallowest EM frequency (15,000 Hz).
Area C

GPR Interpretation

Time slices of the 3D GPR data of Area C reveal interesting patterns. A time slice at a depth of 0 feet, i.e., very near surface and above the archaeological level, exhibits a branching pattern suggestive of tree roots (Figure 5.11).

![Figure 5.11](image)

**Figure 5.11** The above map is of the 3D processed results GPR of Area C. This image is at depth of 0 feet (ground surface). The red indicates the high positive amplitude and the blue represents the high negative amplitude. The high amplitude branching anomalies along the eastern edge and central part of the area are believed to be associated with tree roots.

Careful analysis of the 3D GPR data of Area C reveals a distinct pattern at the archaeological level which appears as a series of high amplitude anomalies in a distinct oval pattern (Figure 5.12). This pattern is outlined by black circles on Figure 5.13 which is an enlarged version of Figure 5.12. Note that the image depth of 1.7 feet is located at the archaeological level. This oval pattern of high amplitude anomalies could possibly be an archaeological feature. Note that the gain function has been increased to show more contrast between the display colors.
Figure 5.12 The above maps are of the 3D processed results of Area C at a depth of 1.7 feet.

Figure 5.13 The above image is an enlarged view of the distinctive pattern of high amplitude anomalies at a depth of 1.7 feet. The oval feature is about 25x15 feet. The smaller pattern of anomalies to the West is about 5x10 feet. The significance of such patterns in the context of Sun Watch is unclear, since habitations tend to be rectangular. Note that the gain function was increased to show more contrast between the display colors.
EM Interpretation

The raw EM data from Area C was brought into SURFER8 and the inphase and quadrature components of each of the individual frequencies were mapped as a series of contour maps. The gridding method used in SURFER8 was Kriging. The initial contour maps were extremely distorted due to the location of a chain link fence along the eastern edge of Area C. Several processing techniques were applied to the data to remove the effect of the fence. The best approach found was to apply an average data value determined, from the data farther from the fence, to all the coordinate locations near the fence. Figure 5.14 – 5.17 are the results using this method.

Figure 5.14 The above contour maps are of EM quadrature (top) and inphase (bottom) survey results at three different frequencies for Area C. From left to right (15,000 Hz, 11,000 Hz, and 7,000 Hz) each image represents deeper layers in the subsurface as a result of skin depth. The area within the black outline represents the location of the unexcavated portion Area C. Anomalies located at or next to the black outline are a result of an edge effect of the platform.
Figure 5.15 The above contour maps are of EM quadrature results at the frequencies of 15,000 (left) and 11,000 Hz (right) and 7,000 Hz (bottom) for Area C. The black rectangles outline areas of high conductivity.
Figure 5.16 The above contour maps are of EM inphase results at the frequencies of 15,000 (left) and 11,000 Hz (right) and 7,000 Hz (bottom) for Area C. The black rectangles outline an area of low magnetic susceptibility. The white square outlines an area of low magnetic susceptibility most likely associated with the chain link fence located along the eastern edge of Area C.

An explanation for the areas of higher conductivity and low magnetic susceptibility could possibly represent clusters of storage/trash pits (Figure 5.15 and 5.16). The higher conductivity could be associated with the organic rich material present within storage/trash pits. The organic material would be the result of the decayed food that would have been discarded in the trash pit. These distinctive anomaly pairs of higher conductivity and low magnetic susceptibility were also detected in Area A (Figure 5.7).
Resistivity Interpretation

The resistivity data was initially examined using RES2DIV. Negative data values or extreme outlier data points were removed from each individual profile. The 2D files were then collated to produce a 3D data volume which was analyzed using RES3DINV. The resulting 3D model was then viewed as series of depth slices (Figure 5.17- 5.19).

Figure 5.17 The above maps are of the results of Area C 3D inversion of the resistivity data. The black outline represents the unexcavated area of Area C where the majority of the electrodes were located.
Figure 5.18 The above plots are maps of the 3D resistivity results of Area C showing 4 different depth slices. Layer 1 is between the ground surface (0 feet) and 0.49 feet depth which is above the archaeological level. Layer 2 is also above the archaeological level between the depths of 0.49–1.05 feet. Layer 3 is located roughly at the archaeological level between the depths of 1.05–1.7 feet. Layer 4 contains the archaeological level and is between the depths of 1.7–2.4 feet. Many of the shallower anomalies may be attributed to tree roots near the tree line to the east.
The above map is of 3D resistivity results from Area C between the depths of 1.7 and 2.4 feet. The results indicate that there is an area of higher resistivity (rectangle) located at the archaeological level. The circles represent two localized areas of higher resistivity possibly associated with archaeological features.

Area C Discussion

In the 3D GPR survey a set of approximately evenly space high amplitude anomalies are evident at a depth of 1.7 feet (the archaeological level). These high amplitude anomalies outline a distinctive oval pattern that is 25 x 15 feet. Clearly within the archaeological level depth, these may represent a unique dwelling or structure of some sort. Perhaps these high amplitude anomalies represent “clinking stones” used to support the post in the postholes. Due to apparent size of the possible structure (25 x 15 feet) it would likely have larger posts that would have penetrate deeper into the ground and possibly reinforced with large “clinking stones” or other hard fill. The “Big House”, the largest building structure recognized at SunWatch so far (dimension: 30 x 20 feet), was reconstructed with posts that were 8-12 inches in diameter and at a depth of 12 to 18 inches. Therefore, large clinking stones were used to support the large post
Based on the reconstruction of the “Big House” there is a possibility that these high amplitude GPR anomalies could be related to large posthole “clinking stones”.

A smaller pattern of anomalies (5 x 10 feet) was evident west of the large oval pattern. Perhaps these were also postholes and associated with an entry way into the larger structure. However, if these anomalies were related to a dwelling structure such a structure is distinctively different from the structures seen so far, which are rectangular. It would also suggest that the inhabitants did not live in a series of “circular” rings but in “semi circular” rings. Therefore, this location is an attractive target for excavations to conclude if the anomaly pattern was in fact associated with of a building structure or not.

The EM survey results of the quadrature data showed that roughly within the center of Area C was an area of higher conductivity running north-south (Figures 5.15). The result of the EM inphase survey (Figure 5.16) indicates an area of low magnetic susceptibility running southwest-northeast through the center of the grid. This features was more evident in the shallower levels (frequencies 15,000 and 11,000 Hz) indicating that the feature could be more modern cultural than archaeological. However, another possible explanation for these features (inphase and quadrature) was that they were associated with clusters of storage trash pits based on their geophysical signature.

A possible problem with the EM survey for Area C was that many data points needed to be removed or manipulated due to the effect of the chain link fence along the eastern edge of the area. The manipulation of the data points could have possibly distorted the rest of dataset. With removal of bad data points a great deal of interpolation was necessary to produce usable maps. In
hindsight, I would suggest that the fence be temporarily removed and the survey be reconstructed to acquire a better dataset for the area.

The electrical resistivity data from Area C (Figure 5.17) did not need to be edited as much as the EM survey, and therefore may have more credibility. Between the depths of 1.7 and 2.4 feet a large area of higher resistivity was located in the northern portion of the grid (Figure 5.19). However, due to the poor correlation with the other geophysical techniques (mainly the EM) it was difficult to characterize these anomalies as archaeological. As previously stated, the EM survey should be reconstructed to better determine if any of the resistivity anomalies correlate.

Area D

GPR Interpretation

![Area D GPR Interpretation](image)

Figure 5.20The above figure is of the 3D processed results of Area D’s GPR survey. This image is at depth 0 feet (ground surface). The red indicates the high amplitude signal (positive) and the blue represents the low amplitude signal (negative). Due to the shape of the platform many the radar lines were conducted not only on the unexcavated area but excavated area as well. The area within the black outline represents the location of the unexcavated portion of Area D. Note that the gain function was increased to show more contrast between the display colors.
Figure 5.21 The above figure is of the 3D processed GPR results of Area D. This image is at depth 1.7 feet (i.e., archeological level). No distinctive features of interest are evident. Note that the gain function was increased to provide more contrast between display colors.

EM Interpretation

The raw EM data for Area A was brought into SURFER8 and the inphase and quadrature components of each of the individual frequencies were mapped as a series of contour maps. The gridding method used in SURFER8 was Kriging (Figures 5.22 and 5.24). The initial contour maps were extremely distorted due how the data was collected. The problem was that the survey transversed not only the unexcavated areas of the platform but also the excavated areas adjacent to the east of the platform.

This data collection method resulted in a rectangular grid of data of 20 x 50 feet but the data from the excavated area needed to be removed so as to not affect the gridding of the data.
over the unexcavated area. This was done by changing the data values in the excavated area to an average data value. The values from data point coordinate (6, 28) were applied to all the data points located in the excavated area. Figure 5.22 and 5.24 are the results from Area D’s EM survey using this method of processing.

Figure 5.22 The above contour maps of Area D are of EM quadrature (top) and inphase (bottom) survey results at three different frequencies. From left to right (15,000 Hz, 11,000 Hz, and 7,000 Hz) each image represents deeper layers in the subsurface as a result of skin depth. The area within the black outline represents the location of the unexcavated portion of Area D. Note that there is a north south grain to the data that is parallel to the acquisition direction and likely an artifact of acquisition.
Figure 5.23 The above contour map is of the EM (quadrature 7,000 Hz) result for Area D.

Figure 5.23 has an area of lower conductivity (white circle) that also corresponds to an area of higher resistivity (Figure 5.26). The black circles represent areas of higher conductivity. A possible explanation could be an area rich in organic matter that more readily conducts electricity.

Figure 5.24 The above contour maps of Area D are EM inphase results at the frequencies of 11,000 Hz (left) and 7,000 Hz (right). The black circles represent areas of high magnetic susceptibility.
Resistivity Interpretation

The resistivity data was initially examined using RES2DIV. Negative data values or extreme outlier data points were removed from each individual profile. The 2D files were then collated to produce a 3D data volume which was analyzed using RES3DINV. The resulting 3D model was then viewed as series of depth slices (Figure 5.25 and 5.26).

Figure 5.25 The above figure is of the results of the 3D inversion of the resistivity data collected at Area D. The area within the black outline represents the location of the unexcavated portion Area C.
The above maps are of the 3D resistivity results of Area D (unexcavated area boxed) showing 3 different depth slices. Layer 1 (left plot) is between the depth of the ground surface (0 feet) and 0.70 feet which is above the archaeological level. Layer 2 (middle plot) is also above the archaeological level between a depth of 0.70 - 1.5 feet. Layer 3 (right plot) is between the depth of 1.5 – 2.4 feet. An area of high resistivity (circled) possibly attributed to an archaeological feature based on its depth.

Area D Discussion

The geophysical surveys conducted within Area D did not reveal any distinctive features. This was somewhat unexpected because the location of Area D was selected due to there was a high probability of having a limestone-covered burials (Figure 3.3). However, none of the geophysical data contained anomalies that might suggest the presence of any limestone slab-covered burials. A possible explanation for this is that during the early stages of excavation the site was transverse with a steel probe looking for the slabs. Most likely they transversed the entire site and if they hit something hard that was larger than a cobble they opened a pit to excavate as much of the site as possible. This could also explain why there were so few features of interest located within any of the other unexcavated areas studied.
Area E

Radar Interpretation

Area E was surveyed two different times with GPR, however both surveys did not result in quality data. The first survey was conducted in August 2011 and the quality of the data was poor, perhaps related to a GPR battery problem. The second survey was collected in September 2011 and during the data acquisition a radar line was skipped over by accident in the north-south dataset. This mistake was not realized until the data was being processed.

Due to time constrains a third dataset was not collected. However, an attempt was made to combine the first and second datasets into one 3D data volume. The south-north profiles were used from the first survey and the west- east profiles were used from the second survey. The process of correcting for the change to position had to be done individually for each of the radar profiles to assure that they would be properly aligned when making the 3D dataset.

![Image](image.png)

Figure 5.27 The above figure is of the 3D GPR processed results of Area E. This image is at depth 0 feet (ground surface). The red indicates the high positive amplitude and the blue represents the high amplitude negative signal. Note that the gain function was increased to produce for more contrast between display colors.
Figure 5.28 The above figure is of the GPR 3D processed results of Area E. This image is at depth 1.7 feet (archeological level). The black box represents the location of a known drainage pipe also seen on the magnetic survey. After analyzing the entire 3D dataset there does not seem to be any distinctive anomalies.

EM Interpretation

The raw EM data for Area A was brought into SURFER8 and the inphase and quadrature components of each of the individual frequencies were mapped as a series of contour maps. The gridding method used in SURFER8 was Kriging. The initial contour maps were extremely distorted due to the presence of a buried drainage pipe that crosses the north east corner of the grid of Area E (Figure 3.5).

Several processing techniques were applied to the data to remove the pipe effect. The method giving the best results was substituting an average data values based to all the data points affected by the buried drainage pipe. Along the eastern edge the grid a series of outlier data values occurred and believed to be the effect of modern day features (fence wire?) because it was located close to the tree line near the old road. These data values were replaced with adjacent data values. Figure 5.29 – 5.31 are the results from using these methods of processing.
The above EM contour maps are of Area E, quadrature (top) and inphase (bottom) at three different frequencies. From left to right (15,000 Hz, 11,000 Hz, and 7,000 Hz) each image represents deeper layers in the subsurface as a result of skin depth. The black rectangles outline areas of high conductivity and low magnetic susceptibility.

An explanation for the areas of higher conductivity and low magnetic susceptibility could possibly represent clusters of storage/trash pits (Figure 5.29) containing more conductive organic rich material. Similar anomalies patterns were detected in Areas A and C.

The above contour maps are of the EM 11,000 Hz (left) and 7,000 Hz (right) quadrature results for Area E. The white parallelograms represent areas of low conductivity. The left two anomalies contained within the parallelograms also appear on the inphase plots of the same frequency as an area of higher magnetic susceptibility (Figure 5.31). These anomalies could possibly be related to an archaeological feature (pottery kiln).
The above contour maps are of the EM 11,000 Hz (left) and 7,000 Hz (right) inphase results for Area E. The white parallelograms represent areas of high magnetic susceptibility. These two anomalies correspond to two areas of low conductivity (Figure 5.30). As previously stated these anomalies could possibly be related to an archaeological feature (pottery kiln). The black circle represents a pair of magnetic susceptibility anomalies orientated east west that also appears on the magnetic gradiometer survey (Figure 5.33).

**Resistivity Interpretation**

The resistivity data was initially examined using RES2DIV. During the examination of the individual lines the incorrect electrode spacing was discovered. The data were collected with 2 foot electrode spacing but the Sting/Swift settings were incorrectly set at 2.5 foot spacing. Attempts to back calculate and fix this problem were not successful. As a result no useable resistivity data are available for Area E.

**Magnetic Interpretation**

The magnetic data were initially gridded using the Kriging method of gridding with 2 foot spacing between the data points. This resulted in an extremely coarse grid. To smooth the contouring the data were gridded in SURFER at a 0.5 foot interval (Figure 5.32).
Figure 5.32 The above contour map is of the Area E’s magnetic survey using the Kriging Method of gridding the data. The spacing that was used was 0.5 feet. The thick black line in the northeast corner represents the location of a buried drainage pipe. The extreme high data point value at coordinate (28, 12) was believed to be an outlier.

The data table was then examined the singular high value at coordinate (28, 12) was removed. The data was then plotted using the Kriging Method with 0.5 spacing, a contour map as well as a 3D relief map were produced (Figure 5.33).
Figure 5.33 The above color contour map (and underlying oblique relief map) are the magnetic survey results for the Area E survey. The outlier data point of Figure 5.32 has been removed. The thick black line in the northeast represents the location of a buried drainage pipe. The distinctive +/- pair of magnetic anomalies (circled) is of unknown origin and located outside the village stockade. This anomaly was also detected on the shallower (15,000 Hz and 11,000 Hz) EM inphase results (Figure 5.31).

Area E Discussion

The 3D GPR results from Area E did not provide any features of interest. However, this may be a consequence of the attempt to combined two different survey datasets into the 3D dataset. There could possibly have been some error with aligning the two datasets. Measures were taken to attempt to edit the files individually, however, when reviewing the 3D dataset it appears that the east and west portions of the grid do not align at depth. For this reason features of archaeological interest may have been lost in the data processing. Therefore, this GPR entire dataset should be recollected in the future to insure no features of interest were overlooked.

The quadrature data EM results indicate three areas of low conductivity (resistive) detected with the 11,000 and 7,000 Hz frequencies (Figure 5.30). Two out of these three low
conductivity anomalies were also detected in the inphase (11,000 and 7,000 Hz) data as areas of high magnetic susceptibility (Figure 5.31).

A possible explanation for the areas of high magnetic susceptibility and low conductivity (Figure 5.30 and 5.31) is a pottery hearth or baked clay, as baking increases the magnetic susceptibility of a soil. This occurs because the weakly magnetic iron oxides (hematite) in the clay and silt are changed into highly magnetic oxides (magnetite) when burned in the presence of organic matter. Therefore, a fire hearth will result in an area of high magnetic susceptibility due to the presence of magnetite and lower conductivity because the organic material would have been burned off and the clay minerals baked (Bartington Instruments, 2008). However, it is puzzling that this feature did not appear on the magnetic survey.

The results of the inphase EM survey indicate that there was pair magnetic susceptibility anomalies (black circle) located along the southern portion of the Area E (Figure 5.31). These anomalies correspond to a pair of +/- anomalies on the magnetic survey (Figure 5.33). The distinctive +/- pair of magnetic anomalies are of unknown origin and located outside the village stockade. The east west orientation of these anomalies suggests a feature that was permanently magnetized.
Area F

GPR Interpretation

Figure 5.34 The above image is of the GPR 3D results of Area F. This image is at depth 0 feet (ground surface). The red indicates the high amplitude signal (positive) and the blue represents the low amplitude signal (negative). The nearly reconstructed stockade projects across the area outline by a dashed line. Note that the gain function was increased to allow for more contrast between display colors.

Figure 5.35 The above image on the left is of the GPR 3D processed results of Area F. This image is at depth 1.07 feet near or just above the archaeological level. There does not seem to be any distinctive anomalies within dashed rectangle. However, there is a high amplitude diffraction anomaly (circled) that appears at a depth of 1 foot on the right hand side of Area F. The above image on the right is a fence diagram intersecting at the distinctive high amplitude anomaly. Based on this anomalies location in relation to the projected location of the know stockade it is not believed to be associated with the stockade but may be an archaeological feature. Note that the gain function was increased to show more contrast between the display colors.
Figure 5.36 The above image is of the 3D results of the Area F GPR survey at a depth of 1.52 feet, which is roughly the archaeological level. There is a high amplitude anomaly (circle) that lies just outside the projected location of the stockade (dashed rectangle). The anomaly appears at depth of 1.48 feet and dissipates at a depth of about 1.60 feet. Note that the gain function was increase to allow for more contrast between the display colors.

Area F Discussion

After analyzing the 3D GPR data volume no distinctive anomalies were found that suggest the presence of postholes. This may not be unexpected because the posts of the stockade were roughly 3 to 5 inches in diameter and may not have significant “clinking stones”. A single local strong anomaly at 1.07 feet was not located near the projected location of the stockade (Figure 5.35). It is difficult to speculate what this feature may represent because no other geophysical techniques were conducted within the area.
Chapter 6: Survey Discussion

After reviewing the results from each of the geophysical techniques, it was apparent that each of the techniques has its own set of advantages and disadvantages for locating archaeological features. Ground penetrating radar was able to detect limestone slab-covered burials and produce quality detailed images of the slabs. This was initially established by Houston (2002) using 2D GPR profiles and confirmed by Miller (2004) using a 3D GPR dataset which he believed was able to delineate the individual slabs (Figure 1.7). A 3D GPR dataset of that same area in the present study was preformed to establish a standard for 3D GPR datasets of other yet unexcavated areas. This 3D GPR dataset was able to image the limestone slabs of this control area well and confirm the results of Houston (2002) and Miller (2004).

A further study at the control area (Area A) previously studied by Houston (2002) and Miller (2004) evaluated the effect of line spacing upon the 3D dataset. Profiles were collected at 6 inch line spacing in the N-S and E-W directions and processed as 3D using both 6 inch spacing and 12 inch spacing by selecting alternate lines. Comparison of the results indicated that the 3D dataset using 6 inch line spacing was incrementally better at defining the subtleties of limestone slabs than the 12 inch line spacing (Figure 5.4). The edges of slabs were imaged with greater detail with the 6 inch spacing compared to the 12 inch spacing, however, the 12 inch line spacing was still quite able to detect and map the limestone slabs. Both 2D and 3D GPR datasets in this study were unable to convincingly image features potentially associated with storage/ trash pits, even with the 6 inch spacing.

The results of the EM survey of Area A were discouraging at first. They did not reveal any significant anomaly associated with the known limestone-covered burial discovered by
Houston (2002). Perhaps thin slabs of low conductivity limestone embedded within a more conductive soil do not produce eddy currents that are needed to produce a conductive anomaly in an EM dataset. Consequently the EM method may not be useful for detecting and mapping limestone slab-covered burials.

Based on the results of both the quadrature and inphase maps it seems evident that EM was able to detect areas of high conductivity and low magnetic susceptibility possibly related to clusters of storage/trash pit features. EM was able to detect a feature that had a high magnetic susceptibility that and a low conductivity suggesting a possible fire hearth. However, this feature did not appear on the magnetic data set, which was contradictory.

Electrical resistivity surveys were found to be extremely effective in previous studies in detecting limestone stone slab-covered burials (Houston, 2002; Miller, 2004). The limestone slabs appeared in the inverted resistivity results as areas of higher resistivity surrounded by more conductive soil (Figure 1.8). In the present study resistivity surveys over other unexcavated areas at SunWatch did not discover similar resistive anomalies. This may suggest that limestone slab-covered burials are less common than expected in the yet unexcavated areas of the village. Also, despite the strong likelihood that storage/trash pits would be common in the unexcavated areas surveyed the resistivity data of this study did not show any clear anomalies likely indicating storage/trash pits. Perhaps the storage/trash pits have electrical properties extremely similar to the surround soil which would make them indistinguishable in the resistivity dataset.

Gradiometer surveys were successful in defining magnetic anomalies that correlate with EM inphase results (Figures 5.10, 5.31 and 5.33). The EM inphase data, however, indicate an area of low magnetic susceptibility suggesting that it is unlikely to be associated with the baked
clay of a fire hearth (Figures 5.10, 5.31 and 5.33). A possible explanation is that the features are located at shallower depth and are related to more modern day cultural features.

Geophysical methods define anomalies which can help target archaeological excavation. Clearly the only way to know for sure the cause of a geophysical anomaly would be to excavate. However, some additional geophysical methods could be tried. A cesium magnetometer is much more sensitive than the proton precession magnetometer used in this study. A study in 2003 at Stanton Drew, England, was conducted with a cesium gradiometer which was able to detect a series of nine circles made up of individual pits, each roughly 1.4 meters in diameter (Figure 6.1). These circles of pits were not evident on the present day surface (David, et al., 2003). Therefore, more a sensitive magnetic survey using a cesium gradiometer at SunWatch might be able to detect subtle difference associated with storage/trash pits.

Figure 6.1. The results from a cesium gradiometer survey conducted in Stanton Drew, England. The image on the left shows the processed results from the survey. The darker areas represent larger pits within the circles. The image on the right is an interpretation of the results. Red indicates positive magnetic anomalies (from David, et al., 2003).

In the present study except for Area A, it would appear that there are no undiscovered limestone slab-covered burials within the areas examined. Areas C and D were targeted in this study because proximity to excavated limestone slab-covered burials, yet in these areas no
geophysical anomalies were discovered that might indicate the presence of limestone slabs. Perhaps few, if any, undiscovered limestone slab-covered burials remain at SunWatch. Perhaps this indicates that previous excavations or agricultural activity discovered and removed them or that the distributions of such burials were not uniform. Trench archaeology undertaken during the amateur phase of excavations in the 1970s excavated along a grid at even spaced intervals and probing was done with a metal rod across the whole site. It is possible that many limestone slabs were discovered with the metal rod and were excavated as a result, but refilled. Areas excavated by professional archaeological have been left at the original village level but older excavations that were refilled may not be recognized as having been excavated. This could explain a general absence of limestone slabs in areas presently thought to have not been excavated.

The SunWatch archaeologist Andrew Sawyer has communicated that over 400 storage/trash pits have been located at SunWatch (Sawyer, pers. comm. 2010). Based on the results of the EM surveys it is possible that a geophysical signature has been determined for storage/trash pits. However, before excavation other geophysical techniques could be investigated. As mentioned above perhaps a more sensitive cesium magnetometer may be successful in mapping the small contrast possibly associated with storage/trash pits (i.e., David, et al., 2003).
Chapter 7 Conclusions

The basic purpose of this geophysical study was to evaluate different geophysical methods for mapping and identifying features associated with SunWatch Indian Village. Based on the results from this survey and previous surveys it is evident that GPR was useful in detecting limestone slab-covered burials (Houston, 2002; Miller, 2004). There also is evidence suggesting that GPR was able to detect possible posthole “clinking stones” associated with a larger building structure of oval outline. On the other hand GPR was not able to detect smaller “clinking stones” associated with stockade postholes. GPR was also not able to detect features associated with storage/trash pits.

It is apparent from this study that EM was able to detect areas of high conductivity and low magnetic susceptibility in several locations. These are interpreted to be related to clusters of storage/trash pits. The EM instrument was also able to detect an area of low conductivity and high magnetic susceptibility that is speculated to be associated with a fire hearth based on this geophysical signature. However, the EM unit was not able to detect the location of a known limestone slab-covered burial.

It is evident based on previous surveys conducted at SunWatch that electrical resistivity was able to detect resistive anomalies associated with limestone slab-covered burials (Houston, 2002; Miller, 2004). On the other hand, resistivity was not able to definitively detect features related to the subtleties of storage/trash pits, perhaps because of the small differences in conductivity involved.
From the magnetic survey with the proton precession magnetometer only a few distinctive anomaly+/− pairs were located. However, it is unclear if they are associated with archeological or modern cultural features.

Another, smaller purpose of this survey was to identify a geophysical signature that is associated with storage/trash pits. Based on the EM quadrature and inphase results it is believed that areas of high conductivity and low magnetic susceptibly are associated with clusters of storage/ trash pit. A possible explanation is that when the food and other organic material that was discarded into a trash pit decayed it would have left the soil with a higher organic content. The higher organic content of the soil would more readily induce eddy currents associated with EM mapping compared to the surrounding in soil. Therefore, areas of high conductivity and lower magnetic susceptibly may suggest areas of clustered storage/ trash pits.

The final purpose of this study was to compare the difference between 6 inch GPR profile spacing to 12 inch GPR profile spacing. Based on the results of this survey it was clear that 12 inch profile spacing was suitable for detecting large anomalies associated with limestone slab-covered burial.

An future study that could be conducted at SunWatch Indian Village to explore mapping of storage/trash pits would be the use of a Cesium Magnetometer. It is believed based on this study that proton precession gradiometer is not sensitive enough to detect the magnetic subtleties associated with storage/ trash pits. However, from studies elsewhere (David, et al., 2003).it is believed that a cesium magnetometer might be able to detect the subtleties associated with storage/trash pits.
This study along with previous studies conducted at SunWatch Indian Village will improve archaeologist understanding of possible features located in unexcavated areas (Houston, 2002; Miller, 2004). Archaeologist will be able to avoid some areas based on the detection of limestone slab cover burials. In addition, excavation could explore a possible fire hearth or kiln suggested by this study outside the stockade in Area E.

Overall, the author feels that this survey conducted at SunWatch Indian Village was a success in mapping many features that could be targeted by archaeological excavations. Also it is the hope of this author as well as the authors of previous studies that a section of the onsite museum be devoted to geophysics a display (Houston, 2002; Miller, 2004). Showing how geophysics can aid in the location of many archaeological features associated with SunWatch Indian Village.
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