MULTISENSOR GEOPHYSICAL FUSION FOR IMPROVED

SUB-SURFACE IMAGING

AT HISTORIC CAMPTOWN CEMETERY, BRENHAM, TEXAS

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

Multisensor Geophysical Fusion for Improved Sub-surface Imaging
at Camptown Cemetery, Brenham, Texas. (May 2014)

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A non-invasive geophysical survey of the historic African American Camptown Cemetery in Brenham, Texas was undertaken to provide the local heritage museum staff with approximate locations, depths, and quantities of marked and unmarked burial sites. We constructed an intuitively understood map describing the uncertainty of our data interpretation. This map consists of three types of zones color-coded according to the confidence we ascribe to the location and depth of a grave site: red for “certain”, yellow for “unclear”, and green for “certainly not”. The completed work helps to define a current "state-of-the-practice" in 3-D historical cemetery geophysical mapping.

Three sub-surface geophysical techniques were used in the mapping of Camptown Cemetery: magnetics (MAG), electromagnetic induction (EMI), and ground penetrating radar (GPR). The approach is to combine, or fuse, the MAG, EMI, and GPR information, rendering a joint interpretation in which the confidence in the fused product is greater than the confidence in the product formed by using any one of the methods working alone.

Our goal was to identify burial sites within the cemetery and, wherever possible, corroborate with existing historical records and death certificates of the city of Brenham. This task is of cultural and historical importance to the families and relatives of those buried in Camptown as they seek to restore the lost African American heritage of their community.

DEDICATION

This work is dedicated to my family.

ACKNOWLEDGEMENTS

The community of Brenham, the Brenham Heritage Museum staff, Bob Wishoff, and Reverend Eddie E. Harrison deserve enormous credit for their dedication to the Camptown Cemetery and the preservation of its history. I thank Timothy de Smet for showing me the ropes of archaeological geophysics. And all students who volunteered to assist the project, especially Charles Stanford. I would like to give a special thanks to Dr. Mark E. Everett. His enthusiasm, work ethic, insight, and humor have made serving as his research assistant a genuine pleasure.

NOMENCLATURE

MAG	Magnetics
EMI	Electromagnetic Induction
GPR	Ground Penetrating Radar
Geomaterial	Earth material, such as a rock formation or other natural body
3-D	Three Dimensional
s	Seconds
ms	Milliseconds – 10^{-3} seconds
ns	Nanoseconds – 10^{-9} seconds
m	Meters – measurement of distance
m^2	Squared Meters – measurement of area
cm	Centimeters – measurement of distance
kHz	Kilohertz, 1000 hertz – measurement of frequency
MHz	Megahertz, 10^6 hertz
GHz	Gigahertz, 10^9 hertz
Tesla	The standardized unit for magnetic field
Tx	Transmitter
Rx	Receiver

CHAPTER I

INTRODUCTION

A site of Texas heritage and cultural importance

The Camptown Cemetery was officially established by Mount Rose Missionary Baptist Church in 1868 (*Harrison*, 2009). One most recent burial is dated 1973. However, Texan archeologist – Bob Wishoff – believes burials in this cemetery date back to the 1830s. Camptown Cemetery is the resting place of the original Texans – those who lived throughout or fought in the Texas Revolution – the families of the first emancipated African Americans, and the American Veterans who bravely served in wars on American soil and overseas. In recent decades the cemetery was abandoned and overgrown with foliage. The Brenham Heritage Museum staff has worked alongside Eddie E. Harrison more than ten years to refurbish Camptown Cemetery and document the historical record with those buried beneath unmarked graves. Recently recognized by the Texas Historical Commission for designation as a historical cemetery, the identification of these burial sites at Camptown Cemetery holds utmost importance.

Figure 1.1

Overturned gravestone of Hiram A. Williams:

Private 9th U.S. Volunteer Infantry

Born: December 20, 1858

Deceased: March 1, 1943

Figure 1.2

Outline map of Texas describing the approximate location of Brenham, Texas

A brief history of the Camptown Cemetery

Run-away slaves had made a home in the densely wooded area between the Hog Branch and Higgins Branch Creeks to the east of Brenham. Here was plenty of water to raise crops and livestock along with an abundance of lumber for fuel and building material (*Harrison,* 2009). In the years following the American Civil War, former slaves cherished a community between the river banks as freed citizens. During this time of dynamic cultural change, Brenham saw violent unrest between the former slave-owners and the African Americans. As a result of the violence, the newly recognized United States Government mobilized the Fifth Military District to Brenham, Texas: ordered to protect and maintain peace among the township (*Harrison,* 2009).

The Fifth Military District control existed from March 1867 through April 1870 by the First Reconstruction Act (*Baggett*). The Army-Post of Brenham had been established between the Hog Branch and Higgins Branch Creeks on the eastern boundary of the African American community. The US Army constructed a camp of canvas tents for resting, a sheltered and furnished dining hall for comfortable dining, and a brush arbor for accommodating church services. The Army-Post held open church services and dinners which the African American citizens were invited to attend. These living quarters were located adjacent to the African American burial site. US troops who lost their life were also buried in the cemetery next to the camp (*Harrison,* 2009). During this period a community was formed between the Army Service Members and the African Americans. The compassion and construction efforts of the US Army founded the Mount Rose Missionary Baptist Church.

Community outreach project

Community support has been the driving force behind this project, as it has been a public commencement to celebrate the Civil War Era of Brenham history. After recognition by the Texas Historical Commission, physical restoration of the Camptown Cemetery began. A local Veteran motorcyclist club *Rolling Thunder* has distinguished the project, commemorating veterans buried at Camptown. The club cleared much of the forested land allowing for any investigation: anthropological or geophysical.

The Texas A&M Geology and Geophysics Department was contacted by Doug Price of the Brenham Heritage Museum staff, requesting the Camptown Cemetery to be mapped. Doug has several goals needing to be accomplished: define the location and extent of cemetery burials – whether on state or private land; determine the purpose of burials within cemetery – as to determine an accurate history of the cemetery; and revitalize the cemetery making it a public and commemorative site. To meet these goals, we have applied Geophysics to this cultural and historical mapping. Our aim is benefit the community of Brenham with an accurate and effective account while making advancements in the applied practice of near-surface geophysics.

Local motorcycle club, *Rolling Thunder*, commemorates veterans buried at Camptown Cemetery during a community celebration.

Figure 1.3

CHAPTER II

GEOPHYSICAL METHODS

The sub-surface mapping of Camptown Cemetery was taken through the use of three geophysical techniques: Magnetics (MAG), Electromagnetic Induction (EMI), and Ground Penetrating Radar (GPR). Because, “geophysical data are insufficient to uniquely determine the distribution of subsurface properties, to any level of precision,” the strength in combining these techniques reveals a greater precision of information about the subsurface (*Everett*, 2013).

Horizontal control network

To spatially corroborate information collected from the field, a horizontal control network must be established for the region under consideration. We picked five vertices – A, B, C, D, E – intuitively arranged as a polygon so the vertex of either adjacent point is visible across the cemetery. The physical location of the stakes is unimportant. However, a line of sight must be established between adjacent vertices to measure the relative information of each vertex. The boundary of the available mapping area is not confined to the area encompassed by the polygon; because, a line of sight may be established between a point of interest and any single vertex to define its spatial coordinates.

Robert H. Hubert	Pvt. US Army
Born: January 17, 1939	Deceased: June 1, 1973
Point of Interest	Measured from Vertex E:
45.577m;	244^{0} 02’ 55”

Figure 2.1

We began by hammering a blaze-orange, non-magnetic stake named vertex A into the soil along the roadside. The color was chosen to enhance visibility and the material was chosen such that the stake would not introduce magnetic anomaly to the area. Then, the surveyor paced approximately 50 meters south, across the cemetery, to a position which established a line of site to point A; a non-magnetic stake was hammered into the soil here at point B. At a position approximately 50 meters east on the line of sight to B, stake C was place in the ground. This process was continued until the five stakes enclosed a polygon with a line of sight between adjacent vertices.

Measuring horizontal angle and distance

Having decided upon a perimeter for the control network, the Topcon GT-313 total station navigation system was selected to measure the horizontal angles and distances between the vertex points. As shown in figures 2.2 and 2.3, the equipment has two components: the main unit and a reflector unit. The main unit is a dual axis, computer-monitored infrared laser with 30x magnified sight and digital display, which secures to a collapsible, telescoping tripod that is positioned vertically through a view finder and may be leveled via the computer or a bubble. The reflector unit, known as the prism by its series of angled plane mirrors, sits atop a telescoping pole leveled by use of a bull's-eye bubble. The equipment produces a horizontal distance measurement to thousandths precision by zapping the laser to the reflector unit, recording the two-way travel time between the positions, and extrapolating a distance in meters from this information. The angles are measured in the standardized, degree – minute – second, format relative to the zenith point of the main unit axes. The equipment is calibrated for both vertical and horizontal angle measurements.

Figure 2.2

In figure 2.2, Texas A&M Geophysics students, Kevin Higby and Qifan Liu, use the main unit to measure the angle and distance to Dr. Richard Carlson of Texas A&M University, figure 2.3, leveling the prism.

Figure 2.3

After centering the total station navigation system above vertex A and holding level the prism at the adjacent vertex B, the interspatial angle and distance may be displayed on the screen of the main unit. This reading, known as foresight, was taken five times to ensure accuracy while measuring to a slightly wavering reflector unit. Once the horizontal angle and distance was recorded the surveyor would move the prism to the opposite, adjacent vertex E. The information from this position, known as backsight, was captured five times and recoded. The main unit was then moved around the perimeter counterclockwise to vertex B. The foresight measurements at vertex C and backsight measurements at vertex A were captured five times each. Although the measurement from vertex A to B had been recorded, the measurement from B to A was recorded to validate the information. The process of rotating the main unit around the perimeter while routing the prism across the cemetery to the corresponding vertices was repeated until all necessary information was obtained. This perimeter is known as a control network or total station. The schematic of the vertex polygon is placed on the following page in figure 2.5.

Placing a grid and work section within the control network

With the control network established, the vertex points may be used as a point of reference for other spatial coordinates. We may use the Topcon GT-313 to network points of interest, such as gravestones or other geographic references, into the total station. By centering the main unit of the navigation system on a perimeter vertex and placing the prism over a point of interest, its location may be tied to the polygon. We measured and staked a 500 m^2 rectangular area, seen in the aerial photograph, figure 2.4, that contained several interesting targets: most notably of which is a two by one meter concrete encasing embossed 25 cm from ground's surface. With the total control navigation system leveled and centered at vertex A, we recorded the relative coordinates of the four corners of our 25 meter by 20 meter area and various points of interest within the cemetery.

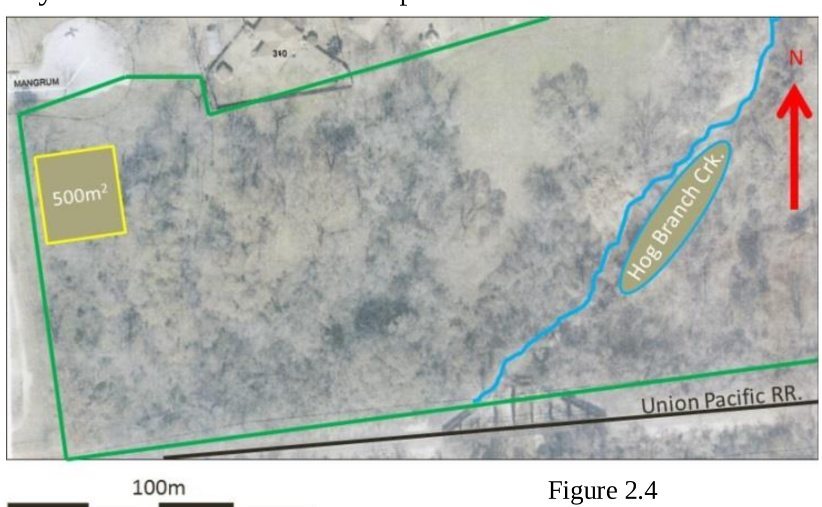


Figure 2.4

An aerial view of Camptown Cemetery

A Cartesian coordinate system must be introduced to give these relative locations a coordinate point within two-dimensional planar space. To do this we picked an arbitrary position in the cemetery as the point intersection for directions x and y: shown in figure 2.6. Just as before, the total station navigation system was centered over our origin. By collecting the angles and distances of two vertices, A and B, from the origin point we have enough information to place our total station within the Cartesian plane. We have now established a horizontal control network. Establishing a horizontal control network is the first goal of several important objectives. With a spatial coordinate representation we can effectively convey the geographical location of field information.

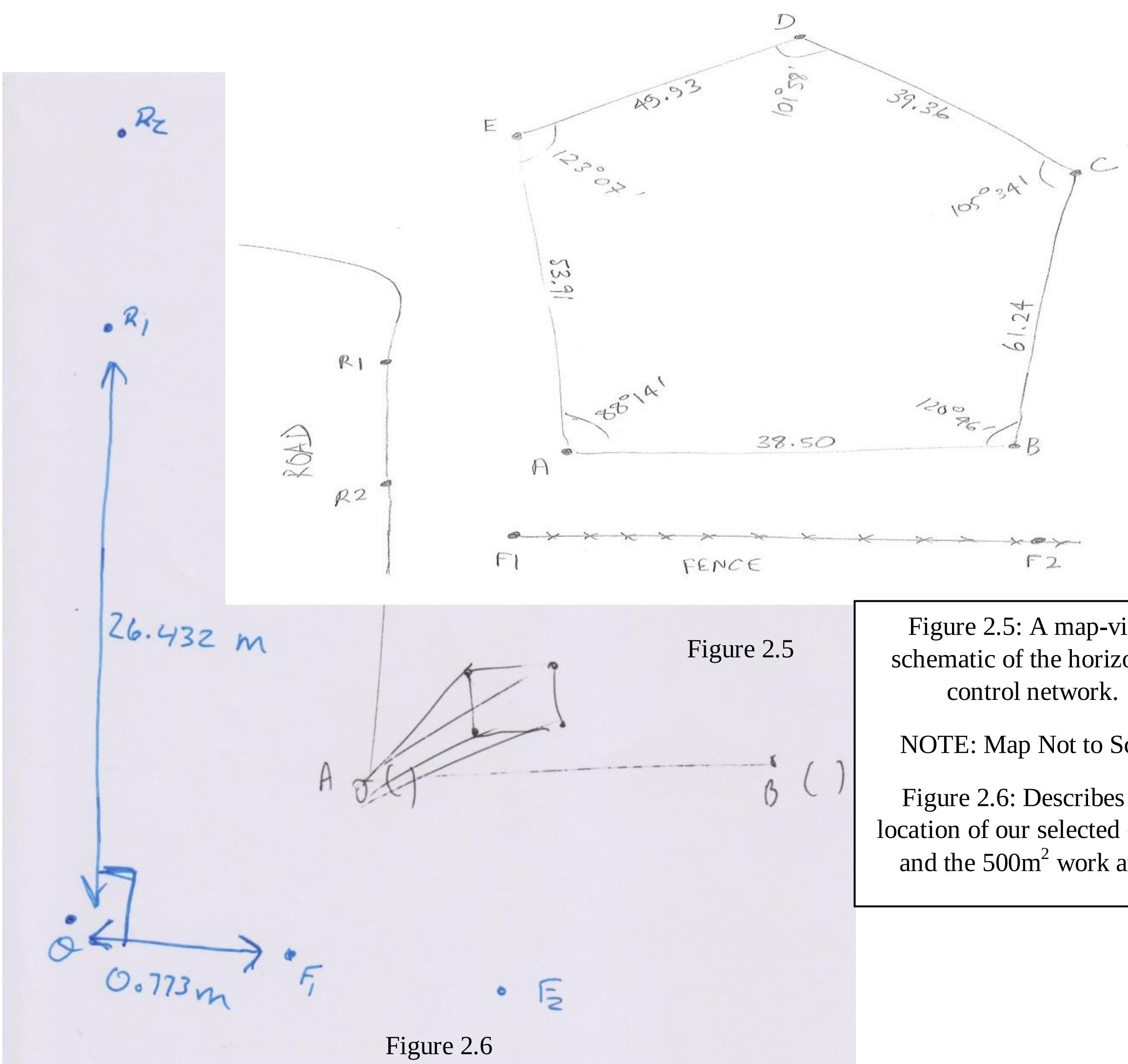


Figure 2.5

Figure 2.6

Figure 2.5: A map-view schematic of the horizontal control network.

NOTE: Map Not to Scale

Figure 2.6: Describes the location of our selected origin and the 500m^2 work area.

Data acquisition

Our goal is to acquire data which will reveal information about the subsurface of Camptown Cemetery upon its interpretation. Information is to be understood as a bit of new knowledge: a structure, feature, material, artifact or property of the subsurface that was not previously known (*Everett*, 2013). We want data that may provide us with a wealth of information when interpreted, and we want to be clever about the way we obtain our data. To satisfy these conditions we decided upon three geophysical techniques – MAG, EMI, and GPR – and the point station data collection method.

Point station data collection method

Data collection occurs along equally spaced lines traced across the workspace. Rather than the continuous data collection method of which data is acquired by the surveyor while continuously walking a line at a slow pace, the point station collection method relies on equally spaced positions along the line. These positions are known as stations. The surveyor moves the equipment to the designated station space along each line and collects the datum while standing still. Line and station spacing is predetermined according to several variables: the geology and size of the mapping zone under consideration, the acceptable time allotment for the collection process, and the requirements established by the strengths or functionality of the chosen technique or techniques. These requirements also dictate whether a geophysical survey may be completed by the continuous approach or not. There are many benefits to both collection methods.

Figure 2.7

For the Camptown Cemetery mapping we have selected 0.5 meter line spacing and 0.25 meter station spacing for all collection techniques. The length of each line is 25 meters and the width of the working area is 20 meters. This equivocates to 41 lines with 101 stations per line: being that, line 1 is the western boundary of the area and station 1 occurs at the 0 meter demarcation. Facing South, captured from vertex A, figure 2.7 is a panoramic view of the 500m^2 work area at Camptown Cemetery.

Targets of interest

Various grave markings are visible within the perimeter of our work space. The true location of these burial sites may not lie in its shown location. Human or natural efforts, such as flooding and erosion, may have relocated the grave marker or burial. We may only assume the apparent location of a burial site by evidence of a marker. If we observe a motion trend between the true and apparent locations across regions of the cemetery, we may infer further information about the locations of marked and unmarked burial sites. This information would be useful when validating reported burial details with families and historical records.

Magnetics – MAG

Measuring anomaly within the geomagnetic field is a powerful technique used to detect soil disturbances or magnetic bodies within the subsurface. The magnetic equipment measures the total geomagnetic field: main field magnetism created by convection of fluid iron within the Earth's core and lithospheric magnetism generated by iron-bearing minerals located in the Earth's crust and shallow subsurface. The magnetic anomaly can be approximately modeled by subtracting the main field magnetism from the total measured field. These anomalies are subtle, regional differences of magnetic field measured in nanoTeslas.

Instrumentation

The Geometrics G-858 cesium vapor magnetic gradiometer was used to complete the MAG survey. The G-858 has two components: a handheld aluminum staff and a belt mounted data logging console. The staff supports the high precision cesium vapor magnetometer sensors. The upper and lower sensors operate actively: detecting the magnetic field in a spherical proximity. They are fixed to the staff by plastic mounts which are secured by a clasp, which is tightened by a Phillips-head screw. The sensors must be positioned in line, spaced apart, and oriented in the same direction. For our use, the sensors were spaced one meter apart with the bottom sensor positioned one meter from the ground. The data logger stores the sampled measurements from the field to be later imported into plotting software. The console rests securely at the surveyor's front side by an adjustable nylon strap with a quick connect clasp. The console operates on a 24 volt system. The two batteries are contained in a pouch mounted to the belt which rests on the operator's lower back. The staff is segmented allowing for efficient packing and adjustable height.

The G-858 instrument, shown in figure 2.8, has the tendency to drift in calibration throughout the acquisition process. To obtain accurate data, we must take one reading before and after each completed line at a location away from any possible sources of magnetic anomaly. We refer to this location as our bay-station. Since we are collecting this base-line from the same location we expect each reading to be consistent. This is not typically the case as the instrument drifts throughout the 15 minutes elapsed between the start and end of a line. The bay-station reading establishes a base-line measurement which serves as point of reference for instrument drift calibration.

Figure 2.9

Figure 2.8: Texas A&M Student Charles Stanford, collecting data with the Geometrics G-858

Figure 2.9: Magnetic debris removed from the survey area pictured in figure

Figure 2.8

Acquisition

As shown in figure 2.9, we combed the survey area and removed any metal objects that may sample as unwanted magnetic information. Before taking any readings with the magnetometer, each surveyor was also required to remove any metallic items from their person: belts, watches, keys, pocket knives. As a rule of thumb, any observer should stand away from the magnetometer while the surveyor is acquiring data.

A metric tape measure is pulled taut across the grid to establish the current collection line. With the magnetic gradiometer set in point station collection mode, the surveyor places the staff oriented vertically on the bay-station. By selecting the start-line command from the console an audible alert is sounded and the base-line measurement is recorded. The surveyor then walks into position on the 0 meter mark of the tape to collect the next sampling. The entire line is collected in 0.25 meter increments according to the point station datum collection method. The surveyor collects the bay-station once more before selecting the end-line command from the console. The data from each line is stored on the console in a separate folder.

The collection process is accomplished in a team of three so the tape measure may be moved 0.5 meters and pulled taught along the next line while the surveyor, equipped with the magnetometer, collects the bay-station reading. Once the MAG data has been collected for the entire grid it is processed for interpretation. The magnetics acquisition required three days in the field over the course two weeks in October 2013.

Electromagnetic induction – EMI

Terrain conductivity meters rely on Faraday's Law of Induction to detect electrically conductive material in the subsurface. To accomplish this, the terrain conductivity meter transmits an electromagnetic wave into the subsurface. This wave is transmitted until steady state current is achieved which occurs after the wave has been transmitted for a magnitude of milliseconds. Once in steady state an electric current exists within the subsurface on a hemisphere of electric potential energy, known as voltage. The electric current generates a magnetic field and the receiver end of the equipment is actively measuring this magnetic signal. Very quickly, on the order of nanoseconds, the initial current is shut off. The quick change in magnetic field induces, or creates, a current within conductive geomaterials or artifacts. This induced current emits a secondary magnetic field which is only detectable for a few milliseconds. The induced secondary magnetic signal is received and transformed into a measurement of apparent conductivity. While the magnetic tool will only detect ferrous material; in the case of the electromagnetic induction tool, any conductive geomaterial – metallic or otherwise – will emit a recordable signal. Because the information provided by these tools is complementary, yet different, the combination of these techniques provides useful insight (*Everett*, 2013).

Instrumentation

The GSSI Profiler EMP-400 is a wireless, portable, lightweight, and weatherproof terrain conductivity meter. Nearly five feet in length, the profiler is shaped like a canoe paddle with the transmitter and receiver coils on opposite ends of a weather coated PVC tube. A nylon strap, with neoprene padding, fixed on either end, supports the profiler on the user's shoulder. When suspended across the user's waist and held parallel to the ground, the EMP-400 looks a bit like airplane wings. The wireless data logger with an integrated GPS system and fully colored touchscreen display can be hand held or mounted to the profiler. A remote attached to a lanyard, worn around the user's neck, is used to control the data collection.

This tool uses a variable-range transmission frequency from 1 kHz to 15 kHz and will transmit three selected frequencies simultaneously. The ability to transmit three frequencies is useful when mapping the subsurface, as this feature allows us to obtain information about the conductivity at three different depths. Generally, a lower frequency signal will penetrate the surface to a greater depth than a higher frequency signal traveling through the same medium.

Data stacking

The GSSI EM Profiler is also capable of stacking a datum as many as 64 times. Datum stacking is the technique of acquiring a data point multiple times to ensure its repeatability. Stacking reduces signal "noise" – unwanted or indistinguishable signals – and improves the data quality. Effectively, the more times you compare one sampling to another of the same source, the signal noise can be reduced and the true signal can be gained. The clarity of the data is understood as a ratio of signal to noise.

Acquisition

For our EMI survey of the Camptown Cemetery, we have chosen the optimal settings on the profiler to meet a host of efficient and effective criteria. Detailed in figure 2.10, we selected a broadside or "airplane mode" profile direction. 1 kHz, 5 kHz, and 15 kHz frequency selections will provide data for deep, intermediate, and shallow conductivity measurements – respectively.

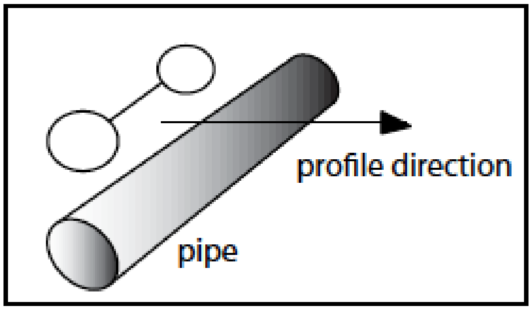


Figure 2.10

Figure 2.11

Figure 2.10: Depicts the broadside orientation, where the transmitter and receiver straddle the profile direction.

Figure 2.11: TAMU Student Charles Stanford collects a data stack with the GSSI Profiler EMP-400

To provide adequate quality data using the point station method, eight stacks were acquired at each station along the profile line. The same lines and stations recorded in the MAG survey were collected again using EMI. A team of students worked shifts to keep the measuring tape taut along the line and collect data. Although the GSSI EM Profiler does not have much tendency for instrument drift, bay-station measurements were collected upon the start and end of each line to ensure accuracy. A sample is captured and recorded on the wireless logger by centering the profiler above the station and clicking the button on the lanyard. A noise is sounded for approximately five seconds while each stack is collected. Once the indicator has gone quiet the surveyor may move 0.25 meters to the next station. The PDA logger shows current measurements of each frequency and also plots a conductivity profile of the current line. After every station has been collected the PDA is synced to a computer for interpretation.

Ground penetrating radar – GPR

Our final method of data acquisition is the GPR technique. Closely spaced antennas transmit and receive electromagnetic wave pulses through the subsurface. The electromagnetic waves transmitted into the ground are reflected by geologic structures or artifacts beneath the ground surface. These waves are traveling with a velocity approximately one third the speed of light. The time elapsed between wave pulse transmission, reflection, and reception is known as the two-way travel time. That is twice the time the wave travels down to a reflector because it must also travel back through the ground to the receiver antenna. The depth of a reflector can be determined by computing the two-way travel time with the electromagnetic wave velocity of the subsurface. The depth of the reflector is recorded by the GPR equipment. Geomaterials have differing velocities depending on factors such as mineral composition, porosity, and percent water content. Water content is the primary constituent of geomaterial which affects the depth of radar-wave penetration. The frequency of the electromagnetic wave pulse is also a primary factor. In general, dry sand has greater penetration depth and imaging quality than wet clay. Lower frequency wave pulses have a greater penetration depth than higher frequency wave pulses, but do not resolve thin reflective interfaces as clearly. It is important to recognize the conditions of the survey environment to select the appropriate GPR equipment (Everett, 2013).

Instrumentation

Ground penetrating radar equipment has a frequency range of 10Mhz – 2 GHz (*Everett*, 2013). For our purpose we have chosen the 500 MHz Sensors and Software PulseEkko PRO ground-penetrating radar system. The 500 MHz frequency will resolve near-surface features sharply at depths approximately equal to a standard cemetery burial of one meter.

The 500 MHz PulseEkko GPR has two main components: the transmitter and receiver antennas and computer console. The 500 MHz antennas are housed on a low friction, flat-bottomed sled 0.5 meters long and are completely encased by shielding. Attached to the sled is a one meter long T-shaped handle which pivots from horizontal to vertical about an axle joint. A 12 volt battery mounted on a woven nylon waist-belt powers the antennas and console unit. The console is fixed into a light-weight rectangular frame erected from tubing and corner fittings so it may be broken down for transport. A harness of nylon straps attach to the frame on its four corners and are worn by the surveyor like a backpack. The console has a digital display with software that can image the reflection data being collected in real-time

.

Figure 2.12:

Texas A&M Geophysics student Tate Meehan collects a point station sampling with the 500 MHz GPR sled.

Figure 2.13:

Large debris must be cleared from the survey area to operate the GPR.

Figure 2.12

Figure 2.13

Acquisition

A sample line was acquired to ensure proper equipment function. Various settings must be adjusted on the console to match the desired collection conditions. The number of datum stacks, stations and lines must be programmed into the console to keep the data organized. Because of velocity variations within the various geomaterials, subsurface conditions must be known to collect the data within an appropriate time-window. A local soil map is required to input the ground conditions.

With the equipment operating as desired, the team pulled the measuring tape across the cemetery and the point station datum collection process began. Bay-station sampling is not required with the GPR equipment as this equipment does not experience drift. The sled must be positioned with the midpoint between the antennas centered over the point station. The radar-wave will penetrate the ground and be reflected in the subsurface about this midpoint. The low friction skid plate of the sled glides smoothly over the rough ground which makes towing the sled into position quite easy. Once the raw data from the cemetery has been collected, further image processing is conducted to reveal the subsurface reflectors.

CHAPTER III

EARLY DATA ANALYSIS

Unusable data-sets

The MAG, EMI, and GPR data sets collected throughout the Fall of 2013 were shown to be of dissatisfactory quality after early processing. The poor quality of these data-sets is attributed to changing soil conductivity, instrument drift between collection days, and the variety of inexperienced students collecting data as a part of the class exercise. Highlighted in figure 3.1, a steep electrical conductivity gradient bisects the cemetery site. A similar feature found in the magnetics has been highlighted on figure 3.2.

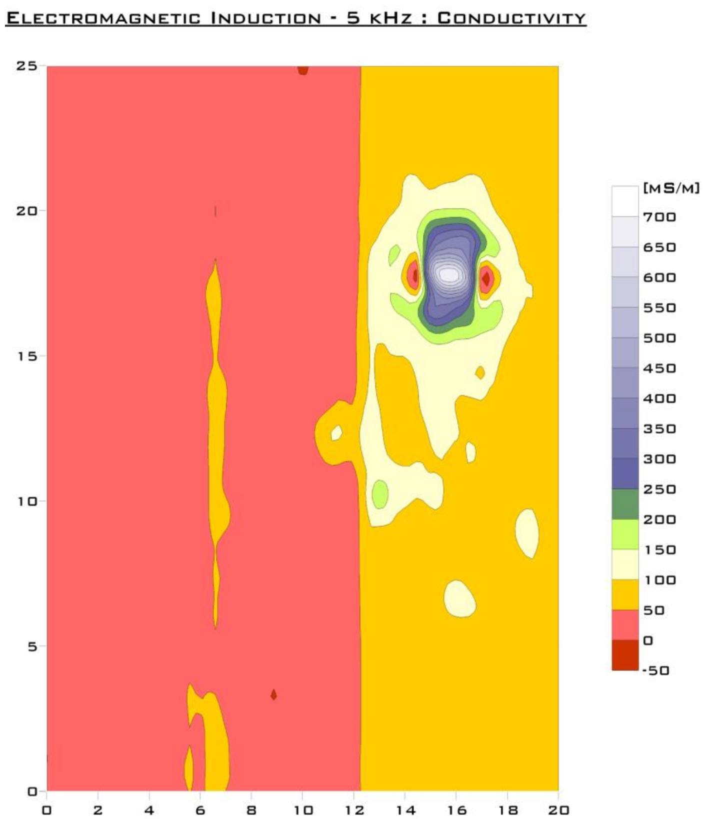


Figure 3.1

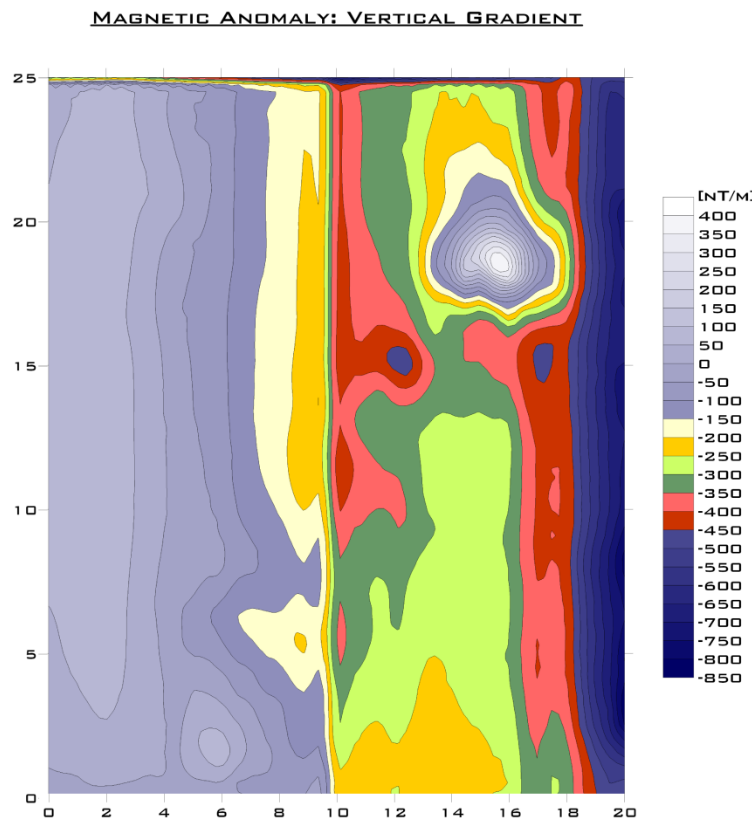


Figure 3.2

The processed data shows a linear trend bisecting the cemetery in both EMI, figure 3.1, and MAG, figure 3.2. The plots have been scaled to highlight this trend.

The steep contour gradient trending across the cemetery is not located in the same line for each data-set. The bisecting trend runs parallel to meter twelve in the EMI data and parallels meter ten in the MAG data. Based on this evidence we have concluded this trend is not a subsurface feature and is an artifact of disjointed data collection. Higher quality data is required for the grand fusion of these data-sets. The choice was made to recollect the magnetics and electromagnetics data.

Poor geophysical imaging was also present after processing the GPR data. The highly conductive clay soil and the unsmooth terrain of the Camptown Cemetery caused a large degree of wave attenuation and topographic abnormalities. This resulted in shallow wave penetration and unmatchable subsurface reflectors. Although various processing techniques were used to gain information from the GPR images, we were unable to recover usable information of the subsurface. We plan to recollect the GPR data with a different approach using lower frequency wave pulses of 200 MHz in the coming months once the soil is arid.

Information detailing our first attempt collection parameters can be withdrawn from these initial data-sets. Although we have not successfully resolved high quality subsurface images, we have learned parameters that will not be successful. We will reconfigure our parameters after learning from our early processing, as the original data should not be considered a total loss. As an important aspect of the scientific method, we must understand this first trial as a learning process of how we can more effectively use our geophysical instruments to map clay based cemeteries.

CHAPTER IV

RECOLLECTION METHODS

These early results were convincing of two details: our collection method was inefficient and inconclusive. The point station datum collection method required more than one day of field work to collect per data-set. As the soil conditions changed over the time between collections inconsistent data was collected. Also our equipment set-up and operation was not ideal. Regional and geologic features are more apparent in these initial data-sets than local soil disturbances. In February 2014 we recollected the magnetic and conductive response data with the goal of acquiring higher quality data at a more efficient pace.

Continuous data collection method

We adopted the continuous collection method to increase our rate of data collection. The equipment may be set to acquire a datum automatically every fraction of a second. By walking a slow pace, the operator may sample many points per meter. Assuming the operator does not walk at a consistent pace, the data will not be evenly distributed along the line. To correct this spatial error a line-mark is taken at consecutive distance intervals. This demarcation is known as a fiducial marker. The fiducial marker acts as a benchmark to define more precisely a Y co-ordinate range in which the data was collected. Several distance measurements are required to group the uneven distribution of data points along the metric line. We issued a fiducial marker every five meters for our continuous survey of the Camptown Cemetery. Although lacking the ideal precision of the point-station method, the continuous method offers great efficiency while sampling without sacrificing data quality.

Gridding irregularly sampled data

Data collected using the continuous sampling method becomes arranged irregularly on a grid. For our purpose it is necessary to interpolate this information onto a regular grid of consistent (*X,Y)* spacing. To interpolate our data with minimal information lost the Moving Least Squares (MLS) method was applied. This method fits a polynomial surface to an irregular grid. This surface can be sampled at desired locations on regular gridded intervals. A brief summary of the mathematical process behind Least Squares (LS) interpolation methods may be found in Nealen, 2004.

Collection parameters

To detect a greater sensitivity to soil disturbances the MAG and EMI equipment parameters were reconfigured. For the MAG recollection, a bi-directional survey method was applied. The surveyor paced the area N-S for line one and S-N for line two continuing this trend with increasing easting for each successive line. The equipment sampled once every 0.3 seconds. We decreased the lower-sensor height from 1 m to 0.3 m. The vertical sensor spacing was changed from 1 m to 0.75 m. The sensor position was lowered to reveal a greater detail of near-surface magnetic anomaly. Figure 4.1 depicts the re-parameterized sensor array of the MAG equipment.

The vertical separation of the G-858 magnetic gradiometer sensors is 0.75 m. The bottom sensor was suspended 0.3m from the ground surface during recollection.

Figure 4.1

For the EMI recollection, a uni-directional survey method was applied. The surveyor paced the cemetery N-S with increasing easting each successive line. The sample rate was set at 0.5 seconds, colleting only one stack. Three frequencies were selected for the electromagnetic wave transmission: 15, 8, and 1 kHz. This range was chosen – following depth of penetration approximately equals half the Tx, Rx coil spacing – to give a broad range of penetration depths. The equipment was calibrated at 0.1 m sensor height. Depicted in figures 4.2 and 4.3, the inline transmission and reception mode was selected. By transecting the cemetery with Tx and Rx perpendicular burial orientation we expect to see a larger signal response over soil disturbances or conductive subsurface targets.

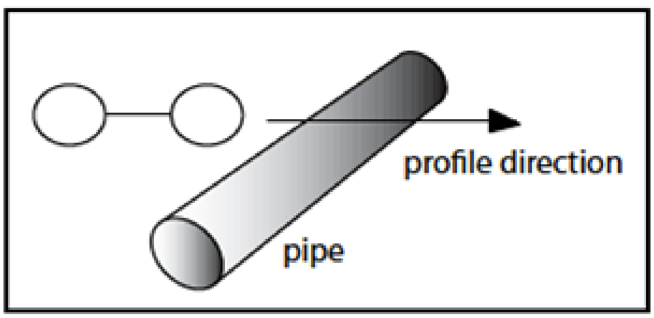


Figure 4.2

Figure 4.3

Figure 4.2: Describes the inline mode which transects the target perpendicular to its axial geometry.

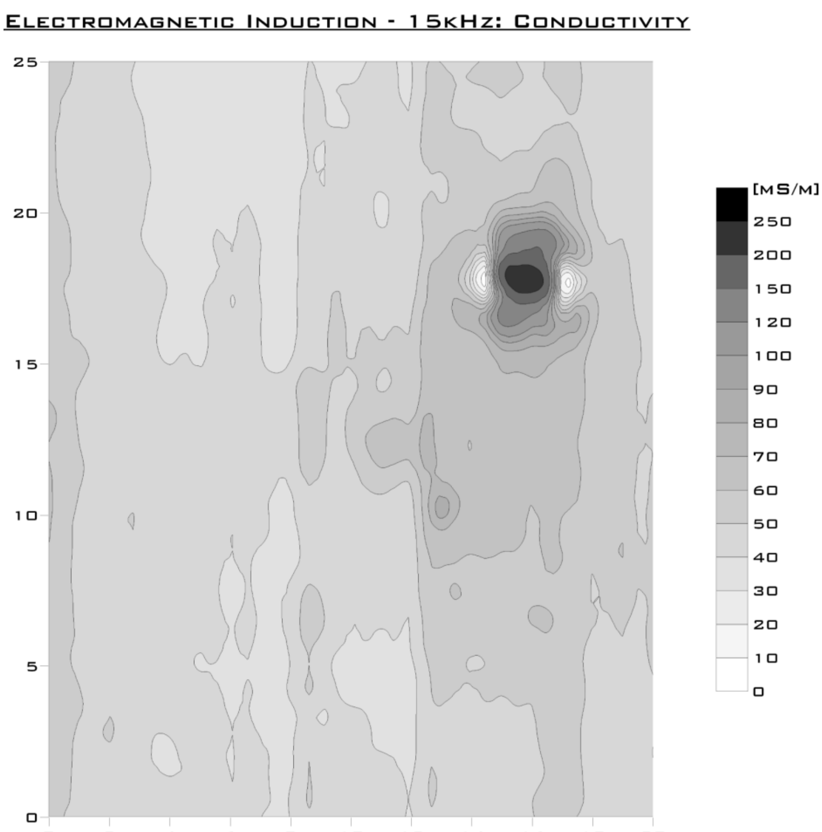
Figure 4.3: Tim de Smet using the GSSI EMP-400 for continuous collection; inline mode.

CHAPTER V

QUALITATIVE DATA ANALYSIS

Fine scale resolution quality

The contours of collected data have been plotted in the figures below. Figure 5.1 is a plot of the first collection of EMI data at 15 kHz. This data-set was collected using the broadside mode with eight stacks per station. Figure 5.2 is a plot of the recollected EMI data. These images were producing using the contouring software Surfer 8 by Golden Software. When comparing these images qualitatively, we can see fine scale detail in the recollected data that does not appear in the first collection. These fine scale details demonstrate the effectiveness of our new collection parameters. This basic analysis is a convincing step forward into the later stages of our image analysis for the multisensory data fusion.



The original EMI data captured at frequency of 15kHz. These data have insufficient resolution of archaeological features. This data-set was collected as a class exercise spanning many days.

Figure 5.1

Electromagnetic Induction: Quadrature - 15 kHz

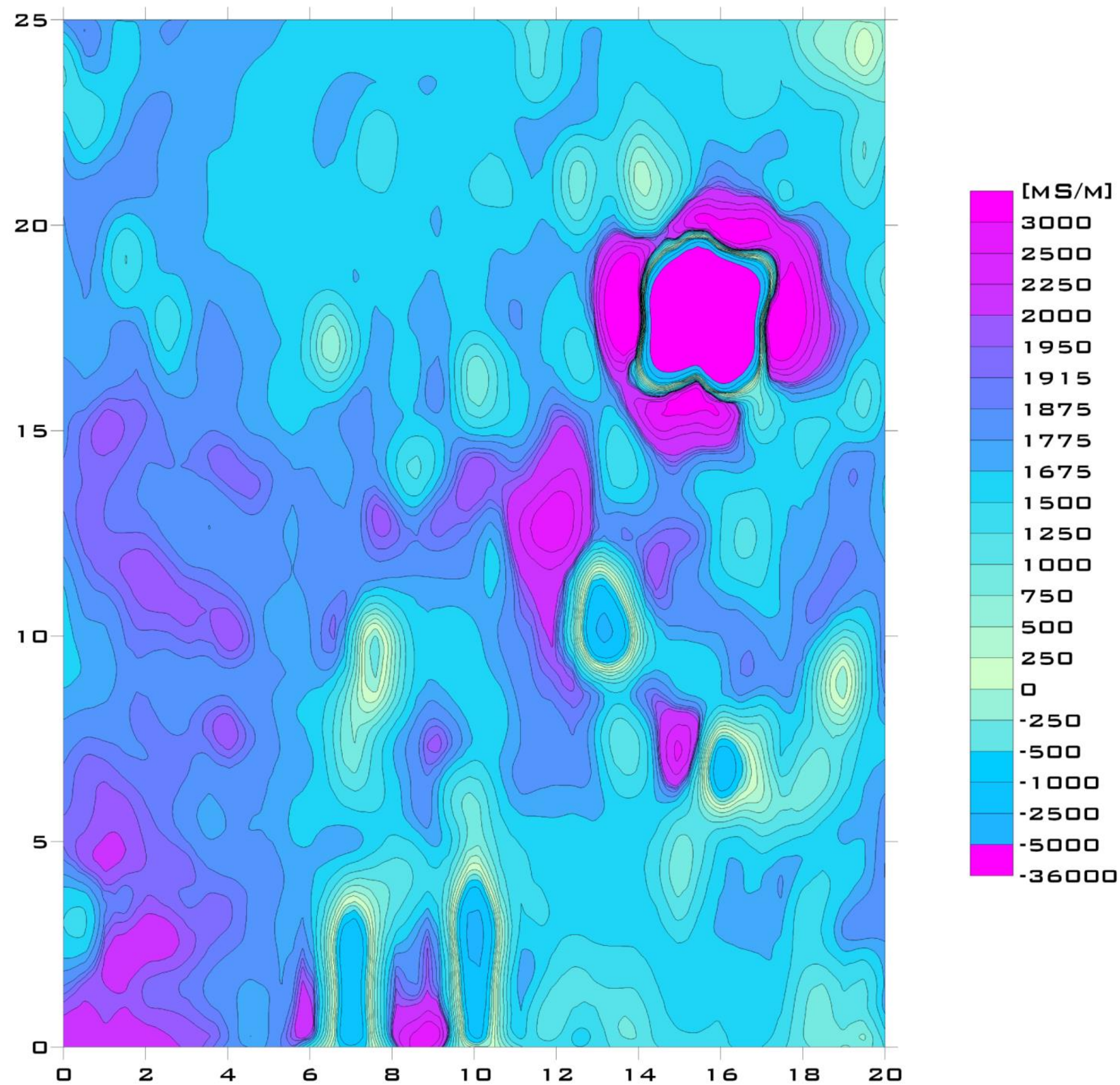


Figure 5.2

The recollected EMI data: This information was collected privately using more effective parameters during one day of field work. Fine scale anomalies are present in this data-set, represented by circular contour rings. This information set shows sufficient detail for image fusion.

A note on quadrature response

Quadrature information is a measurement of the electromagnetic wave response of conductive bodies within the subsurface. Geomaterial impedes the transmitted signal penetrating the subsurface. The degree of this impedance is dependent on the material property, as some earth allows for electric charge migration more freely than others. Material with a high degree of free charge migration yields a greater quadrature response and is understood as a conductive material. Figure 5.3 is a plot of the lower frequency 1 kHz – induction response. These data also depict localized artifacts to a high degree of clarity.

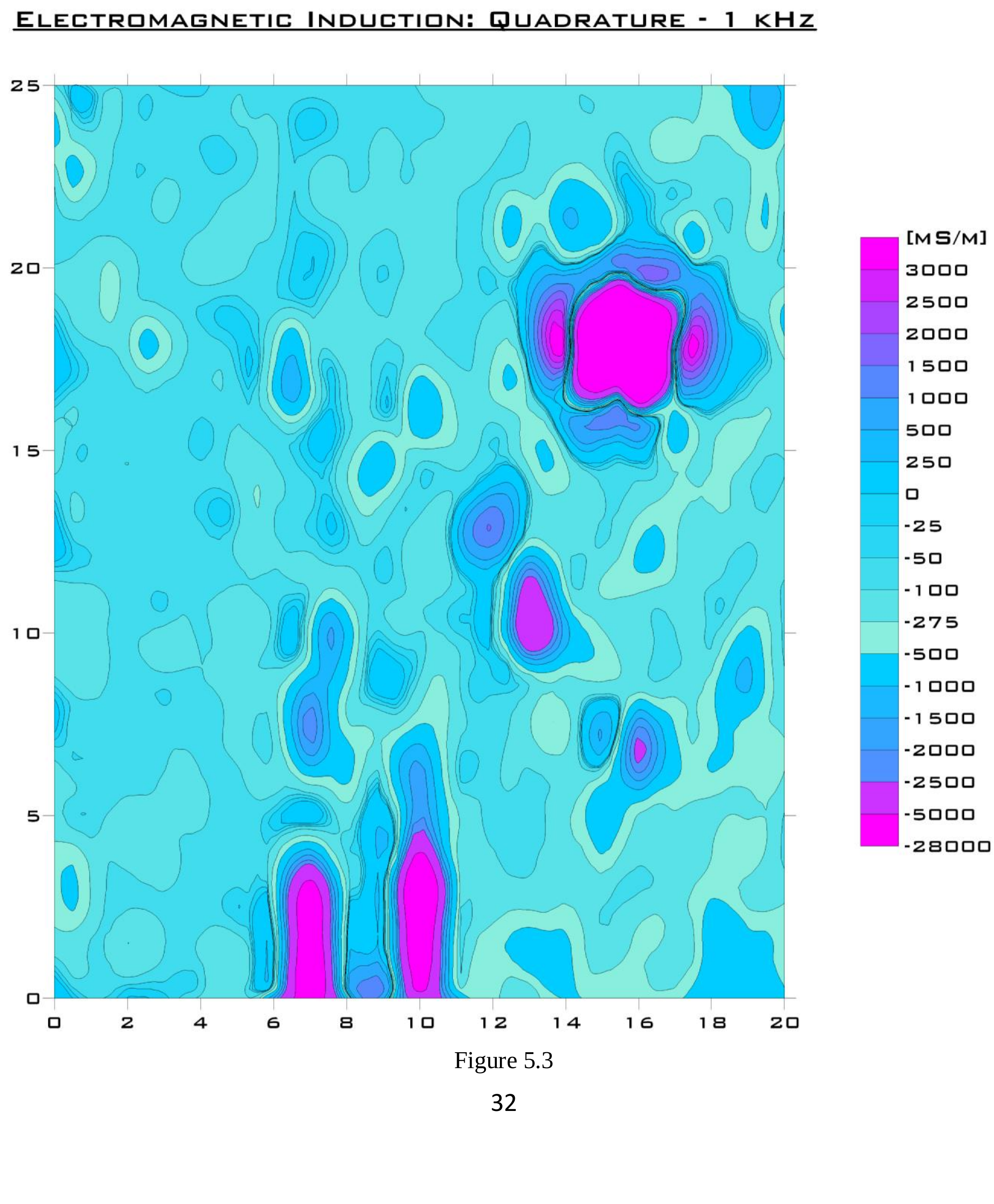


Figure 5.3

The recollected magnetics data also revealed greater subsurface detail. Many fine scale features of the cemetery have been imaged by the magnetic vertical gradient in figure 5.4.

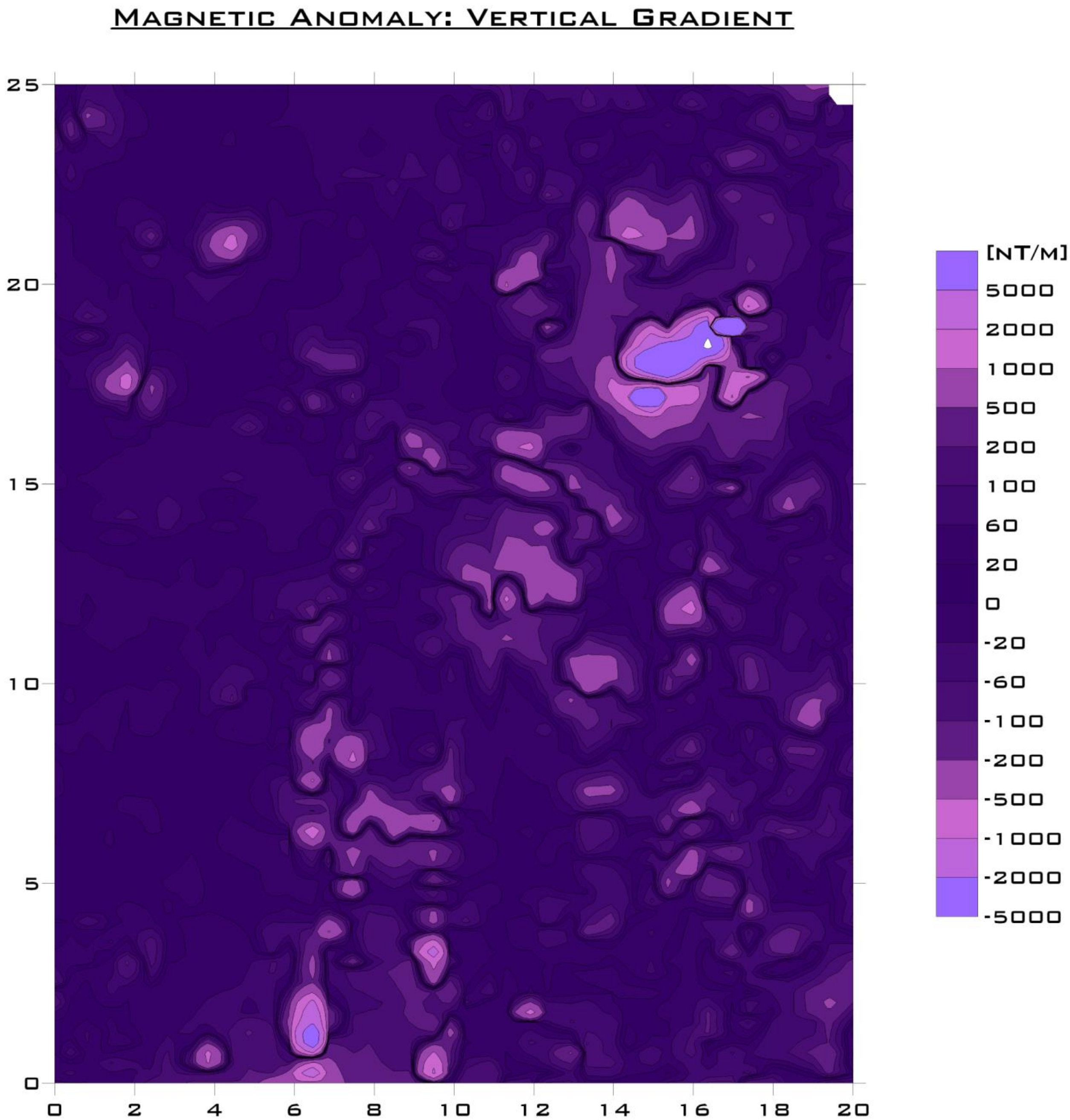


Figure 5.4

Strong localized variances in Magnetic Signature are highlighted by the Vertical Gradient Technique. These readings are visible in the lighter hues of figure 5.4. Top and Bottom sensor readings of similar magnitude resolve as background signature.

A note on magnetic vertical gradient

The magnetic vertical gradient is a measurement of information collected by each of the magnetometer sensors. Typically the signature recorded by the bottom sensor, nearer to the ground, is stronger than the signal recorded by the top or higher sensor. The vertical gradient information is computed by subtracting the bottom sensor reading from the top and dividing by vertical separation distance of the sensors. This information is understood as a localized signature, and may be regarded as an accurate approximation of localized magnetic anomaly.

Qualitative comparison

A simplistic visual comparison of the data sets is an important step toward combining our images. A qualitative comparison is an elementary approach to estimate the plausibility of combining dissimilar data sets. At a first glance, we can see representative features indicating a possible correlation. In figure 5.5 a side by side comparison makes several features apparent in both data sets. These features are representative of archaeological targets within the cemetery.

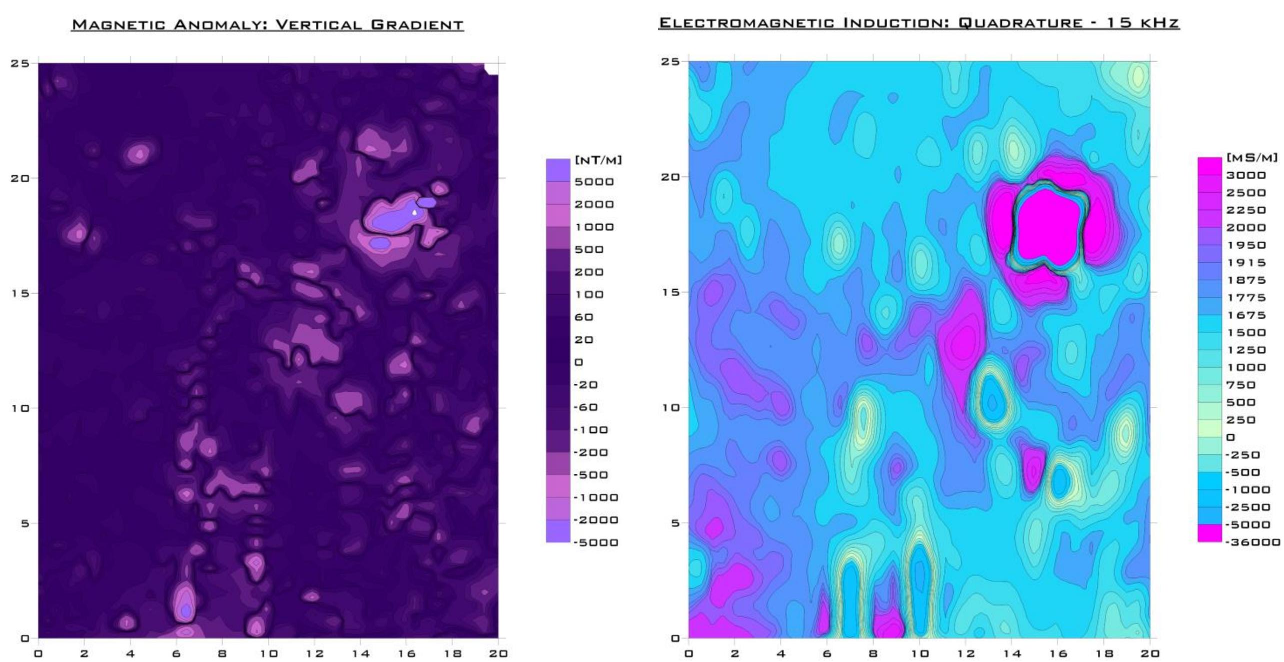


Figure 5.5

Targets of interest

The strong signatures in the EMI and MAG data sets are representative of cemetery artifacts on the surface or below ground. Several of the large signatures have been associated with surface artifacts by inspection and are imaged in figure 5.6 below.

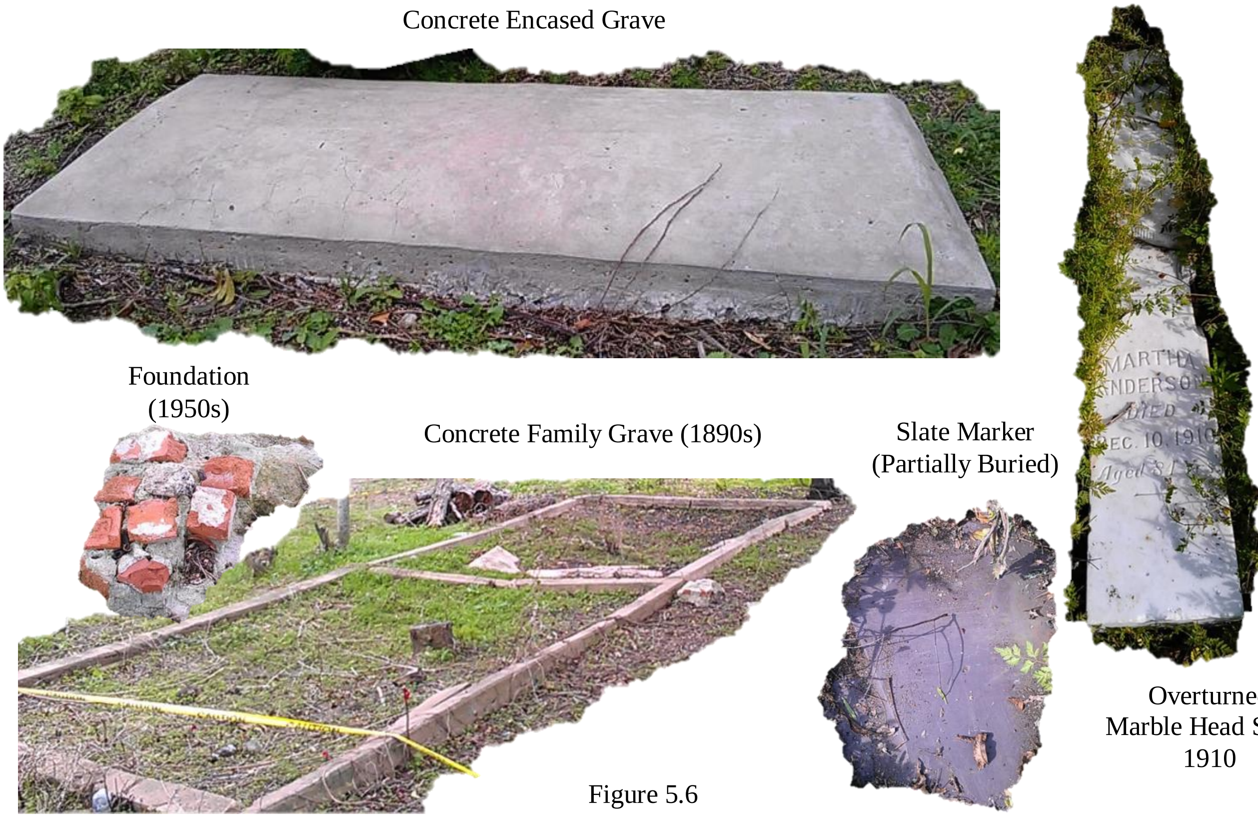


Figure 5.6

Concrete structures and headstones comprised of various geomaterial tend to generate a conductive signature in the EMI quadrature measurement while also exciting a modest magnetic anomaly. Ferrous material such as an iron casket or fence will produce large magnetic and conductive responses. It is interesting to note the regions within the grid which create a response on both instruments. The large circular signature corresponds to a mysterious concrete encased grave which appears to have been placed recently in the cemetery. No date or marking has been found identifying the nature of this large artifact. However, the object has generated a tremendous magnetic anomaly and apparent conductivity.

A visual inspection of the cemetery served as a non-invasive ground truthing of the data, enabling artifact locations to be correlated to observed geophysical measurements. The rectangular signature between meters six and ten along the X axis and extending to meter eight on the Y axis shows resistive and magnetic characteristics. This signature corresponds with the characteristics and location of the large concrete family grave imaged in figure 5.5. It was found that many signatures recorded by the instrumentation are cited beneath shallow depressions in the surface with no apparent grave markings. For the instance of an observed magnetic signature and non-zero induction signature, it is intuitive to reason the existence of a buried conductive source here in the subsurface.

CHAPTER VI

QUANTITATIVE DATA ANALYSIS

Quantitative correlation

Observations concerning qualitative features of these complementary data sets can be a convincing justification for the numerical correlation of the information sets. It is intuitive that a strong qualitative correlation exists between the MAG and EMI information. However challenging is providing a scientific method of comparison to corroborate this immediate visual comparison. By means of a quantitative methodology, we aim to decrease the uncertainty of this intuitive assumption. An analytical analysis will fix a quantity to the spatial correlation exhibited by the MAG and EMI information sets.

Pearson Product-Moment Correlation

Our goal is to combine the EMI and MAG images into a single grid describing the correlation of the data sets. The Pearson Product-Moment Correlation, equation. 6.1, was elected to measure the correlation of our MAG and EMI information sets.

$$corr(X,Y) = \frac{cov(X,Y)}{\sigma_X \sigma_Y}$$

Equation 6.1

$$\theta = \frac{\lambda - \lambda_{min}}{\lambda_{max} - \lambda_{min}}$$

Equation 6.2

This approach will require a normalized numerical scale to correlate the data. The calculated correlation value $corr(X,Y)$ ranges from -1 to 1. A positive value corresponds to a positive correlation, a negative value corresponds to an inverse correlation and a value near zero shows no correlation. Normalized information is a unitless quantity and is necessary to compute a relationship between information of inherently different value-types. Equation 6.2 nondimesionalizes the data into a unitless quantity, where θ represents the normalized value of arbitrary variable λ.

Further reading on computation of statistical analyses may be found in D.L. Harnett et al. 1980.

Standard (X,Y) correlation

For $corr(X, Y)$ variable X is assigned to the normalized magnetics data and Variable Y is assigned to the normalized electromagnetic induction data. Figure 6.1 is a scatter plot correlating *(MAG,EMI)* information collected from the initial point station sampling in October 2013. A point on the scatter graph represents a coordinate *(X,Y)* from the nomalized data set. The average correlation value of this data set is 0.109. Much of this data is centralized within a bull's-eye in quadrant four. Very few data points show positive correlation values for *(X,Y)* coordinates.

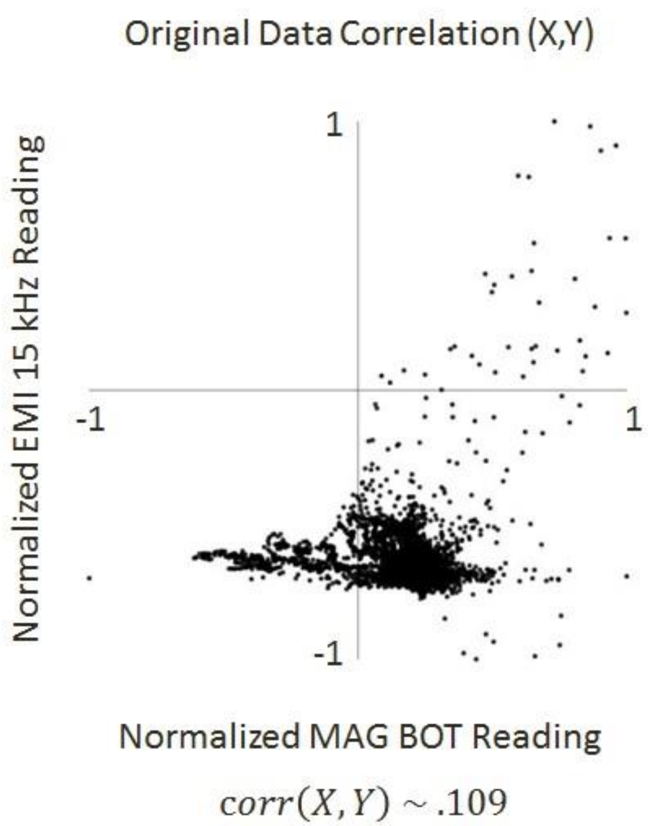


Figure 6.1

The Pearson Product-Moment Correlation of the original MAG and EMI collection has an average *corr(X,Y)* value of 0.109

Moving window averaged correlation

Rather than averaging a correlation value over the broad range of our entire grid space, a correlation characterizing a domain scaling the size of an artifact will resolve a more accurate data construction. We have selected a ten pixel by ten pixel window size which equivocates to rectangle five meters by two and a half meters in the field. The10 x 10 window smoothly characterizes larger artifacts like a cemetery burial. The $corr(X, Y)$ values residing within the window space are averaged and the value is plotted in the center of the window. This is a moving window which increments one value beside its original position to calculate the next averaged correlation. Incrementation ensures a precisely calculated average. Information around the border cannot be averaged, as a completed window cannot frame such coordinates; the missing information will be represented in the gridded moving window correlation plots. Table 6.1 lists the moving window average for several different combinations of MAG and EMI information.

	EMI Q 15 kHz	MAG BOT Sens.	MAG TOP Sens.	MAG $\frac{B}{\Delta h}$
EMI Q 1 kHz	0.95	-0.017	-0.23	0.13
EMI Q 15 kHz		0.044	-0.21	0.19
MAG BOT Sens.			0.55	0.85
MAG TOP Sens.				-0.020

Table 6.1

Congruous information correlations show strongly positive correlation.
Incongruous information correlations display a variety of correlation outcomes.

Correlation of congruous information sets

Congruous information sets are to be understood as information of the same type; whereas 1-kHz quadrature is of the same type as 15-kHz quadrature. The moving window average Pearson Product-Moment Correlation shows congruous information sets to be of high intrinsic correlation. Figure 6.2 is a contour plot of the moving window average correlation values for the congruous EMI information sets. Regions of dark contrast designate positive correlation values and regions of light contrast designate negative correlation values.

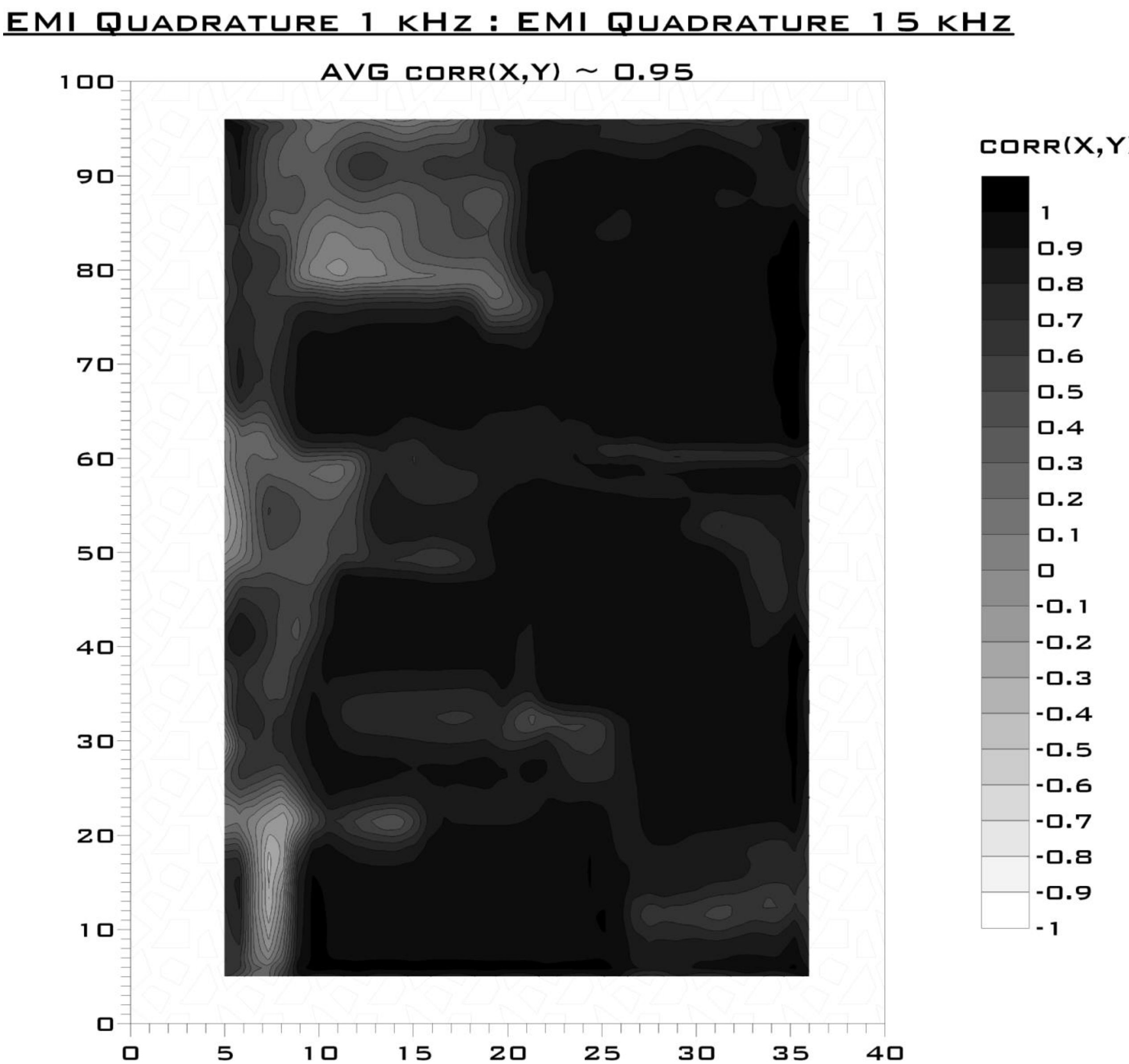


Figure 6.2

The congruous EMI information set displays a largely dark contrasted region throughout the cemetery ground. This area has a correlation value of 0.95, nearly unity. At high correlation values the uncertainty between the correlated information sets is almost entirely reduced. Figure 6.3 is a contour plot of the congruous MAG information set which maps the bottom sensor information against the top sensor information. This correlation shows a considerable positive value of 0.55.

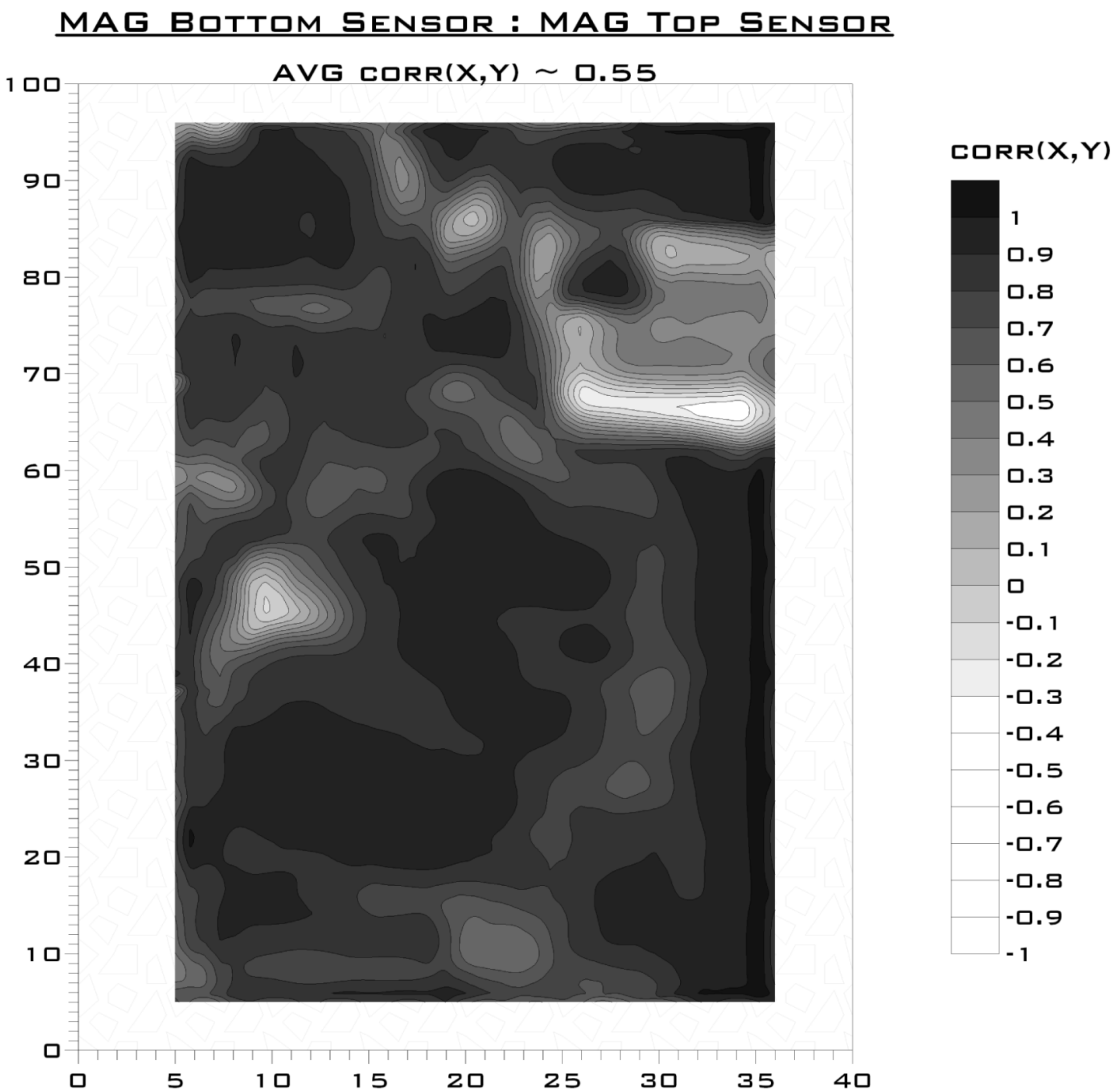


Figure 6.3

Correlation of incongruous information sets

Incongruous information sets are to be understood as information of different type; whereas EMI information – a measure of quadrature – is different from MAG information – a measure of magnetic field. Successful correlation of incongruous information was the ultimate goal of this project. The moving window average Pearson Product-Moment Correlation shows our incongruous information sets to be of low intrinsic correlation. Plotted in figures 6.4 and 6.5 is the EMI quadrature of different frequency correlated to the magnetic vertical gradient.

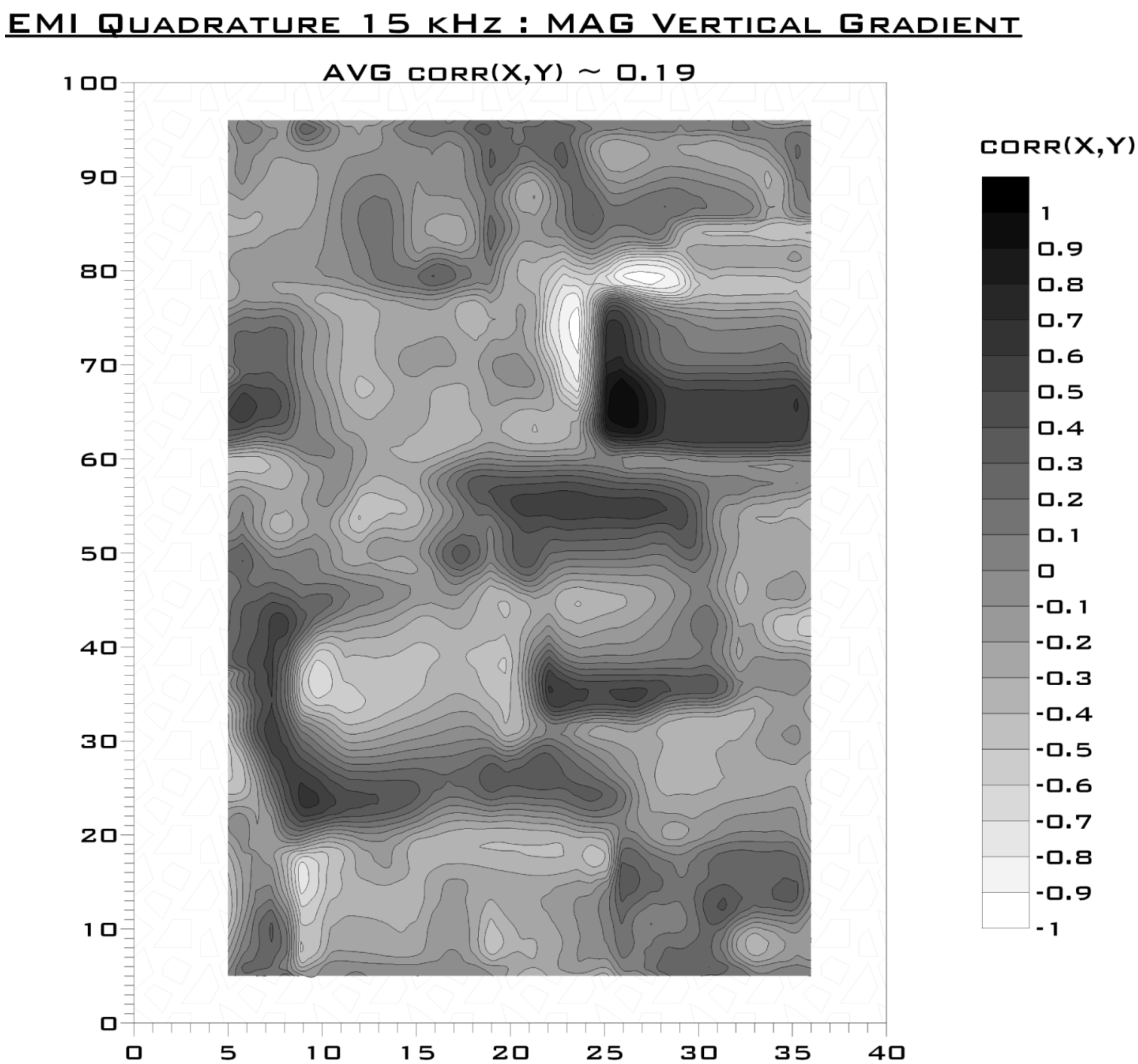


Figure 6.4

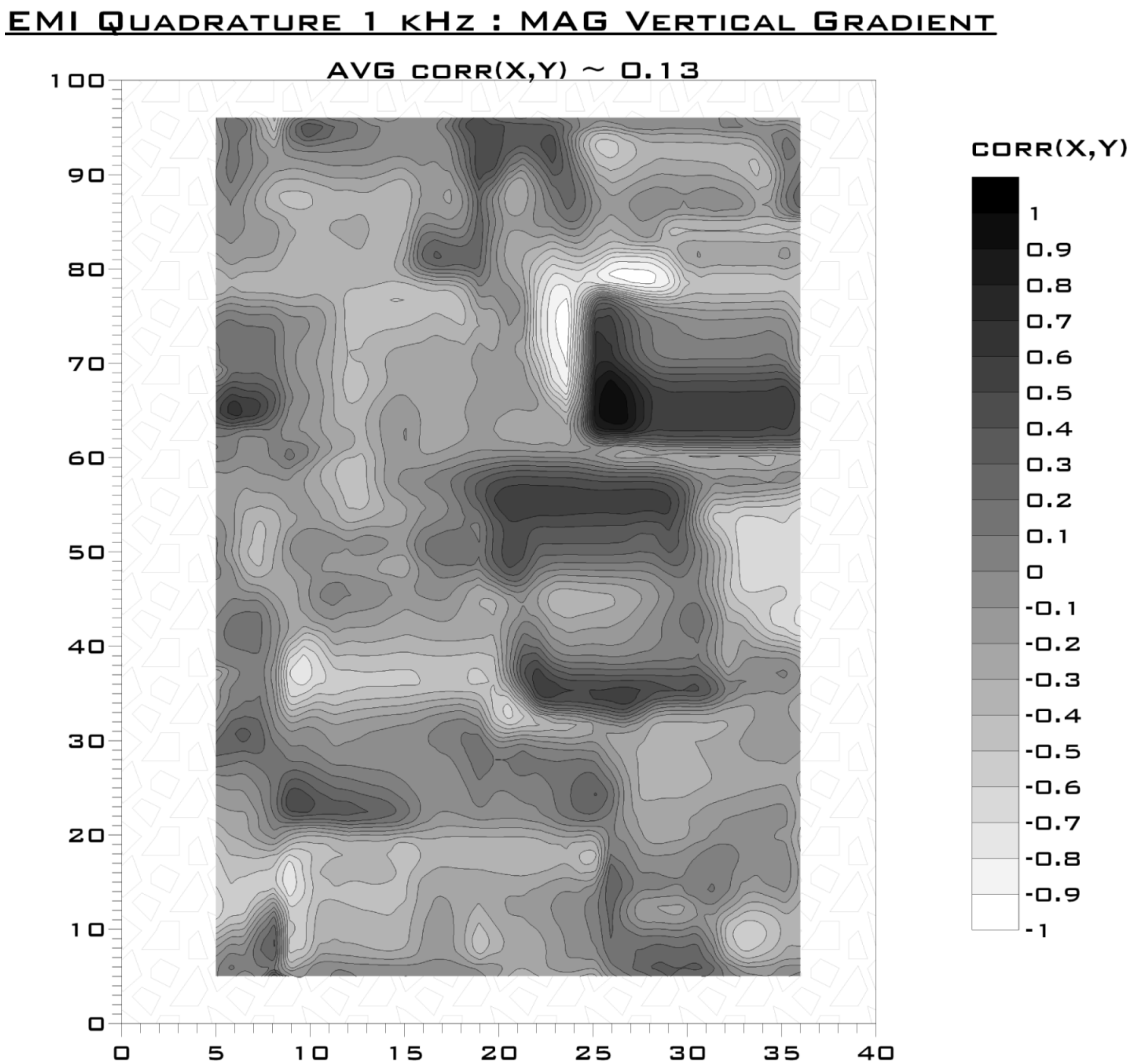


Figure 6.5

The region containing the large concrete encased grave yields correlation near one. However, much of the region is background signature wavering near zero. Interpreting the usefulness of the correlated data requires an understanding of all variables. Many inferences can be withdrawn from these constructed data sets. Hidden explanations for statistical causation should not be overlooked.

CHAPTER VII

CONCLUSIONS

This project became an opportunity to enrich local heritage and explore future possibilities of near-surface geophysics. After being contacted by the town of Brenham, Texas, we have been excited and honored to work as a part of the grassroots Camptown Cemetery mapping. We plan to serve as the primary source of investigative research for many seasons to come. As volunteers clearing brush, and geophysicists collecting and interpreting information this project has come full cycle. The following topics will discuss the results and interpretations concerning these correlation data and the historical and future implications of the Camptown Cemetery geophysical mapping investigation.

Correlation conclusions

Making inferences about data characterization must be approached with tentativeness and the validity of our correlations must be balanced. We do consider the interpretation procedure to be a success. As two incongruous geophysical information sets have been combined into one image, the characterization depicts a reduction in localized subsurface information uncertainty. Although the constructed correlation information provides a secondary insight of Camptown Cemetery, the results shown have a range of variables that may considerably alter the outcome of the correlation process. The information listed in table 6.1 contains many important artifices for interpreting the correlation information

.

Observations made regarding correlated data-sets and strength of correlation

The correlation plots are best intended as a localized artifact detector. The strongly correlated signals are to appear as a localized target while background information are intermittent grey area. The imaging was inconsistent throughout the region, showing a signal that varied noisily.

Adjunctly, the global value has a skew created by parameters of equipment and data collection. The magnetic sensor positioning height has an apparent effect on the strength of the correlated information. When comparing each sensor relative to the vertical gradient it is evident that the bottom sensor records the dominating signature of the magnetics information. Examining the region concerning the concrete encased grave in figure 6.3, a correlation of the bottom sensor to the top sensor, reveals an alternating correlation of positive and negative values. This is a rather interesting result, as both top and bottom sensors detect a very broad anomaly in the region. Knowledgably, these data contain a strong magnetic dipole: a positive signature matched equally by a negative signature. After this information is normalized [-1, 1] these signatures of opposite sign are included in the correlation. This unintentionally breaks down the strength of $corr(X, Y)$ as the signature of the magnetic dipole is dependent on sensor height. Meaning negative and positive magnetic information is not localized vertically.

The EMI information returns a zero to inverse correlation with the individual magnetic sensors. As the sensor position increases in height the correlation increases in negativity. This is a global averaging effect. The variation of magnetic signal as a function of height above regional magnetic anomaly does not correlate well to quadrature measurement which maintains fairly consistent depth of sub-surface penetration.

Historical implications

This paper provides significant research for the purpose of preserving the Camptown Cemetery, as it is shown to contain numerous unmarked burials after completing the survey of a small, preliminary section. By better defining the history of this cemetery through archaeological geophysics, the historical contexts concerning Brenham and the origins of the state of Texas can potentially be re-written.

Camptown Cemetery was literally a dead end only one year ago, though after tremendous community support, is now a preserved cemetery registered by the Texas Historical Commission.

Figure 7.1

On March 22, 2014 an inauguration ceremony was held for the dedication of Camptown Ceremony. Located where this “DEAD END” road-sign was planted for decades, now rests an official Texas Historical Commission plaque.

Figure 7.2

Considerations for improvement and future work

Expected to continue for several years, we have the ambitious task of mapping the remaining acreage of the Camptown Cemetery with dense data coverage from three geophysical information sources. It is therefore imperative to collect data using the most efficient and effective approach. Throughout the research process we have learned valuable information regarding our methodology and correlation approach. Yet many hypotheticals remain.

Improving upon collection techniques to resolve stronger correlation values

By applying the continuous collection approach, we significantly improved the efficiency and quality of our data. We have successfully produced correlation images given these first-run parameters; however, much can be altered within the strategy to further strengthen our results.

Errors concerning the correlation of magnetic vertical gradient information have been addressed in the observations section of this chapter. Collecting horizontal gradient information may prove be a useful approach when correcting the correlation breakdown as a function of sensor height. Because the sensors have equivalent elevation in this collection mode, the strong variation of magnetic dipole signature can be eliminated. This hypothetical can be tentatively bolstered by the congruous EMI correlation; stating consistent sensor elevation yields a stronger positive correlation than vertically separated sensor information.

Covering the grid with greater data density will improve the quality of data-sets. Although, increasing coverage will decrease the efficiency of data collection, an improved correlation value may be returned. Decreasing the geographic size of the correlation window would resolve a more localized correlation providing for a more definite detection of artifacts. By sampling the X axis with 0.25 meter line spacing, the geographic window would cover an area half the current size.

Valid GPR data has not been collected within the Camptown Cemetery. Recollecting this information is required for advancing the image fusion process The Pearson Moment-Product Correlation was a simplistic and successful approach for image fusion; however, the incorporation of a the third information source will require a new method of data fusion. Reconfiguring the current methodology and considering other methods of image combination leaves an entirely new construction of image analysis to be researched.

Engineering applications of near-surface geophysics at historic Camptown Cemetery

We will continue our work at the historic Camptown Cemetery with a secondary application of near-surface geophysics. In an effort to reduce erosion on the cleared landscape, the Brenham Heritage Museum staff has asked that we survey a pathway of natural rain water drainage. We have been asked to identify route such that a concrete gutter may be constructed across the cemetery without disturbing any burial sites. This application will provide a means to improve upon our methodology, challenged by a topic faced widely in today's industry.

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