Geophysical Investigations at the Ellsworth Rock Garden Site (21SL1006), Voyageurs National Park

By
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Midwest Archeological Center
Technical Report No. 111

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This report has been reviewed against the criteria contained in 43CFR Part 7, Subpart A, Section 7.18 (a) (1) and, upon recommendation of the Midwest Regional Office and the Midwest Archeological Center, has been classified as

Available

Making the report available meets the criteria of 43CFR Part 7, Subpart A, Section 7.18 (a) (1).

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1. INTRODUCTION

The geophysical survey at Voyageurs National Park (VOYA) was conducted as part of the archeological investigations of the Ellsworth Rock Gardens Site (21SL1006). The site was located on the south side of the Kabetogama Peninsula overlooking Kabetogama Lake (Figure 1). The geophysical survey included a magnetic survey with a fluxgate gradiometer, a resistance survey with a resistance meter and twin probe array, a conductivity survey with an electromagnetic induction meter (EMI), and a ground penetrating radar survey (gpr) with a gpr cart system with 400 mHz antenna. The geophysical investigations were part of a larger park wide archeological site condition assessment project conducted by the Midwest Archeological Center (MWAC) in the summer of 2006. The geophysical survey was also conducted in order to determine the feasibility of geophysical techniques at archeological sites within VOYA. The geophysical survey was conducted by MWAC supervisory archeologist Jeffrey J. Richner, archeologist Steven L. DeVore, and archeological technicians John Banks, Brennan Dolan, and Kyle Klemme.

The site is located within the Superior Upland province of the Laurentian Upland division of the North American continent (Fenneman 1938:537-558). The region is part of the submaturely dissected and recently glaciated peneplain that lies on a complex base of crystalline, Pre-Cambrian rocks. Although the Superior Upland is structurally different from the Central Lowland province, the differences are masked by the Pleistocene glaciations (Hunt 1967:211-214). The site also lies within the western part of the Superior Stoney and Rocky Loamy Plains and Hills land resource region of the Northern Lake States Forest and Forage major land resource area (USDA 2006:287-288). The region consists of a young surface dominated by glacial features including drumlin fields, moraines, outwash plains, bedrock controlled uplands, and small glacial lake plains (USDA 2006:287). Lakes, ponds, bogs, and closed depressions are found throughout the area. Rainy Lake is the major hydrologic unit in the land resource area. The site is located on the right side of Clyde Creek near its confluence with Kabetogama Lake.

The area is also part of the Canadian biotic province of North America (Dice 1943:13-16). Although the biotic province has a deciduous forest climax, several coniferous species form important subclimaxes throughout the region. Northern Minnesota is also part of the southern extension of the boreal coniferous forest (Shelford 1974:120-151). In northern Minnesota, patches of pine and hemlock occur in the maple-beech-hemlock forests (Shelford 1974:143). Dominant trees include white pine, eastern hemlock, beech, yellow birch, sugar maple, and basswood. The pines prefer poor sandy soils. Black spruce, tamarack, and northern white cedar occur in the region's numerous bogs and swamps (Dice 1943:17). Fauna in the region include moose, white-tailed deer, black bear, smaller mammals, numerous songbirds, insects, spiders, reptiles and amphibians (Shelford1974:136-138,144; Sutton and Sutton 1985:36-42). The wolf, lynx, bobcat, and eagle are important predators. Migratory birds and marine species are also important elements of the faunal inventory and food chain (USDA 2006:288).

Entisols, Histosols, and Inceptisols dominate the soil groups in the region (USDA 2006:288). Parent materials include glacial till, drift, and outwash along with lake sediments, alluvium, and loess with isotic or mixed mineralogy. Soils are dominated by shallow and moderately deep soils which are very poorly drained to excessively drained. The soils range from level to very steep depending on their topographic setting. The soil temperature is frigid. The soils also have an udic soil moisture regime (USDA 2006:288). The soil within the geophysical project area consists of a nearly level, well drained sandy loam.

The climate of the region is classified as a temperate continental climate with cool summers (Trewartha and Horn 1980:302-305). The cold winters are moderately long and relatively severe. Annual precipitation ranges from 63 to 76 cm. Most of the precipitation occurs in the form of rain between April and September. Snowfalls can be heavy with the snow staying on the ground throughout the winter season. The average annual temperature ranges between 2 and 4 degrees C. Temperatures at International Falls range from a January average of -16° C to a July average of 20° C. Extreme temperatures range from a minimum of -45° C to a maximum of 39° C (Hovde 1941:925-934). The region has a freeze free period of approximately 150 days (USDA 2006:287).

The Ellsworth Rock Gardens Site (21SL1006) contains approximately 160 rock sculptures and 52 flower beds constructed by Chicago contractor Jack Ellsworth between the 1940s and 1960s (figure 2). The footprint of his cabin has been preserved as a park picnic shelter. The open area below the rock gardens is presently used as a day picnic area for park visitors (Figure 3). In the 1920s and 1930s, the site was the location of a logging camp. Depressions of the bunkhouse, barn, and other outbuildings are still visible at the site. The purpose of the geophysical investigations is to determine the nature and to identify buried archeological resources related to the ca. 1920s-1930s logging camp. The information will be used in the evaluation of the archeological significance of the Site 21SL1006.

2. SURVEY METHODOLOGY

The geophysical survey project at the Ellsworth Rock Gardens Site (21SL1006) within Voyageurs National Park was conducted in 20-meter by 20-meter grid units, which were used to control the placement of the instruments during data acquisition. Using the base of the sundial as the grid reference point, a baseline stake was set two meters north of the reference point. The grids were established along an east-west baseline and a north-south baseline using an Ushikata S-25 TRACON surveying compass (Ushikata n.d.) The north-south line was oriented to magnetic north. Wooden hug stakes were set at 20 meters north and 20 meters south of the baseline grid stake. Wooden hub stakes were driven into the ground at 20-meter intervals along the baselines to mark the corners of the complete grid units or at the end of the line to mark the partial grid unit corners. The established baseline hubs were used as survey stations for the placement of the remaining grid corner hubs. The 20-meter grid corners of the east-west lines were set out in the clearing below the rock gardens (Figure 4). Two complete and 10 partial 20-m by 20-m grid units were established for the geophysical survey at the site. The total area investigated by the geophysical survey was 3,135 m^2 or 0.77 acres.

Twenty-meter ropes were placed along the east-west base lines connecting the grid unit corners. These ropes formed the north and south boundaries of each grid unit during the data collection phase of the survey. Additional ropes were placed at one-meter intervals across the grid unit in a north-south orientation. These ropes serve as guides during the data acquisition. The ropes were marked with different color tape at half-meter and meter increments designed to help guide the survey effort. A sketch map was completed for the geophysical project area (Figure 5). The data were acquired across the grid units beginning in the lower left hand (southwest) corner of each grid unit (Geoscan Research 1987:43-54,2003:5/2-5/11).

GEOPHYSICAL INVESTIGATIONS VOYAGEURS

3. GEOPHYSICAL TECHNIQUES

Geophysical prospection techniques available for archeological investigations consist of a number of techniques that record the various physical properties of earth, typically in the upper couple of meters, however, deeper prospection can be utilized if necessary. Geophysical techniques are divided between passive techniques and active techniques. Passive techniques are primarily ones that measure inherently or naturally occurring local or planetary fields created by earth related processes under study (Heimmer and DeVore 1995:7,2000:55; Kvamme 2001:356,2005:424). The primary passive method utilized in archeology is magnetic surveying. Other passive methods with limited archeological applications include self-potential methods, gravity survey techniques, and differential thermal analysis. Active techniques transmit an electrical, electromagnetic, or acoustic signal into the ground (Heimmer and DeVore 1995:9,2000:58-59; Kvamme 2001:355-356). The interaction of these signals and buried materials produces altered return signals that are measured by the appropriate geophysical instruments. Changes in the transmitted signal of amplitude, frequency, wavelength, and time delay properties may be observable. Active methods applicable to archeological investigations include electrical resistivity, electromagnetic conductivity (including ground conductivity and metal detectors), magnetic susceptibility, and ground penetrating radar. Acoustic active techniques, including seismic, sonar, and acoustic sounding, have very limited or specific archeological applications.

Magnetic Survey

A magnetic survey is a passive geophysical survey technique used to measure local changes in the earth's magnetic field (Bevan 1991,1998:29-43; Breiner 1973;1992:313-381; Burger 1992:389-452; Clark 2000:92-98,174-175; David 1995:17-20; Dobrin and Savit 1988:633-749; Gaffney and Gater 2003:36-42,61-72; Gaffney et al. 1991:6,2002:7-9; Heimmer and DeVore 1995:13,2000:55-56; Kvamme 2001:357-358,2003:441, 2005:434-436,2006a:205-233,2006b:235-250; Lowrie 1997:229-306; Milson 2003:51-70; Mussett and Khan 2000:139-180; Nishimura 2001:546-547; Robinson and Çoruh 1988:333-444; Scollar et al. 1990:375-519; Telford et al. 1990:62-135; Weymouth 1986:343; and Witten 2006:73-116 for more details on magnetic surveying). The Geoscan Research FM36 fluxgate gradiometer (Figure 6) is a vector magnetometer, which measures the strength of the magnetic field in a particular direction. The sensors must be accurately balanced and aligned along the direction of the field component to be measured. The magnetic balance and aligning reference point for the gradiometer is located at N20/E60.

A magnetic survey is a passive geophysical prospection technique used to measure the earth's total magnetic field at a point location. Its application to archeology results from the local effects of magnetic materials on the earth's magnetic field. These anomalous conditions result from magnetic materials and minerals buried in the soil matrix. Iron artifacts have very strong effects on the local earth's magnetic field. Other cultural features, which affect the local earth's magnetic field, include fire hearths, and soil disturbances (e.g., pits, mounds, wells, pithouses, and dugouts), as well as, geological strata. Magnetic field strength is measured in nanoteslas (nT; Sheriff 1973:148). In North America, the earth's magnetic field strength ranges from 40,000 to 60,000 nT with an inclination of approximately 60° to 70° (Milsom 2003:43; Weymouth 1986:341). The project area has a magnetic field strength of approximately 59,4500 nT (Peddie 1992; Sharma 1997:72-73) with an inclination of approximately 75° 45' (Peddie and Zunde 1988; Sharma 1997:72-73). Magnetic anomalies of archeological interest are often in the ±5 nT to ±20 nT range, especially on prehistoric sites. Magnetic anomalies of archeological interest on historic sites may range over ±20 nT. Target depth in magnetic surveys depends on the magnetic susceptibility of the soil and the buried features and objects. For most archeological surveys, target depth is generally confined to the upper one to two meters below the ground surface with three meters representing the maximum limit (Clark 2000:78-80; Kvamme 2001:358). Magnetic surveying applications to archeological investigations have included the detection of architectural features, soil disturbances, and magnetic objects (Bevan 1991; Clark 2000;92-98; Gaffney et al 1991:6; Heimmer and DeVore 1995,2000; Weymouth 1986:343).

Two modes of operation for magnetic surveys exist: the total field survey and the gradient survey. The instrument used to measure the magnetic field strength is the magnetometer (Bevan 1998:20). The total field survey uses a single magnetic sensor. Three different types of magnetic sensors have been used in the magnetometer: 1) proton free precession sensors, 2) alkali vapor (cesium or rubidium) sensors, and 3) fluxgate sensors (for a detailed description of the types of magnetometers constructed from these sensors see Clark 2000:66-71; Milsom 2003:45-47; Scollar et al. 1990:450-469; Weymouth 1986:343-344).

The total field magnetometer is designed to measure the absolute intensity of the local magnetic field. This type of magnetometer utilizes a single sensor. Due to diurnal variation of the earth's magnetic field, the data collected with a single sensor magnetometer must be corrected to reflect these diurnal changes. One method is to return to a known point at regular intervals throughout the survey and take a reading that can be used to correct the diurnal variation. A second method is to use two magnetometers with one operated at a fixed base station collecting the diurnal variation in the magnetic field. The second magnetometer is used to collect the field data in the area of archeological interest. Common magnetometers of this types used in archaeological investigations include the proton precession magnetometer, the Overhauser effect magnetometer (a variation of the proton-precession magnetometer), and the cesium magnetometer.

The magnetic gradient survey is conducted with a gradiometer or a magnetometer with two magnetic sensors at a fixed vertical distance apart. The instrument measures the magnetic field at two separate heights. The top sensor reading is subtracted from the bottom sensor reading. The resulting difference is recorded. This provides the vertical gradient or change in the magnetic field. Diurnal variations are automatically canceled. This setup also minimizes long range trends. The gradiometer provides greater feature resolution and potentially provides better classification of the magnetic anomalies. Two commonly used gradiometers in archeological investigations are the cesium gradiometer and the fluxgate gradiometer. They are capable of yielding 5 to 10 measurements per second at a resolution of 0.1 nT (Kvamme 2001:358). Cesium gradiometers record the absolute total field values like the single sensor total field magnetometers. It also records the gradient change between the bottom and top sensors. The fluxgate sensors are highly directional, measuring only the component of the field parallel to the sensor's axis (Clark 2000:69). They also require calibration (Milsom 2003:46-47). Both cesium and fluxgate gradiometers are capable of high density sampling over substantial areas at a relatively rapid rate of acquisition (Clark 2000:69-71; Milsom 2003:46-47).

The two magnetic sensors in the fluxgate gradiometer are spaced 0.5 meters apart. The instrument is carried so the two sensors are vertical to one another with the bottom sensor approximately 30 cm above the ground. Each sensor reads the magnetic field strength at its height above the ground. The gradient or change of the magnetic field strength between the two sensors is recorded in the instrument's memory. This gradient is not in absolute field values but rather voltage changes, which are calibrated in terms of the magnetic field. The fluxgate gradiometer provides a continuous record of the magnetic field strength across each traverse.

The magnetic survey was designed to collect eight samples per meter along one-meter traverses or eight data values per square meter. The data were collected in a zigzag fashion with the surveyor alternating direction of travel for each traverse across the grid. A total of 3,200 data measurements were collected for each complete 20-meter by 20-meter grid unit. The magnetic data were recorded in the memory of the gradiometer and downloaded to a laptop computer when the instrument's memory became full or at the completion of data acquisition at each survey area location. The magnetic data were imported into Geoscan Research's GEOPLOT software (Geoscan Research 2001) for processing. Both shade relief and trace line plots were generated in the field before the instrument's memory was cleared.

Resistance Survey

The resistance survey is an active geophysical technique, which injects a current into the ground (see Bevan 1991,1998:7-18; Burger 1992:241-318; Carr 1982; Clark 2000:27-63,171-174; David 1995:27-28; Dobrin and Savit 1988:750-773; Gaffney and Gater 2003:26-36,56-61; Gaffney et al. 1991:2;2002:7; Hallof 1992: 39-176; Heimmer and DeVore 1995:29-35,2000:59-60; Kvamme 2001:358-362,2003:441-442,2005:434-436; Lowrie 1997:206-219; Milson 2003:83-116; Mussett and Khan 2000:181-201; Nishimura 2001:544-546; Robinson and Çoruh 1988:445-478; Scollar et al. 1990:307-374; Sharma 1997:207-264; Somers 2006:109-129; Telford et al. 1990:522-577; Van Nostrand and Cook 1966; Weymouth 1986:318-341; and Witten 2006:299-317 for more details on resistivity surveys). The voltage is measured and by Ohm's Law, one may compute the resistance at any given point (**R=V/I** where **R** is resistance, **V** is voltage, and **I** is current). Resistance or opposition to the current flow is measured in ohms (Sheriff 1973:156,184). Due to the problem of contact resistance between two electrodes in the ground, a typical resistance survey makes use of four electrodes or probes. The current passes through two electrodes and the voltage is measured between the other two probes. The configuration of the electrodes also varies (see Milsom1996:73 and Weymouth 1986:324 for common configurations).

Resistance or resistivity changes result from electrical properties of the soil matrix. Changes are caused by materials buried in the soil, differences in soil formation processes, or disturbances from natural or cultural modifications to the soil. In archeology, the instrument is used to identify areas of compaction and excavation, as well as, buried objects such as brick or stone foundations. It has the potential to identify cultural features that are affected by the water saturation in the soil, which is directly related to soil porosity, permeability, and chemical mature of entrapped moisture (Clark 2000; Heimmer and De Vore 1995:30). Its application to archeology results from the ability of the instrument to detect lateral changes on a rapid data acquisition, high resolution basis, where observable contrasts exist. Lateral changes in anthropogenic features result from compaction, structural material changes, buried objects, excavation, habitation sites, and other features affecting water saturation (Heimmer and De Vore 1995:37).

The Geoscan Research RM15 resistance meter uses the PA5 multiple probe array (Geoscan Research 1996). Arranged as a twin probe array, a current and voltage probes are located on a mobile frame, which is moved around the site (Figure 7). Two additional probes are located away from the survey area, which also consist of a current probe and voltage probe. The remote probes are set a distance 30 times the mobile probe separation. The probes on the frame are located at a fixed distance apart. A general rule of thumb for the depth investigation of resistance survey is the depth is equal to the distance of probe separation. This value is not a unique number but an average for the volume of soil 0.5 meters depth and a surface radius of 0.5 meters under the center point of the instrument frame. The probes are connected to the resistance meter, which is also on the frame. Wings may be added to the frame to expand the separation distance of the probes; however, this requires the resurvey of the grid for each change in the probe separation distance. The measurement is taken when the mobile probes make contact with the ground and complete the electrical circuit. The readings are stored in the resistance meter’s memory until downloaded to a lap-top computer.

The resistance survey was designed to collect 2 samples per meter along one-meter traverses or 2 data values per square meter. The data were collected in a zigzag fashion with the surveyor maintaining the alternating the direction of travel for each traverse across the grid. Only grid units 8 and 9 were surveyed with the resistance meter and twin probe array. For a complete 20-m by 20-m grid unit, a total of 800 measurements will be recorded. The resistance data were recorded in the memory of the resistance meter and downloaded to a laptop computer at the completion of the survey. The resistance data were imported into Geoscan Research’s GEOPLOT software (Geoscan Research 2003) for processing. Both shade relief and trace line plots were generated before the instrument’s memory was cleared.

Conductivity Survey

The conductivity survey is an active geophysical technique, which induces an electromagnetic field into the ground (see Bevan 1983,1998:29-43; Clark 2000:171; Clay 2001:32-33,2002; Davenport 2001:72-88; David 1995:20; Dobrin and Savit 1988:773-837; Gaffney and Gater 2003:42-44; Gaffney et al. 1991:5,2002:10; Heimmer and De Vore 1995:35-41,2000:60-63; Klien and Lajoie 1992:383-535; Kvamme 2001:362-363,2003:441-442; Lowrie 1997:222-228; Mussett and Khan 2000:210-219; Nishimura 2001:551-552; Robinson and Çoruh 1988:490-500; Scollar et al. 1990:520-590; Sharma 1997:265-308; Telford et al. 1990:343-521; Weymouth 1986:317-318,326-327, and Witten 2006:147-213 for more details of conductivity surveys). This survey technique measures the apparent soil conductivity. The present survey is conducted with a Geonics EM38 ground conductivity meter or electromagnetic induction (EMI) meter (Geonics 1992). The instrument is lightweight and 1.45 meters in length (Figure 8). The self-contained dipole transmitter (primary field source) and self-contained dipole receiver (sensor) coils are located at opposite ends of the meter. The intercoil spacing is 1 meter.

An electromagnetic field is induced into the ground through the transmitting coil. The induced primary field causes an electric current flow in the earth similar to a resistivity survey. In fact, a conductivity survey is the inverse of a resistivity survey. High conductivity equates to low resistivity and vice versa. The materials in the earth create secondary eddy current loops, which are picked up by the instrument’s receiving coil. The interaction of the generated eddy loops or electromagnetic field with the earthen materials is directly proportional to terrain conductivity within the influence area of the instrument. The receiving coil detects the response alteration (secondary electromagnetic field) in the primary electromagnetic field. This secondary field is out of phase with the primary field (quadrature or conductivity phase). The in-phase component of the secondary signal is used to measure the magnetic susceptibility of the subsurface soil matrix.

Changes result from electrical and magnetic properties of the soil matrix. Changes are caused by materials buried in the soil, differences in soil formation processes, or disturbances from natural or cultural modifications to the soil. EMI instruments are also sensitive to surface and buried metals. Due to their high conductivity, metals show up as extreme values in the acquired data set. On occasion, these values may be expressed as negative values since the extremely high conductivity signal of the metals cause the secondary coil to become saturated.

In archeology, the instrument has been used to identify areas of compaction and excavation as well as buried metallic objects. It has the potential to identify cultural features that are affected by the water saturation in the soil (Clark 2000; Heimmer and De Vore 1995:35-41). Its application to archeology results from the ability of the instrument to detect lateral changes on a rapid data acquisition, high resolution basis, where observable contrasts exist. Lateral changes in anthropogenic features result from compaction, structural material changes, buried metallic objects, excavation, habitation sites, and other features affecting water saturation (Heimmer and De Vore 1995:37). The conductivity survey can sometimes detect the disturbed soil matrix within the grave shaft. It can also locate large metal objects. Metallic trash on the surface and other small objects buried in the upper portion of the soil can degrade the search of the buried archeological resources including graves (Bevan 1991:1310).

The meter was connected to the DL720 Polycorder for digital data acquisition (Geonics 1998). The conductivity survey was designed to collect in the continuous or automatic mode with readings collected every quarter of a second resulting in four samples per meter. Prior to the start of the conductivity survey, the conductivity meter was nulled and calibrated at the magnetic reference point located a N20/E60. The data in grid units 8, 9, 10, 11, and 12 were collected in a parallel fashion or unidirectional mode with the surveyor conducting the data acquisition in the same the direction of travel for each traverse across the grid. The conductivity data were collected along one-meter traverse at a sampling density of four samples per meter or four samples per square meter. For a complete 20-m by 20-m grid unit, a total of 1,600 measurements will be recorded. The data and header files stored in the polycorder were downloaded into the laptop computer at the end of the survey. The survey of the grid unit began in the lower left hand or southwest corner of the grid. The EM38 was used in the quadrature or conductivity phase, the vertical dipole mode, and one orientation parallel to the direction of travel along the traverses. It provided an exploration depth of approximately 1.5 meters with its effective depth around 0.6 meters in the vertical dipole mode.

Ground Penetrating Radar Survey

The ground-penetrating radar (gpr) survey is an active geophysical technique that uses pulses of radar energy (i.e., short electromagnetic waves) that are transmitted into the ground through the surface transmitting antenna (see Bevan 1991,1998:43-57; Clark 2000:118-120,183-186; Conyers 2004,2006:131-159; Conyers and Goodman 1997; David 1995:23-27; Gaffney and Gater 2003:47-51,74-76; Gaffney et al. 1991:5-6,2002:9-10; Heimmer and DeVore 1995:42-47,2000:63-64; Kvamme 2001:363-365,2003:442-443;2005:436-438; Lowrie 1997:221-222; Milson 2003:167-178; Mussett and Khan 2000:227-231; Nishimura 2001:547-551; Scollar et al. 1990:575-584; Weymouth 1986:370-383; and Witten 2006:214-258 for more details on ground-penetrating radar surveys). This radar wave is reflected off buried objects, features, or interfaces between soil layers. These reflections result from contrasts in electrical and magnetic properties of the buried materials or reflectors. The contrasts are a function of the dielectric constant of the materials (Sheriff 1973:51). The depth of the object or soil interface is estimated by the time it takes the radar energy to travel from the transmitting antenna and for its reflected wave to return to the receiving antenna. The depth of penetration of the wave is determined by the frequency of the radar wave. The lower the frequency, the deeper the radar energy can penetrate the subsurface; however, the resulting resolution, or the ability to distinguish objects, features, and soil changes, decreases. These low frequency antennas generate long wavelength radar energy that can penetrate several tens of meters under certain conditions, but can only resolve larger targets or reflectors. The higher the radar wave frequency, the higher the resulting resolution but the penetration depth decreases. High frequency antennas generate much shorter wavelength energy, which may only penetrate a meter into the ground. The generated reflections from these high frequency antennas are capable of resolving objects or features with maximum dimensions of a few centimeters. A resulting tradeoff exists between subsurface resolution and depth penetration: the deeper the penetration then the resulting resolution is less or the higher the resolution then the resulting depth penetration is much shallower.

As radar antenna system (transmitting and receiving antennas) is moved along the survey line, a large number of subsurface reflections are collected along the line. The various subsurface materials affect the velocity of the radar waves as they travel through the ground (Conyers and Goodman 1997:31-40). The rate at which these wave move through the ground is affected by the changes in the physical and chemical properties of the buried materials through which they travel. The greater the contrast in electrical and magnetic properties between two materials at the interface results in a stronger reflected signal. As each radar pulse travels through the ground, changes in material composition or water saturation, the velocity of the pulse changes and a portion of the energy is reflected back to the surface where it is detected by the receiving antenna and recorded by ground-penetrating radar unit. The remaining energy continues to pass into the subsurface materials where it can be reflected by deeper reflectors until the energy finally dissipates with depth. The radar system measures the time it takes the radar pulse to travel to a buried reflector and return to the unit. If the velocity of the pulse is known, then the distance to the reflector or the depth of the reflector beneath the surface can be estimated (Conyers and Lucius 1996).

The success of the survey is dependent on soil and sediment mineralogy, clay content, ground moisture, depth of the archeological resource, and surface topography and vegetation. The ground-penetrating radar signal can be lost or attenuated (i.e., quickly dissipated) in soils that have high moisture content, high electrical conductivity, highly magnetic materials, or high clay contents. Dry soils and sediments, especially those with low clay content, represent the best conditions for energy propagation. A ground-penetrating radar survey, with its capability for estimating the depth and shape of buried objects, may be an extremely valuable tool in the search of grave shafts and trenches. At times, radar cannot profile deep enough or the strata may be so complex as to render the trenches, graves, and other types of excavations indistinguishable from the surrounding soil profile.

The TerraSIRch SIR System-3000 survey cart system (GSSI 2003) operated an antenna at a nominal frequency of 400 megahertz (mHz). The antenna was mounted in a cart that recorded the location of the radar unit along the grid line (Figure 9). The gpr profiles were collected along 0.5 meter traverses beginning in the southwest corner of the grid block. The data were collected in a zigzag or bidirectional fashion with the surveyor alternating the direction of travel for each traverse across the grid. A total of 279 radar profile lines and segments were collected across survey grid units 3, 4, 5, 6, 8, 9, 10, 11, and 12 at the Ellsworth Rock Gardens Site, including 61 radar profile lines and segments (gpr file VOYAA) from grid units 8 and 9, 97 radar profile lines and segments (gpr file VOYAB) from grid units 6, 7, and 12, and 121 radar profile lines and segments (gpr file VOYAC) from grid units 3, 4, and 5. Ground penetrating radar surveys generally represent a trade-off between depth of detection and detail. Lower frequency antennas permit detection of features at greater depths but they cannot resolve objects or strata that are as small as those detectable by higher frequency antennas. Actual maximum depth of detection also depends upon the electrical properties of the soil. If one has an open excavation, one can place a steel rod in the excavation wall at a known depth and use the observed radar reflection to calibrate the radar charts. When it is not possible to place a target at a known depth, one can use values from comparable soils. Reasonable estimates of the velocity of the radar signal in the site's soil can be achieved by this method (Conyers and Lucius 1996). Using one of the hyperbolas on a radargram profile (Goodman 2005:76), the velocity was calculated to be approximately 7 cm per nanosecond (ns) at the fort clearing and 5 cm per nanosecond at the fort clearing. For a time slice between 5 and 15 ns with the center at 10 ns (two way travel time), the approximate depth to the center of the gpr slice would be 35 cm with a depth of investigation to 1.75 m bs.

The TerraSIRch SIR System-3000 survey cart contained a data-logger with a display that allowed the results to be viewed almost immediately after they were recorded (GSSI 2003). The SIR 3000 was set to collect gpr data with the 400 mHz antenna at an antenna transmit rate of 100 mHz and the distance mode selected for use of the survey wheel on the cart. The scan menu was set with 512 samples, 16 bit format, 50 ns range or window, a dielectric constant of 8 (the default value), a scan rate of 100, and 50 scans per meter. The gpr system was moved around the project survey area prior to the start of the survey to adjust the gain. If a location caused the trace wave to go off the screen, the gain was set to auto and then back to manual. The position was set to the manual mode with the offset value at the factory default and the surface display option set to zero. The filters were left at the default settings. With the setup completed, the run/stop button at the bottom of the display screen was selected and the collect mode was initiated. The gpr unit was moved across the grid and at the end of the traverse, the next file button was selected and data acquisition was halted. The gpr unit was placed at the start of the next line before saving the profile. Once the profile data was saved, the gpr unit was ready to collect the next profile line. The gpr data were recorded on a 512 mb compact flash card and transferred to a lap-top computer at the end of the survey.

4. DATA PROCESSING AND INTERPRETATION

Processing of geophysical data requires care and understanding of the various strategies and alternatives (Kvamme 2001:365; Music 1995; Neubauer et al. 1996). Drs. Roger Walker and Lewis Somers (Geoscan Research 2003) provide strategies, alternatives, and case studies on the use of several processing routines commonly used to process magnetic, resistance, and conductivity data in the GEOPLOT software. Dr. Kenneth Kvamme (2001:365) provides a series of common steps used in computer processing of geophysical data:

> *Concatenation of the data from individual survey grids into a single composite matrix;*
>
> *Clipping and despikin*g of extreme values (that may result, for example, from introduced pieces of iron in magnetic data);
>
> *Edge matching* of data values in adjacent grids through balancing of brightness and contrast (i.e., means and standard deviations);
>
> *Filtering* to emphasize high-frequency changes and smooth statistical noise in the data;
>
> *Contrast enhancement* through saturation of high and low values or histogram modification; and
>
> *Interpolation* to improve image continuity and interpretation.

It is also important to understand the reasons for data processing and display (Gaffney et al. 1991:11). They enhance the analyst's ability to interpret the relatively huge data sets collected during the geophysical survey. The type of display can help the geophysical investigator present his interpretation of the data to the archeologist who will ultimately use the information to plan excavations or determine the archeological significance of the site from the geophysical data.

Processing Magnetic Data

Upon completion of the magnetic gradient survey, the data were processed in GEOPLOT. The grid data file was transformed into a composite file and a zero mean traverse was applied to remove any traverse discontinuities that may have occurred from operator handling or heading errors. Upon completion of the zero mean traverse function, the data were interpolated by expanding the number of data points in the traverse direction and by reducing the number of data points in the sampling direction to provide a smoother appearance in the data set and to enhance the operation of the low pass filter. This changed the original 8 x 1 data point matrix into a 4 x 4 data point matrix. The low pass filter was then applied over the entire data set to remove any high frequency, small scale spatial detail. This transformation may result in the improved visibility of larger, weak archeological features. The data were then exported as an ASCII dat file and placed in the SURFER 8 contouring and 3d surface mapping program (Golden Software 2002). An image map of the magnetic gradient data was generated for both survey grid areas. The magnetic data after the application of the zero mean traverse function ranged from –213.2 nT to 224.2 nT with a mean of 0.17 nT and a standard deviation of 19.464 nT. The data were then exported as an ASCII dat file and placed in the SURFER 8 contouring and 3d surface mapping program (Golden Software 2002). Image and contour plots of the magnetic data were generated for the entire magnetic survey area (Figure 10).

Processing Resistance Data

Upon completion of the resistance survey, the data were processed in GEOPLOT. The grid files were combined to form a composite file and further processed in GEOPLOT. The resistance data composite file was first cleared of several erroneous readings resulting from the incorrect dummy value being recorded during the survey. A search and replace routing was selected to remove the 2047 value and replace it with 2047.5. A search and replace was also used to remove the negative values in the data set and replace them with the dummy value of 2047.5. The resistance composite data set was then despiked to remove any extreme erroneous value spikes in the data set. Despiking may be accomplished with the processing routine in GEOPLOT or manually by editing each individual grid file. The data were interpolated in the x and y directions to change the original 2x1 matrix to a 4x4 data matrix. A high pass filter was applied to the composite data set to remove low frequency, large scale spatial detail such as a slowing changing geological ‘background’ trend. The resistance data after the application of the search and replace and the despiking routines ranged from 963.5 ohms to 2043.5 ohms with a mean of 1568.14 ohms and a standard deviation of 199.395 ohms. The data were then exported as an ASCII *.dat file and placed in the SURFER 8 mapping program. The data were gridded and both an image map and a contour map were generated for the three project areas (Figure 11).

Processing Conductivity Data

The data were downloaded to a laptop computer at the end of the survey of the geophysical project. The data were processed using the DAT38W software (Geonics 2002). After the transfer of the data and header files to the laptop computer, the files were automatically converted from the raw EM38 format to DAT38 format with the extension name of G38 (Geonics 2002:12-14). The data were then displayed as data profile lines (Geonics 2002:14-15). The individual EM38 data file was then converted to XYZ coordinate file in the Surfer data format. To create the XYZ file, the orientation or direction of the survey line was selected in the DAT38W program along with the data type and format (Geonics 2002:20-23). The resulting XYZ data file was transfer to the SURFER 8 mapping software (Golden Software 2002). The conductivity data were reviewed and an image plot was generated in SURFER 8. To further process the conductivity data, it was transferred to

GEOPLOT. The conductivity data were stripped of the X and Y coordinates and then the Z values (measurements) were imported into GEOPLOT for further processing (Geoscan Research 2001). The resulting grid was formatted to form a composite file in GEOPLOT. A search and replace routine was applied to the data set to remove a few negative erroneous measurements and replace them with more correctly adjusted values. The interpolation routine was applied to the data set to arrange the data from the 4 x 1 data matrix to an equally spaced 4 x 4 square matrix. A high pass filter was then applied over the composite data set. The high pass filter was used to remove low frequency, large scale spatial detail such as a slowing changing geological 'background' trend. The data were then exported as an ASCII dat file and placed in the SURFER 8 mapping program. The conductivity data after the application of the search and replace function ranged from -147.0 mS/m to 110.2 mS/m with a mean of -1.81 mS/m and a standard deviation of 11.227 mS/m. The data were then exported as an ASCII dat file and placed in the SURFER 8 mapping program. An image and contour plot of the resistance data was generated for the survey area (Figure 12).

Processing Ground Penetrating Radar Data

The gpr radargram profile line data are imported into GPR-SLICE (Goodman 2005) for processing. The first step in GPR-SLICE is to create a new survey project under the file menu. This step identifies the file name and folder locations. The next step is to create the information file. The number of profiles are entered, along with the file identifier name, .dzt for GSSI radargrams, the profile naming increment of 1, the first radargram name (generally this is 1), direction of profiling, x and y beginning and ending coordinates, units per marker (set to 1), the time window opening in nanoseconds (50 ns), samples per scan (512 s/scn), the number of scans per meter (these profiles were collected at 50 scans per meter), type of data (16 bit). Selecting the create info file button completes the information file for the project. The information file can be edited if necessary to correct profile lengths. The 16-bit GSSI radargrams are imported into the GPR-SLICE project folder for further processing. The 16-bit data are then converted to remove extraneous header information and to regain the data. During the conversion process, the signal is enhanced by applying gain to the radargrams. Once the conversion process is completed, the next step is to reverse the profile data. Since the radargrams were collected in the zigzag mode, every even line needs to be reversed. The reverse map button shows the radargrams that are going to be reversed. The next step is to insert navigation markers into the resample radargrams. The GSSI SIR 3000 and the artificial markers button are selected to apply markers based on the total number of scans in the radargram. The show markers button allows one to view an example of a radargram with the artificial markers in place. The next step is to create the time slices of the profile data (Conyers and Goodman 1997; Goodman et al. 1995). The program resamples the radargrams to a constant number of scans between the markers and collects the time slice information from the individual radargrams. The number of slices is set to 20 slices. The slice thickness is set to 30 to allow for adequate overlap between the slices. The offset value on the radargram where the first ground reflection occurs is viewed in the search 0 ns subroutine. This value is used to identify the first radargram sample at the ground surface. The end sample is 512. The offset value in entered in the samples to 0 ns box. The cut parameter is set to square amplitude with the cuts per mark set to 4. The slice/resample button is selected for processing the radargrams. The final step in the slice menu is to create the XYZ data file. The grid menu is entered next in the processing steps. The beginning and ending values for the x and y coordinate are entered. The help set button is selected to set the x search radius, y search radius and the blanking radius. The grid cell size is set to 0.1 and the search type is rectangular. The number of grids equal 20 for the number of slices, and the starting grid number is 1. The Kriging algorithm is utilized to estimate the interpolated data. The Varigram button is selected to set the Kriging range, nugget and sill parameters. The start gridding button is selected and the gridded dataset is created. In this menu, a low pass filter may be applied to the dataset to smooth noisy data in the time slices.

At this point, one may view the time sliced radar data in the pixel map menu. Figure 13 illustrates the time slices from the project survey area. In addition, the original processed grid slices and the low pass filtered grid slices can be exported in the Surfer grid format. The surfer grid file is transformed into an image plot in Surfer. Generally, one time slice is selected for further display and analysis. Time slice 4 from 7 to 10 ns (Figure 14) represents the resulting gpr data from the project survey area. The gain may be readjusted for any time slice. This is done in the transforms submenu. The interpolations value is set to 5 and the interpolate grids routine is selected. The new interpolated grids are all normalized. The next step is to create the 3D dataset in the grid menu. The number of grids is now equal to 95 ((20-1)*5). The 3D database is created under the create 3D file routine. The 3D data may be displayed as a series of z slices in the creation of a 3D cube with a jpeg output for animating the 3D cube.

5. INTERPRETATIONS

Andrew David (1995:30) defines interpretation as a "holistic process and its outcome should represent the combined influence of several factors, being arrived at through consultation with others where necessary." Interpretation may be divided into two different types consisting of the geophysical interpretation of the data and the archaeological interpretation of the data. At a simplistic level, geophysical interpretation involves the identification of the factors causing changes in the geophysical data. Archeological interpretation takes the geophysical results and tries to apply cultural attributes or causes. In both cases, interpretation requires both experience with the operation of geophysical equipment, data processing, and archeological methodology; and knowledge of the geophysical techniques and properties, as well as known and expected archeology. Although there is variation between sites, several factors should be considered in the interpretation of the geophysical data. These may be divided between natural factors, such as geology, soil type, geomorphology, climate, surface conditions, topography, soil magnetic susceptibility, seasonality, and cultural factors including known and inferred archeology, landscape history, survey methodology, data treatment, modern interference, etc. (David 1995:30). It should also be pointed out that refinements in the geophysical interpretations are dependent on the feedback from subsequent archeological investigations. The use of multiple instrument surveys provides the archeologist with very different sources of data that may provide complementary information for comparison of the nature and cause (i.e., natural or cultural) of a geophysical anomaly (Clay 2001). Each instrument responds primarily to a single physical property: magnetometry to soil magnetism, electromagnetic induction to soil conductivity, resistivity to soil resistance, and ground penetrating radar to dielectric properties of the soil to (Weymouth 1986:371).

Interpretation of Magnetic Data

Interpretation of the magnetic gradient data (Bevan 1998:24) from the project requires a description of the buried archeological feature of object (e.g., its material, shape, depth, size, and orientation). The magnetic anomaly represents a local disturbance in the earth's magnetic field caused by a local change in the magnetic contract between buried archeological features, objects, and the surrounding soil matrix. Local increases or decreases over a very broad uniform magnetic surface would exhibit locally positive or negative anomalies (Breiner 1973:17). Magnetic anomalies tend to be highly variable in shape and amplitude. They are generally asymmetrical in nature due to the combined affects from several sources. To complicate matters further, a given anomaly may be produced from an infinite number of possible sources. Depth between the magnetometer and the magnetic source material also affect the shape of the apparent anomaly (Breiner 1973:18). As the distance between the magnetic sensor on the magnetometer and the source material increases, the expression of the anomaly becomes broader. Anomaly shape and amplitude are also affected by the relative amounts of permanent and induced magnetization, the direction of the magnetic field, and the amount of magnetic minerals (e.g., magnetite) present in the source compared to the adjacent soil matrix. The shape (e.g., narrow or broad) and orientation of the source material also affects the anomaly signature. Anomalies are often identified in terms of various arrays of dipoles or monopoles (Breiner 1973:18-19). A magnetic object in made of magnetic poles (North or positive and South or negative). A simple dipole anomaly contains the pair of opposite poles that relatively close together. A monopole anomaly is simply one end of a dipole anomaly and may be either positive or negative depending on the orientation of the object. The other end is too far away to have an affect on the magnetic field.

Magnetic anomalies of archeological objects tend to be approximately circular in contour outline. The circular contours are caused by the small size of the objects. The shape of the object is seldom revealed in the contoured data. The depth of the archaeological object can be estimated by half-width rule procedure (Bevan 1998:23-24; Breiner 1973:31; Milsom 2003:67-70). The approximations are based on a model of a steel sphere with a mass of 1 kg buried at a depth of 1.0 m below the surface with the magnetic measurements made at an elevation of 0.3 m above the ground. The depth of a magnetic object is determined by the location of the contour value at half the distance between the peak positive value of the anomaly and the background value. With the fluxgate gradiometer, the contour value is half the peak value since the background value is approximately zero. The diameter of this contour (Bevan 1998:Fig. B26) is measured and used in the depth formula where depth = diameter – 0.3 m (Note: The constant of 0.3 m is the height of the bottom fluxgate sensor above the ground in the Geoscan Research FM36 were I carry the instrument during data acquisition. This value needs to be adjusted for each individual that carries the instrument.). The mass in kilograms of the object (Bevan 1998:24, Fig. B26) is estimated by the following formula: mass = (peak value - background value) * $(\text{diameter})^3/60$. It is likely that the depth and mass estimates are too large rather than too small, since they are based on a compact spherical object made of iron. Archeological features are seldom compact but spread out in a line or lens. Both mass and depth estimates will be too large. The archaeological material may be composed of something other than iron such as fired earth or volcanic rock. Such materials are not usually distinguishable from the magnetic data collected during the survey (Bevan 1998:24). The depth and mass of features comprised of fired earth, like that found in kilns, fireplaces, or furnaces could be off by 100 times the mass of iron. If the archeological feature were comprised of bricks (e.g., brick wall, foundation, or chimney), estimates could be off by more than a 1000 times that of iron. The location of the center of the object can also be determined by drawing a line connecting the peak positive and peak negative values. The rule of thumb is that the center of the object is located approximately one third to one half of the way along the line from the peak positive value for the anomaly. One should also be cautious of geophysical anomalies that extend in the direction of the traverses since these may represent operator-induced errors. The magnetic gradient anomalies may be classified as three different types: 1) dipole, 2) monopole, and 3) linear.

There are numerous dipole and monopole magnetic anomalies in the data set from the Ellsworth Rock Gardens Site (Figure 15). Concentrations of these magnetic anomalies appear to occur in the general location of archeological surface features F1 and F3 that are identified as structures based on parallel depressions associated with F1 and foundation stones and small berms associated with F3. Four concentrations of magnetic anomalies may also be associated with possible structures. The modern fire rings and steel posts area also evident in the magnetic data set. A raised path across F1 is also visible in the magnetic data set.

Interpretation of Resistance Data

Interpretation of the resistivity data results in the identification of lateral changes in the soil. Since the array parameters are kept constant through out the survey, the resulting resistance values varies with changes in the subsurface sediments/soil matrix and buried archeological resources. For each probe separation, the depth penetration is approximately the same as the distance between the current and potential probe on the mobile array frame, which was 0.5 meters. The resistance measurement for each point represents the average value for the hemispheric volume of soil with the same radius. If the soil below the survey area was uniform, the resistivity would be constant throughout the area. Changes in soil characteristics (e.g., texture, structure, moisture, compactness, etc.) and the composition of archeological features result in differences in the resistances across the surveyed grid. Large general trends reflect changes in the site's geology whereas small changes may reflect archeological features.

The resistance survey was limited to grid units 8 and 9 in the northeastern portion of the geophysical survey area (Figure 16). The survey was placed over the foundation stones and berms of F3. The resistance data indicated the location of the structure identified as F3 and the possible structure to the east of F3 from the comparison of high and low value resistance anomalies.

Interpretation of Conductivity Data

Ground conductivity surveys are much faster to complete than the resistivity surveys but are also more complicated (Bevan 1998:29). Like the resistivity surveys, ground conductivity surveys detect changes in soil contracts. These soil contracts can result from natural conditions or from cultural activities (Bevan 1988:31-33). The conductivity anomalies represent the location and approximate shape of the features; however, different kinds of features can produce similar conductivity anomalies. They also detect metal objects. The resulting conductivity anomalies from buried metal (e.g., utility lines, pipes, and objects) may hide other features in immediate vicinity.

The conductivity survey was limited to grid units 8, 9, 10, 11, and 12 in the northeastern portion of the geophysical survey area (Figure 17). A few negative dipoles were present in the conductivity data from these grid units. The sources for these conductivity anomalies were interpreted as metallic objects. Since a number of the negative conductivity dipole was located at the same spot as the magnetic dipoles, it was assumed that those conductivity anomalies were caused by ferrous metal objects. The conductivity data also indicated the location of the structure identified as F3 and the possible structure to the east of F3. A rectangular conductivity low outlined the stone foundation of F3. The possible structure to the east of F3 consists of a series of low conductivity anomalies that appear to be associated with the small depressions or post holes identified in the northeast corner of the survey area.

Interpretation of Ground Penetrating Radar Data

Analysis and interpretation of the gpr data may be conducted in several different ways. The individual radargrams for each profile line may be analyzed for hyperbolic reflections. The radargrams may be combined and processed to provide planar time slices of the data. The time slices may also be combined to form 3D cubes of the gpr data. The majority of the gpr radargrams show numerous small reflections along any given profile.

The ground penetrating radar data has several strong amplitude values across the grid (Figure 18). The parallel depressions of F1, identified as the bunkhouse structure, are evident in the time slice 4 (7-10 ns). A possible structure to the northwest of F1 consisted of a relatively low amplitude strength rectangular outline with several high amplitude strength reflections on the interior of the rectangular outline that suggested the location of a possible structure. The foundation stones and berms associated with F3 were identified in the gpr time slice, as well as two possible structures adjacent to F3.

Overlaying the Geophysical Data Sets

A different way of looking at the geophysical data collected during the investigations of the geophysical survey in the northeastern portion of the Ellsworth Rock Gardens Site is to combine the four complementary data sets into one display (Figure 19). When a number of the different geophysical anomalies overlap, they suggest a strong correlation between the geophysical data and the buried archeological features (Ambrose 2005). There appear to be direct correlations between the geophysical anomalies and the foundation stones and berms of F3. The two possible structures flanking F3 area are also identified the complementary data sets

6. CONCLUSIONS

During the week of July 16-23, 2007, Midwest Archeological Center staff conducted geophysical investigations at the Ellsworth Rock Gardens Site (21SL1006) in Voyageurs National Park in St, Louis County, Minnesota. The geophysical investigations were part of the larger park wide archeological condition assessment project conducted by the Midwest Archeological Center. The geophysical investigations included a magnetic gradient survey with a fluxgate gradiometer, a resistance survey with a resistance meter and twin probe array, a conductivity survey with a ground conductivity meter, and a ground penetrating radar survey with a ground penetrating radar cart system and 400 mHz antenna. A total of 3,135 m^2 or 0.77 acres were surveyed with the geophysical instruments.

The surveys resulted in the identification of numerous subsurface anomalies. The magnetic gradient, resistance, conductivity, and ground penetrating radar data collected at the site provided information of the physical properties (magnetic, soil resistance, and ground-penetrating radar reflection properties) of the subsurface materials. Standard methodology for conducting geophysical investigations was used with standard 20-meter by 20-meter grid sizes where feasible. The results of the geophysical survey indicated the presence of two structures, which were also identified by surface depressions and foundation stones, as well as other possible buried structures. Numerous magnetic and conductivity anomalies indicated the presence of buried ferrous and non-ferrous objects across the site.

Finally, refinement of the archeological and geophysical interpretation of the survey data is dependent on the feedback of the archeological investigations following geophysical survey (David 1995:30). Should additional archeological investigations occur at the site investigated during this project, the project archeologist is encouraged to share additional survey and excavation data with the geophysical investigator for incorporation into the investigator’s accumulated experiences with archeological problems. Throughout the entire geophysical and archeological investigations, communication between the geophysicist and the archeologist is essential for successful completion of the archeological investigations. It is also important for the investigators to disseminate the results of the geophysical survey and archeological investigations to the general public. It is through their support in funds and labor that we continue to make contributions to the application of geophysical techniques to the field of archeology.

This report has provided a cursory review and analysis of the geophysical data collected during the geophysical investigations of the Ellsworth Rock Gardens Site (21SL1006) at the Voyageurs National Park. This information will be used by the Midwest Archeological Center and the Voyageurs National Park staffs to guide further archeological inquiry into the nature of the archeological resources at the site and help direct future National Park Service geophysical surveys and archeological excavations at other sites within the boundary of the Voyageurs National Park.

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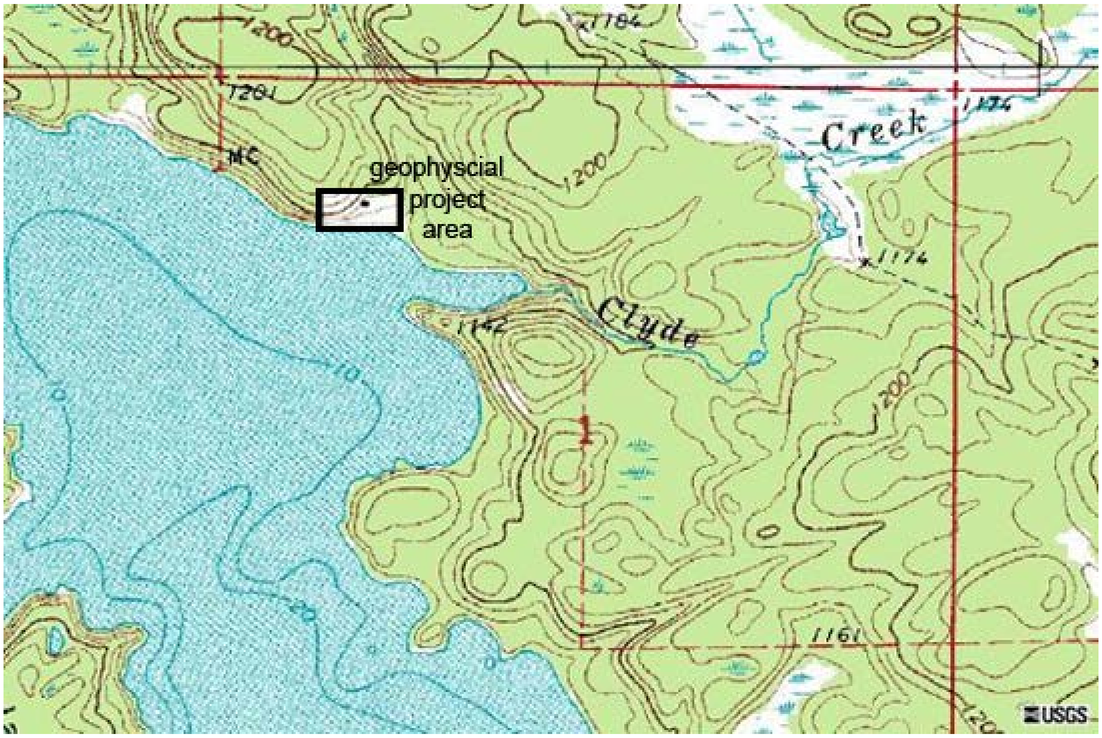
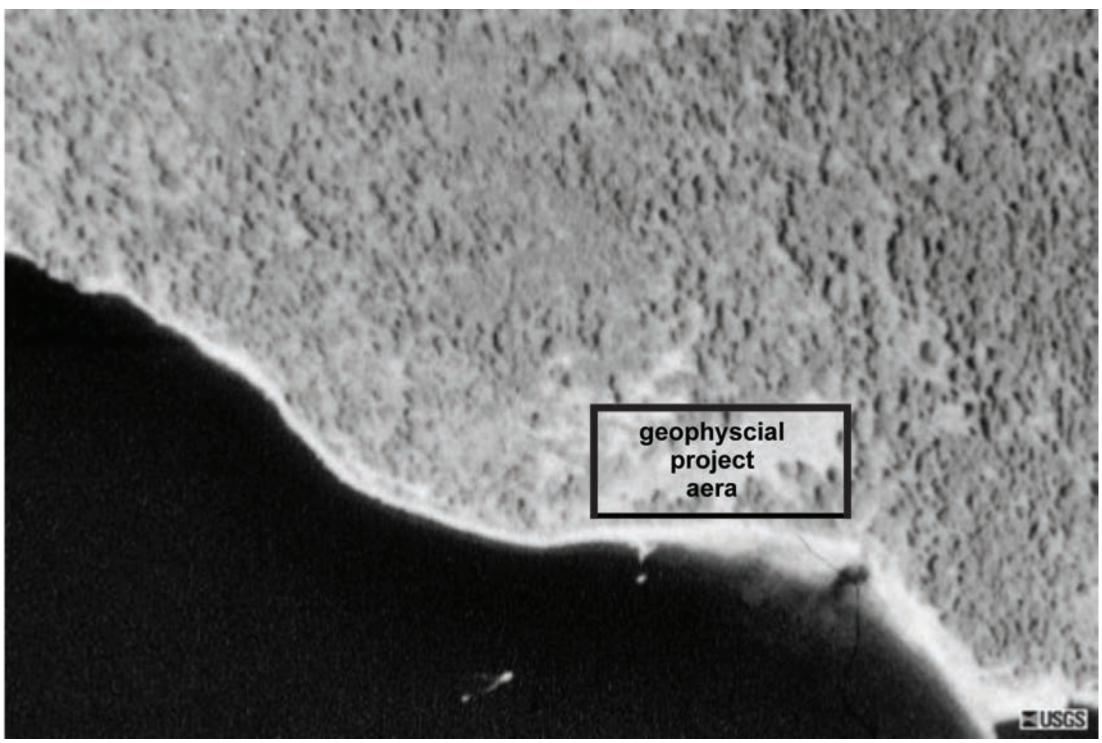


a) USGS 7.5 minute topographic map (7 km NE of Kabetogama, Minnesota, United States, dated 01 Jul 1987).



b) USGS aerial photograph (8 km NE of Kabetogama, Minnesota, United States, dated 5/19/1991).

Figure 1. Geophysical survey area at the Ellsworth Rock Gardens Site (21SL1006) within Voyageurs National Park.

Figure 2. General location of the geophysical project area at the Ellsworth Rock Gardens Site (view to the northeast).

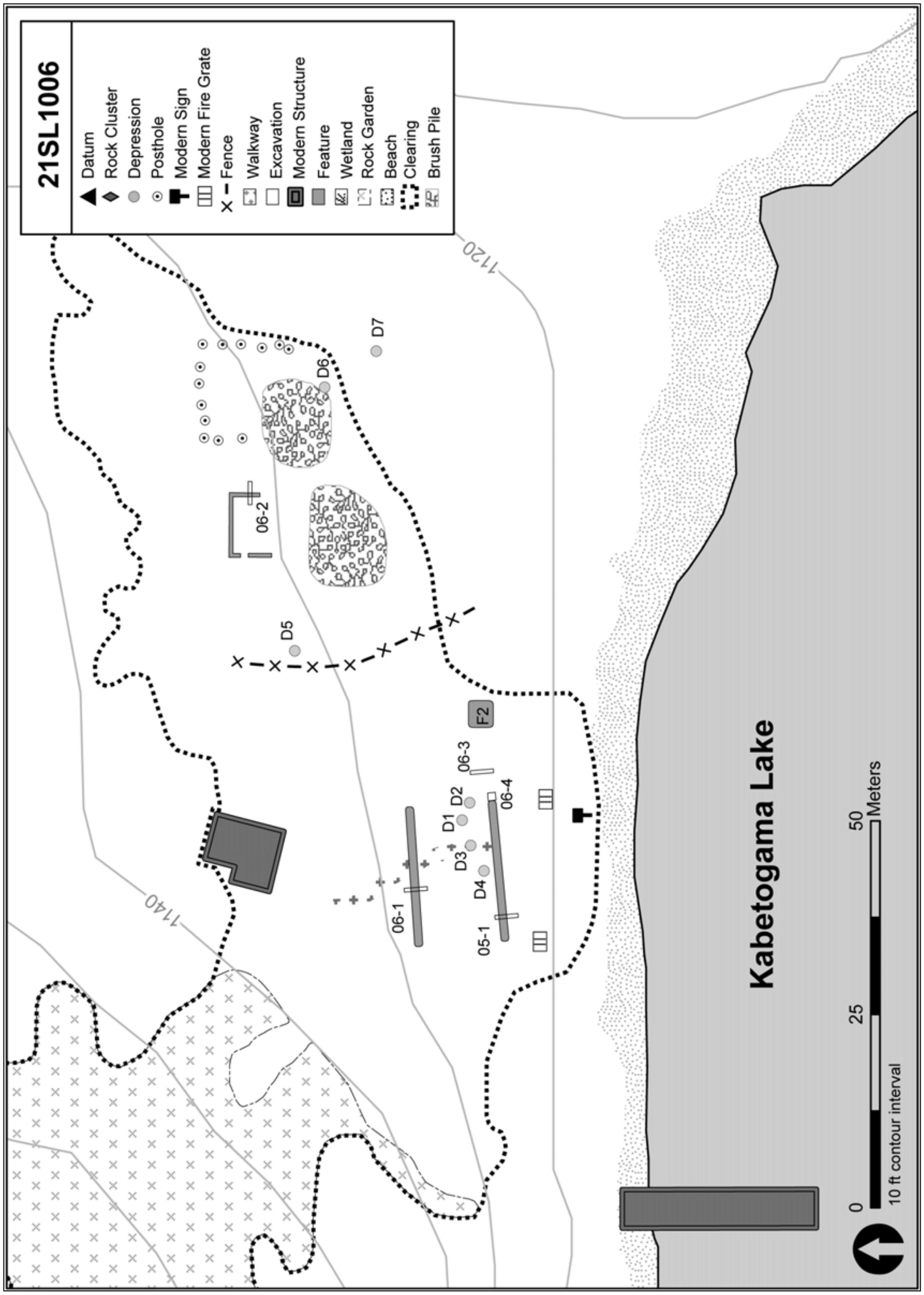


Figure 3. Ellsworth Rock Gardens archeological site map.

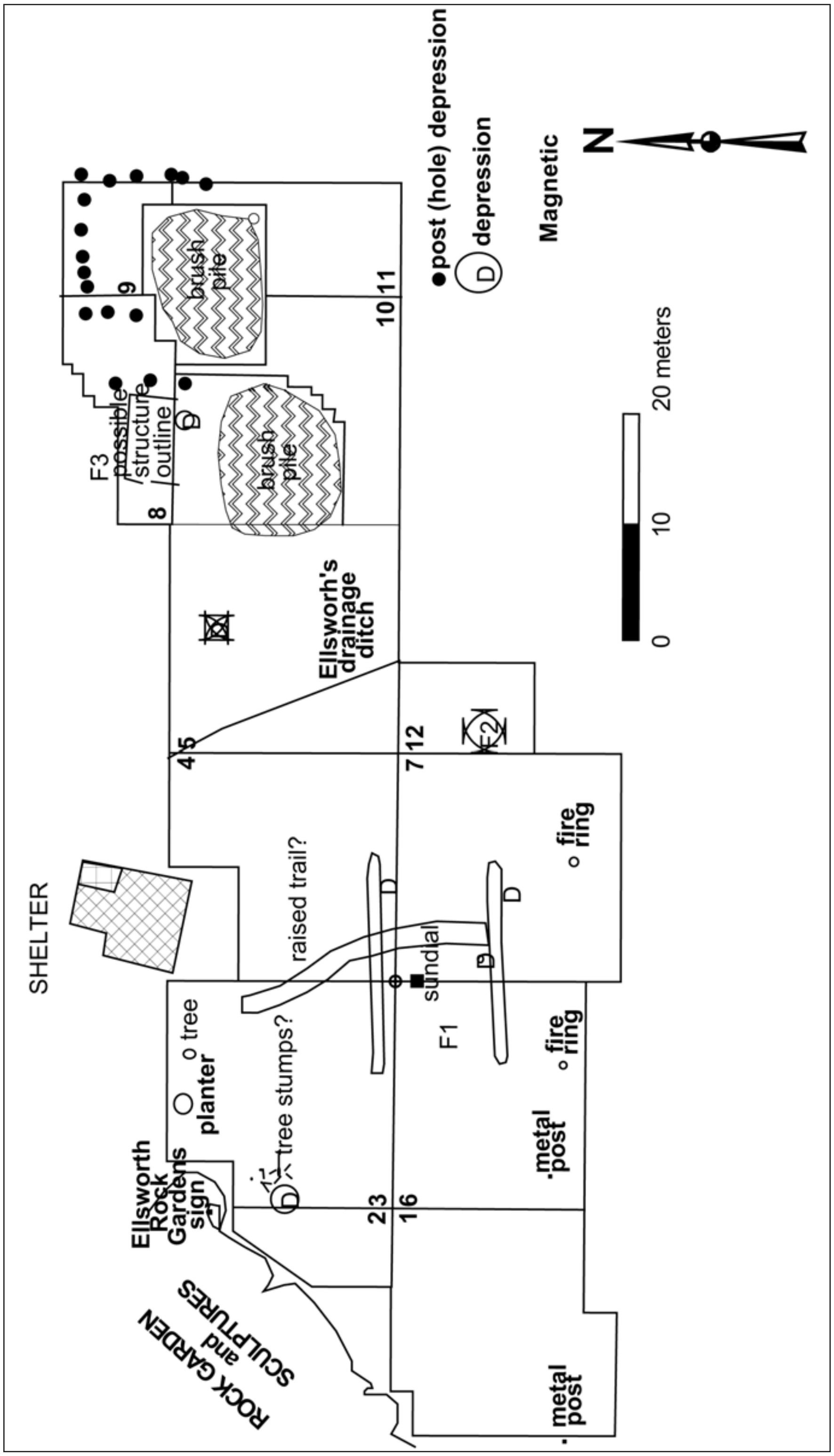


Figure 4. Sketch map of Ellsworth Rock Gardens Site geophysical survey grid.

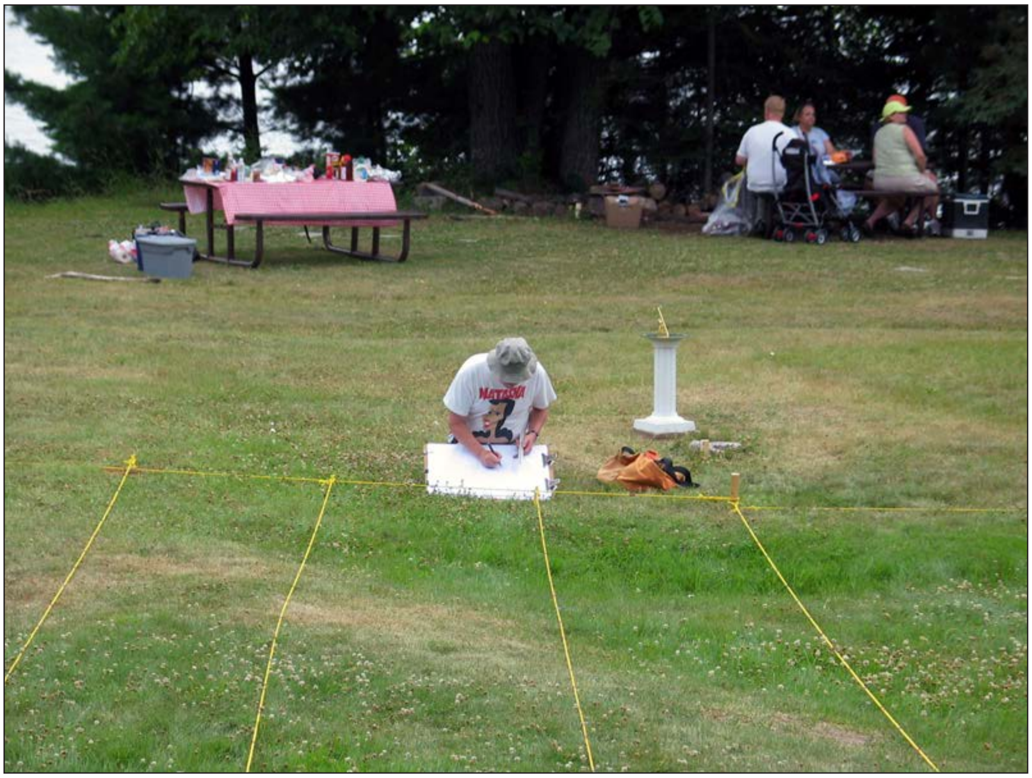


Figure 5. Preparing site sketch map (view to the south).

Figure 6. Magnetic gradient survey with fluxgate gradiometer (view to the west).

Figure 7. Resistance survey with resistance meter and twin probe array (view to the northeast).

Figure 8. Conductivity survey with electromagnetic induction meter (view to the west).

Figure 9. Ground penetrating radar survey with cart system and 400 mHz antenna.

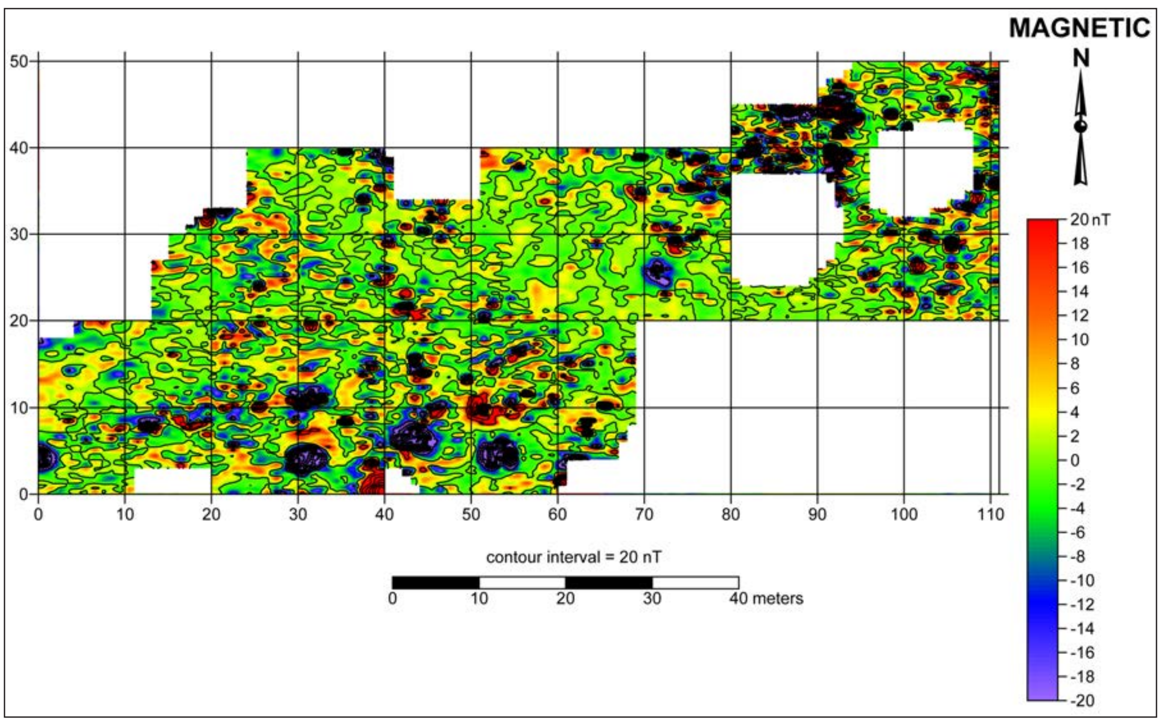


Figure 10. Image and contour plot of magnetic data from the project survey area.

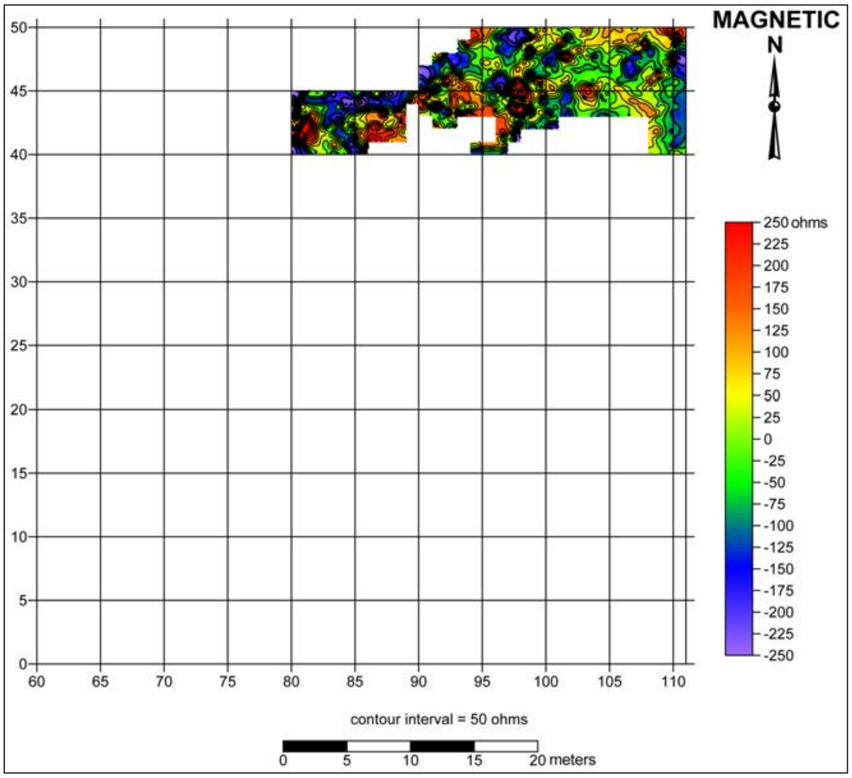


Figure 11. Image and contour plot of resistance data from the project survey area.

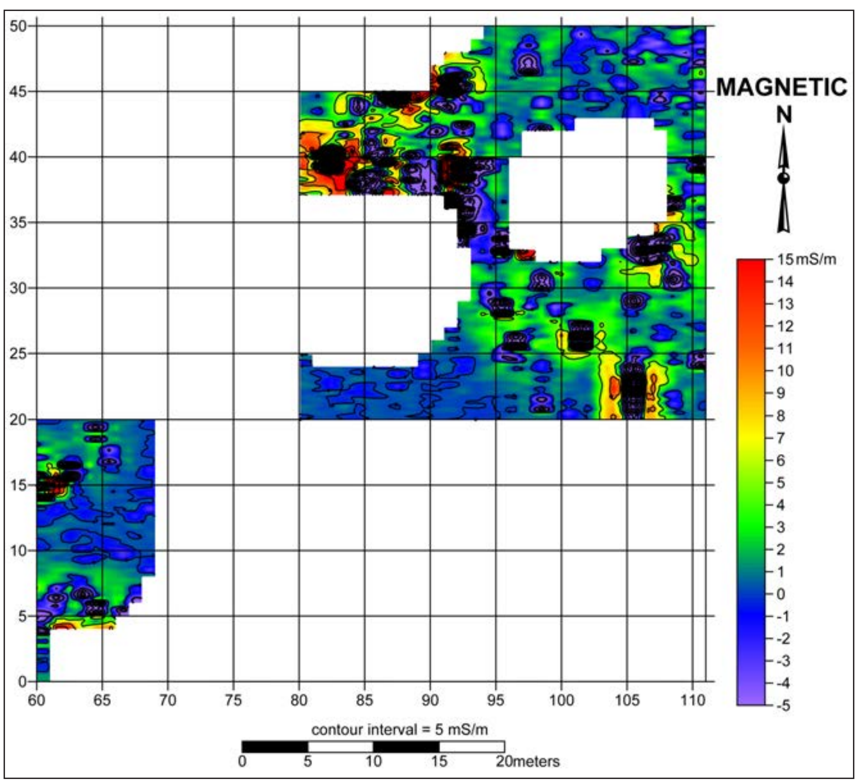


Figure 12. Image and contour plot of conductivity data from the project survey area.

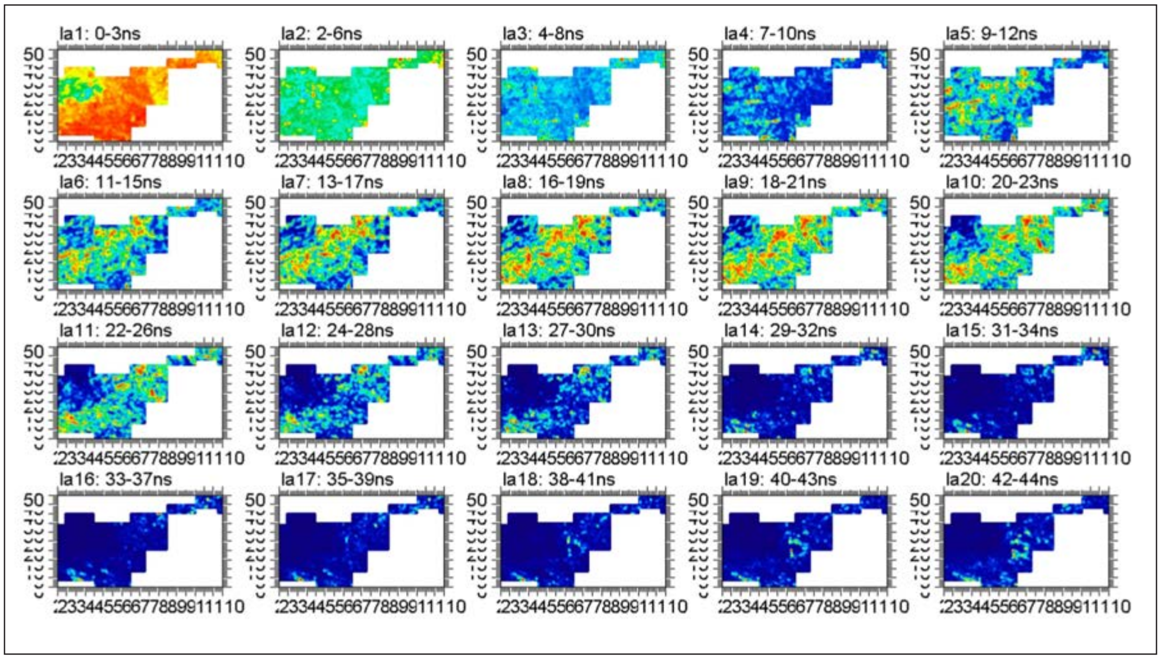


Figure 13. Time slice gpr data from the project survey area

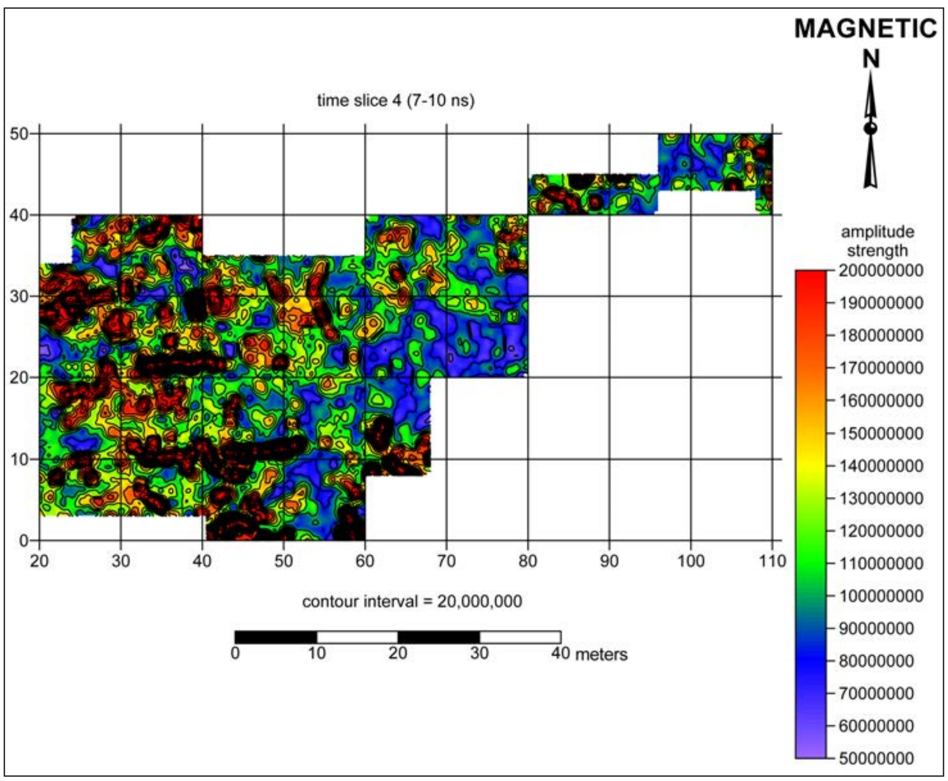


Figure 14. Image and contour plot of time slice 4 (7-10 ns) ground penetrating radar data from the project survey area.

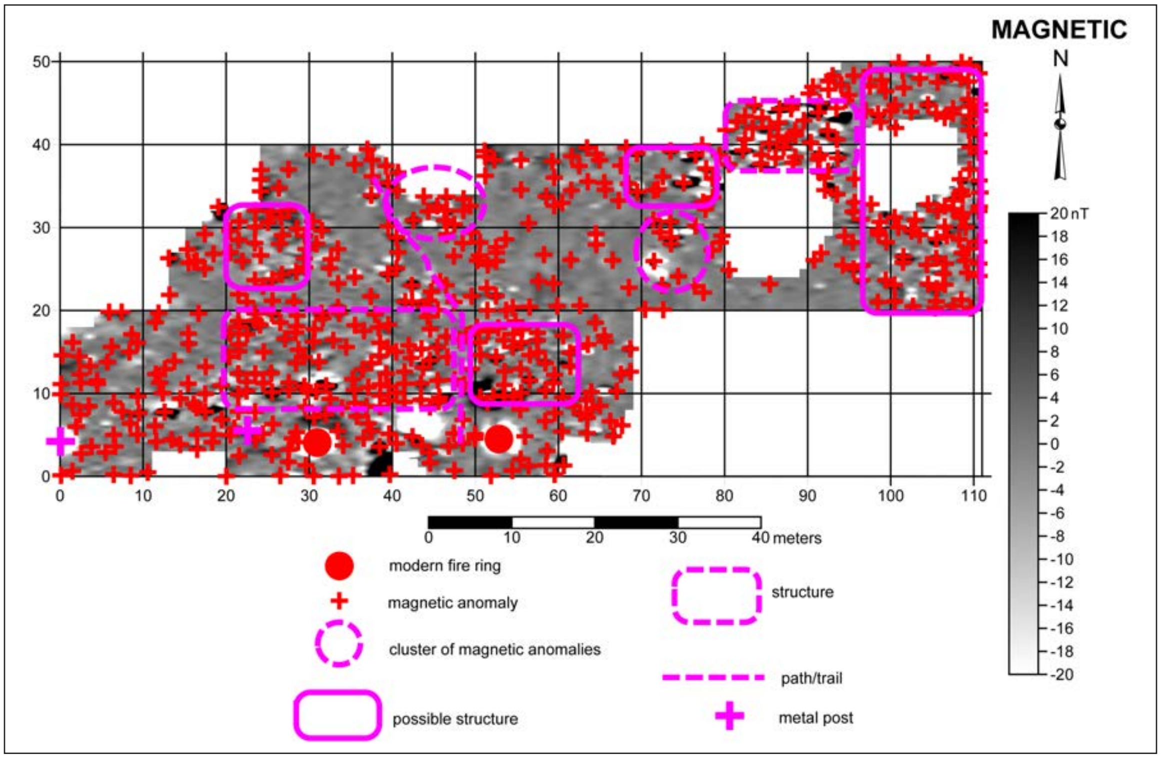


Figure 15. Interpretative map of magnetic data from the project survey area.

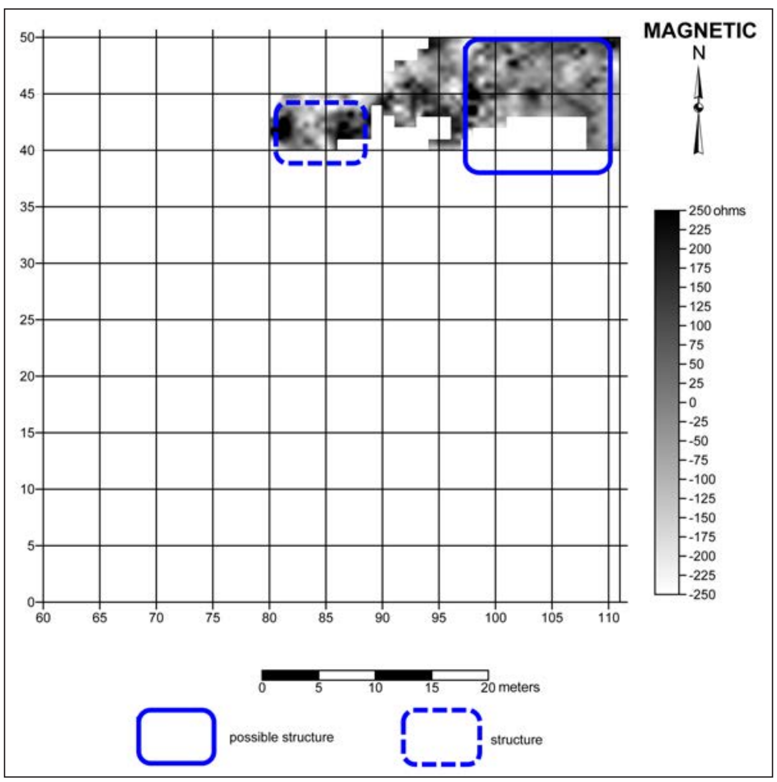


Figure 16. Interpretative map of resistance data from the project survey area.

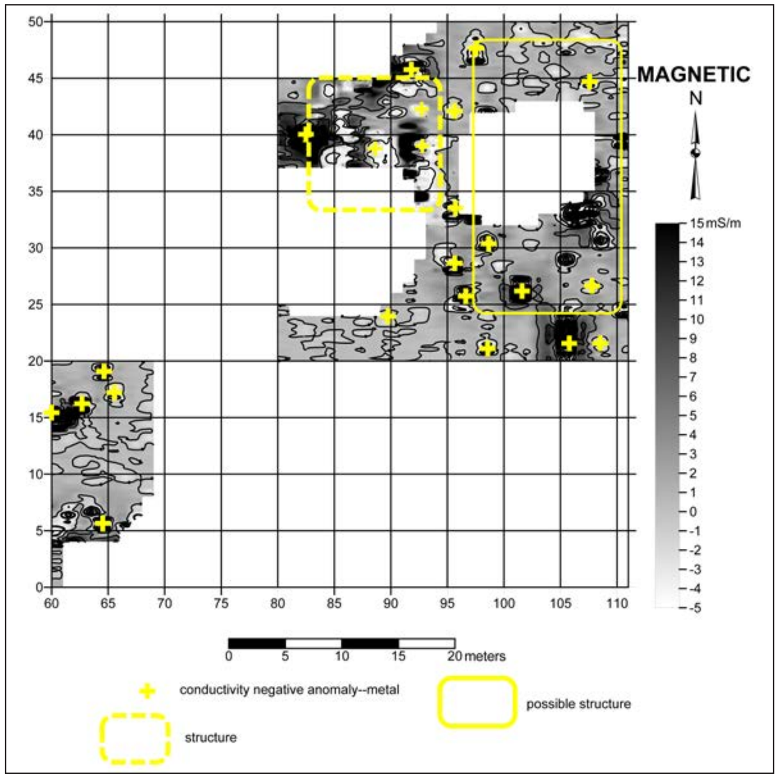


Figure 17. Interpretative map of conductivity data from the project survey area.

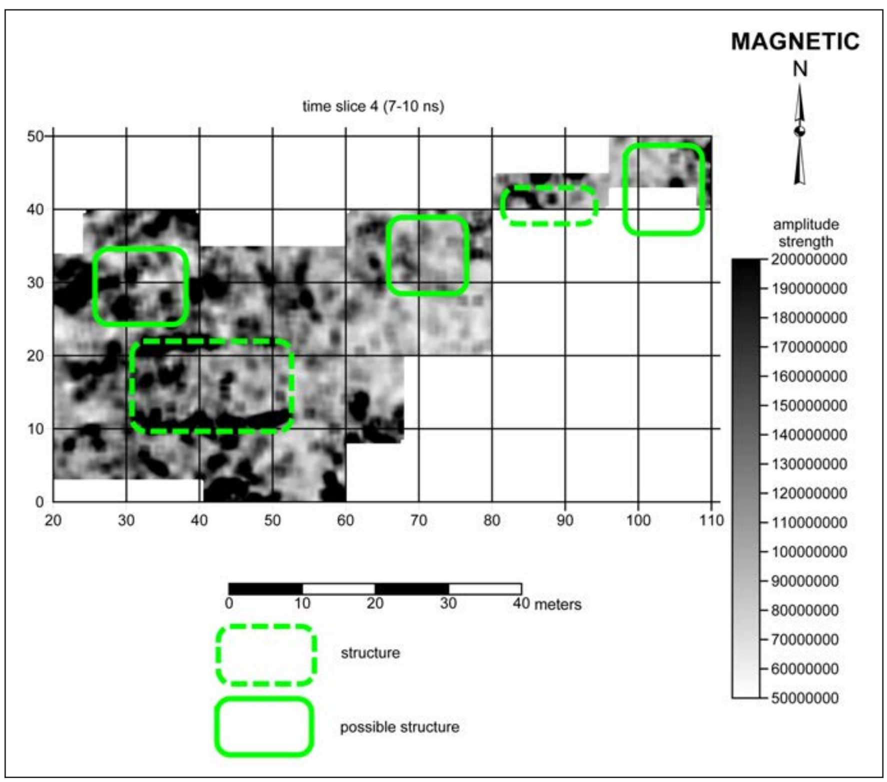


Figure 18. Interpretative map of time slice 8 (7-10 ns) gpr data from the project survey area.

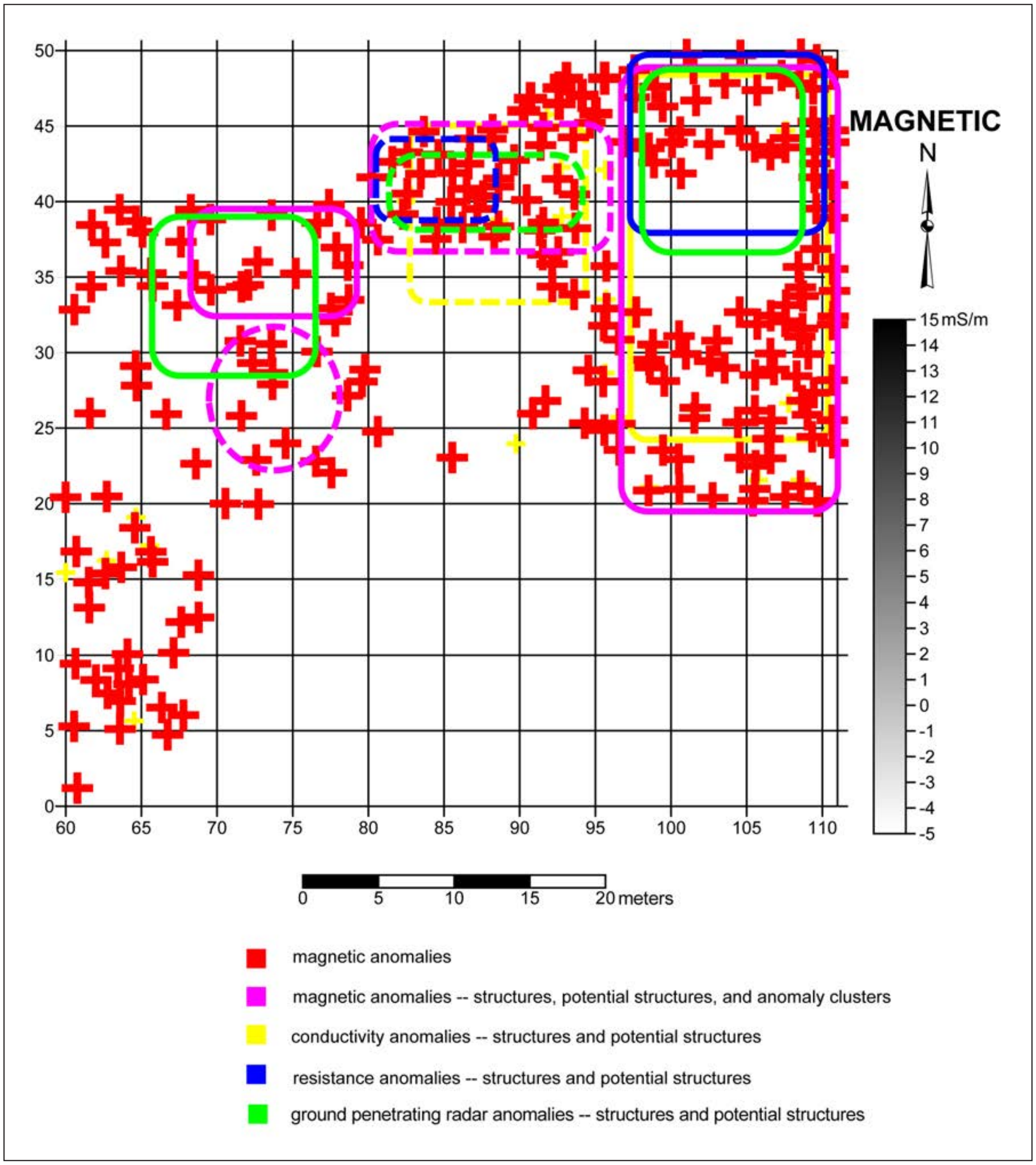


Figure 19. Combined geophysical interpretative map of the northeast corner of the project survey area.