Fort St. Joseph is a 17th-18th century French (and later English) mission-garrison-trading post complex located in southwest Michigan. A geophysical survey was performed and the results of the survey were tested through archaeological excavation. The geophysical methods included ground penetrating radar, electromagnetic induction, electrical resistivity, magnetic gradiometry, and magnetic susceptibility. The results of the archaeological excavations demonstrate that magnetic gradiometry was the preferred geophysical method at this particular site. The magnetic gradiometer survey included both terrestrial and possible submerged portions the site. Laboratory analysis of the magnetic susceptibility and magnetic viscosity of soils and rocks demonstrated that the archaeological features at Fort St. Joseph have a statistically significant magnetic contrast with those of the natural soils. This study has the potential to contribute to the fields of French colonial archaeology, wet site archaeology, and soil and rock magnetism. Recommendations for future research are suggested, including investigating a possible submerged cultural resource located a few meters north of the existing riverbank.
A GEOPHYSICAL SURVEY OF FORT ST. JOSEPH (20BE23),
NILES, MICHIGAN

by

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CHAPTER I

PROJECT BACKGROUND

Geophysical methods applied to archaeological problems are increasingly being recognized as a valuable tool for characterizing subsurface cultural deposits prior to excavation (Johnson 2006). Archaeological geophysics encompasses an assortment of noninvasive methods for the analysis and delineation of subsurface archaeological deposits. The noninvasive nature of geophysical methods is attractive to the modern archaeologist, tasked with managing the balance between conducting field research and implementing a site conservation management plan.

The geophysical surveys discussed in this project helped guide excavations during the 2002 Western Michigan University Archaeological Field School at the Fort St. Joseph site (20BE23). Prior to initiating this work, some project goals for the 2002 season were outlined. This study describes how geophysical methods were used to meet some of those project goals and subsequently help answer some important questions about the Fort St. Joseph archaeological site.

Fort St. Joseph Archaeological Project: 2002 Project Goals

During October of 1998, faculty and students from the Western Michigan University Anthropology Department discovered a deposit of eighteenth century artifacts and associated animal bones at a location suspected to contain evidence
of Fort St. Joseph in Niles, Michigan (Nassaney et al. 2003; Nassaney 1999). The results of the 1998 survey were promising, but the high ground water table resulting from a milldam constructed downstream made it impossible to determine whether or not the cultural deposits had integrity. In 2002, the Western Michigan University Archaeological Field School returned to the site under the auspices of the Fort St. Joseph Archaeological Project (FSJAP) in order to conduct a geophysical survey and continue subsurface investigations. The research team proceeded with a number of goals in mind. The goals were to: (1) establish the vertical stratigraphic relationships of the cultural deposits, (2) recover a larger sample of undisturbed artifacts and biological remains, and (3) identify in situ subsurface features including in situ architectural remains to establish site integrity and assist in interpretation (Nassaney et al. 2002-2004: 310).

As the 2002 research goals suggest, the 1998 survey team was uncertain regarding the integrity of the cultural deposits within the project area. The high water table prohibited visual inspection and identification of the subsurface cultural deposits, making it impossible to determine their integrity. Moreover, local artifact collections and historic photographs suggested that the location of Fort St. Joseph was laid to the plough and under cultivation during the nineteenth century (Ballard 1973). Furthermore, the site is closely bound on the south and east by a twentieth century landfill, complicating the issue of site integrity. To overcome the problem of the high water table, we employed a sophisticated well point drainage system (Cremin 2002; Nassaney et al. 2002-2004). With the drainage system in place, a stratified random subsurface testing strategy and a multi-instrument geophysical survey were initiated.
The Geophysical Problem

When we considered using geophysics to help locate the remains of Fort St. Joseph, our research questions were twofold. First, can geophysics help the FSJAP locate in situ subsurface features including architectural remains? Second, if geophysics could help us, what types of geophysical instruments are best suited to find archaeological remains at this location? These research questions are closely allied with the greater FSJAP goals stated above. In order to test our research questions and meet our project goals we: (1) performed geophysical surveys with multiple instruments, (2) determined which geophysical anomalies were likely cultural in origin by examining their geophysical response characteristics, and (3) tested a series of geophysical anomalies through archaeological excavation in order to determine if they represent in situ cultural deposits associated with colonial Fort St. Joseph. At the beginning of the 2002 field season, we were unsure whether the cultural remains on the bank of the St. Joseph River had integrity. The research presented within this study will demonstrate how geophysics assisted in the identification and evaluation of undisturbed archaeological deposits at Fort St. Joseph.

Significance of the Research

As described above, the purpose of this work is to employ a geophysical survey and evaluate its results within the context of the greater FSJAP 2002 project goals. Beyond the context of the project goals, this research has the potential to inform on the application of geophysics on other French colonial
archaeological sites, as well as sites located in wet environments. Moreover, some of the research on soil and rock magnetic properties will be of interest to specialists in soil/rock magnetism and archaeological geophysics.

**French Colonial Sites**

A brief overview of the history of geophysical surveys at French colonial sites in the Midcontinental United States is provided in Chapter II. This background research supplies an introduction for individuals considering a geophysical survey at a French colonial site in the region. Magnetometer surveys dominate the research at these sites, and the research reported in this study is no different. Two types of features previously detected with magnetometry at French colonial sites are stone hearths and cylinder shaped pits (water wells) (Huggins and Weymouth; von Frese 1978, 1984). These types of features were also found during our magnetometer survey. Cylinder shaped pits and fire hearths are excellent targets for magnetometry. Furthermore, burnt daub (burnt clay chinking) has been reported at some of these sites and this material is also an excellent target for magnetometry.

French colonial archaeologists might be interested in learning what types of archaeological features are detected during geophysical surveys at these types of sites. The literature review in Chapter II demonstrates that stone hearths, water wells, and burnt daub architectural elements have been detected with magnetometry at French colonial sites in the past and the findings reported here in Chapter V are similar.
Wet Environments

Wet environments can significantly interfere with some geophysical methods. Electrical resistivity (ER) and electromagnetic methods such as electromagnetic induction (EM) and ground penetrating radar (GPR) are hindered by the electrical properties of water. The high conductivity of water and water-saturated soils can ‘mask’ underlying archaeological deposits from the ER and EM methods. Moreover, water saturation of the soil tends to flatten out the geophysical results and lessen the contrast between the archaeological and natural deposits. With the GPR method, high water content increases the dielectric permittivity of the soil, limiting the effective depth of investigation. When the soil is both wet and highly conductive, all three of these geophysical methods are limited in their ability to detect archaeological deposits.

The site drainage method discussed in this study (Chapter III) will be of interest to those archaeologists who desire to conduct a geophysical survey at wet sites. The drainage system facilitated the removal of large quantities of water from the Fort St. Joseph site, allowing for the use of geophysical methods that are otherwise not appropriate for use on wet sites.

Soil and Rock Magnetism

The study of soil and rock magnetism is an important element of many disciplines including humanitarian de-mining, rock geology, environmental magnetism, geophysics, paleomagnetism, and paleoclimatology among others. Chapter VI explores the differences between the magnetic properties of the natural and culturally emplaced soils at Fort St. Joseph. Of particular interest
are the relationship between magnetic susceptibility and the frequency dependence of susceptibility (also known as magnetic viscosity) between the natural and cultural soils.

The study of soil and rock magnetism is a broad discipline with a wide variety of applications in many fields. In archaeology, it has long been known that humans change the magnetic characteristics of the soil, mostly through the use of fire. In this study, Chapter VI outlines the use of soil and rock magnetism techniques to discriminate culturally emplaced soil from that of natural soil. These methods, although commonplace in many disciplines, are rarely applied at North American archaeological studies, especially at historic sites. Hopefully, the positive results of this study will influence others to attempt similar research at other historic sites. At the very least, the application and outcome of these techniques, as reported in Chapter VI, will contribute to the small but growing list of research into this sub-discipline of archaeological geophysics in North America.

Organization of this Study

This study begins with a literature review (Chapter II), which provides an overview of the history of Fort St. Joseph, a brief history of archaeological geophysics, and a look at previous geophysical work conducted at French colonial sites in North America. A description of the relatively recent change in the site geology is covered in Chapter III, including an explanation of the water drainage methodology we used to dry out this site. Chapter IV describes the field and laboratory methods used to collect and process the geophysical data reported in this study. Select geophysical anomalies and their associated
excavation results are presented in Chapter V. Chapter VI follows with explanations derived from experimental and laboratory results as to why some geophysical methods worked better at this site than others. The concluding chapter (Chapter VII) summarizes the results of the study in relation to the FSJAP goals, and also presents some potential directions for future research.
CHAPTER II

LITERATURE REVIEW

A Brief History of Fort St. Joseph

In 1679, the French explorer René-Robert Cavalier de La Salle explored the St. Joseph River during his travels through the western Great Lakes. The strategic importance of this area was recognized by the French and by the 1680s, a group of Jesuits were granted a tract of land near Niles, Michigan. In 1691, a mission-garrison-trading post was established, which came to be known as Fort St. Joseph.

The location of the fort was selected because it is near an important portage linking the St. Joseph River and the Great Lakes basin to the Mississippi River drainage. This strategic location was one point along the trade and communication network that connected the French territories in the western Great Lakes basin to the other French colonies along the Mississippi River. The establishment of the mission-garrison-trading post at this location served to intensify the fur trade, solidify relations with the western tribes, and also served to check the expansion of the Five Nations Iroquois Confederacy (Brandão 1997; Brandão and Nassaney 2006; Eccles 1972; Meyers and Peyser 1991).

From 1691-1781, Fort St. Joseph served as an important center of religious, military and commercial activity for Native peoples and European colonists in southwestern Michigan. During the eighteenth century, the fort
ranked fourth among New France’s trading posts in the volume of furs traded (Harris 1987). Fort St. Joseph had become one of the most important frontier posts in the western Great Lakes region (Brandão and Nassaney 2006).

Fort St. Joseph also played an important role in the interactions between Native Americans and their French and English counterparts on the western frontier. The fort acted as a supply center during the 1720s and 30s for military contingents in the Fox Wars and also later (1736-40) throughout a campaign against the Chickasaw nations (Nassaney et al. 2003). With the onset of the Seven Years War in 1755, the French garrison stationed at the fort was withdrawn, leaving behind approximately one dozen fur traders and their families.

Beginning in 1761, after 70 years of French occupation, the British military began their occupation of the fort, and some English traders joined them to continue the fur trade with the remaining French traders (Meyers and Peyser 1991). British rule in the region marked an era of increased tension between Native Americans and the English. In the spring of 1763, a group loyal to the powerful Ottawa leader Pontiac attacked the fort. This attack was part of a conflict historically known as ‘Pontiac’s Rebellion’ and also included attacks on other forts in the region. The British did not regarrison Fort St. Joseph after Pontiac’s Rebellion, but an estimated 10-15 households remained and continued the fur trade.

In 1781, a small group of French and Native Americans, with the support of the Spanish Governor in St. Louis, raided and occupied the fort for one day. The fort was not reoccupied after the Spanish-sponsored raid, however traders remained in the region until eventually becoming part of America’s Northwest
Territory during the nineteenth century (Nassaney et al. 2003).

**Types of Archaeological Features Expected**

Brandão and Nassaney (2006) overview the built environment and demographics of Fort St. Joseph based upon documentary sources. The documentary literature suggest that at various times Fort St. Joseph contained ~15 households, a commanders house, a home for a Native leader, a blacksmith/gunsmith, a stone built jail with iron architectural elements for security, a storehouse, a barracks for ~20 soldiers, and a ‘post in ground’ type palisade around either some or all of Fort St. Joseph. The total permanent population of the fort probably did not exceed 45 people, although the seasonal population could have been significantly higher during the summer months, a time of heavy trading activity.

The types of buildings at Fort St. Joseph could have possibly been *poteaux sur sole* architecture. This type of architecture is built upon stone foundations in contrast to post in ground constructions. Furthermore, French colonial architecture often used clay daub, or *bouzillage* as a chinking material (Moogk 1977; Peterson 2001:41-44; Thurman 1984:2; Waselkov 2002:9). One would also expect to find water wells inside of the palisade because during times of conflict, access to the water in the river may have been limited. Moreover, given the cold climate in southwest Michigan during the winter months, one would expect to find fireplaces or hearths at the site.
In 1938, Mark Malamphy conducted the first documented archaeological geophysical survey at Williamsburg VA (Bevan 2000). Malamphy used an equipotential instrument that was unsuccessful in identifying cultural features (there were none at the location surveyed), but he did map a naturally occurring high resistance anomaly. Eight years later, English archaeologist Richard Atkinson conducted the first electrical resistivity survey of an archaeological site (Clark 1996:12). Around this time, similar electrical resistivity experiments were employed in Mexico to locate fossilized human remains (De Terra 1947). Martin Aitken (1958) was the first archaeologist to experiment with magnetometry, demonstrating the great potential of this method. In the Midwestern United States, Glenn Black was the first North American archaeologist to use the electrical resistivity method (Black and Johnston 1962; Johnston 1964). In 1958, he conducted a survey with a relative resistivity instrument at the Angel site, a Mississippian mound center, in Indiana. A few years later, Black used magnetometry at the Angel site, again becoming the first archaeologist to employ this method on North American soil (Black and Johnston 1962, 1967; Johnston 1964). During this period, Richard Ford was among the first to experiment with resistivity in Michigan at both the Schultz site and Norton Mound Group (Ford 1964; Ford and Keslin 1969).

These early surveys were time-consuming endeavors, owing to the relatively slow sampling speed of the instruments. With the advent of faster instruments and digital recording methods, geophysical applications have been used by the archaeological community as time saving methodologies that are capable of pinpointing excavations right on top of archaeological features of
interest, lowering the cost of expensive and time consuming subsurface testing (Linington 1961, Linington 1963, Weymouth 1986, Wynn 1986). Other arguments used to justify the use of geophysics in archaeology include the non-invasive nature and repeatability of the techniques (Kvamme 2003; Smekalova 1992).

Recent advances in geophysical instrumentation and digital processing of data allow users of the technology to obtain higher densities of data over larger areas very rapidly (Kvamme 2000). This revolution enables archaeologists to map entire sites in high detail, often employing multiple types of instruments. Results from modern geophysical surveys can actually resemble features, structures, palisades, roads and entire settlements, whereas traditional archaeological testing can only reveal what has been excavated, often representing a very small sample (Kvamme 2003).

Recent Trends in Archaeological Geophysics

The trend towards larger and larger surveys has led to a small but growing compilation of literature that asserts archaeologists should use geophysical data for more than just finding features (Anuskiewicz 1998; Dalan 1993; Kvamme 2000; Kvamme 2003; Somers 2002; Summers et al. 1996; Toom and Kvamme 2002). Dalan (1993) was one of the first to suggest that geophysical data can be used to look at archaeological deposits that are both larger and smaller than an individual feature (see also Dalan and Banerjee 1996, 1998; Dalan and Bevan 2002). At Cahokia Mounds State Historic site, the premier mound group in North America, Dalan used geophysics at larger scales than most archaeologists employ at typical sites. This led her to suggest that
geophysics has broader application such as, “...understanding site or feature formation processes, geomorphic settings, human impact on the landscape, community organization, settlement patterns, and many other issues” (Dalan 1993:69). Other researchers have argued that geophysical studies should be used as “primary” data to formulate questions of archaeological significance concerning spatial relationships and settlement organization (Kvamme 2003, Summers et al. 1996, Toom and Kvamme 2002). For example, Toom and Kvamme (2002) hypothesize that one uncharacteristically large and well-defined geophysical anomaly, clearly in the shape of a large prehistoric lodge, might have had different social significance than the smaller structures at the Whistling Elk Village site (39HU242). This is significant because they are able to start posing hypotheses about the nature of geophysical anomalies, prior to the start of archaeological excavations.

Geophysical Prospection at Midcontinental French Colonial Sites

Since the 1970s, there have been numerous high quality geophysical surveys conducted at French Colonial sites in the Midwest and Great Lakes region. Underwater archaeologists first used metal detection during 1973 at Fort Charlotte, MN to recover metal artifacts from wet mucky sediments around the area of a cedar log crib dock (Wheeler et al. 1975). Excavations and subsequent plotting of artifact recoveries from around the crib dock provide excellent spatial information about the informal underwater dumping ground that had built up (Wheeler et al. 1975:42). Fort Charlotte was later surveyed with a total field proton magnetometer that readily detected stone “fireplaces” (Huggins and Weymouth 1979:3).
In 1974, a cooperative research team from Purdue University and Michigan State University initiated magnetometer research at Fort Quiatenon (12-T-9) on the Wabash River in northwestern Indiana (von Frese 1978, 1984; von Frese and Noble 1984). The magnetometer survey at Fort Quiatenon recorded many anomalies that subsequent excavations revealed as concentrations of burnt daub, large pits, wells, linear anomalies, and iron artifacts. Other magnetometer surveys near Fort Quiatenon in the Wabash River valley have documented a contemporary Native American village site (12-T-6), and a mixed French and Native American settlement called Kethtippecanunk (Jones 1987; Trubowitz and Jones 1987). At the Notre Dame University campus, magnetometry was unsuccessful in locating the 17th century Jesuit mission site of Ste. Marie des Lacs, but successful in locating 19th century cultural deposits (Schurr 1993).

In Illinois, Missouri, and Kansas, numerous surveys were conducted at French Colonial sites. Fort de Chartres III was surveyed by magnetometry (Bevan 1977) and later revisited with electrical resistivity (Melburn 1982). Fort de Chartres I was successfully investigated with electromagnetics and magnetometry (Weymouth 1982; Bevan 1983; Weymouth and Woods 1984). Fort Kaskaskia was investigated by magnetometry with good results (Weymouth 1982; Weymouth and Woods 1984). Across the Mississippi River in Ste. Genevieve, MO, there have been two magnetometer surveys and one resistivity survey (Bevan 2002). In Kansas, a proton gradiometer survey pinpointed “the location of the Catholic Mission to the Miami Indians near Paola, Kansas”, however the cultural affiliation of the Catholic missionaries are not mentioned in this news brief (Myers 1979).
Surprisingly, there has been very little geophysical work on French Colonial sites in Michigan. The notable exception was the electrical resistivity survey conducted immediately outside of Fort Michilimackinac in search of the 18th century village site (Williams and Shapiro 1982). During the late summer of 1978, Williams and Shapiro employed the double-dipole electrical resistivity technique and surveyed nearly one acre. Even by today’s standards, this is a relatively large survey. The survey also employed modern survey strategies and post processing techniques, including the use of standard sized grids, post-processing of data on an IBM compatible computer, and computer generated contour maps. NASA donated the computer program used for the project, and the computer-generated contour maps were printed out at the University of Georgia Computer Center. The authors recorded 84 electrical resistivity anomalies, but at the time of writing their report, none had been tested. The later English and American sites of Fort Wilkins and Mackinac were also surveyed with geophysical methods (Grange 1987; Young and Droege 1986).

Summary

In consideration of all previous work on French Colonial sites in the region, the magnetometer survey conducted at Fort Quiatenon is the most useful for comparative purposes. Quiatenon is relatively close to Fort St. Joseph and the two sites are contemporaneous.

At Quiatenon, von Frese (1978, 1984) reported rock, daub, and well-like features during the testing of his magnetometer survey. Along with these features, he recorded numerous magnetic anomalies, likely from iron objects, a seemingly ubiquitous material on historic sites.
Since Fort St. Joseph and Fort Quiantenon are culturally and temporally related, and geographically close, one should not be surprised if these two sites had similar material remains. The documentary research performed by Brandão and Nassaney (2006) suggest that Fort St. Joseph might indeed contain material remains that are very similar to what was found at Fort Quiatenon, including stone building materials, iron objects, and daub.
CHAPTER III

SITE GEOLOGY AND DRAINAGE METHODOLOGY

Site Geology

The project area is located in a low-lying, seasonally wet area on the south side of the St. Joseph River in Niles, Michigan (Figure 1). The project area is surrounded on the east and south by a 20th century landfill, and bounded on the north by the St. Joseph River.

![Figure 1. Fort St. Joseph Archaeological Site 2002 Project Area. Red excavation units represent geophysical anomaly test locations.](image)

The uppermost 25-30 cm of sediment consist of highly organic alluvium. This sediment was deposited during the past 60+ years as the result of local
hydrology changes. Sometime after 1938, the 1914 French Paper Company dam, located 375 m downstream, was raised by approximately 60 cm. This 60 cm increase in dam height raised the ground water table and increased the frequency of flooding resulting in the recent organic alluvial deposition found at the site. Soundings of the St. Joseph River were made with the site transit while the stadia rod was positioned in a small boat powered with an electric trolling motor (Figure 2).

Figure 2. Schematic Cross-section of the St. Joseph River. Fort St. Joseph archaeological site stratigraphy. I) Organic alluvium; II) 19th-20th-century plowzone; III) 18th-century cultural deposits; IV) Yellow-brown sterile sand. View looking upstream. Vertical scale is exaggerated ten times (Modified after Nassaney et al. 2002-2004: Figure 9).

The organic layer is underlain by a late 19th – early 20th century gray silt loam plow zone. Locals surface collected artifacts from this plow zone nearly a century ago, many of which are currently curated in the Fort St. Joseph Museum located in Niles, Michigan. The buried plow zone yielded hundreds of 18th century artifacts, and thousands of faunal remains during the 2002 field
season (Becker and Martin 2002; Giordano and Nassaney 2002).

Immediately below the old plow zone are undisturbed cultural deposits associated with the 18th century occupation of the site. The soil matrix in this stratum varies across the site from yellow brown silty sand “B horizon” soils to heavily mottled, gleyed silty-loams. All of the intact cultural features discovered during the 2002 field season originate from within this stratum.

Below the B horizon soils are sterile yellow brown sands. These sands extend down to from ~2 meters to ~ 8 meters below the ground surface. Below the yellow brown sterile sand is a layer of silty clay that extends to a depth of at least 10 meters (Stevens 2000).

Drainage Methodology

When the 2002 Western Michigan University Archaeological Field School entered the field on May 13, the St. Joseph River was in flood stage. At this time the site was covered by nearly one meter of water. One week later the site remained covered by 10-15 cm of water. We could not begin site drainage until the river’s water had receded back within its banks. This occurred during the last week of May, so we dispatched a crew of able-bodied students to start clearing the site of brush, deadfall trees and sixty years of flotsam. The yearly flooding had washed in flotsam in the form of both metallic and non-metallic trash, as well as organic materials. There were numerous large deadfall trees and tree limbs that had to be removed. Other small live trees and brush were cut down flush with the ground surface so that the GPR antenna could remain coupled with the ground during survey. Fine grooming of the site was performed with iron rakes to further remove smaller organic and historic debris.
prior to setting up the site grid.

On May 31, DeWind Dewatering of Zeeland, Michigan arrived and installed 65 well points connected (in series) to a single large diesel pump located on top of the landfill just downstream (east) of the site (Figures 1, 3). The well point drainage array encompassed an area of approximately 2,200 square meters (Nassaney et al. 2002-2004). The array was arranged in a horseshoe shape with the open end facing downstream. The on-site components of the drainage array consisted of ‘geophysical friendly’ materials including: PVC well points, PVC pipe main line, flexible plastic tubing, and rubber elbows. The large diesel engine (pump) was located off site so as not to interfere with the magnetic gradiometer results.

Summary

When we started the 2002 archaeological field season, Fort St. Joseph was under nearly one meter of floodwater. Once the water receded the banks of the St. Joseph River, we were able to employ a sophisticated well point array to further remove standing water and rapidly dry out the site. With the site drained of standing water, we were able to clear the site of debris, layout a survey grid, and perform a geophysical survey of the project area. Without the well point drainage system, none of this research would have been possible during the 2002 field season.
Figure 3. Well Point Drainage System. Installation of the well point site drainage system by DeWind Dewatering of Zeeland, Michigan (Photo courtesy of M. Nassaney).
CHAPTER IV

GEOPHYSICAL SURVEY METHODOLOGY

On June 5th, 2002, Professor William Sauck and the WMU Field Geophysics Class (GL 564) arrived at the project area to conduct the geophysical surveys. Four geophysical methods were employed in the field including ground penetrating radar (GPR), electromagnetic induction (EM), electrical resistivity (ER), and magnetic gradiometry (magnetometer). In addition to the field geophysics, numerous soil samples were collected and brought back to the lab for magnetic susceptibility studies (MS). After excavations were completed, we extended the magnetometer survey to cover an area of 2800 square meters to further delineate and determine if any submerged portions of Fort St. Joseph could be detected beneath the St. Joseph River.

Because floodwaters kept us off the site for nearly three weeks, the geophysical survey had to be conducted at the same time as on going excavations. Stratified random excavations, based upon artifact densities recovered during the 1998 shovel test pit survey, were place along the riverbank along the north edge of the drainage array. We roped off a 475 square meter geophysical grid immediately south of the test excavations. Students participating in the test excavations were instructed to keep all metal tools and objects as far away from the geophysical grid as possible. On more than one occasion, the field school students were asked to step away from their excavations while the geophysical survey came into close proximity.
Ground Penetrating Radar (GPR) Methodology

The GPR survey encompassed an area of 430 square meters collected as 64 transects of a combined 780 linear meters (Figure 4, Appendix A). The GPR data were acquired with a Geophysical Survey Systems Inc. SIR-10A+â“ digital radar control unit with a bistatic 500 MHz antenna (model 3102A).

![Ground Penetrating Radar Survey Area](image)

Figure 4. Ground Penetrating Radar Survey Area. The area (430 sq/m) covered by the ground penetrating radar survey.

All data files were collected as 16 bit (.dzt) files with a 60ns time window. The parallel GPR profiles were located 0.5 meters apart with 2 m fiducial markers located along all transects. The relative dielectric permittivity ($\varepsilon_r$) was estimated by the hyperbolic fit method between $\varepsilon_r=18-22$. The high relative dielectric permittivity can be attributed to the high water content of the organic rich soils. Raw data were processed with multiple software packages, including
RADAN™, GRORADAR™ and GPR_PROCESS. Two dimensional radar profiles were combined to produce 3D time–slice amplitude images of the subsurface, and displayed in the mapping program SURFER™ v. 7.0 (Appendix A).

Electromagnetic Induction (Conductivity) Methodology

The electrical conductivity survey encompassed an area of 475 square meters (Figure 5; Appendix B). Conductivity data were acquired with a Geonics Limited, Model EM38 DLM-H™ (40.3 KHz operating frequency).

Figure 5. Electromagnetic Induction Survey Area. The area (475 sq/m) covered by the electromagnetic conductivity survey.

A DAP Microflex™ hand held computer running MS DOS 6.62™ operating system was used as a data logger. Geonics proprietary DAT38pro logging software was used to record data in the field. The survey occurred over parallel transects located 0.5 m apart. Readings were taken at 0.5 m stations, with a
stack (average) of 10 readings at each station location. Data were compiled in DAT38™ for WINDOWS™, and exported to the mapping program SURFER™ for display (Appendix B).

Magnetic Gradiometer Methodology

The first magnetometer survey, conducted in June 2002, encompassed an area of 475 square meters (Figure 6, Appendix C). This first survey was used to make decisions in the field about the placement of archaeological excavations.

Figure 6. Magnetic Gradiometer Survey Area. The area (2300 sq/m) covered by the magnetometer surveys.
Magnetometry data were acquired with a Geometrics model 858 Mag Mapper™ cesium-vapor gradiometer with sensors spaced at 0.8m. The bottom sensor was held ~ 0.3m off the ground during survey. Parallel magnetometer transects were located 0.5 meters apart, with 2 m fiducial markers located along each line. During this first survey, the survey lines were all traversed heading from south to north as a ‘one way’ survey. The instrument was programmed to record ten readings per second. All data was exported to the mapping program SURFER™ to create display maps.

The second magnetometer survey, conducted during July 2002, extended out into the St. Joseph River in an attempt to acquire data over the possible submerged portions of the site. The second survey increased the area coverage to 1050 square meters (Figure 6). This survey required wading in nearly chest high water with the magnetometer held at shoulder height. Long wooden stakes marked the grid corners, and floatable plastic rope with painted markers marked out the survey lines. Excluding the chest high water and floating grid lines, all survey procedures and instrument setup were identical with the first survey. However, the greater height of the sensors when held above the water led to smoothing, attenuation, and decreased spatial resolution of sub-bottom magnetic features.

A third wintertime magnetometer survey extended out over the frozen St. Joseph River for combined area coverage of 2300 square meters (Figure 6, Appendix C). We extended the grid out over the ice with a standard builders level. Grid corners were marked out with spray paint. Because of safety concerns regarding thin ice, we decided to survey this portion of the grid in a bi-directional, zigzag pattern. Reducing the amount of walking on potentially thin
ice. This introduced a ‘saw tooth’ heading error of about 0.35 m into the data, a common defect of zigzag surveys. Furthermore, we had to use a loaned instrument (courtesy of Geometrics) during this portion of the survey that was not in ideal working condition. The sensors on the rental instrument registered weak signals and recorded sporadic ‘0’s’. These were easily removed during post-processing, and since the data rate was 10 readings per second, a few missing points still allowed for very dense coverage along lines. The instrument also had a considerable amount of operational ‘noise’, which mapped out as linear streaks in the final map (Appendix C). Regardless of these instrument related issues, the data remains useful, with some underwater anomalies present.

**Electrical Resistivity Methodology**

The electrical resistivity survey encompassed an area of 300 square meters (Figure 7, Appendix D). Electrical resistivity data were acquired with an IRIS SYSCAL R-2™ resistivity system set up with a custom built Wenner probe array (“a” spacing of 0.5m), specifically made for archaeological investigations.

Readings were taken at 0.5 m stations along transect lines separated by 0.5 m. The apparent resistivity ($\rho_a$) from the recorded voltage (V) and current (I) was determined using the formula:

$$\rho_a = 2\pi \frac{V}{I} a$$

All readings were recorded by hand in the field. Resistivity data were entered into Microsoft EXCEL™ and imported into SURFER™ to create contour maps.
Magnetic Susceptibility Methodology

Field Methods

One hundred ml soil samples were acquired during fieldwork from selected archaeological test excavations (Appendix E). Soil samples were assigned standard field accession numbers associated with the arbitrary level from which they were removed. In some test excavations, the soil samples were collected at 10 cm arbitrary levels, and in some cases, by natural stratigraphic units. All soil samples were brought back to the WMU archaeological lab for further analysis with a Bartington MS2B™ laboratory grade dual frequency sensor. Furthermore, field measurements were made on 116 random stones and
boulders along the St. Joseph River with a Bartington MS2D™ field coil (Figure 8, Appendix F).

The measurement of the magnetic susceptibility on the random sample of local stones helped us better understand the magnetic properties of local building materials that would have been available to the occupants of Fort St. Joseph and will be discussed further in Chapter VI.

Figure 8. Field Magnetic Susceptibility Survey. The author performing a field magnetic susceptibility survey of naturally occurring rocks along the St. Joseph River (Photograph courtesy of B. A. Bilodeau Lynch).

Laboratory Methods

All soil samples were dried at room temperature in open air. The dried samples were broken up and manually ground with a non-metallic mortar and
pestle. Ground samples were visually inspected for the removal of large root inclusions. To remove smaller root and organic contamination, the samples were then sieved thru graduated cylinders, with the finest mesh being 0.85 mm (0.0331”). The soil was then recombined, excluding only those inclusions that exceeded 2 mm in size. The processed soil samples were then weighed and stored in 10 ml polyethylene vials for final analysis. Three unique samples of stone, burnt daub and soil from a 1” diameter core were also processed (see Appendix E). The stone sample (02-1-174) recovered from Feature 6 was crushed and stored in a 10 ml sample vial. The second special sample (02-1-172) was a chunk of fired daub recovered from Feature 7, Zone 2. The last special sample (02-1-207) was a soil sample recovered from a 1” diameter soil core recovered in the center of Feature 2, at 10 cm below the 2002 excavations. All three special samples were processed in a similar manner to the regular soil samples and stored in 10 ml vials.

Dried, sieved and weighed 10 ml samples were subjected to volumetric ($\kappa$), mass specific ($\chi$), and frequency dependence ($\chi_{fd}$%) magnetic susceptibility measurements (see Appendix E). Magnetic susceptibility measurements were acquired with a Bartington MS2™ meter attached to the dual frequency MS2B™ laboratory grade sensor. Mass specific measurements ($\chi$) were acquired at both high frequency (4.6 kHz) and low frequency (0.46 kHz) in order to determine the frequency dependence percentage of $\chi_{fd}$% (also known as magnetic viscosity). Bartington’s proprietary software MULTISUS™ corrected for the instrument drift during each measurement. Results were exported to a PC compatible spreadsheet for further analysis and graphic display.
Summary

A multi-instrument geophysical survey was carried out at Fort St. Joseph during the 2002 field season. Methods employed include GPR, ER, EM, and magnetic gradiometry. The area covered by the different geophysical methods varied. In addition to the field surveys, soil and rock samples were collected and studied to determine their magnetic susceptibility and magnetic viscosity characteristics in order to aid in the interpretation of the magnetic gradiometer survey. Furthermore, a field magnetic susceptibility survey of locally occurring rocks in the St. Joseph River valley helped us to understand the range of variability in that parameter.
CHAPTER V

GEOPHYSICAL ANOMALY TESTING

During the period May 31 thru June 21 2002, the FSJAP investigated 20 square meters, representing 12 excavation units of various sizes (Figure 1). Seven excavations units were outside the geophysical grid near the riverbank where shovel test pits, conducted in 1998, indicated high artifact densities. To identify in situ subsurface features, including in situ architectural remains within the geophysical grid, we tested five geophysical anomalies in five separate excavations (8 m²) (Table 1). Nominal designations for all test excavation locations designated their southwestern XY grid coordinates (e.g., N27 E14).

Four of the five geophysical guided excavations recovered indisputable evidence of the Fort St. Joseph occupation (Table 1). We avoided high frequency magnetic dipole anomalies typical of surface iron artifacts, and opted to test locations that had a higher probability of being architectural remains and features represented by monopole and low frequency dipole signatures. In short, we targeted anomalies that had a high probability of being archaeological features, and a low probability of being singular artifacts.

Primarily, we used magnetometer data to guide the excavations because some anomalies resembled archaeological features. Three of the excavations relied solely on magnetometer data (Anomalies #1, #3, and #4). One excavation was based upon combined magnetometer, GPR, and electrical resistivity data (Anomaly #2). The only unsuccessful test excavation depended solely upon GPR data (Anomaly #5).
<table>
<thead>
<tr>
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<td>Feature 7 Possible well</td>
</tr>
<tr>
<td>N22 E02</td>
<td>MAG</td>
<td>Anomaly #2. Magnetic dipole, high amplitude GPR reflector, high electrical resistivity</td>
<td>Feature 6 Stone hearth</td>
</tr>
<tr>
<td>N25 E08</td>
<td>MAG</td>
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<td>N36 E39</td>
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<tr>
<td>N17 E06</td>
<td>GPR</td>
<td>Anomaly #5. GPR reflector.</td>
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Table 1. Geophysical Anomalies. List of the location and findings of the anomalies tested during this study

Anomaly #1 (Feature 7)

Conductivity and Resistivity Anomaly #1 (Feature 7)

Neither the EM nor the ER surveys could detect Anomaly #1 (Figures 9-A, 9-B). At this location there was a low resistivity / high conductivity southwest to northeast trend. This trend was resultant from a naturally occurring swale of low-lying wet organic soil. The moist, organic surface layer
‘masked’ Anomaly #1 from detection with the EM and ER instruments.

**Magnetometer Anomaly #1 (Feature 7)**

Anomaly #1 was most readily identified as a > 3 m diameter, +75 nT/m monopolar magnetic anomaly (Figure 9-C). This anomaly immediately caught our attention due to its large size, round shape, high amplitude and low-frequency smooth contours. Generally, deeply buried objects and features exhibit smooth contours. Magnetometry was the sole method used in selecting this anomaly for excavation.

**GPR Anomaly #1 (Feature 7)**

Anomaly #1 showed up on GPR profiles: File 12, File 13, and File 14. Initial field observations on the 2D raw data records indicated that this was an area of interest. Unfortunately, the data was very noisy and did not translate well into 3D time-slice amplitude maps (Figure 9-D). There was however, a ring of high amplitude (+80 to +120 relative amplitude) apparent in the time slice amplitude map at this location. GPR results were not used to choose this anomaly for excavation.
Figure 9. Anomaly #1 Geophysical Results. A) Electromagnetic conductivity; B) Electrical resistivity; C) Magnetic gradiometry; D) GPR time-slice amplitude; E) Excavation location; F) Photograph of Feature 7 (Anomaly #1).
Excavation Results Anomaly #1 (Feature 7)

We placed a 1 x 2 meter (east/west orientation) excavation with the southwest corner at N27 E14 (Figure 9-E). We selected this location so the south wall of the excavation would cut through the heart of the magnetic Anomaly #1 and provide a good profile. This location also allowed us to catch the western edge of the anomaly in plan view. Our initial observations of the smooth (low frequency) magnetic contour lines of Anomaly #1 indicated that the source was likely to be deeply buried.

Excavation began by removal of the ~0.35 m organic overburden without screening. The underlying gray silty loam plow zone was sampled by removing arbitrary 0.5m x 0.5m x 0.1m soil columns for wet screening with a 3.2 mm mesh. After numerous complaints of “there is nothing here” by the student excavators, the source of the magnetic anomaly was finally identified at 0.7 m below ground surface and designated Feature 7.

Feature 7 consists of two distinct stratigraphic ‘zones’ of cultural deposits. The uppermost (0.7 m-1.15 m below ground surface) Zone I consist of a dark, organic layer containing well-preserved faunal remains including antler and bone. This zone also contained diagnostic ceramics including English creamware (TPQ 1762) from 80-90 cm below ground surface (Figure 10). The general pit-like shape and associated artifacts were consistent with identifying this zone as a pit midden, temporally related to the later occupation of Fort St. Joseph (ca. 1762 to abandonment).
The second zone (1.15 m - >1.40 m below ground surface) contrasted sharply with the first. Zone II was well defined with steep cylindrical walls. Zone II consisted of mostly thumbnail to fist size chunks of burnt daub, intermittent with charcoal and faunal remains. Some of the larger pieces of burnt daub exhibited whitewashed surfaces and log impressions, indicating that these architectural elements almost certainly originate from French colonial architecture chinked with *bouzillage*. Unlike Zone I, Zone II did not contain any English ceramics, indicating that this earlier deposit was possibly associated with the French occupation of Fort St. Joseph.

The two zones within this feature were not only different visually and possibly culturally, but also distinguished by their magnetic properties (Figure 11; Appendix E). Subsequent magnetic susceptibility studies of the daub from this Zone II indicated that it had the highest levels recorded at Fort St. Joseph. The high magnetic susceptibility, combined with the deeply buried origin and cylinder-like shape of Zone II within Feature 7 accounted for the anomaly’s high amplitude and smooth contours.
Figure 11. Magnetic Profile of Feature 7 (Anomaly #1). Profile shows a significant increase in the mass specific magnetic susceptibility ($\chi_{lf}$) and frequency dependence % ($\chi_{fd}$) associated with the cultural stratigraphy of Feature 7.

At Fort Quiatenon, a very similar magnetic anomaly turned out to be a water well (von Frese 1984: Figure 5). The general shape of our Anomaly #1 (Feature 7) and monopole signature was consistent with a vertical cylinder-like archaeological feature such as a well or deep pit (von Frese 1984: 6). Our excavations confirmed that this feature was at least a deep, cylinder-like pit, but it could possibly also be a filled in water well. We never reached the bottom of this feature, ending excavation at a depth of ~140 cm below ground surface during the 2002 field season.
Conductivity and Resistivity Anomaly #2 (Feature 6)

Although the EM and ER methods are supposed to give similar results, only the ER method detected Anomaly #2 (Figures 12-A, 12-B). As with Anomaly #1, the organic surface layer likely ‘masked’ the underlying anomaly from detection by the EM-38. Furthermore, the dynamic range on the conductivity survey is very low, leaving little room for more sophisticated display options that might resolve the anomaly (Figure 12-A). However, the Wenner array ER results indicate a southwest to northeast trending, L-shaped, ‘high’ running through the location of our excavation (Figure 12-B). Resistivity results at Anomaly #2 correlates to a high degree with our excavation results that revealed a dry laid stone hearth designated Feature 6 (Figure 12-F) (see Excavation Results below).

Magnetometer Anomaly #2 (Feature 6)

The magnetometer results over Anomaly #2 were definitive. This anomaly was most readily identified as a +40 nT/m to –20 nT/m pair of magnetic dipole anomalies. The two dipole anomalies were in close proximity, likely resulting from two distinct sources (Figure 12-C). The northernmost dipole anomaly was aligned with the magnetic low to the north and the high to the south. This type of alignment is typical of an in-situ magnetic object, possibly something that was burnt in place. The second (southern) dipole was oriented opposite of the first with its magnetic low oriented towards the southwest. This type of dipole anomaly is typical of an object containing remnant magnetization
(such as stone) that was rotated and displaced from its original orientation. The close proximity of the two dipole anomalies combined to make what appeared to be a single pear-shaped anomaly. This magnetic anomaly was chosen for excavation because it resembled to a high degree both the ER and GPR anomalies.

Figure 12. Anomaly #2 Geophysical Results. A) Electromagnetic conductivity; B) Electrical resistivity; C) Magnetic gradiometry; D) GPR time-slice amplitude at 21.75-29 ns; E) Excavation location; F) Photograph of dry laid stone hearth (Feature 6).
GPR Anomaly #2 (Feature 6)

Anomaly #2 was apparent on three GPR profiles: File 50, File 51, and File 52 (Figures 12-D, 13). This anomaly consisted of a series of closely spaced, semi-parabolic and flat reflectors beginning at approximately 17 nanoseconds (two-way travel time) below ground surface. Because one would not expect to find a series of closely spaced reflectors on a naturally sorted flood plain, we considered this a high probability target. Furthermore, the time-slice amplitude planview map produced from the combined GPR profiles, resembled (to a high degree) the size and shape of the magnetometer, and also corresponded with the resistivity anomalies (Figure 12).

![GPR Profile at Anomaly #2](image)

Figure 13. GPR Profile at Anomaly #2. This file clearly shows Feature 6 (Anomaly #2). Crosshairs located at the top of the anomaly. Depth calculations of 66 cm on the right are estimates only. The top of this feature was revealed to be 1/2 of that depth (31 cm).
Excavation Results Anomaly #2 (Feature 6)

We placed a 1 x 2 meter (north /south orientation) excavation with the southwest corner at N22 E02 (Figure 12-E, 12-F). The geophysical anomalies from the different instruments were in slightly different locations (± 0.5 m). We selected our excavation so it would catch at least part of the magnetic, resistivity and GPR anomalies. This excavation location was also placed so the southern portion would contain natural soil and catch the southern end of the anomaly in planview.

Excavation began by removal of the relatively shallow organic overburden without screening. The underlying gray silty loam plow zone was sampled by removing arbitrary 0.5 m x 0.5 m x 0.1 m soil columns for wet screening with a 3.2mm mesh. Immediately below the plow zone (31 cm BD), we uncovered the very top of numerous large flat stones. Further excavations at this location revealed that the large flat stones were part of a dry-laid stone hearth designated Feature 6 (Figure 12-F). Feature 6 contained domestic ceramics, including painted English creamware (TPQ 1762), from an excavation depth of between 28-44 cmbd (Figure 14). Feature 6 displayed a very high degree of similarity to a contemporaneous hearth excavated from House C of the Southeast Row House at Fort Michilimackinac (Halchin 1985). Stone hearths/fireplaces were also readily detected with magnetometry at other French colonial sites including Fort Charlotte, MN (Huggins and Weymouth 1979:3) and Fort Quiatenon, IN (von Frese 1978, 1984).
A magnetic susceptibility test on one of the hearth stones indicated that it had enhanced magnetization, making the stone the likely dominant source of the southern magnetic dipole anomaly (Figure 12-C, Appendix E: Sample 02-01-174). Furthermore, the northeast corner of the excavation contained evidence of intense burning, including fire-reddened soil. Laboratory magnetic susceptibility measurements demonstrated enhanced susceptibility of these fire-reddened soils (Appendix E: Sample 02-01-175). The induced magnetization combined with the enhanced magnetic susceptibility resulting from the in-situ burning of the hearth soil was the likely cause of the smaller, northernmost dipole anomaly (Figure 12-C).

Conductivity and Resistivity Anomaly #3 (Feature 5)

Neither the EM nor the ER methods were able to detect Anomaly #3 (Figures 15-A, 15-B). As with Anomalies #1 and #2, the highly conductive surface layer likely masked the underlying archaeological deposits at this
Magnetometer Anomaly #3 (Feature 5)

Anomaly #3 was most readily identified as a +30 nT/m monopole magnetic high (Figure 15-C). This was the lowest magnitude magnetic anomaly that we tested. The anomaly was trivet shaped with its highest magnetic readings located in its northern most section. We felt that this anomaly could have represented the eastern edge of a larger structure that was associated with the stone hearth previously designated Anomaly #2 / Feature 6 (Figure 12).

Figure 15. Anomaly #3 Geophysical Results. A) Electromagnetic conductivity; B) Electrical resistivity; C) Magnetic gradiometry; D) GPR time-slice amplitude; E) Excavation location.

Excavations of Anomaly #3 were based solely on the magnetometer data (Figure
Excavations at this location revealed a lens of dark, mottled, charcoal-bearing soil designated Feature 5. This feature was interpreted as possibly associated with the demolition of a structure at this location.

**GPR Anomaly #3 (Feature 5)**

The ground penetrating radar method was not able to detect Anomaly #3 (Figure 15-D). It is likely that the high conductivity and high water content of the overburden at this location attenuated the GPR signal.

**Excavation Results Anomaly #3 (Feature 5)**

The excavation of Anomaly #3 was based exclusively on the magnetometer results (Figure 15-C). We placed a 1 x 2 meter (east/west orientation) excavation with the southwest corner at N25 E08 (Figure 15-E). We originally laid the southwest corner of this excavation at N25 E08 but a tree forced us to move this excavation 1 meter South to N25 E08. This caused us to miss the heart of the highest magnetic readings in the northern section of this anomaly.

Our excavation at N25 E08 recorded a mottled, charcoal-bearing lens of soil (~15 cm deep) that also contained some well preserved faunal remains (Figure 16). We interpreted this lens as the remains of a demolished wall (wall fall) from a structure and designated it Feature 5. Laboratory measurements of Feature 5 soil samples exhibited a slight enhancement of magnetic susceptibility, possibly due to the effects of burning (Appendix E: Sample 02-01-135). No evidence of *in-situ* burning (e.g., fire reddened soil) was recorded.
during excavation but copious amounts of charcoal were noted at this location.

Feature 5 could be part of a larger structure that once housed the stone hearth designated as Feature 6. The soil lens encompassed the entire 1 x 2 meter excavation unit and we did not encounter its edges. We bisected the soil lens and took out its southern ½ in order to record the profile. Feature 5 is ~15 cm deep in section and was excavated from a depth of between 45-60 cm BD. Below Feature 5 were more intact cultural deposits including some well preserved faunal remains.

![Figure 16. Bone Artifact. Well preserved bone implement (function unknown) recovered from Feature 5 (Anomaly #3)](image)

Thin planar or lens-type features will always produce a lesser amplitude anomaly than cylinder shaped features composed of similar magnetic materials (Clark 1996: Table 3). It was apparent from our excavations and laboratory studies of the magnetic properties of the soil that Feature 5 has enhanced magnetic susceptibility probably due to fire.
Anomaly #4

Conductivity and Resistivity Anomaly #4

The EM method was unable to detect Anomaly #4 (Figure 17-A). Like all of the other anomaly locations tested during this project, the highly conductive and organic surface layer likely masked any underlying archaeological deposits. The Wenner array ER survey did not cover this portion of the project area so, it will not be included in this discussion.

Figure 17. Anomaly #4 Geophysical Results. A) Electromagnetic conductivity; B) Magnetic gradiometry; C) GPR time-slice amplitude; D) Excavation location.
Magnetometer Anomaly #4

Anomaly #4 was identified as an oval +75 nT/m monopole magnetic high (Figure 17-B). The dimensions of the anomaly were approximately 0.75 m east/west by 0.5 meters north/south. This anomaly was similar to both Anomaly #1 and Anomaly #3 in that it is a monopole. It had similar amplitude compared to Anomaly #1 while its amplitude was nearly double that of Anomaly #3. This type of magnetic anomaly could be typical of basin shaped pit or cylinder shaped archaeological features. We chose to excavate this anomaly based exclusively upon the magnetic data.

GPR Anomaly #4

The ground penetrating radar method was not able to detect Anomaly #4 (Figure 17-C). It is likely that the high conductivity and high water content of the overburden at this location attenuated the GPR signal. This location was very close to a small drainage stream and the ground water table was high here resulting in poor penetration of the GPR signal.

Excavation Results Anomaly #4

The excavation of Anomaly #4 was based exclusively on the magnetometer results (Figure 17-B). We placed a 1 x 1 m excavation with the southwest corner at N36 E39 (Figure 17-D). We began excavation by removing the ~0.25 meter organic overburden without screening. The underlying gray silty loam plow zone was sampled by removing arbitrary 0.5 m x 0.5 m x 0.1 m soil columns for wet screening with a 3.2 mm mesh. Immediately below the
plow zone (~54 cm BD), we uncovered a large, oval stone with dimensions of approximately 0.4 m x 0.2 m x 0.35 m. The soil surrounding the large oval stone contained some charcoal and some faunal remains. The large stone rested directly on another similar stone of equal size.

We did not formally designate the area as an archaeological feature because it was amorphous and not well defined. However, the soils did contain colonial period artifacts and the stones were certainly not a natural occurrence on this well sorted floodplain. Although not formally designated as an archaeological feature, it is likely that the stones were culturally emplaced. Furthermore, the surrounding soils were culturally modified, evidenced by the artifacts, charcoal, faunal remains and enhanced magnetic susceptibility (Appendix E).

The likely source of this magnetic anomaly was the combination of the culturally emplaced soils and two large stones that were stacked one on top of the other. These two stones, in effect, created a cylinder shaped magnetic body buried within the soil matrix. The monopole anomaly (Figure 17-B) recorded during this survey was similar to anomalies created by cylinder shaped targets (Bevan 2006). In the next chapter, it will be demonstrated through experiment that many naturally occurring stones within the lower St. Joseph River Valley area were highly magnetic and likely detectable with a magnetometer at the Fort St. Joseph archaeological site.
Anomaly #5

Conductivity and Resistivity Anomaly #5

This location within the project area was located in a low-lying swale that was ~0.3 m lower than the surrounding site. After draining the site of water (see Chapter III), this area dried out slower than the rest of the site, and at the time of the geophysical survey it was still relatively wet. Both the Wenner array electrical resistivity and electromagnetic conductivity methods were unable to detect Anomaly #5 (Figures 18-A, 18-B). The conductive and organic surface layer likely masked any underlying archaeological deposits. It is important to note that none of the geophysical methods were successful at detecting archaeological deposits at this location because there were none to be found.

Figure 18. Anomaly #5 Geophysical Results. A) Electromagnetic conductivity; B) Electrical resistivity; C) Magnetic gradiometry; D) GPR time-slice amplitude; E) Excavation location.
**Magnetometer Anomaly #5**

The magnetometer survey did not record an anomaly at this location (Figure 18-C).

**GPR Anomaly #5**

Students from Professor William Sauck’s 2002 Field Geophysics course (GL 564) created a single time-slice amplitude map (Appendix A) of the GPR survey area (Figure 4). Interestingly, this map (Figure 18-D, Appendix A) showed some anomalies that were not apparent on other time-slice amplitude maps created with a different computer program (Appendix A). We decided to test a single anomaly based upon the GL 564 class time-slice amplitude map.

**Excavation Results Anomaly #5**

The excavation of Anomaly #5 was based exclusively on the GPR results (Figure 18-D). We placed a 1 x 1 m excavation with the southwest corner at N17 E06 (Figure 18-E). We began excavation by removing the ~0.25 meter organic overburden without screening. The underlying gray silty loam plow zone was sampled by removing arbitrary 0.5 m x 0.5 m x 0.1 m soil columns for wet screening with a 3.2 mm mesh. Immediately below the plowzone the silty B-horizon soils contained the source of Anomaly #5. The anomaly turned out to be a relatively recent rodent burrow. It is likely that the burrow, with less compaction and higher air content caused our GPR reflection at this location. The small air void in the loose fill acted to decrease the relative dielectric permittivity of the soil, resulting in a strong radar reflection at this location.
Summary

In order to determine if geophysics will help the FSJAP locate *in situ* subsurface features including architectural remains, we performed a multiple instrument survey and tested the results with archaeological excavation. Four of the five geophysical anomalies excavated contained significant archaeological deposits, including subsurface features and architectural remains. These excavation results answer this project’s first research question in the affirmative: geophysical methods are successful at locating *in situ* subsurface features including architectural remains at the Fort St. Joseph archaeological site. The next chapter will focus on the second research questions: what instruments are best suited to discover archaeological deposits at Fort St. Joseph?
CHAPTER VI

UNDERSTANDING THE GEOPHYSICAL SURVEY RESULTS

The excavation results described in the previous chapter demonstrated that geophysical methods were successful in locating archaeological deposits at Fort St. Joseph. These excavation results confirmed that geophysics can, and did help the FSJAP locate in situ subsurface features including architectural remains, contributing to a successful field campaign that met all project goals. For future considerations and research at the site, the FSJAP must know what type of geophysical instruments are best suited for work at this site and why.

The magnetometer survey contributed to finding in situ archaeological deposits in four successful test excavations (Anomalies 1-4). Electrical resistivity and GPR both contributed to finding archaeological deposits in one test excavation (Anomaly #2), while electromagnetic conductivity did not contribute to finding any of the archaeological deposits.

We chose a series of geophysical anomalies for testing, and excavated those anomalies to determine the potential source. It is clear from the excavation results that the magnetometer survey was the most successful at discovering in situ archaeological deposits, including architectural remains, at Fort St. Joseph. But why was this method successful at finding cultural deposits while the other methods failed?
Understanding the GPR, EM, and ER Survey Results

As described in Chapter I, wet soil conditions can have an adverse effect upon the GPR, EM, and ER methods. The night before Professor Sauck arrived with his Field Geophysics class (GL 564) on Wednesday, June 5th, the town of Niles turned off the diesel pump that powered the well point drainage system because a neighbor had complained about the noise. Without the aid of the 65 well points doing their duty, the soil began to turn back to its natural saturated state. The orders had come down from City Hall; our giant diesel pump was to be shut off every evening after we left the site. The pump had only been running for an hour and a half by the time the geophysical surveys were underway. This was hardly enough time to dry out the site adequately.

Torrential rainstorms exacerbated the wet situation on the site during the entire EM survey and parts of the GPR survey. The rain was so severe at one point, all of the archaeological students ran for the safety of the school van and storage trailer while the geophysical students industriously continued at their work. I remained with the geophysical students and watched them simply cover the top of my personal Geonics EM38™ with a plastic bag and continued on with the survey.

The results of the GPR, EM, and ER surveys should be contextualized with the untimely intervention of City Hall turning off the pump and the unfortunate timing of the severe rainstorm. Both the GPR and ER methods were able to detect Anomaly #2 (Feature 6), the shallowest cultural deposit discovered during the 2002 excavation season. Anomaly #2 only had ~31 cm of soil over the top of it, and was located on a slight topographic rise relative to its surroundings so it was drier than other locations.
GPR, EM, and ER Recommendations

The relatively poor results from the GPR, EM, and ER methods could simply be explained by the wet conditions found on the site during the surveys. If the surveys had been conducted a day earlier, these results might have looked significantly different. One particular ER anomaly not excavated during the 2002 has potential to be a cultural feature. The anomaly is centered at grid coordinate N23.75 E7 (Appendix D) and is similar in size and amplitude to Anomaly #2 (Feature 6). A magnetic anomaly also corresponds near this location (Appendix C).

Future research might benefit from trying GPR, EM, and ER methods during the height of the summer dry season, when the river and local water table are much lower. However, it is apparent that when the soils are wet at Fort St. Joseph, these methods should be avoided.

Understanding the Magnetic Gradiometer Results

In order for archaeological deposits to be detected with the magnetic gradiometer, they must possess a significant contrast in their magnetic properties from the surrounding natural soils. To better understand how these anomalies contrasted with the surrounding natural soils, we collected soil and rock samples to perform magnetic susceptibility analysis at the WMU archaeological laboratory. Our rock sample was however, very small (n=1) because most of the excavated rocks were very large and left in-situ. We suspected that the magnetometer was able to detect rocks from archaeological
context at Fort St. Joseph, so we conducted a magnetic susceptibility survey of local rocks from the lower St. Joseph River valley (Figure 8). The results of the rock magnetic susceptibility survey were imported into POTENT™ v.4.07, a computer ‘forward model’ application, to determine how these rocks will respond to a magnetic gradiometer survey under similar conditions to those encountered at Fort St. Joseph (Geophysical Software Solutions 2003).

**Magnetic Susceptibility Results From Archaeological Context**

We collected 48 soil samples, 1 daub sample, and 1 rock sample from our excavations (Appendix E). The soil samples separated into two broad categories, natural and cultural. The natural soils were collected from the plowzone (Group B”) and the organic overburden (Group B’) at the site. These samples were used to establish the natural background levels of magnetic susceptibility at the site. The remaining soil samples were collected from culturally emplaced soils such as pits, fireplaces, hearths or other cultural stratigraphy (Group A).

The soil samples were subjected to both low and high frequency mass specific magnetic susceptibility test ($\chi$) (see Chapter IV). The difference between the two readings is known as the frequency dependence % of $\chi$ ($\chi_{fd}$), or commonly as ‘magnetic viscosity’, and was determined with the following formula:

$$\chi_{fd}\% = \left(\frac{\chi_{lf} - \chi_{hf}}{\chi_{lf}}\right) \times 100$$

When these results are plotted as an x-y plot, the cultural soils (Group A) are
well discriminated from the natural soils (Group B’ and Group B”) (Figure 19).

Naturally occurring soils derived from weathered bedrock tend to have larger and more stable multi-domain magnetic grains than culturally emplaced soils do (Clark 1996:103). When the natural soils are measured for magnetic susceptibility at different frequencies (high and low), they will have a low $\chi_{fd}$. The difference between the low and high frequency readings will be minimum.

Higher $\chi_{fd}$ results from ultra-fine (<0.03 µm) magnetic particles in the soil referred to as superparamagnetic (SP) ferromagnetic minerals (Dearing 1999:46).

Figure 19. Magnetic Susceptibility X-Y Plot. Frequency dependence of magnetic susceptibility vs. magnetic susceptibility demonstrates good discrimination between the cultural (Group A) and natural (Group B) soils.

The measured apparent magnetic susceptibility of these SP minerals falls off
sharply at higher frequencies due to their unstable nature and the effects of magnetic viscosity. The end result is a lower measurement of the apparent magnetic susceptibility at higher frequencies ($\chi_{hf}$) than that recorded at a lower frequency ($\chi_{lf}$).

Soils can develop SP minerals from the effects of burning, pedogenic processes, and bacterial activity (Dearing 1999: 44). Culturally emplaced soils often develop a higher percentage of SP minerals (and associated $\chi_{fd}$), primarily due to burning resulting from the ubiquitous presence of fires at archaeological sites. The oxygen reducing and subsequent oxidizing effects of fire converts a small percentage of weakly magnetic iron oxides into the strongly magnetic maghemite (Le Borgne 1955, 1960).

**Statistical Examination of the Natural and Cultural Soils**

The soil samples plotted in Figure 19 demonstrate good discrimination between the cultural Group A, and the natural Group B. But is the discrimination between these soils, as represented in the X-Y plot (Figure 19) statistically significant? To answer this question, firstly the Group B soils were divided into two subgroups, Organic (Group B’) and Plowzone (Group B”). The Group B soils from Fort St. Joseph came from two primary soil strata, the organic overburden and the buried plowzone. The cultural soils primarily came from feature context.

Before I could run an ANOVA test on these thee soils types, I first had to determine if the organic overburden (Group B’) and plowzone (Group B”) were statistically different from each other. Using a Student’s t-test, the two types of natural soils (Group B’ and Group B”) demonstrate that there is not a statistical
difference between the magnetic properties of these soil types (Table 1: Test 1, 2). Although a plowzone is ‘culturally modified’ by definition, it is included in the natural grouping because it is a stratigraphic layer that covers the entire site and not a discrete depositional deposit like an archaeological feature.

Knowing that there is no statistical difference between the Group B soils was an important step, because now both Groups B’ and B” can be combined into a single Group B. After determining that Group B soils had no significant intra-group variation, a Student’s t-test with Group B versus the cultural Group A soils could be conducted (Table 1: Test 3, 4). Equally important, I can separate the Group B soils back into B’ and B” and run an ANOVA between the three soil types and be confident that a “null rejected” outcome is due to the difference between the natural and cultural soils and not due to any intra-group variance found in the Group B soils (Table 1: Test 5, 6, 7).

<table>
<thead>
<tr>
<th>Test</th>
<th>Group A</th>
<th>Group B</th>
<th>Group B’</th>
<th>Group B”</th>
<th>Results</th>
<th>Notes</th>
</tr>
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<tr>
<td>1) t-test</td>
<td>Organic $\chi$</td>
<td>APZ $\chi$</td>
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<td></td>
<td></td>
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<td>APZ $\chi$</td>
<td>Null Accepted, p=0.88</td>
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<td>3) t-test</td>
<td>Cultural $\chi$</td>
<td>Natural $\chi$</td>
<td>Null Rejected, p=&lt;. 0001</td>
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<td></td>
<td></td>
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<td>4) t-test</td>
<td>Cultural $\chi$</td>
<td>Natural $\chi$</td>
<td>Null Rejected, p=. 0005</td>
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<td></td>
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<td>Organic $\chi$</td>
<td>APZ $\chi$</td>
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<tr>
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<td>APZ $\chi$</td>
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<td></td>
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</tbody>
</table>

Table 2. Statistical Test. Various combinations of test demonstrate a highly significant statistical difference in the magnetic properties between the cultural (Group A) and natural (Group B) soils at Fort St. Joseph. All test performed at 95% confidence intervals.

In contrast to the statistical similarities found between the Group B soils,
the entire range of statistical tests performed between Group A and Group B soils demonstrate either a ‘highly significant’ or ‘significant’ statistical difference between the magnetic properties of the cultural and natural soils at the Fort St. Joseph archeological site (Table 1: Test 3-6).

Results of the Statistical Findings

The results of these findings indicate that the cultural soils can be statistically discriminated from the natural soils based upon their magnetic characteristics alone. The primary mechanism for the increased magnetic properties of the cultural soils is likely due to fire, and many of the cultural soils exhibit telltale signs of burning activity. This is a significant finding in support of our geophysical and excavation results that demonstrate magnetic gradiometry is the best method to discover archaeological deposits including in-situ architectural remains at the Fort St. Joseph archaeological site.

Magnetic Susceptibility Results From Experimental Archaeology on Naturally Occurring Stone Along the St. Joseph River

Two of the geophysical anomalies (Anomalies 2 & 4) tested during this study have significant amounts of stone. We performed various magnetic susceptibility tests on one sample of stone recovered from Anomaly #2 (Feature 6) and discovered that it has enhanced susceptibility (Appendix E: Accession # 02-01-174). Although outside of the scope of this project, other archaeological features discovered during the 2002 excavations were also made of stone (Nassaney et al. 2002-2004). The 2002 excavations of magnetic anomalies proved that stone was used as architectural elements in at least some of the
structures at Fort St. Joseph and these stones are potentially detectable with magnetic methods.

In order to better understand the magnetometer response to the variation in the magnetic properties of locally available stone, volumetric magnetic susceptibility (\(\kappa\)) tests were performed on naturally occurring stones (n=116) along the banks of the St. Joseph River (Figures 8, 20, Appendix F, see also Chapter IV). The stones sampled in this study came from the area between the Fort St. Joseph archaeological site and the Lower Buchanan Dam. The results for 30 stones, spread out across the spectrum of readings, were entered into a potential field forward modeling computer application called POTENT™ (Geophysical Software Solutions 2003) in order to model how these stones would appear during a magnetic gradient survey at Fort St. Joseph (Figure 21, Appendix F).

![Figure 20. Magnetic Susceptibility of Naturally Occurring Rocks From the St. Joseph River Valley. Rock samples are ordered from lowest (left) to highest value (right). Any rock located above the threshold line will create a +2 nT/m or greater magnetic anomaly in the POTENT™ computer simulation.](image-url)
The range of readings recorded during the rock magnetic susceptibility survey is greater than an order of magnitude larger than that recorded for the soil samples (Figure 20, Appendix F). The rocks range from slightly negative, or diamagnetic (\(\kappa = -0.5 \times 10^{-5} \text{ SI}\)) to strongly magnetic (\(\kappa = 4130 \times 10^{-5} \text{ SI}\)). The average background magnetic susceptibility of the plow zone and organic overburden at the Fort St. Joseph archaeological site is \(\kappa = 66 \times 10^{-5} \text{ SI}\).

For the purpose of the 30 magnetic models, the estimated size of a typical stone at Fort St. Joseph is 0.3 x 0.3 x 0.6 m and buried at 0.5 m below ground surface. The magnetic field in southwest Michigan (year 2002) is estimated at 55,717 nT, with an inclination of 70.4 and a declination of –4.3. The remnant magnetization of the stones is not included in these models because they are not known. These models are simply made with the recorded \(\kappa\) of our rock samples buried in the average soil \(\kappa\) at the archaeological site and placed into a magnetic field similar to that found in southwest Michigan during the summer of 2002.

Results of the Magnetic Gradient Forward Models

The magnetic dipole forward models listed in Appendix F range from a low of –1.34 nT/m to a high of +84.57 nT/m. The minimum \(\kappa\) that a typical stone (0.3 x 0.3 x 0.6 m) at Fort St. Joseph needs in order to produce a +2 nT/m dipole anomaly is \(\kappa = 166 \times 10^{-5} \text{ SI}\), an increase of 100 \(\times 10^{-5} \text{ SI}\) over the average soil readings (Figure 21, Appendix F, Rock #57).

The +2 nT/m level is set as a reasonable ‘threshold’ for detection of stone at Fort St. Joseph. In reality, the equipment used during the geophysical survey can detect changes in the earth’s local magnetic field as small as 0.01 nT/m, but in practice it is unlikely that any archaeologist would ever select an anomaly.
that small for excavation.

Figure 21. Forward Model of a +2nT/m Magnetic Anomaly at Fort St. Joseph. Top: Total field simulation. Middle: Gradiometer simulation of a +2 nT/m magnetic anomaly. Bottom: 0.3 x 0.3 x 0.6 m modeled rock (κ = 166 x 10^-5 SI) inside of a soil matrix (κ = 66 x 10^-5 SI).

The threshold of κ = 166 x 10^-5 SI produced a +2 nT/m response in the forward model. The rock with the highest magnetic susceptibility reading in the study (Appendix F, Rock #116) produced a +84 nT/m anomaly in the forward model. If the κ = 166 x 10^-5 SI threshold is used, it means that 51% of the stones (n=60) in the sample can be detected with a magnetic gradiometer at Fort St. Joseph. If the sample of stone tested for this project is representative of the local building materials available to the settlers at the time of building the fort, then roughly 1 out of 2 stones used in building construction can be detected with magnetic gradiometry. The results of the forward model indicate that approximately 37% of the stones in this study produce a ≥ +5 nT/m anomaly,
27% of the stones produce a $\geq +10$ nT/m, while 15% of the stones produce a $\geq +20$ nT/m anomaly (Appendix F). These experimental results support our field observations that some of the stones uncovered during excavations contribute to the source of the magnetic anomalies.

Summary

At the time of the geophysical survey, the conditions at Fort St. Joseph were not favorable for the GPR, EM and ER methods. The site was relatively wet because the site drainage system (65 well points) had been turned off the night before. Furthermore, heavy rain poured down during the EM and GPR surveys, adding considerably to the soil moisture content. However, the GPR and ER methods were able to detect the most shallow of cultural deposits discovered during the 2002 field season (Feature 6). It is recommended that if these methods are revisited at Fort St. Joseph, it should be done during the summer dry season when the water table and river are lowered.

The magnetic gradiometer method is not affected by soil moisture content. The magnetometer was able to detect cultural deposits, including intact architectural remains. In order to better understand why the magnetometer worked so well at this site, soil and rock samples were retained and their magnetic properties were studied back at the WMU archaeological laboratory. Statistical analysis of the magnetic properties of the soils, namely magnetic susceptibility and magnetic viscosity, demonstrated with a high level of certainty that archaeological soils (features) at Fort St. Joseph are magnetically different from the natural soils. The magnetic contrast between the cultural and natural soils allowed the magnetometer to detect the
archaeological deposits at Fort St. Joseph. But what about the stone found in the excavations? Did the stone contribute to the magnetic anomalies recorded at Fort St. Joseph?

To answer these questions, I had to conduct considerably more research. Because only one rock sample from archaeological context was retained for magnetic testing, a field survey of naturally occurring stone in the St. Joseph River Valley was initiated. The stones (N=116) were analyzed \textit{in-situ} (see Figure 8) and volume magnetic susceptibility ($\kappa$) was recorded. The magnetic susceptibility values of these stones were then used to ‘forward model’ a gradiometer survey in a computer simulation. The results of the forward model indicate that 51\% of the stone could have been detected with the magnetic gradiometer as \geq +2 \text{nT/m} magnetic anomaly while 27\% of the stones produced a \geq +10 \text{nT/m} magnetic anomaly. This is a significant finding considering that stone hearths and features exist at Fort St. Joseph. Magnetic gradiometry is probably the best method to find these stone features considering the wet conditions found at this site.
CHAPTER VII

SUMMARY AND CONCLUSIONS

The research described here demonstrates how geophysical techniques were employed and evaluated in the archaeological search and discovery of colonial Fort St. Joseph. Principally, two separate but related questions drove this research project. First, could geophysics help the FSJAP locate in situ subsurface features including architectural remains? And if geophysics could help us, what types of geophysical instruments are best suited to find archaeological remains at this location?

In order to determine if geophysics will help the FSJAP locate in situ subsurface features including architectural remains, we performed a multiple instrument survey and tested the results with archaeological excavation. Four of the five geophysical anomalies excavated contain significant archaeological deposits, including subsurface features and architectural remains. The excavation results verify that geophysical methods can contribute and help the FSJAP meet project goals including: (1) establishing the vertical stratigraphic relationships of the cultural deposits, (2) recovering a larger sample of undisturbed artifacts and biological remains, and (3) identifying in situ subsurface features including in situ architectural remains to establish site integrity and assist in interpretation (Nassaney et al. 2002-2004: 310)
Addressing the Research Questions

In order to answer these research questions, the FSJAP team first drained the project area of water by employing a sophisticated well point drainage system (Chapter III). With the drainage system in place, a multi-instrument geophysical survey was conducted. Excavation of selected geophysical anomalies followed and the first research question was immediately answered. Excavations to investigate two anomalies revealed indisputable evidence of subsurface archaeological features including architectural remains (Chapter V). Moreover, four of the five geophysical anomalies tested proved to contain significant cultural deposits.

It is important to note that seven of the twelve excavation units from the 2002 field season were not based on geophysical results. These excavation units were also very successful in finding intact cultural features at Fort St. Joseph. The seven excavations were located in areas where previous shovel test pits (Nassaney 1999) recovered high artifact densities. The geophysical grid was located just south of the high artifact density area. Because the seven excavations are based on prior knowledge regarding artifact densities, it is problematic to attempt to compare and contrast the results of each method because the geophysical survey was located in an area known to have lower artifact densities. Therefore, I can state with confidence that both methods were successful at finding intact cultural deposits at Fort St. Joseph.

The results of the geophysical survey, subsequent excavations, and laboratory analysis all contributed to answer the second research question: what types of geophysical instruments are best suited to find archaeological remains at this location? The research presented in Chapters V and VI demonstrates
that magnetic gradiometry is best suited for finding archaeological remains at Fort St. Joseph, particularly features made of local stone, and burnt soil.

Analysis of the magnetic properties of soil proves with a high degree of certainty, that the cultural soils are significantly different from the natural soils at Fort St. Joseph. This contrast in the magnetic properties of the soils is an essential factor contributing to a successful magnetic gradiometry survey. Furthermore, magnetic analysis demonstrates that a good percentage of locally available stone is also highly magnetic. Computer simulations (forward modeling), placing these stones in the magnetic field and soil conditions at Fort St. Joseph, reveal that 51% of them could have been detected during our magnetic gradiometer survey. The 2002 excavations prove that stone was available and used as a building material by the occupants of Fort St. Joseph. The results of this project demonstrate that stone is one archaeological material that can be detected with magnetic gradiometry at Fort St. Joseph.

Future Considerations

Significant additional areas were surveyed with magnetometry after the 2002 field excavations were finished. The survey was extended over a frozen St. Joseph River in order to determine if any archaeological deposits exist under the waters of the river. The extension of the survey over the river and the areas not covered by the original 2002 survey allow FSJAP researchers to recognize some large-scale patterns that are potentially cultural in origin.

The magnetometer survey distinguished three rectangular outlines, probably barracks or row houses, on land and underwater. The two rectangular anomalies on land were tested and found to contain stone fireplaces and hearths
(Figure 22, Nassaney et al. 2002-2004: Figures 6, 7, 8). The hearth and fireplace are principally constructed with dry laid stone, and contain magnetically enhanced soil, and given the results of this study, the stone was probably magnetic as well. Another smaller stone feature (Feature 1) was also detected with the magnetic gradiometer (Figure 22). The rectangular magnetic outlines, likely structures (row houses, block houses or barracks), probably once enclosed these stone features.

Figure 22. Two Possible Structures Discovered with Magnetic Gradiometry. A) Probable row house: I = Feature 6 (Anomaly #2), stone hearth; II = Feature 5 (Anomaly #3), collapsed wall; B) Larger structure: III = Feature 2, stone fireplace; IV = Feature 1, stone rubble. Solid lines excavated, while dotted lines are conjecture. (Modified after Nassaney et al. 2002-2004: Figure 7).
Another exciting prospect is that the magnetic gradiometer survey might have delineated the northwestern edge of Fort St. Joseph (Smart et al. 2005). The survey into the river (see Figure 23) does not show the many small magnetic anomalies that the survey over the land does. Of interest is the increased frequency of magnetic anomalies at and immediately north of the river’s edge (in the river) that generally follows a westerly trend and then decreases toward the southwest (Figure 24, Appendix C). The increase in magnetic anomalies along the river edge may indicate the northwestern edge of the fort.

Figure 23. Over Water Magnetometer Survey. Professor William Sauck wading into the St. Joseph River with the magnetic gradiometer upon his shoulder and the battery pack around his neck during the July 2002 survey. The author is holding a marked rope to help keep the survey grid from floating away (Photograph courtesy of Laura Smart).
The third rectangular anomaly (underwater) is located directly north of the river bank and centered on the grid coordinate N42.5 E7.5, although no anomalies are located at that particular coordinate (Figures 23, 24, Appendix C). When we surveyed this particular area in July 2002, the water in the river was only waist high (Figure 23). This anomaly is approximately 10 x 6 meters in size and could represent a significant submerged cultural deposit. Could this be the northern entrance to the fort, or possibly another rowhouse or barracks?

To demonstrate the scale of the possible northwestern edge of the fort, an outline of Fort Michilimackinac is overlaid on top of the magnetic gradient map of the project area (Figure 24). Fort St. Joseph is contemporary with Fort Michilimackinac and both were likely similarly constructed. The Fort Michilimackinac overlay is oriented with an entrance facing towards the river that corresponds with the 10 x 6 meter underwater magnetic anomaly. Interestingly, the underwater anomaly is a similar size to the Michilimackinac entrance. If the northwestern boundary of the fort has been delineated and if the dimensions of the two forts are similar, than more than 2/3rds of the fort may still lie beneath the 20th century landfill located to the south of the river and current project area.

Further archaeological and geophysical work could help delineate the boundaries of this site. This work would benefit greatly if it could be conducted during the summer dry season when the river is low. It would be interesting to build a small sandbag cofferdam around a portion of the underwater anomaly while the water level is low, remove the standing water with a simple pump, and test the location. As the research in Chapter VI suggest, these underwater anomalies could very well be stone remnants of a former structure associated
with Fort St. Joseph. Stone would also make sense on another level, as it is one material strong enough to resist the erosion caused by the French Paper Co. Dam. Stone would be easy to recognize archaeologically, even in the mucky silt that the St. Joseph River has to offer. Hopefully, future research at Fort St. Joseph will be able to test these hypotheses.

Figure 24. Fort Michilimackinac Outline Overlaid on Fort St. Joseph Project Area. The Fort Michilimackinac outline is scaled and overlaid to the Fort St. Joseph magnetometer map (Modified after Smart et al. 2005).
Appendix A

Ground Penetrating Radar Time Slice Amplitude Maps
Depath = 0.25 - 0.75 meters
Appendix B

Electromagnetic Induction (Conductivity) Map
ELECTROMAGNETIC INDUCTION (CONDUCTIVITY)

METERS EAST

METERS NORTH

mS/m

0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40

0 10 20 30
Appendix C

Magnetic Gradiometry Map
MAGNETIC GRADIOMETRY

Meters North

Meters East

nT/m

-7000 -5000 -3000 -1000 -500 -200 -100 -50 0 5 10 15 20 25 30 35 40 45 50
Appendix D

Electrical Resistivity Map
ELECTRICAL RESISTIVITY (WENNER ARRAY)

Ohm/m

METERS EAST

METERS NORTH

0 2 4 6 8 10 12 14 16 18 20

0 2 4 6 8 10 12 14 16 18 20

10 12 14 16 18 20

20 22 24 26 28 30

75 72 70 65 60 55 50 45 40 35 34 32 31 30 29 28 27 26 25 24
Appendix E

Soil Magnetic Susceptibility Data
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<th>Sample / Accession #</th>
<th>Strata / Feature #</th>
<th>Depth (cm)</th>
<th>Weight (g)</th>
<th>LF $\chi$ (m³kg⁻¹ x 10⁻⁸)</th>
<th>HF $\chi$ (m³kg⁻¹ x 10⁻⁸)</th>
<th>Freq. Dep.%</th>
<th>$\gamma$ (SI) x 10⁻⁵</th>
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