**Document Title:** Detecting Buried Firearms Using Multiple Geophysical Technologies

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# NIJ Final Report

# Detecting Buried Firearms Using Multiple Geophysical Technologies

## (2007-DN-BX-K304)

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# ABSTRACT

Geophysical technologies are non-destructive remote sensing tools that are routinely used as part of the multidisciplinary protocol in death investigations to search for buried bodies and forensic evidence. The purpose of a forensic geophysical survey is to detect a buried object (e.g., clandestine grave or buried body) that is recognized as an anomaly, or an area of contrasting properties in the soil. The most useful method for determining the applicability of using geophysical tools to detect buried evidence is to set up a controlled research site to monitor and detect the specific items in question. For example, controlled geophysical research has been very important in demonstrating how ground penetrating radar (GPR) can be used to locate buried bodies from forensic contexts (Davenport, 2001a; Mellett, 1992; Nobes, 2000; Reynolds, 1997; Schultz, 2007).

The objective of this research project was to improve standard geophysical detection methods used to search for street-level firearms, commonly involved in crimes, that have been buried for the purposes of concealing or discarding them. This project entailed burying 32 metallic objects including 16 different firearms that represent various weapon types (revolver, derringer, shotgun, semi-automatic rifle, and pistol), 10 miscellaneous weapons (blunt and sharp edged items) and six pieces of scrap metal. Then the weapons were tested at depths of 5cm increments using five different geophysical technologies: GPR with 500- and 800-MHz antennae, an all-metal detector, advanced digital metal detector with a standard and large size search coil, a ground conductivity meter, and a magnetic locator. This research served to address how the type of firearm and the metallic materials that comprise the weapons affect detection. Ultimately, this project provides guidelines for buried weapons searches.

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# CHAPTER 1: PURPOSE, GOALS, & OBJECTIVES

By using the information provided by this research an investigator can perform a buried weapons search in a more reliable and timely manner. Law enforcement personnel generally use a generic metal detector, with or without limited discrimination technology, to search for a buried weapon used in a crime. All too often, personnel using the detector have very little training with metal detectors, and the geophysical survey results in an abundance of false hits that need to be intrusively checked by digging. Most investigators that have been involved in these types of searches would confirm that a considerable amount of time is required to check all of the geophysical hits and would welcome research that improves general search guidelines. Also, considering that the advanced metal detectors and magnetic locators that will be used for this research are reasonably priced, geophysical research that focuses on the application of these affordable tools in locating buried firearms would be beneficial to law enforcement. In particular, this research has generated search guidelines that are specific to the weapon, and/or the metallic materials that comprise the weapon, and the type of geophysical tool that should be used for a search.

The purpose of this research project was to improve standard geophysical detection methods used to search for street-level firearms, commonly used in crimes, which have been buried for the purpose of concealing or discarding them. It is important to note that this research was expanded from the original proposal to include 10 miscellaneous weapons (blunt and sharp force items) and six scrap metals for a total of 32 items that were tested.

The goals and objectives of this project included the following:

- Determine the applicability of using multiple geophysical technologies to search for buried street-level weapons.
- Determine which firearms and/or metallic materials can be detected by geophysical instruments and whether specific instruments are better at detecting specific weapons due to the materials that comprise each weapon.
- Determine the maximum depth that different buried firearms can be located.
- Provide basic guidelines for forensic investigators using geophysical technologies so they will be better prepared to search for buried firearms.
- Provide guidelines for forensic investigators that are aimed at locating different types of weapons using a specific geophysical tool or multiple geophysical tools.

# CHAPTER 2: LITERATURE REVIEW

Forensic geoscience (the study and application of earth materials to legal investigations) is a burgeoning field that has the potential to significantly assist criminal investigations (Murray, 2004; Murray and Tedrow, 1975; Pye and Croft, 2004; Ruffell and McKinley, 2005). In particular, the application of geophysics can greatly assist forensic investigations through the use of geophysical technologies. Geophysical technologies are non-destructive remote sensing tools that are becoming routinely used as part of the multidisciplinary protocol in death investigations to search for buried bodies and forensic evidence. The purpose of a geophysical survey is to detect a buried object that is recognized as an anomaly, or an area of contrasting properties in the soil. In forensic contexts, geophysical methods are generally used to locate small anomalies near the ground surface that are produced by graves, weapons, and other buried evidence comprised of, or buried with, metallic materials. Geophysical surveys are not only important to locate clandestine graves and weapons, they are also important to clear suspected areas so that searches may be directed elsewhere.

One of the most useful methods for gaining experience in performing geophysical surveys for buried evidence or features is to set up a controlled research site to monitor and detect the specific items in question for some length of time. Since operator experience is a major limiting factor when using geophysical technologies, controlled studies not only provide operators with experience in a known setting that is invaluable when they perform real-life searches, they also provide operators with the knowledge of the limitations and applicability of different geophysical tools for varying situations. Proponents of using geophysical surveys for archaeological contexts have stressed the importance of controlled research to develop techniques and approaches that increase the effectiveness of geophysical surveys (Isaacson et al., 1999; Schurr, 1997). This has resulted in the construction of controlled archaeological test sites to provide training and research in archaeogeophysics (e.g., Isaacson et al., 1999).

More specifically, controlled forensic geophysical studies have been very important in determining the utility of ground-penetrating radar (GPR) for body searches in various soils and in providing GPR operators with experience in a known setting (Davenport et al., 1990; France et al., 1992; France et al., 1997; Freeland et al., 2003; Schultz, 2003; Schultz et al., 2006). Controlled GPR studies have generally used buried pig cadavers as proxies for human bodies to distinguish the type of geophysical response that is produced over time by a decomposing buried body in varying soil conditions and depths. As a result of this past controlled research, GPR is now being used to successfully locate clandestine burials of homicide victims in different soil conditions (Davenport, 2001a; Mellett, 1992; Nobes, 2000; Reynolds, 1997; Schultz, 2007).

Another tool that may show promise for forensic contexts is a conductivity meter. Conductivity is a tool often used for mapping archaeological sites such as 5000-year-old shaft tombs in Jordan and Greek settlements dating from the Roman and Early Byzantine periods (Rowlands and Sarris, 2007; Wynn, 1986). Although conductivity has shown potential on archaeological sites, this technique remains mostly untested in forensic settings. Only one case study is presented in the academic literature describing the use of an older conductivity meter in conjunction with GPR to detect a grave (Ruffell and McKinley, 2005; Nobes, 2000). In recent years, conductivity meters such as the Geonics EM-38 models have been greatly reduced in size to allow for uses in different fields. This new design is ideal for forensic scenes where the anomalies created by clandestine burials and buried forensic evidence tend to be shallower than anomalies seen in archaeology. The smaller conductivity meters are more sensitive to conductivity changes at shallow depths, thus maximizing the chances to uncover buried evidence on forensic scenes (Davenport, 2001a).

The geophysical tool most often used by crime scene personnel to search for weapons tossed into fields (Goddard, 1977) and spent projectiles and casings that are generally located on the ground surface or directly under the ground surface is a metal detector. Metal detectors are generally used to locate small objects at shallow depths and large objects at deeper depths (Garrett, 1998; Nelson, 2004). While numerous sources identify geophysical technologies as appropriate tools that can be used to search for buried firearms, bullets and casings, and items comprised of metallic material (Clark, 1990; Connor and Scott, 1998; Davenport, 2001a; Davenport, 2001b; Dupras et al., 2006; Gaffney and Gater, 2003; Garrett, 1998; Goddard, 1977; Hunter and Cox, 2005; Killam, 2004; Nickell and Fischer, 1999; Nielson, 2003; Scott and Fox, 1987; Sonderman, 2001), there have been no controlled geophysical studies reported in the academic literature that focus on the application of locating buried firearms and weapons using these technologies. Unfortunately, only a few references (Murray and Tedrow, 1975; Nielsen, 2003; Schonstedt Instrument Company, 1998) briefly discuss locating weapons using a metal detector or magnetic locator by suggesting that handguns may be located down to a maximum depth of a foot or so beneath the ground surface. However, no consideration is given to the weapons type, the size, or the metallic materials of handguns. Considering that all-metal detectors, advanced metal detectors, and magnetic locators are reasonably priced, research that focuses on the application of locating buried firearms using these types of technologies would be beneficial to law enforcement because a number of these tools should be within the means of their budgets.

# CHAPTER 3: RESEARCH DESIGN & METHODS

## Research Site

An undeveloped, flat, open section of the Orange County Sheriff's Office (OCSO) Lawson Lamar Firearms and Tactical Training Center in Orlando, Florida was designated as the research site for this project (Figure 3-1). Centered in the overflow portion of a retention pond, the research area is frequently mowed, but otherwise inactive. Soil in the research area is classified as a Spodosol, specifically in the Smyrna series, which consists of poorly drained soils with spodic horizons (dark organic layers which may consist of aluminum, carbon, and/or iron) which have formed in sandy marine sediment (Doolittle and Schellentrager, 1989). However, when the range was developed, extra fill was incorporated into the area to raise and level the ground surface.

Figure 3-1. Aerial Photograph of Lawson Lamar Firearms and Tactical Training Center in Orlando, Florida. The box represents the approximate size and location of the grid measuring 16m west to east by 19m south to north.

A 16m (west to east) by 19m (south to north) grid was constructed (Figures 3-1 and 3-2) for this research project. The research grid contained a total of 32 buried metallic objects and one control hole (consisting of only backfill) (Figure 3-2). Two control holes (consisting of only backfill) were also located outside the grid. Six rows each contained five buried items, while row G contained two buried items and one control hole. Rows A and B contained only buried firearms, rows C and D contained both firearms and scrap metal, rows E and F contained only blunt or edged weapons, and the final row G was added to incorporate two additional firearms and a control hole.

## Forensic Targets

Included in this research were 16 firearms, ten miscellaneous weapons (blunt or sharp edged), and six pieces of assorted scrap metals (Tables 3-1 to 3-3 and Figures 3-3 to 3-6). A collection of firearms most commonly associated with street-level crime in Central Florida was provided for this research by the Orange County Sheriff's Office (OCSO), and consisted of a derringer, eight pistols, four revolvers, two shotguns, and a rifle (Table 3-1 and Figure 3-3 to 3-4). The firearms selected represent a variety of metallic compositions, finishes, and lengths. The majority of the firearm frame compositions consist of steel, with several utilizing other metals or materials, such as zinc, aluminum, or polymer.

In order to gain access to the weapons for research, all protocols outlined by the OCSO's security procedures, including the decommissioning of the firearms, were followed. Firearms were decommissioned by removing or filing firing pins and blocking the firing pin channel and barrel with JB Weld® cold weld compound. Of note is G11, the Glock 9mm; due to the minimal amount of metal in the polymer frame, the firing pin was removed and welded into the grip, and both the firing pin channel and barrel were blocked.

A variety of blunt (mallet, hammer, prybar, baton, brass knuckles) and edged (machete, sword, Buck knife, Philip's head screwdriver, scissors) weapons which have been recovered from OCSO crime scenes were also included, and primarily consisted of steel (Table 3-2 and Figure 3-5). The scrap metals included pieces of copper, aluminum, and iron (including rebar), representing trash metals which are frequently encountered during weapons searches (Table 3-3 and Figure 3-6).

## Burial Protocol

The maximum depth of detection was determined for all items using each of the geophysical tools except for the GPR unit. Data collection started at a depth of 20-25cm. Once data collection was completed for each depth, the items and control hole were dug 5cm deeper for each re-burial and the weapons were placed on their flat side (Figure 3-7). Plastic stakes and pin flags with plastic shafts were placed in the loose soil of each hole to mark the location of the items and control hole. When time permitted, intervals of approximately one to two weeks from burial to data collection allowed for soil compaction.

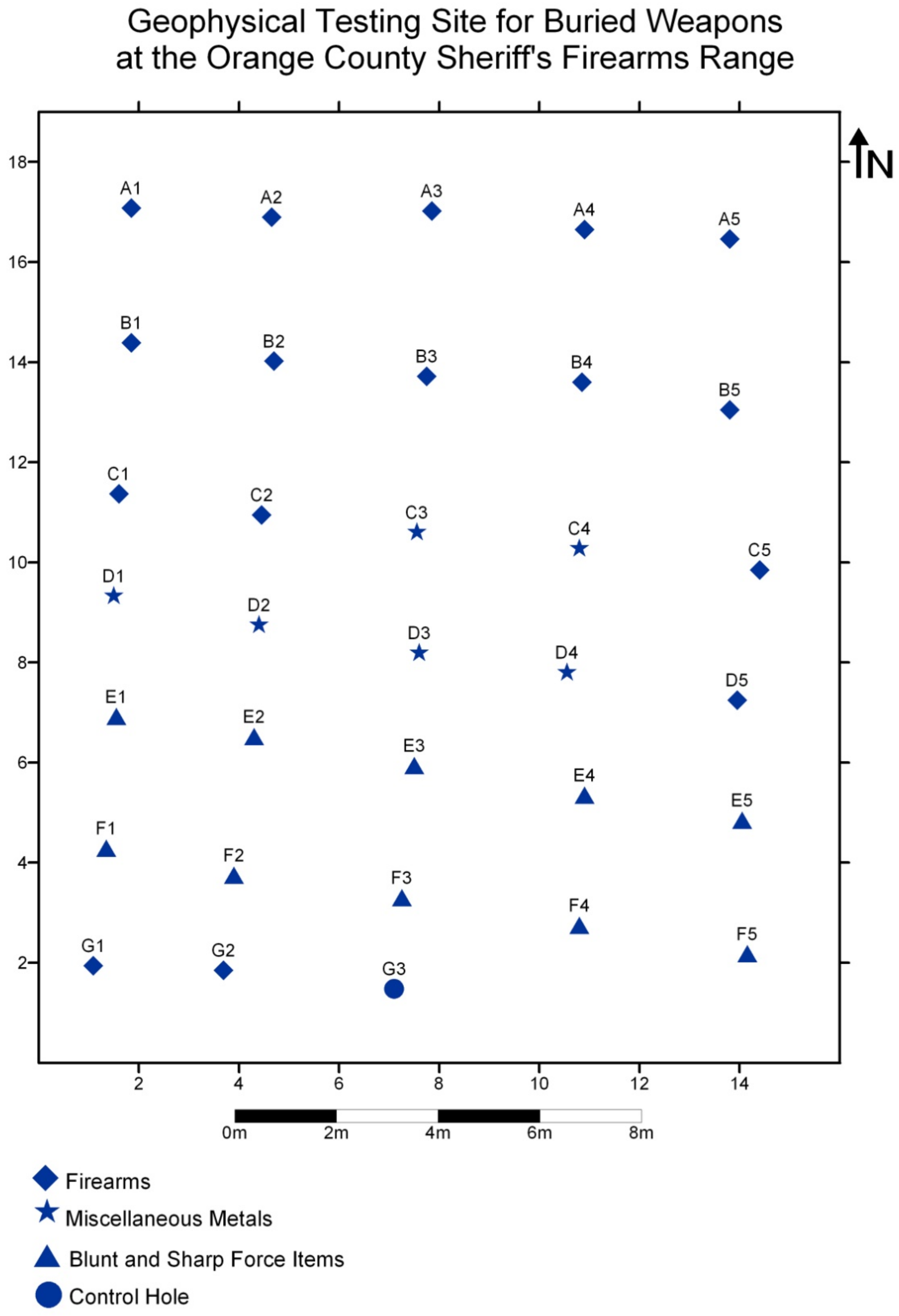

Figure 3-2. Map of research area containing a total of thirty-two buried metallic objects and one control hole.

*Table 3-1. Detailed information for the firearm sample.*

| **Grid Location** | **Firearm** | **Type/Ammunition** | **Metal/Composition** | **Special Finish** | **Length (mm)** | **Unloaded Weight** |
|---|---|---|---|---|---|---|
| A1 | Davis Derringer D9 | Derringer/ 9mm | Steel | Chrome-plated | 119 | 12.8 |
| A2 | Raven Arms MP-25 | Pistol/.25 | Zinc Alloy/Steel | Chrome-plated | 123 | 14.4 |
| A3 | Hi-Point Model C | Pistol/9mm | Steel/Polymer | Blued | 178 | 35 |
| A4 | Smith & Wesson 5906 | Pistol/9mm | Stainless Steel | | 190 | 38.3 |
| A5 | Glock Model 19 | Pistol/9mm | Polymer Frame/ Steel Slide and Firing Pin | Blued/Tenifer | 187 | 20.6 |
| B1 | North American Arms Mini-Magnum | Revolver/.22 Magnum | Stainless Steel | | 130 | 6.4 |
| B2 | Jennings Bryco 59 | Pistol/9mm | Zinc Alloy/ Steel Magazine | Satin Nickel-plated | 170 | 33.6 |
| B3 | Smith & Wesson Model 686 | Revolver/.357 Magnum | Stainless Steel | | 235 | 37 |
| B4 | Lorcin L380 | Pistol/.380 | Aluminum Frame, Magazine, Slide/Steel | Blued | 171 | 30.4 |
| B5 | Colt Commander | Pistol/.45 ACP | Steel | Blued | 196 | 27 |
| C1 | Smith & Wesson Model 37 | Revolver/.38 Special | Steel | Nickel-plated | 167 | 25 |
| C2 | RG Industries RG23 | Revolver/ .22 Long rifle | Aluminum Frame/ Steel Barrel and Cylinder | Blued | 148 | 14.4 |
| C5 | Norinco AK Hunter, Wooden Stock | Rifle/7.62 | Steel/ Polymer | Blued | 1067 | 125.5 Includes Wooden Stock |
| D5 | Mossberg Model 500A, Pistol Grip | Shotgun/ 12 Gauge | Steel/ Polymer | Blued | 711 | 96 |
| G1 | Remington 870,Front Folding Knoxx COPstock | Shotgun/ 12 Gauge | Steel | Parkerized | 762 | 116 (estimate) |
| G2 | Ruger P89 | Pistol/ 9mm | Aluminum/Stainless Steel | Terhune Anticorro | 203 | 32 |

*Table 3- 2. Miscellaneous weapons*

| Grid Location | Type | Metal/Composition | Length (mm) |
|---|---|---|---|
| E1 | Scissors | Steel | 200 |
| E2 | Buck Knife | Stainless Steel | 222 |
| E3 | Prybar | Steel | 322 |
| E4 | Mallet | Steel/fiberglass handle | 384 Includes handle |
| E5 | Machete | Steel | 682 |
| F1 | Baton | Steel | 257 |
| F2 | Philip's Head Screwdriver | Steel | 262 |
| F3 | Brass Knuckles | Brass (Copper and Zinc) | 116 |
| F4 | Claw Hammer | Steel | 350 |
| F5 | Sword | Steel/Brass Hilt? | 810 |

*Table 3-3. Scrap Metals*

| Grid Location | Type | Metal/ Composition | Length (mm) |
|---|---|---|---|
| C3 | Aluminum Edging | Aluminum | 530 |
| C4 | Solid Iron Pipe | Iron | 480 |
| D1 | Hollow Copper Tube | Copper | 685 |
| D2 | Rusty Iron Pipe | Iron | 570 |
| D3 | Solid Aluminum Pipe | Aluminum | 477 |
| D4 | Thin Rebar | Iron | 665 |

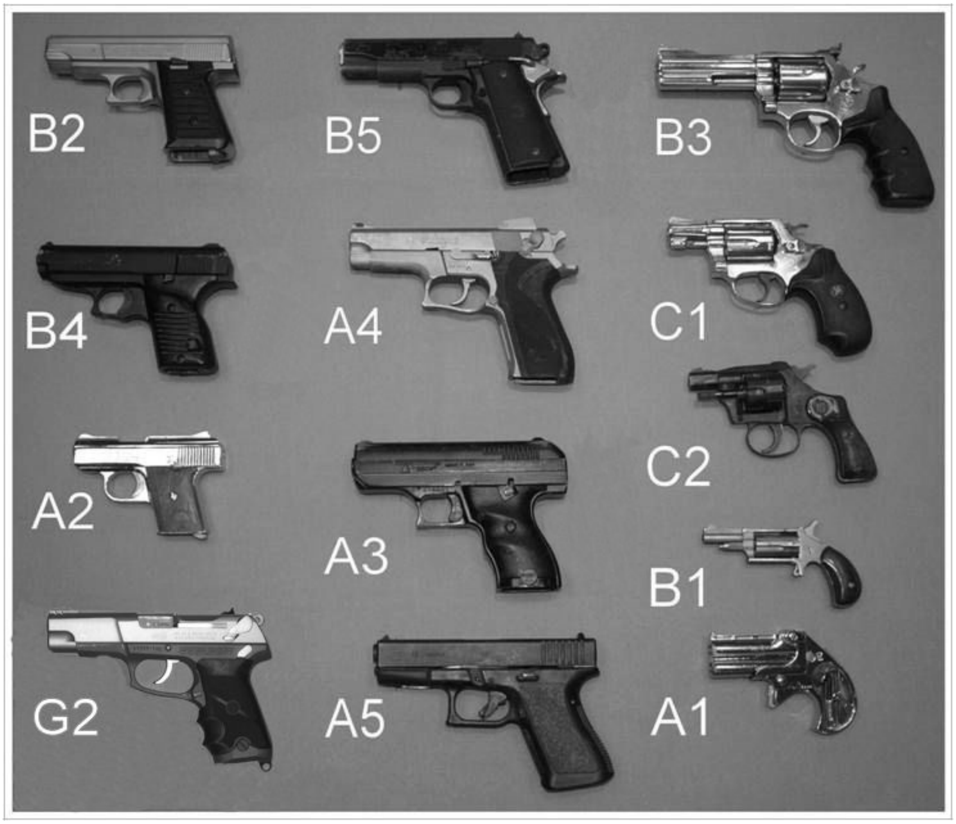

Figure 3-3. Thirteen of the decommissioned firearms utilized in the project represented a derringer, revolvers, and pistols.

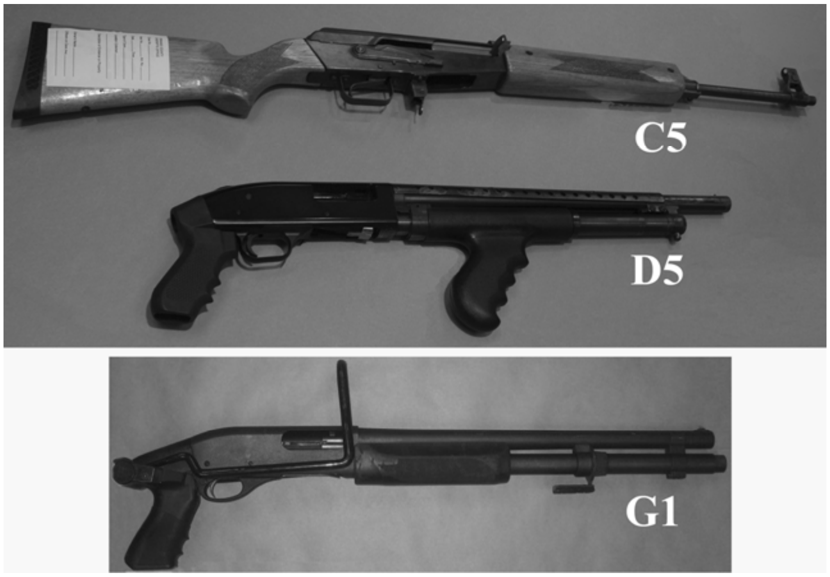

Figure 3-4. The other three decommissioned firearms utilized in the project represented two shotguns and a rifle.

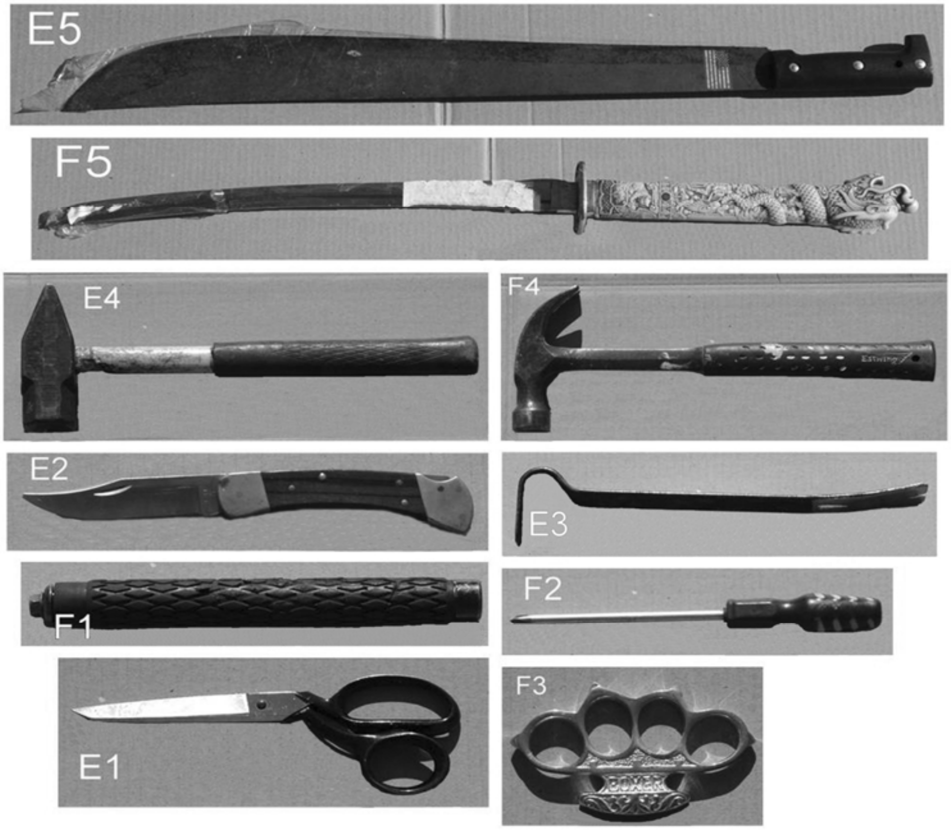

Figure 3-5. Ten blunt and edged weapons utilized for the project (items not scaled to size)

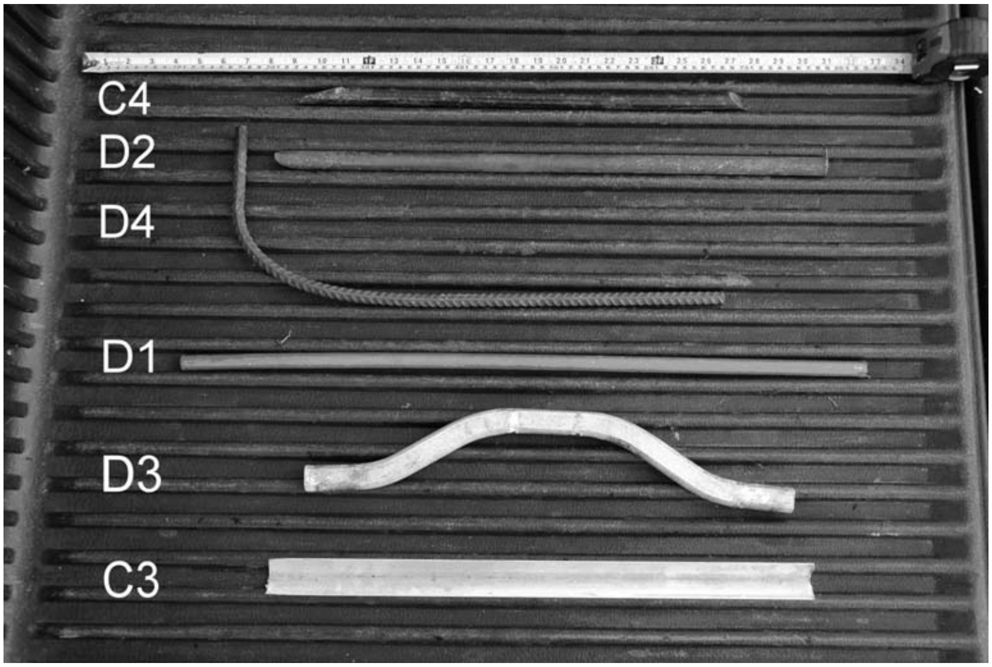

Figure 3-6. Six pieces of assorted scrap metals utilized for the project

Figure 3-7. Example of how a firearm (pistol) was placed back in hole after deepening the hole.

## Quality Control

During the summer of 2008, due to considerable storms and the rainy season in the Central Florida area, the field site was periodically flooded and the ground was excessively saturated with water. Through our quality control, we realized that the results were affected by the amount of water present in the ground. Therefore, much of the data collection was redone once the field site had dried. Quality control for the conductivity meter consisted of processing the data for each depth prior to data collection for the following depth to ensure there were no spurious results due to the ground being saturated by water. If any issues were noted, data collection was redone.

In order to maintain quality control for the magnetic locator, the all-metal detector, and the advanced metal detector, we instituted a number of safeguards. Ground water saturation and foreign metallic debris that were added to the site had to be addressed. Due to the fact that the research site is a live firearms range, we learned that our site would periodically become littered with foreign bullet debris due to training. As a result, we re-tested the entire sample individually using the magnetic locator, the all-metal detector, and the advanced metal detector during the dry period in holes devoid of any foreign metallic debris by continually digging up and reburying the weapons until the maximum depth of detection was determined. Each item was tested at least once or twice to confirm the results. Collecting data without allowing two weeks for soil compaction was not a problem because it was determined early on that the loose soil did not produce false anomalies.

Data were collected directly over the buried metallic targets using the magnetic locator, the all-metal detector, and the advanced metal detector. A probe was used to verify the exact target location that was marked by a plastic stake. By knowing the exact spot where the target was located, it was possible to confirm that the readings were due to the buried target and not the result of foreign metallic material in the soil outside the hole. When assessments were made as to whether the target was detected, two additional project members provided inter-observer confirmation of the author’s results. Also, surveying over each buried target with the magnetic locator, the all-metal detector, and the advanced metal detector was conducted in both north/south and east/west direction.

## Geophysical Tools Tested

The geophysical tools used for this research have the ability to detect metallic objects and provide consistent readings, allowing for dependable results which should be replicable during actual forensic search scenarios. Chosen due to their use in archaeology and forensics, and their accessibility and efficiency, many law enforcement agencies will find a number of these tools (metal detectors and magnetic locators) easy to purchase, relatively inexpensive, and easy to use. Five different geophysical instruments were tested that represent the most common types of geophysical tools used to search for buried evidence comprised of metal:

- magnetic locator
- all-metal detector with 11 inch (27.9cm) search coil
- advanced digital metal detector with 10.5 inch (26.7cm) search coil an additional aftermarket 15 inch (38.1cm) search coil
- ground conductivity meter
- cart mounted GPR unit with 500-MHz and 800-MHz antennae

# CHAPTER 4: MAGNETIC LOCATOR

## Magnetic Locator Theory

Magnetic locators utilize sensors (one or two, depending upon model) to measure local variations in the earth's magnetic field and to detect ferromagnetic objects (Davenport, 2001; Dupras et al., 2006; Hunter and Cox, 2005; Schonstedt Instrument Company, 1998). The use of magnetic profiling requires basic familiarity with the locator but is relatively easy to learn, and the devices themselves are some of the more inexpensive geophysical tools (Davenport, 2001; Hunter and Cox, 2005).

The magnetic locator that was used for this research project is manufactured by Schonstedt Instrument Company (model #: GA-72Cd) (Figure 4-1) and is essentially a simple magnetometer configured as a magnetic gradiometer (two sensors instead of one). The two sensors are spaced roughly 14 inches (35.6cm) apart and respond to the differences in the magnetic field around the locator. Magnetic locators are generally designed as a walking staff consisting of a long shaft and a small control box at the top end (Figure 4-1). The shaft, which is swept from side to side in front of the operator, contains two sensors that respond to changes in magnetic fields created by buried ferromagnetic objects. The magnetic locator is designed to detect the magnetic field of ferromagnetic materials such as iron and steel, while ignoring non-metallic materials such as gold, silver, copper, brass, and aluminum (Schonstedt Instrument Company, 1998). In addition, the manufacturer asserts that this equipment can aid explosive ordnance-disposal technicians and law enforcement officers during area search operations for improvised explosive devices, buried ordnance, and covered weapons (Schonstedt Instrument

Company, 1998). The readout and sound alarm operate very similarly to metal detectors as one moves closer to a target, the audible tone and/or digital readout will increase.

The Schonstedt GA-72Cd magnetic locator includes Low, Medium, High, and Maximum sensitivity settings. According to the manufacturer, the level of sensitivity required for accurate detection differs based upon background interference and depth of object. Maximum sensitivity will allow for deeper detection, but also increases the sensitivity of the machine to unwanted signals that produce background noise (Schonstedt Instrument Company, 1998).

Audio and visual indications of signal strength and polarity register in the unit when a magnetic object is located. A more advanced use of the magnetic locator includes simultaneous use of both indications to pinpoint a target and determine its orientation. Increasing audio strength and a change in the numerical values displayed on the screen indicate that a magnetic object is being located. If the object is buried horizontally, the positive and negative ends of the target can be determined, providing information in regards to shape and size of the target. If an object is buried vertically, the audio signal will only sound directly over the object, and can appear either positive or negative.

According to the manufacturer, materials which may be located with the Schonstedt GA-72Cd include magnetic markers, stakes, manholes, septic tanks, magnetically detectable nonmetallic duct and cable, well casings, barbed wire, chain link fence, valve boxes, cast-iron pipes, steel drums, weapons, projectiles, hunting knives, and hand guns (Schonstedt Instrument Company, 1998). In addition, the magnetic locator data collection may be performed in different environmental conditions such as over snow and water. According to the manufacturer's manual, the maximum depth of detection for a 55 gallon steel drum should be 8 feet (2.44m), a hunting knife should be 16 inches (40.64cm), and a discarded handgun should be 12 inches (30.48cm) (Schonstedt Instrument Company, 1998).

## Data Collection Parameters

The GA-72Cd magnetic locator was used very much like a metal detector in that it was slowly waived in front of the operator, pointing at the ground. When the audio and visual readings became stronger, an object was located by running the locator in an “x” type fashion over the area. The point of strongest readings was therefore the buried magnetic object. The Low sensitivity setting did not adequately detect the targets, and the Maximum setting reflected too much background interference. The Medium and High settings provided the best balance between audible target responses and constant background noise. Data was then collected as one of three detection categories: *no*, *slight* and s*trong*. *Slight* detection readings meant that a minor change in the normal hum was audible but would not have been discernable during real-world searches involving areas that are littered with trash metals and/or have a high mineral content as there may be extensive background noise or other distractions.

Figure 4-1. Schonstedt GA-72Cd magnetic locator

## Results

### Firearms

Data collection on the buried firearms with the magnetic locator on Medium setting (Figure 4-2) determined that all but two firearms (14 of 16; 87.5%) produced *strong* audible responses, although at varying depths. Only two weapons, the Lorcin L380 (B4) and the Raven Arms MP-25 (A2), were not detected with a *strong* response and only detected as *slight* to shallow depths. The four deepest detected firearms included the Remington 870 (G1) to 50-55cm, the Norinco rifle (C5) to 45-50cm, the Colt Commander (B5) to 40-45cm, and the Mossberg 500A shotgun (D5) to 25-30cm. Two of the medium-sized handguns, the Smith & Wesson 5906 (A4) and the Smith & Wesson 37 (C1), were detected with a *strong* audible response to 20-25cm. Five of the handguns representing large, medium, and small sizes were detected with a *strong* response to 15-20cm and include the Smith & Wesson Model 686 (B3), Ruger P89 (G2), Glock Model 19 (A5), Hi-Point Model C (A3), and the North American Arms Mini-Revolver (B1). The Jennings Bryco 59 (B2) was detected to 10-15cm. The smallest handgun, the Davis Derringer (A1), was only detected with a *strong* response to 5-10cm, while the RG Industries RG23 (C2) was only detected to 0-5cm.

When data was collected with the magnetic locator on High setting (Figure 4-3), all 16 firearms produced *strong* audible responses, although at varying depths. The two largest firearms, the Norinco AK rifle (C5) and the Remington 870 (G1) shotgun, produced *strong* responses to 70-75cm. The Mossberg 500A (D5) shotgun and the large Colt Commander (B5) were detected to 55-60cm, while the second largest handgun, the Ruger P89 (G2) was detected to 40-45cm, and the Smith & Wesson 5906 (A4), a larger handgun, was detected to 35-40cm. The largest handgun and three medium-sized handguns produced a *strong* response down to 30-35cm: the Smith & Wesson Model 686 (B3), the Glock 19 (A5), the Jennings Bryco 59 (B2), and the Smith & Wesson Model 37 (C1). Two medium-to-small handguns, the Hi-Point Model C (A3) and the North American Arms Mini-Revolver (B1) were detected to 25-30cm, while the smallest handgun, the Davis Derringer (A1), was detected to 20-25cm. The RG Industries RG-23 (C2) was only detected to 10-15cm. Finally, the Lorcin L380 (B4) and the Raven Arms MP-25 (A2) were only detected down to 5-10cm.

### Miscellaneous Weapons

Data collection on the buried miscellaneous weapons with the magnetic locator on Medium setting showed that nine out of ten miscellaneous weapons (90%) produced *strong* audible responses (Figure 4-4). Only the brass knuckles (F3) did not produce any audible response once buried and only produced a *slight* audible response pre-burial. The most strongly detected weapon was the Philip's head screwdriver (F2) which produced a *strong* response to 70-75cm. Two weapons, the claw hammer (F4) and the scissors (E1), were also deeply detected with *strong* responses down to 60-65cm, while the buck knife (E2) was detected with a *strong* response to 25-30cm. The sword (F5), the mallet (E4), the prybar (E3), and the baton (F1) produced *strong* responses to 15-20cm. Finally, the machete (E5) was only detected with a *strong* audible response down to a depth of 0-5cm.

When data collection with the magnetic locator was used with the High setting (Figure 4-5), the Philip's head screwdriver (F2) was the deepest detected item with a *strong* response down to 80-85cm. The claw hammer (F4) and the scissors (E1) were also deeply detected with *strong* audible responses to 60-65cm. The sword (F5) was detected to 40-45cm, the Buck knife (E2) was detected to 35-40cm, and three targets produced *strong* responses to 25-30cm: the machete (E5), the prybar (E3), and the baton (F1). Finally, the mallet (E4) produced a *strong* response only to 20-25cm, while the brass knuckles (F3) only detected down to 0-5cm.

### Scrap Metals

Data collection on the scrap metals with the magnetic locator on Medium setting (Figure 4-6) showed that only three of the scrap metal targets (50%), the rebar (D4), the solid iron pipe (C4), and the rusty iron pipe (D2) produced *strong* audible responses prior to burial; the hollow copper tube (D1), the aluminum edging (C3), and the solid aluminum pipe (D3) did not produce any audible responses prior to burial. Once buried, the rusty iron pipe (D2) produced a *strong* audible response to 55-60cm, the solid iron pipe (C4) produced a *strong* response to 40-45cm, and the rebar (D4) produced a *strong* response down to a depth of 5-20cm.

When data collection was used with the magnetic locator on the High setting (Figure 4-7) the rebar (D4), the rusty iron pipe (D2), and the solid iron pipe (C4) were still the only scrap metals detected with *strong* audible responses down to depths of 65-70cm , 55-60cm, and 25-30cm, respectively.

Control Holes

It is important to note that a number of control holes (one inside the grid (G3) and two outside the grid) were tested during data collection. The disturbed soil of the control holes did not produce any audible response for the various depths when tested with the magnetic locator.

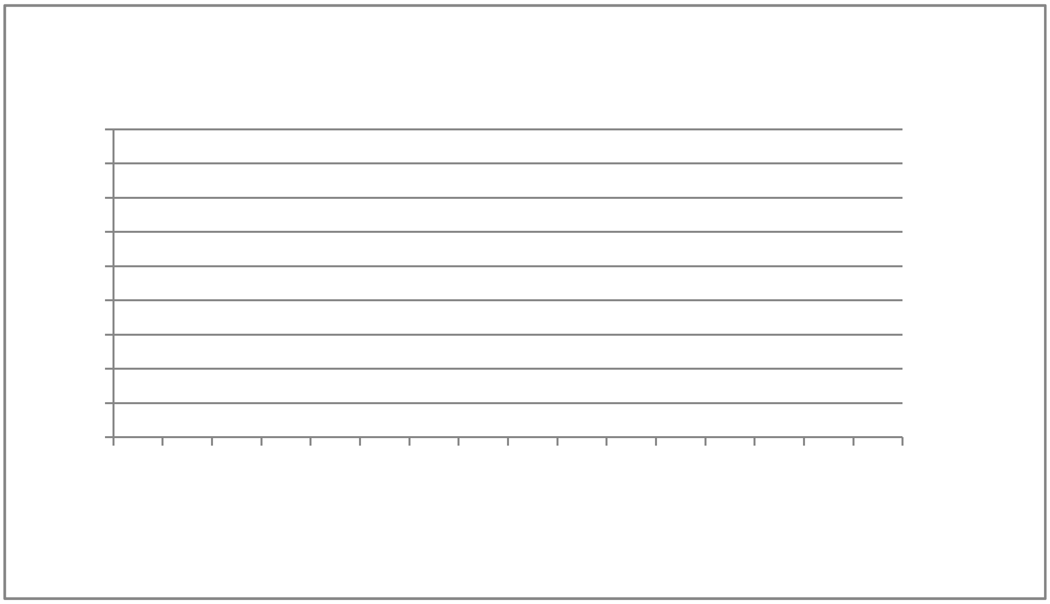

Figure 4-2. Results from firearm detection with GA-72Cd on Medium setting

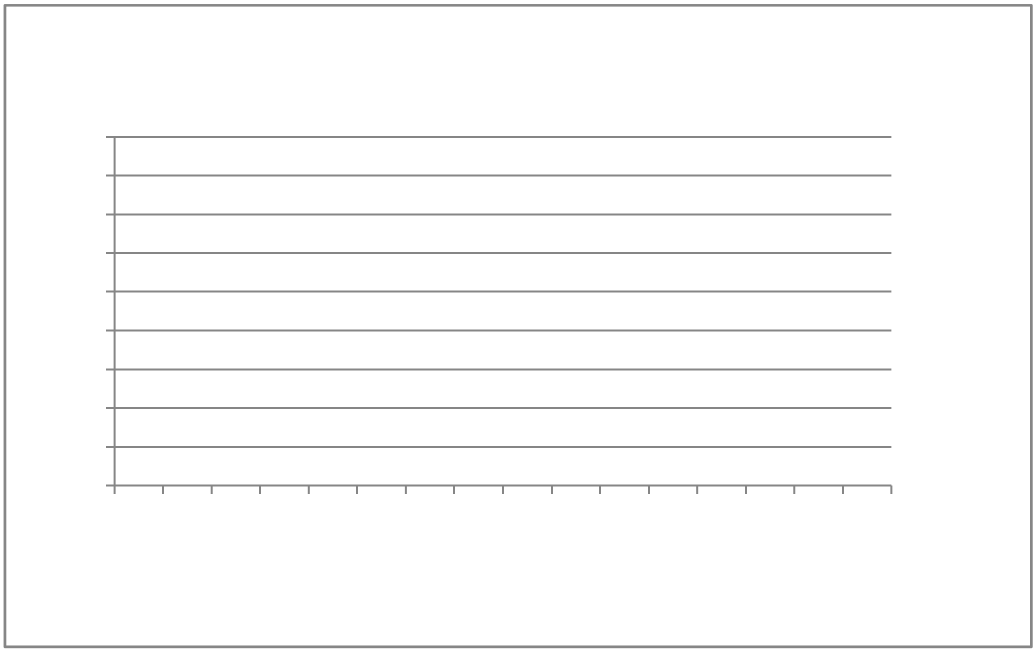

Figure 4-3. Results from firearm detection with GA-72Cd on High setting

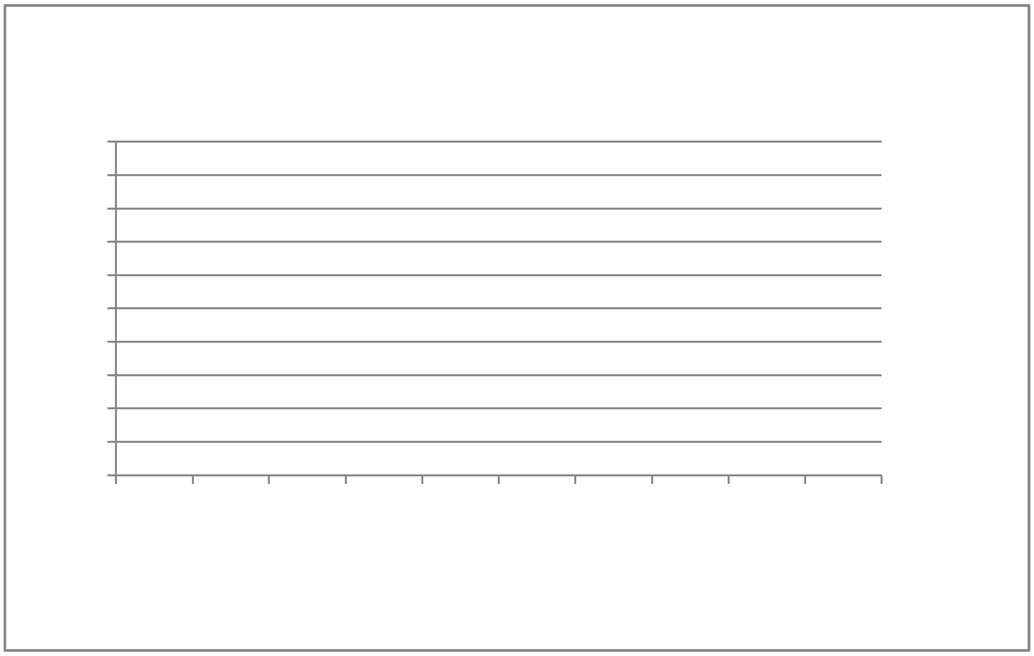

Figure 4-4. Results from miscellaneous weapon detection with GA-72Cd on Medium setting

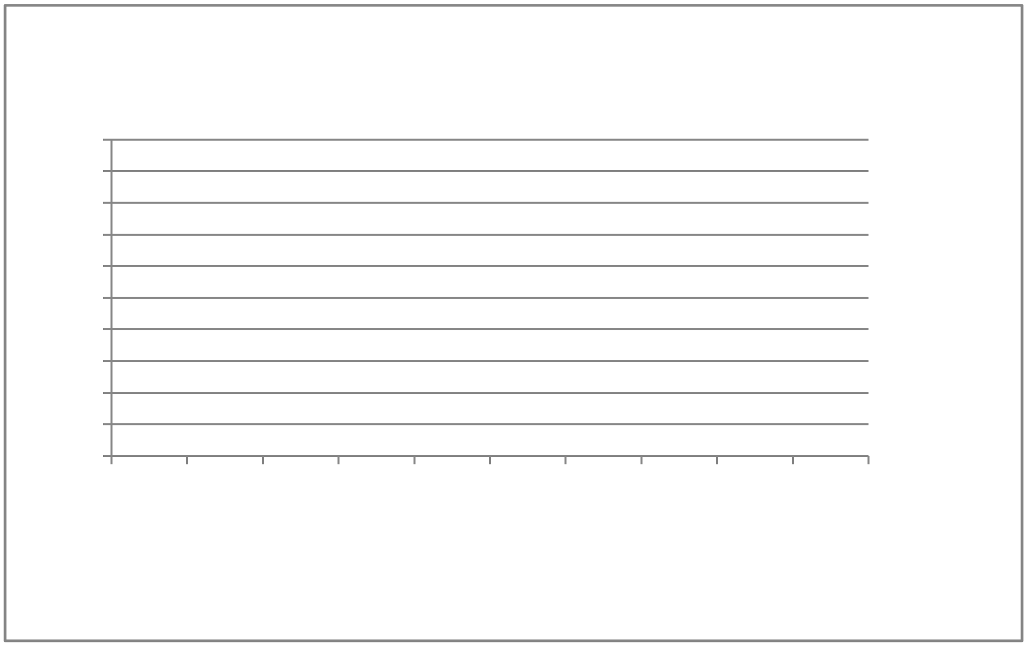

Figure 4-5. Results from miscellaneous weapon detection with GA-72Cd on High setting

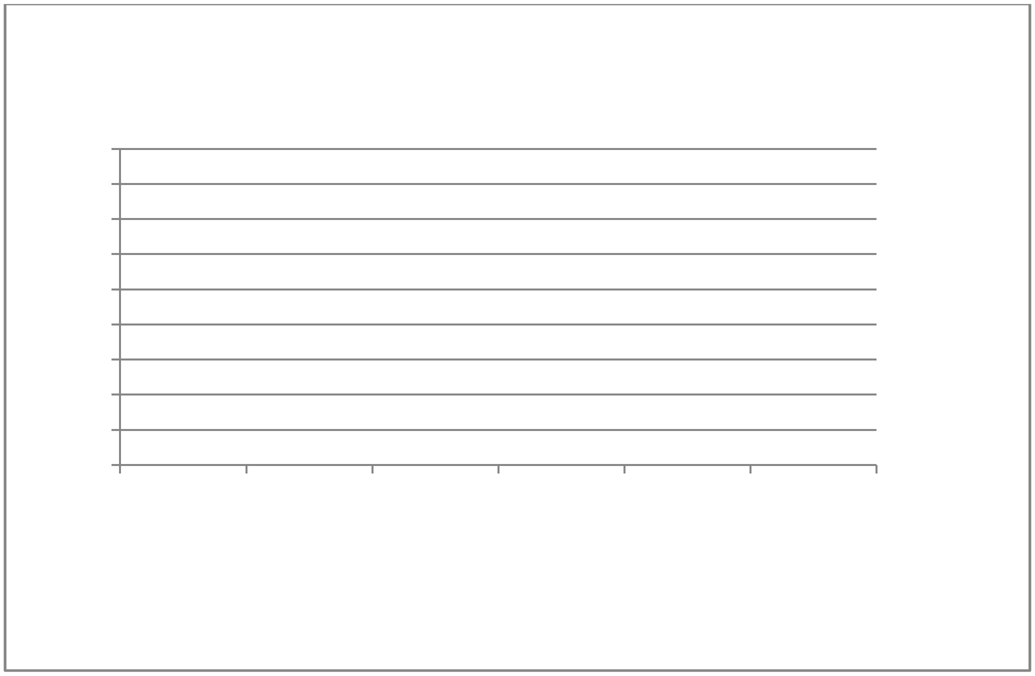

Figure 4-6. Results from scrap metal detection with GA-72Cd on Medium setting

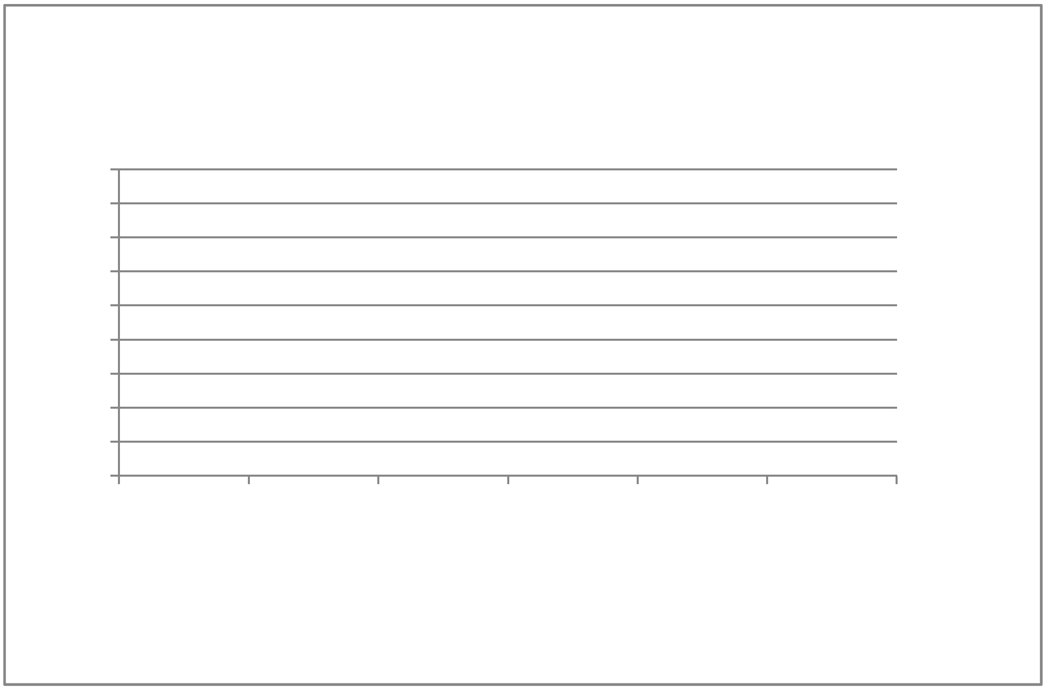

Figure 4-7. Results from miscellaneous weapon detection with GA-72Cd on High setting

# CHAPTER 5: ALL-METAL DETECTOR

## All-Metal Detector Theory

Metal detectors are electromagnetic devices that operate on the same principle as electromagnetic surveying equipment. The antenna head, or search coil, contains a transmitter and a receiver. An electromagnetic field is transmitted into the ground in the immediate vicinity of the search coil and penetrates the material surrounding the coil including soil, sand, rock, wood, brick, stone, masonry, water, concrete, vegetable, some mineral sources, and air. The field enters conductive objects producing tiny eddy currents across the surface of these objects that create a secondary field circulating and flowing outward into the surrounding soil. The secondary field is then detected by the receiver in the antenna head (Connor and Scott, 1998; Dupras et al., 2006; Garrett, 1998; Nielson, 2003; Nelson, 2004).

The metal detector used for this research project is a Fisher M-97, an affordable, rugged, and simple to use all-metal detector which utilizes a waterproof 11 inch (27.9cm) Double-D search coil to identify metallic objects with both visual and audio responses (Figure 5-1). According to the manufacturer, the Fisher M-97 is designed to search for buried or paved-over valves, boxes, manhole covers, or any other concealed metallic object, and can be used over concrete and asphalt. Detected metals include iron, aluminum, brass, and lead. The M-97 features high sensitivity, ground effect rejection of wet ground foliage, pavement, or mineralized ground, and auto-tune for stabilizing ground interference. The M-97 consists of 10 ground balancing levels, a Normal sensitivity setting, and a High sensitivity setting, allowing the user to customize the detector to the soil conditions (Fisher Research Laboratory, n.d.). The ground balancing levels of the M-97 are used to compensate for the search area's mineral content. The manufacturer's recommendations include first selecting ground balancing level 5, and the Normal sensitivity setting (Fisher Research Laboratory, n.d.). Generally, these settings do not require much ground balancing adjustment, and provide a "turn on and go" mode. Tuning the machine higher or lower depends upon ground conditions; the machine is tuned when there is no change in the audible hum when the detector is lifted 12-18 inches off of the ground. High setting is recommended for increasing the mineral sensitivity and depth of detection (Fisher Research Laboratory, n.d.). Retuning the machine once High is chosen allows the detector to correctly rebalance itself to the ground conditions.

## Data Collection Parameters

The M-97 all-metal detector was initially used in the manufacturer's recommended "turn on and go" (Normal sensitivity, level 5) setting as the research area did not require much balancing. Swinging the detector side-to-side and low and even to the ground, the sound of the detector's hum increased and the readings on the display meter changed when a metallic object was encountered. Detection was categorized into *no*, *slight*, and *strong* and was performed on Normal and High settings on all targets. It is important to note that *slight* detection readings meant that a *slight* change in the detector's hum was audible. However, the *slight* audible response may not be discernable during real-world searches involving areas that are littered with trash metals and/or have a high mineral content because there may be extensive background noise.

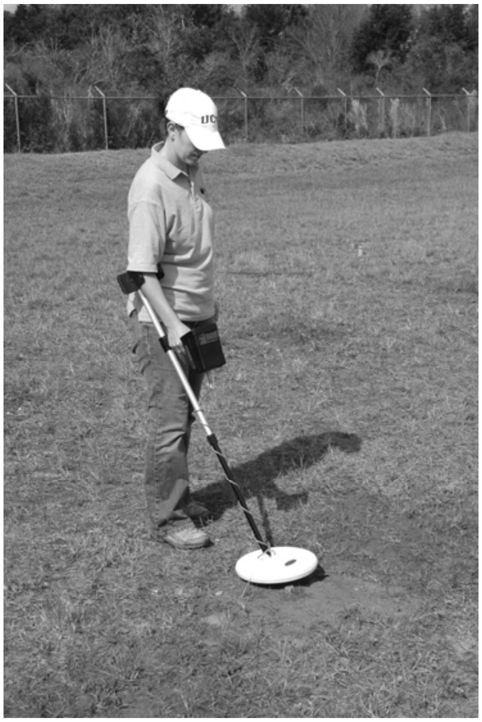

Figure 5-1. Fisher M-97 basic all-metal detector with 11 inch (27.9cm) coil

## Results

### Firearms

All 16 firearms produced *strong* audible responses using the all-metal detector on Normal setting, although at varying depths (Figure 5-2). The deepest detected firearm was Remington shotgun 870 (G1) down to a depth of 30-35cm with a *strong* response. Next, the Norinco AK rifle (C5), the Mossberg 500A shotgun (D5), and the Colt Commander (B5) produced *strong* responses down to 25-30cm. Three of the largest handguns, the Smith & Wesson 686 (B3), the Ruger P89 (G2), and the Smith & Wesson 5906 (A4) produced *strong* responses to 20-25cm. Seven medium-to-small handguns (the Glock Model 19 (A5), the Hi-Point Model C (A3), the Lorcin L380 (B4), the Jennings Bryco 59 (B2), the Smith & Wesson Model 37 (C1), the RG Industries RG23 (C2), and the Raven Arms MP25 (A2)) produced *strong* responses to 15-20cm.

Finally, two of the three smallest handguns, the North American Arms Mini-Revolver (B1) and the Davis Derringer (A1), produced *strong* responses to a depth of only 10-15cm.

When data collection on the buried firearms with the all-metal detector was collected using High setting, all 16 firearms produced *strong* audible responses to deeper depths (Figure 5-3). The deepest detected was the Remington 870 (G1) to 50-55cm, followed by the Norinco AK rifle (C5) to 45-50cm, and the Mossberg 500A (D5) to a maximum depth of 40-45cm. Six large-to-medium handguns (the Smith & Wesson 686 (B3), the Ruger P89 (G2), the Colt Commander (B5), the Smith & Wesson 5906 (A4), the Hi-Point Model C (A3), and the Jennings Bryco 59 (B2)) were detected to a depth of 35-40cm. Four medium-to-small handguns (Lorcin L380 (B4), the Smith & Wesson Model 37 (C1), the RG Industries RG23 (C2), and the Glock Model 19 (A5)) were detected to 30-35cm, while three firearms (the North American Arms Mini-Revolver (B1), the Raven Arms MP25 (A2), and the Davis Derringer (A1)) were detected at the shallowest depth of 25-30cm.

## Miscellaneous Weapons

When using Normal setting with the all-metal detector, all 10 miscellaneous weapons produced a *strong* audible response (Figure 5-4). The claw hammer (F4) was detected at the deepest depth down to 25-30cm, while four weapons (the sword (F5), the machete (E5), the mallet (E4), and the baton (F1)) representing large, medium, and small targets were produced audible response down to 20-25cm. The prybar (E3) was detected to 15-20cm, while the Buck knife (E2), the scissors (E1), and the brass knuckles (F3) down a depth of 10-15cm. Finally, the Philip’s head screwdriver (F2) was the shallowest detected at 5-10cm.

A *strong* audible response was produced for all 10 buried miscellaneous weapons with the all-metal detector on High setting, although at varying depths (Figure 5-5). The claw hammer (F4) produced a *strong* response down to a maximum depth of 40-45cm. Three miscellaneous weapons, representing large targets, produced *strong* responses to 35-40cm: the sword (F5), the machete (E5), and the mallet (E4). The prybar (E3) and the baton (F1) produced a *strong* response to 30-35cm, while the Buck knife (E2), the scissors (E1), and the brass knuckles (F3) all produced *strong* responses to 25-30cm. Finally, the Philip's head screwdriver (F2) produced a *strong* audible response down to a maximum depth of 15-20cm.

### Scrap Metals

Data collection on the buried scrap metals with the all-metal detector on Normal setting indicated that all six scrap metals produced *strong* responses, although at varying depths (Figure 5-6). Two scrap metal targets produced *strong* responses down to 25-30cm: the rusty iron pipe (D2), and the solid iron pipe (C4). The rebar (D4) and the aluminum edging (C3) produced *strong* audible responses to 15-20cm. Finally, two scrap metal targets, the hollow copper tube (D1) and solid aluminum pipe (C4), produced *strong* responses to a depth of 10-15cm.

When all-metal detector was used on High setting, all six scrap metals produced *strong* audible responses at deeper depths (Figure 5-6). The rusty iron pipe (D2) and the solid iron pipe (C4) were detected to 40-45cm, while the rebar (D4) and the aluminum edging (C3) were detected to a depth of 30-35cm. Finally, the hollow copper tube (D1) produced a *strong* response to 25-30cm, while the solid aluminum pipe (C4) produced a *strong* audible response down to a maximum depth of 20-25cm.

## Control Holes

It is important to note that a number of control holes (one inside the grid (G3) two outside the grid) were tested during data collection. The disturbed soil of the control holes did not produce any audible responses for the various depths when tested with the all-metal detector.

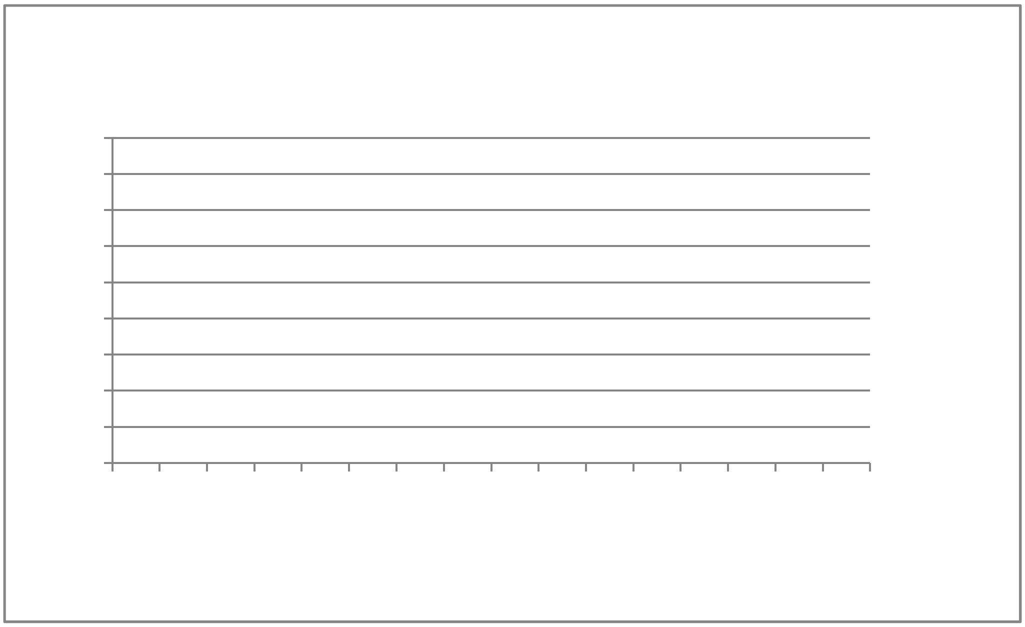

Figure 5-2. Results from firearm detection with M-97 on Normal setting

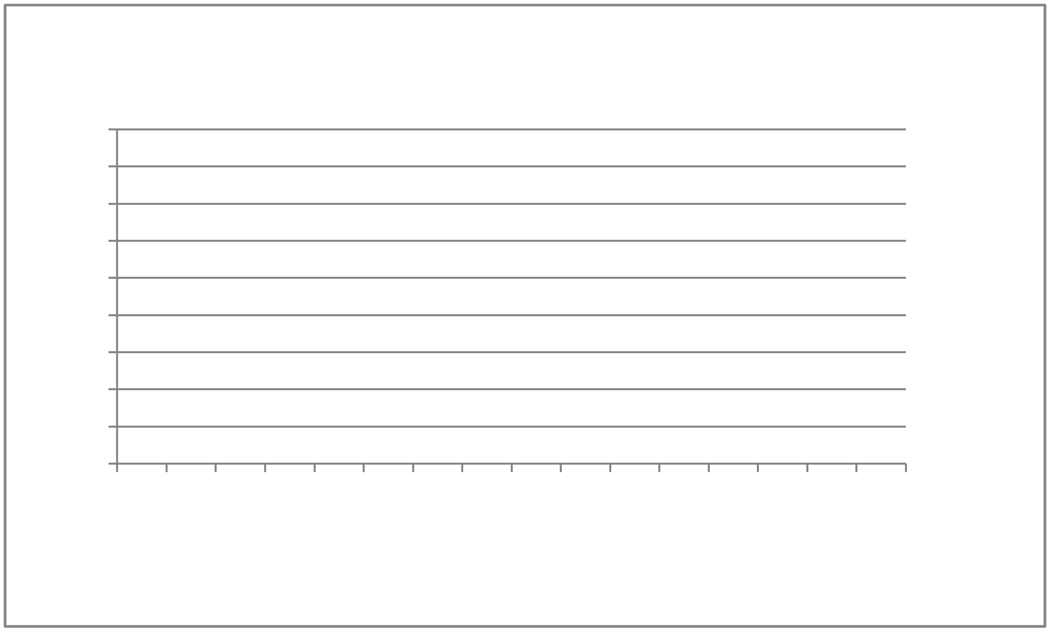

Figure 5-3. Results from firearm detection with M-97 on High setting

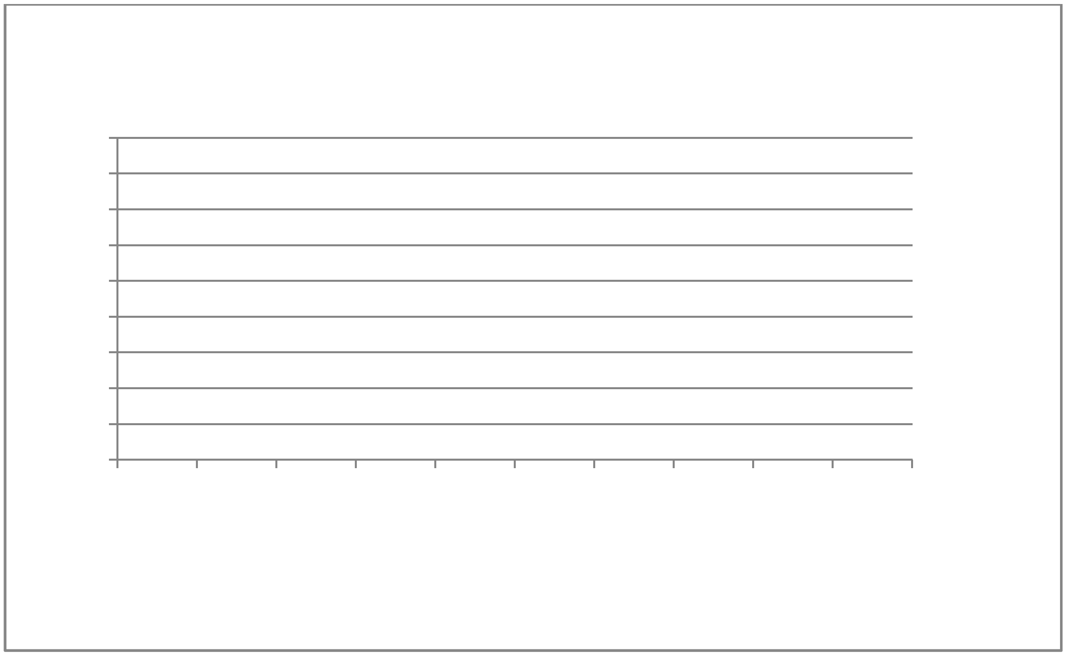

Figure 5-4. Results from miscellaneous weapon detection with M-97 on Normal setting

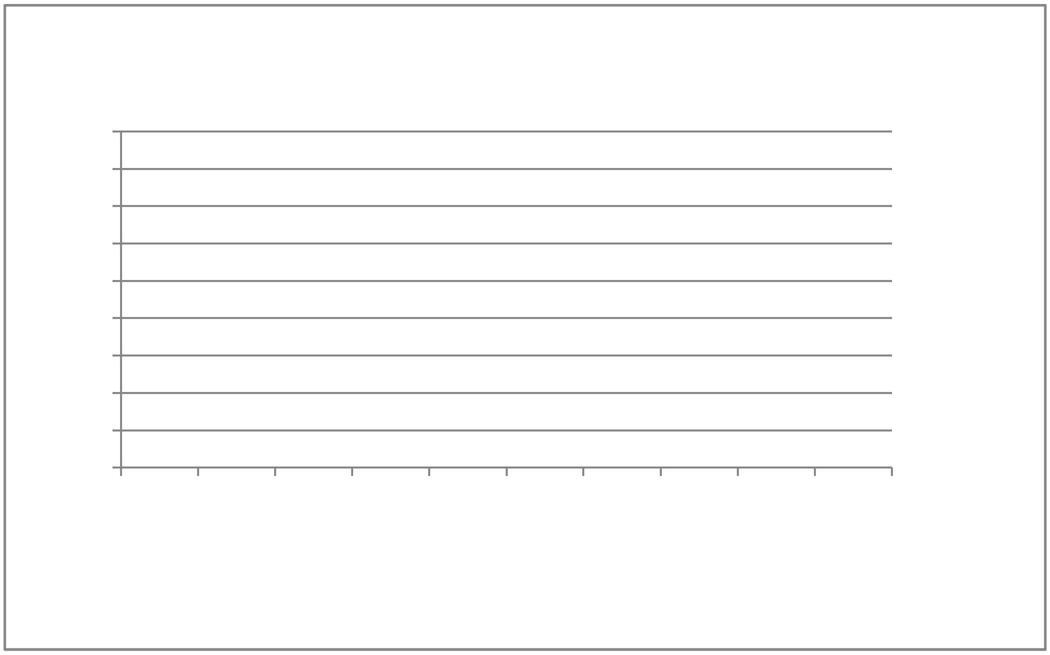

Figure 5-5. Results from miscellaneous weapon detection with M-97 on High setting

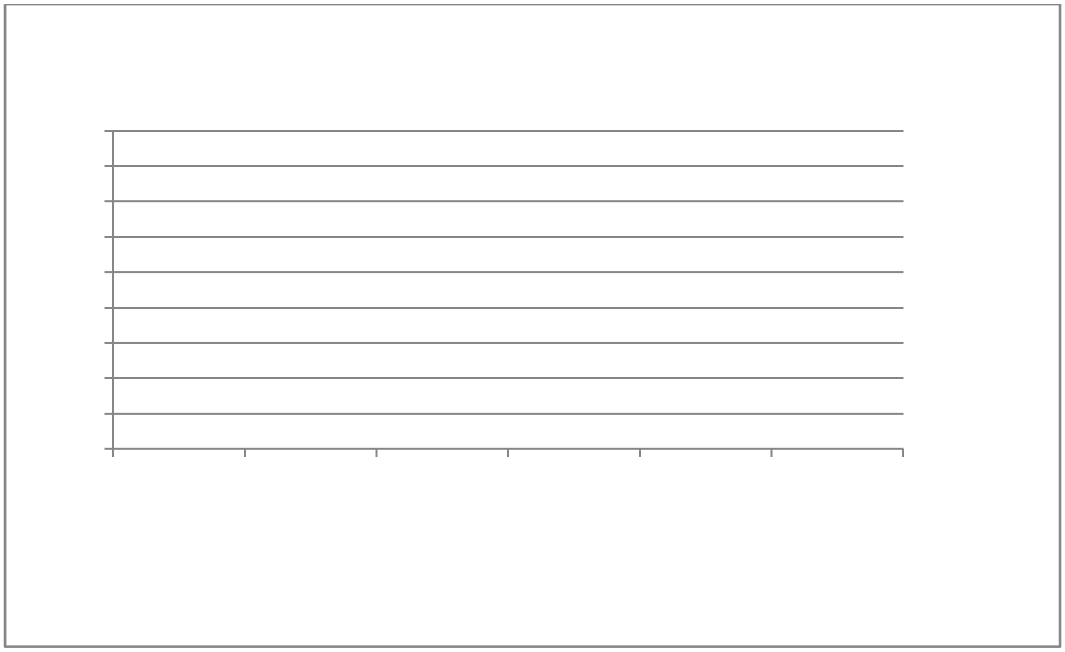

Figure 5-6. Results from scrap metal detection with M-97 on Normal setting

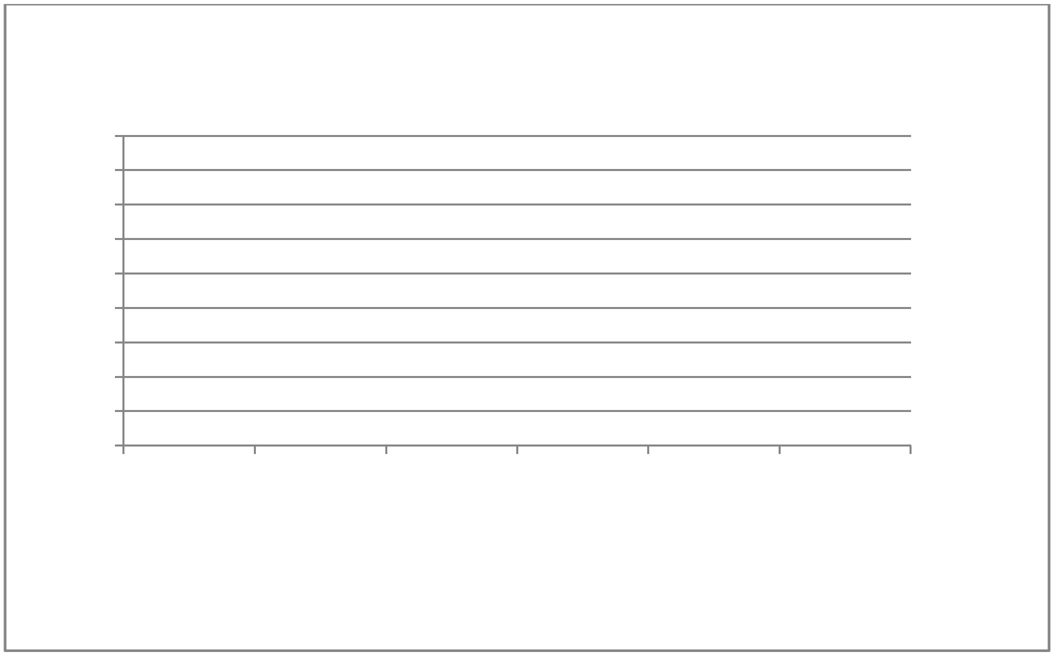

Figure 5-7. Results from scrap metal detection with M-97 on High setting

# CHAPTER 6: ADVANCED DIGITAL METAL DETECTOR

## Advanced Metal Detector Theory

The advanced metal detector that was used for this project is a second generation Minelab Explorer II™ with a waterproof 10.5 inch (26.7cm) medium sized Double-D (DD) search coil. A second search coil, a larger 15 inch (38.1cm) Coiltek DD manufacturer-specific after-market coil, was utilized on the detector (Figure 6-1). The larger after-market search coil was incorporated to determine if an increase in depth of detection over the standard coil would be noted. Larger search coils are generally better for increased depth of penetration for detecting larger objects. Conversely, smaller coils are better suited for detecting smaller objects at shallower depths.

Improving upon the single and dual frequency Broad Band Spectrum (BBS) technology of previous metal detectors, the Minelab Explorer II™ is a digital metal detector with Full Band Spectrum (FBS) technology, which automatically transmits 28 frequencies simultaneously from 1.5 to 100 kHz. Advanced target discrimination (SMARTFIND™ 2-dimensional discrimination) improves upon previous detectors by detecting specific objects once their unique metallic signature is determined. In Advanced mode, a “Learn” function allows signature ranges to be determined for targets and/or metal components and loaded into the machine for easy discrimination upon searching (Minelab Electronics Pty Ltd, n.d.).

The advantages of the FBS technology are increased depth detection, accurate target identification at greater depths, improved detection of desired targets among iron trash, greater recognition of ground mineralization, enhanced searching on salt-water beaches, consistent sensitivity over a wide range of targets, less interference from electromagnetic sources, advanced digital filtering to eliminate the influence of ground signals, and more accurate identification of target characteristics such as size (Minelab Electronics Pty Ltd, n.d.).

The advanced detector locates metallic objects, alerting the operator with both visual and audio responses. The Explorer II is held and maneuvered as any other metal detector, low and even to the ground in a swaying motion. When an object is located, the pitch of the detector's hum increases, with highly conductive objects emitting high-pitched sounds and low-pitched tones being emitted by less conductive, more ferrous, objects. Large targets or targets close to the ground surface emit louder signals. The Explorer II has two detection modes: Quickstart and Advanced.

The Explorer II was initially used in the manufacturer's recommended "turn on and go" (Quickstart) setting to provide information regarding basic detection of the targets. Quickstart uses factory presets for Discrimination (non-ferrous coin-type targets) and Iron Mask (-6, non-ferrous metals). The Quickstart Digital display screen shows numerical values when a metallic object is encountered indicating the ferrous content and conductivity with values ranging from 0-31; a value of 0 represents the lowest ferrous content or conductivity, and the highest ferrous content or conductivity is represented by a value of 31. For example, a reading of 0-24 would be mean a ferrous content (always first) of 0 and a conductivity value of 24.

The Explorer II was also used in advanced mode for target discrimination. The advanced mode allows for the specification of custom targets, enabling the user to edit and save target profiles in order to recognize those objects and reject others. Discrimination is the ability of a metal detector to identify a desired metallic target while eliminating unwanted signals from false metallic targets. Advanced Mode was used for customization of a number of "signatures" for a carefully selected sample of firearms.

## Data Collection Parameters

Three types of data collection parameters were incorporated using the Explorer II: 1) simple detection of the targets, 2) ferrous content and conductivity readings using the Quickstart method, and 3) signature metallic composition patterns using the Advanced Learn feature to test if all targets could be recognized against specific targets of known metallic compositions. First, it was determined whether the buried forensic target was detected at specific depths using both coils. Second, the ferrous content and conductivity values were recorded using the standard coil. Third, the Advanced Learn feature was utilized with the standard coil pre-burial to program the signature patterns of a selection of six targets representing the firearm sample in order to test if each target would be detected by a specific metallic composition.

Factory presets of the Quickstart mode allowed for detection at multiple depths. Once detection was established, the conductivity and ferrous content values were recorded to determine if any metallic composition patterns could be established. Although, originally planning on collecting multiple passes on each target to replicate the signatures, the operators were advised by the manufacturer that the detector should be passed over each target only two to three times as more than two to three passes might skew the readings by detecting individual metallic signatures as opposed to the metallic composition of the target as a whole.

A selection of targets was programmed into the Learn feature to determine if the discrimination feature of the advanced detector is more useful than a basic all-metal detector at detecting the variety of objects included in this project. Based upon metallic composition, a selection of six firearms was programmed into the Learn feature following manufacturer instructions. Examples of stainless steel, aluminum/stainless steel, aluminum/synthetic, basic steel, and tenifered steel compositions were included. A large stainless steel handgun was included as well as a smaller handgun to test the contribution of size in signature readings. As data collection using the preset signatures can only be conducted using one programmed signature at a time, the detector was set to each saved signature one at time (S1-S6, sequentially) and therefore passed over the individual buried items a total of six times, one time with each signature.

- S1-Smith & Wesson 686
- S2- North American Arms Mini-Magnum
- S3-Raven Arms MP-25
- S4-Ruger P89
- S5-Mossberg 500A
- S6-Glock Model 19

Figure 6-1. Minelab Explorer II™ with (a) medium 10.5 inch (26.7cm) coil, and (b) 15 inch (38.1cm) Coiltek search coil

## Results

### Simple Detection: Firearms

Data collection on the buried firearms using the advanced metal detector with the medium coil indicated that 14 of 16 firearms (87.5%) were detected, although to varying depths (Figure 6-2). The Colt Commander (B5), the Smith & Wesson 5906 (A4), and the Jennings Bryco 59 (B2) were the three firearms detected to the deepest depth at 45-50cm. Four firearms, ranging in size from a shotgun to the smallest handgun, were detected down to 40-45cm and included the Remington 870 (G1), the Smith & Wesson 686 (B3), the RG Industries RG23 (C2), and the Davis Derringer D9 (A1). Five firearms, ranging from the largest shotgun to the second smallest handgun, were detected down to a maximum depth of 35-40cm that included the the Mossberg 500A (D5), the Ruger P89 (G2), the Hi-Point Model C (A3), the Lorcin L380 (B4), and the Raven Arms MP25 (A2). The Smith & Wesson Model 37 (C1) was detected down to 30-35cm. The Norinco AK rifle (C5) was detected the shallowest, down to a maximum depth of only 20-25cm. Finally, the North American Arms Mini-Magnum (B1) was not detected once buried and the Glock Model 19 (A5) was not detected at all, including pre-burial.

Data collection on the buried firearms using the advanced metal detector with the large coil also indicated that 14 of 16 firearms (87.5%) were detected (Figure 6-3). Several firearms were detected deeper with the large coil, while one was detected deeper with the medium coil (Table 6-1).

## Simple Detection: Miscellaneous Weapons

Eight of the 10 miscellaneous weapons (80%) were detected to varying depths (Figure 6-4) using the advanced metal detector with the medium coil. The claw hammer (F4), was detected down to the deepest depth at 55-60cm, while the second longest weapon, the machete (E5), was detected down to the next deepest depth at 40-45cm. The two smallest weapons, the scissors (E1) and the brass knuckles (F3), were detected next down to 35-40cm. The longest miscellaneous weapon, the sword (F5), and third longest weapon, the mallet (E4), were detected down to 30-35cm. The prybar (E3) and the Buck knife (E2) were detected down to 25-30cm. Finally, the Philip’s head screwdriver (F2) and the baton (F1) were not detected at all once buried. When the large coil was used, eight of the 10 miscellaneous weapons (80%) were still detected with more than half of the items were detected at the same depth as the medium coil (Figure 6-5).

## Simple Detection: Scrap Metals

Three of the six scrap metals (50%) were detected using the advanced metal detector with the medium coil shows (Figure 6-6). The aluminum edging (C3) was detected down to 40-45cm, followed by the solid aluminum pipe (D3) at 30-35cm, and longest piece of scrap metal, the hollow copper tube (D1), was detected to 25-30cm. The rebar (D4), rusty iron pipe (D2), and solid iron pipe (C4) were not detected at all, even pre-burial. When the large coil was used, only the hollow copper tube (D1) was detected deeper at 30-35cm (Figure 6-7).

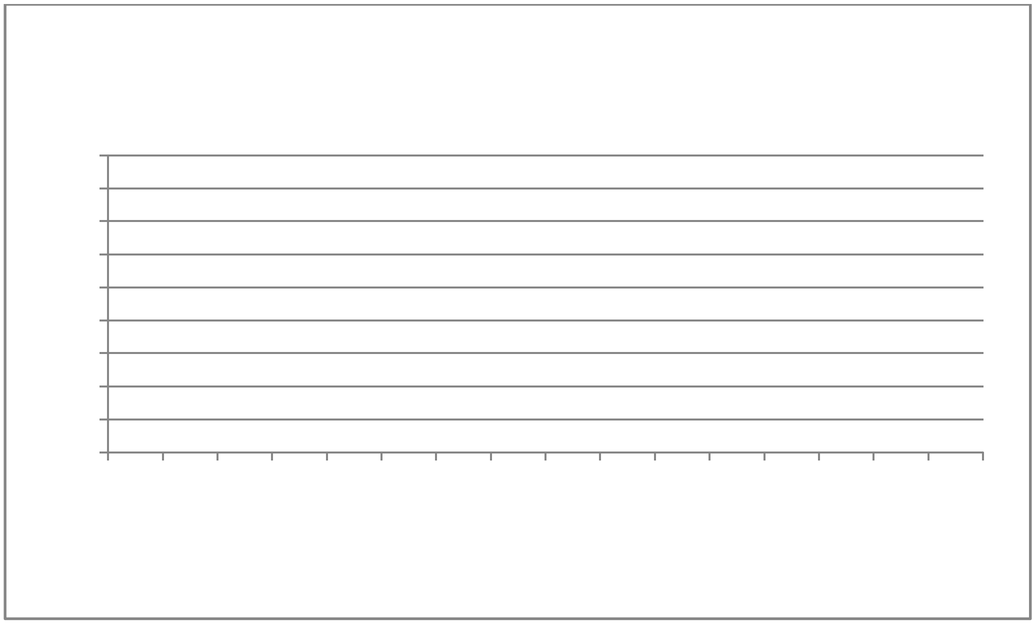

Figure 6-2. Simple detection results for firearm detection with Minelab Explorer using the medium search coil

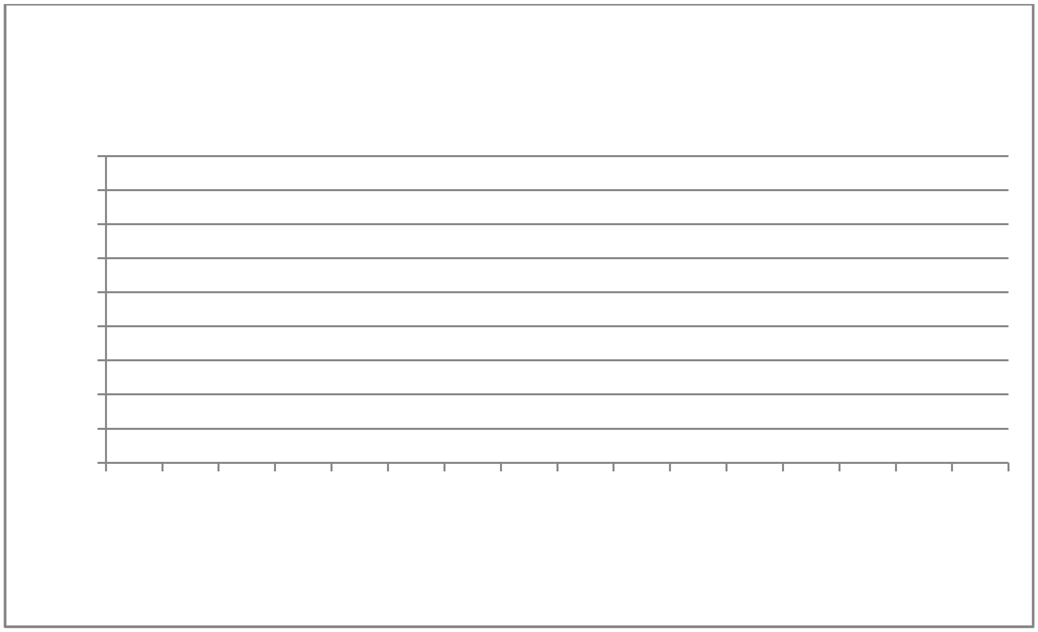

Figure 6-3. Simple detection results for firearm detection with Minelab Explorer using the large search coil

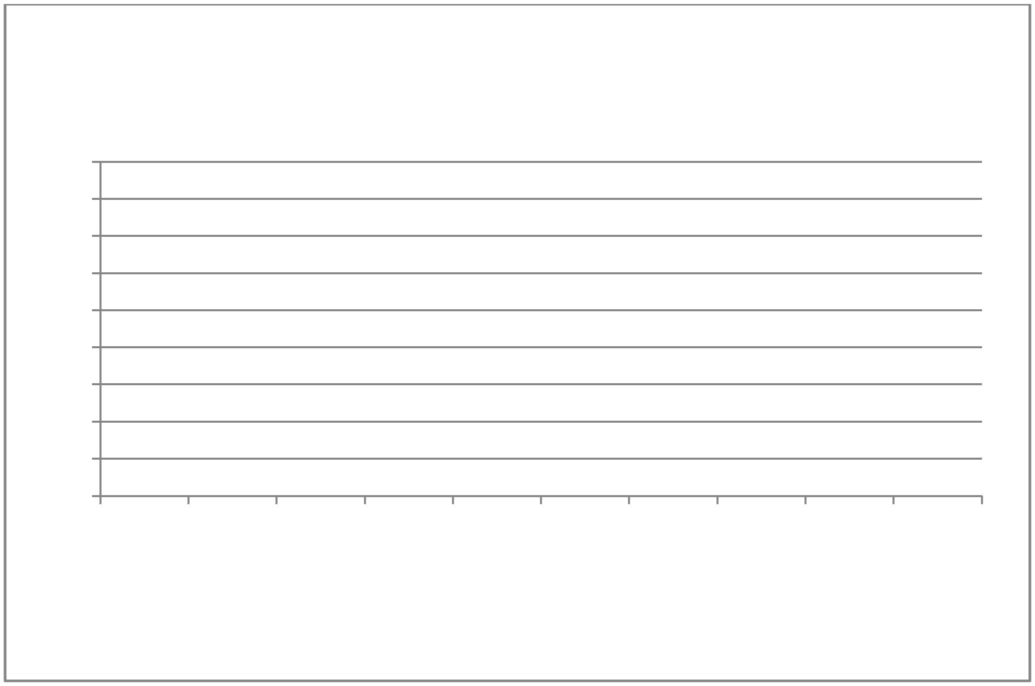

Figure 6-4. Simple detection results for miscellaneous weapon detection with Minelab Explorer using the medium search coil

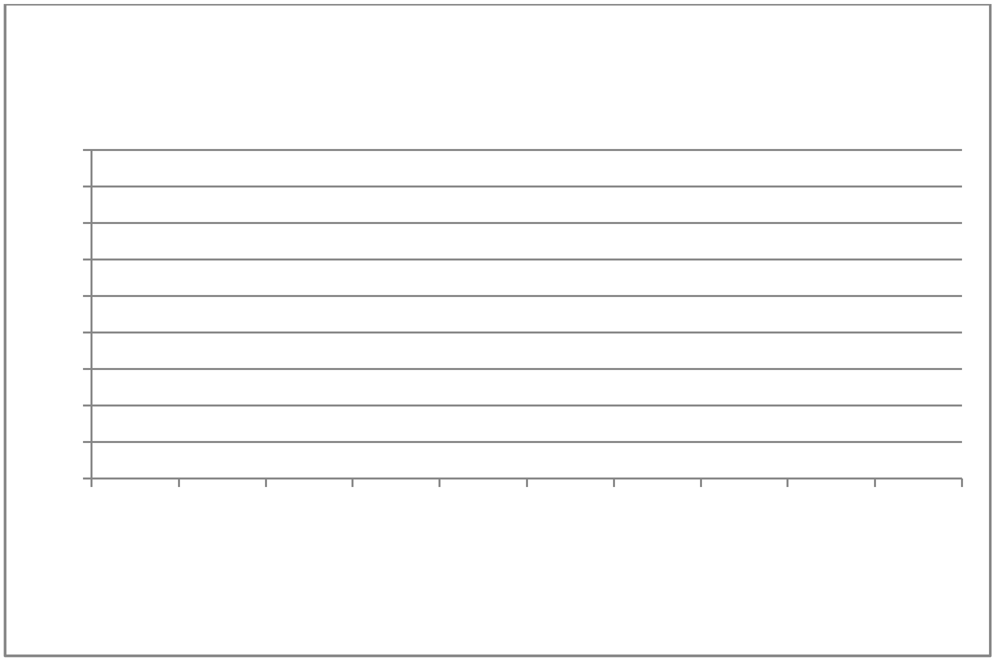

Figure 6-5. Simple detection results for miscellaneous weapon detection with Minelab Explorer using the large search coil

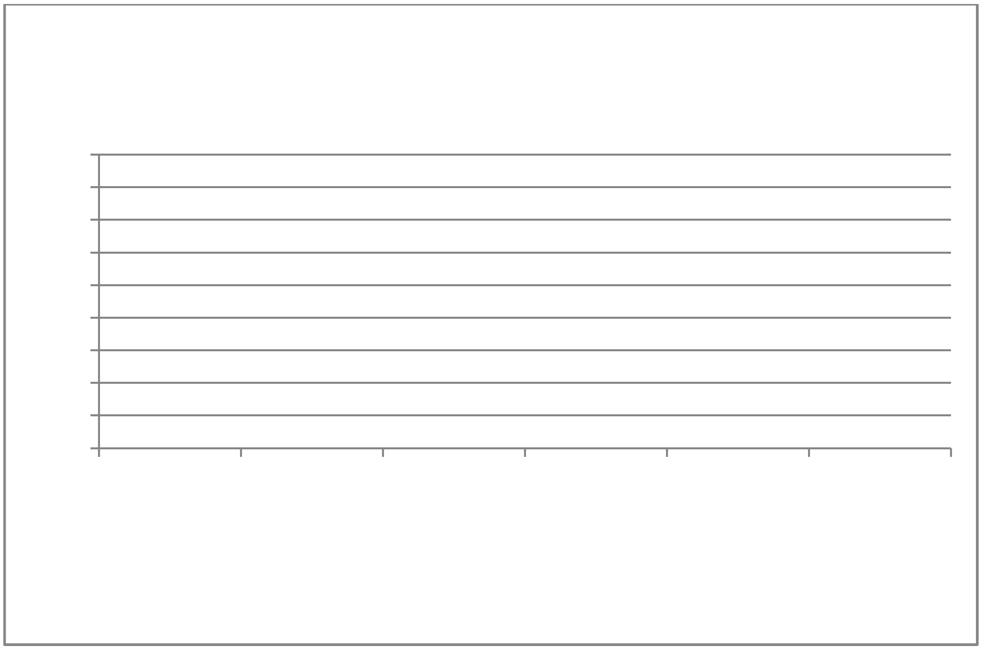

Figure 6-6. Simple detection results for scrap metal detection with Minelab Explorer using medium search coil

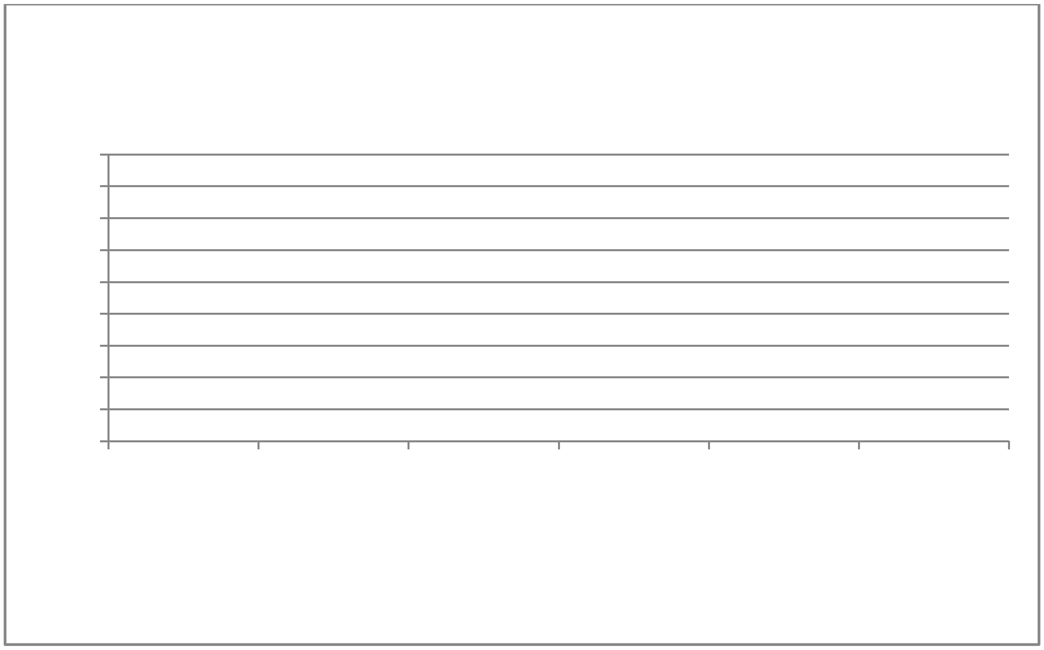

Figure 6-7. Simple detection results for scrap metal detection with Minelab Explorer using the large search coil

## Comparison of Medium and Large Search Coils

With both advanced metal detector coils, 25 out of 32 weapons were detected (78%). Out of the 25 weapons detected, fourteen were firearms, three were scrap metals, and eight were miscellaneous weapons. Also, of the 25 detected weapons, two were best detected by the medium coil, seven were best detected by the large coil, and sixteen were equally detected by both coils (Figures 6-8 to 6-10).

Within the firearm sample, only the Davis Derringer D9 (A1) was detected the deepest with the medium coil. Five firearms were detected deeper with the large coil: the Norinco AK Hunter (C5), the Remington 870 (G1), the Mossberg Model 500A (D5), the Ruger P89 (G2), and the RG Industries RG23 (C2). The remaining eight detected firearms were all detected down to the same maximum depth with both coils: the Smith & Wesson Model 686 (B3), the Colt Commander (B5), the Smith & Wesson 5906 (A4), the Hi-Point Model C (A3), the Lorcin L380 (B4), the Jennings Bryco 59 (B2), and the Smith & Wesson Model 37 (C1), and the Raven Arms MP25 (A2). The North American Arms (B1) and the Glock Model 19 (A5) were not detected using either coil (Figure 6-8). Overall, the larger firearms were detected the deepest with the large search coil (Figure 6-8). Both coils had similar results with the medium-sized targets, and the medium coil was better suited for the smallest targets.

Out of the ten miscellaneous weapons comprising the sample only the claw hammer (F4) was best detected using the medium coil (Figure 6-9). Conversely, only two miscellaneous weapons (the mallet (E4) and the prybar (E3)) were detected deeper using the larger coil, while five miscellaneous weapons were detected down to the same maximum depth with both coils: the sword (F5), the machete (E5), the Buck knife (E2), the scissors (E1), and the brass knuckles (F3). The Philip’s head screwdriver (F2) and baton (F1) were not detected once buried with either coil.

Out of the six scrap metals, only three weapons (the hollow copper tube (D1), the aluminum edging (C3), and the solid aluminum pipe (D3)) were detected with both coils. One piece of scrap metal, the hollow copper tube (D1), was best detected by the large coil, while the other two, the aluminum edging (C3), and the solid aluminum pipe (D3) were detected down to the same maximum depth using both coils.

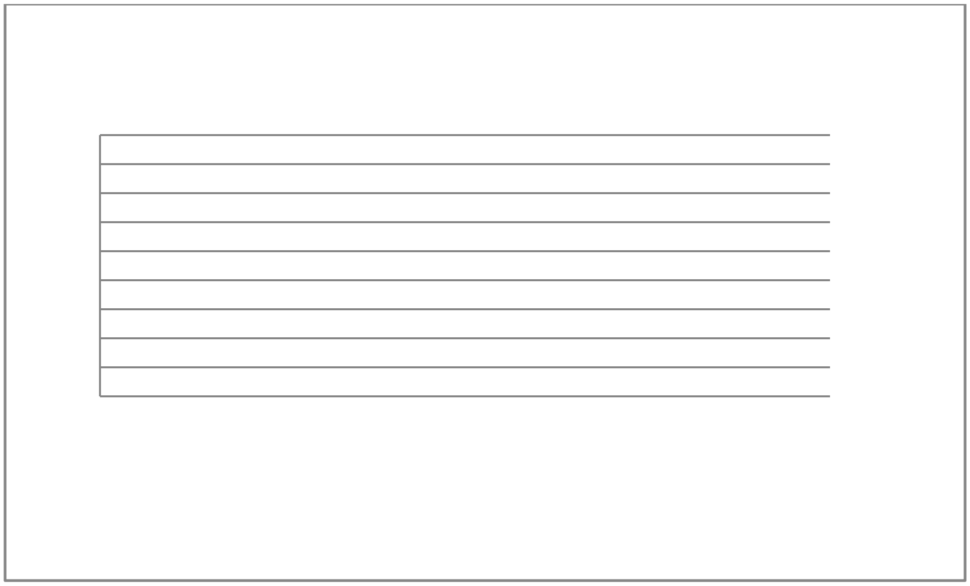

Figure 6-8. Comparison of maximum depth of detection of firearms using the advanced metal detector with medium and large coils.

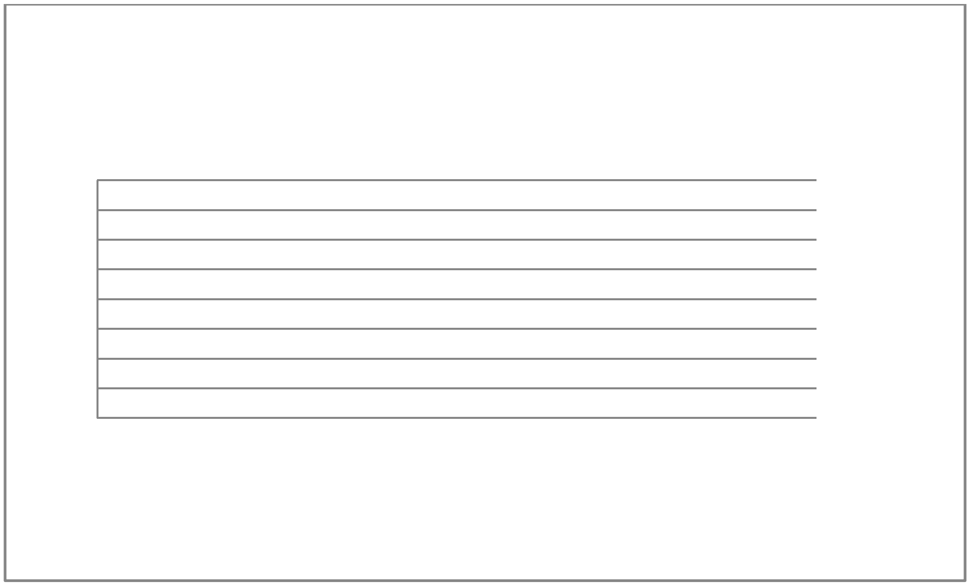

Figure 6-9. Comparison of maximum depth of detection of miscellaneous weapons using the advanced metal detector with medium and large coils.

Figure 6-10. Comparison of maximum depth of detection of scrap metals using the advanced metal detector with medium and large coils.

Quickstart Ferrous Content/Conductivity Readings

As advised by the manufacturer, data were collected in three passes over each target so as to ensure proper detection of the metallic target as a whole, rather than as the individual metallic components that comprise the metallic items. Since both ferrous content and conductivity readings provided values ranging from 0-31, three categories were assigned: Low (0-10), Medium (11-20), and High (21-31). Five patterns were noticed while analyzing the data collected on the buried firearms, scrap metal, and miscellaneous weapons using the advanced metal detector with the Medium Coil (Tables 6-1 thru 6-3): Low/Medium, Low/High, Medium/Low, Medium/High, and Variable.

The Norinco AK rifle (C5) was the only target that produced a Low/Medium pattern. The Low/High was the most frequent pattern, consisting of a total of sixteen targets, including eleven firearms (the Davis Derringer (A1), the Raven Arms MP25 (A2), the Hi-Point Model C (A3), the North American Arms Mini-Magnum (B1), the Jennings Bryco 59 (B2), the Lorcin L380 (B4), the Colt Commander (B5), the Smith & Wesson Model 37 (C1), the RG Industries RG23 (C2),the  Mossberg 500A (D5), and the Ruger P89 (G2)), three miscellaneous weapons (the Buck knife (E2), the brass knuckles (F3), and the claw hammer (F4)), and two scrap metals (the aluminum edging (C3) and the hollow copper tube (D1)).  The Smith & Wesson 5906 (A4) was the only target that produced the Medium/Low pattern.  Finally, two targets, the Remington 870 (G1) and the mallet (E4), produced the Medium/High pattern.

The Variable pattern was noticed in only six of the 32 tested targets, and was defined as instances in which the pre-burial pattern was different than the pattern observed once the target was buried (the Smith & Wesson 686 (B3), the scissors (E1), the prybar (E3), and the machete (E5), the sword (F5), and the solid aluminum pipe (D3)).

As so many targets of differing metallic compositions fell into each pattern, especially the Low/High pattern, it would therefore be problematic to use this technique during real-world forensic searches in order to distinguish a suspected target as a firearm, scrap metal, or miscellaneous weapon.

*Table 6-1. Firearm results for the Quickstart ferrous content/conductivity readings.*

| Target | Pre-Burial | 20-25cm | Pattern |
|---|---|---|---|
| **A1** | 0-23, 0-25, 03-27 | 0-26, 0-25, 0-26 | Low/High |
| **A2** | 0-19, 0-24, 0-26 | 3-28, 3-27, 0-26 | Low/High |
| **A3** | 0-24, 0-26, 0-23 | 0-23, 0-25, 0-24 | Low/High |
| **A4** | 15-05, 15-08, 15-7 | 15-5, 16-5, 7-5 | Medium/Low |
| **A5** | | | |
| **B1** | 9-30, 12-27, 6-28 | 3-23, 11-28, 9-30 | Low/High |
| **B2** | 9-24, 8-26, 0-26 | 0-24, 0-24, 0-26 | Low/High |
| **B3** | 5-23, 11-19, 10-24 | 14-11, 13-18, 13-18 | Variable |
| **B4** | 0-25, 0-27, 0-22 | 11-25, 0-25, 2-24 | Low/High |
| **B5** | 7-26, 3-28, 2-27 | 3-26, 6-27, 8-28 | Low/High |
| **C1** | 2-28, 5-29, 8-28 | 5-28, 1-25, 6-27 | Low/High |
| **C2** | 0-27, 0-25, 1-28 | 0-19, 4-28, 0-25 | Low/High |
| **C5** | 11-17, 7-17, 10-16 | 7-16, 7-20, 7-16 | Low/Medium |
| **D5** | 6-29, 3-27, 7-27 | 6-27, 5-28, 2-28 | Low/High |
| **G1** | 12-26, 11-27, 11-26 | 18-23, 10-26, 11-27 | Medium/High |
| **G2** | 0-23, 0-17, 7-26 | 8-26, 7-25, 4-23 | Low/High |

*Table 6-2. Miscellaneous weapons results for the Quickstart ferrous content/conductivity readings.*

| Target | Pre-Burial | 20-25cm | Pattern |
|---|---|---|---|
| **E1** | 11-14, 0-5, 11-14 | 14-8, 11-10, 7-3 | Variable |
| **E2** | 10-18, 6-29, 0-28 | 2-23, 6-27, 4-28 | Low/High |
| **E3** | 8-27, 7-26, 3-26 | 12-16, 9-12, 3-8 | Variable |
| **E4** | 13-23, 11-21, 9-16 | 12-24, 12-24, 11-23 | Medium/High |
| **E5** | 12-23, 6-28, 10-27 | 7-19, 11-25, 12-21 | Variable |
| **F1** | | | |
| **F2** | | | |
| **F3** | 0-25, 3-26, 11-27 | 0-27, 0-26, 3-27 | Low/High |
| **F4** | 11-26, 3-26, 11-8 | 6-4, 6-28, 4-28 | Low/High |
| **F5** | 4-16, 9-29, 11-28 | 11-17, 10-17, 10-23 | Variable |

*Table 6-3. Trash Metal results for the Quickstart ferrous content/conductivity readings.*

| Target | Pre-Burial | 20-25cm | Pattern |
|---|---|---|---|
| **C3** | 0-26, 0-25, 0-28 | 7-31, 0-25, 12-24 | Low/High |
| **C4** | | | |
| **D1** | 0-29, 0-30, 0-29 | 9-18, 3-29, 5-26 | Low/High |
| **D2** | | | |
| **D3** | 0-20, 0-23, 0-22 | 0-23, 11-26, 11-16 | Variable |
| **D4** | | | |

### Advanced Learn Feature

Using the Advanced Learn feature to program signature patterns of the firearms, scrap metals, and miscellaneous weapons proved just as difficult as the use of the Quickstart ferrous content/conductivity readings, as many of the targets could be detected with several of the programmed signatures (Tables 6-4 thru 6-6). Twelve out of the 16 firearms hit on all six programmed signatures, and the remaining four hit on five out of six programmed signatures. Interestingly, programmed signature S-6 was the Glock Model 19 (A5), which is comprised of a polymer frame and enough steel components to allow for the recognition of 13 out of 16 firearms by its programmed signature. The miscellaneous weapons and the trash metals were also detected by many of the programmed signatures; all of the miscellaneous weapons and all but one of the trash metals hit on at least four of the programmed signatures. While this feature is of no doubt great use in the detection of items with standardized metallic composition (i.e. coins and jewelry), the variation in the production of firearms, scrap metals, and miscellaneous weapons included in this study did not allow for a distinction to be made.

*Table 6-4. Firearm results for the Learn feature indicating which forensic targets were detected, marked by the 'x' when the advanced detector was set to a saved signature (S1 to S6).*

| Target | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|
| **A1** | x | x | x | x | x | x |
| **A2** | x | x | x | x | x | |
| **A3** | x | x | x | x | x | x |
| **A4** | x | x | x | x | x | x |
| **A5** | x | x | x | x | | x |
| **B1** | x | x | x | x | x | x |
| **B2** | x | x | x | x | x | x |
| **B3** | x | x | x | x | x | x |
| **B4** | x | x | x | x | x | |
| **B5** | x | x | x | x | x | x |
| **C1** | x | x | x | x | x | x |
| **C2** | x | x | x | x | x | x |
| **C5** | x | x | x | x | x | |
| **D5** | x | x | x | x | x | x |
| **G1** | x | x | x | x | x | x |
| **G2** | x | x | x | x | x | x |

*Table 6-5. Miscellaneous weapon results for the Learn feature indicating which forensic targets were detected, marked by the 'x', when the advanced detector was set to a saved signature (S1 to S6).*

| Target | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|
| **E1** | x | x | x | x | x | x |
| **E2** | x | x | x | x | x | x |
| **E3** | x | x | x | x | | x |
| **E4** | | x | | x | x | x |
| **E5** | x | x | x | x | x | x |
| **F1** | x | x | x | x | x | x |
| **F2** | x | x | x | x | | x |
| **F3** | | x | x | x | x | |
| **F4** | x | x | x | x | x | x |
| **F5** | x | x | x | x | | x |

*Table 6-6. Trash metal results for the Learn feature indicating which forensic targets were detected, marked by the 'x', when the advanced detector was set to a saved signature (S1 to S6).*

| Target | S1 | S2 | S3 | S4 | S5 | S6 |
|---|---|---|---|---|---|---|
| **C3** | | | x | x | x | x |
| **C4** | x | x | x | x | | x |
| **D1** | | | x | | | |
| **D2** | x | x | x | x | | x |
| **D3** | | x | x | x | x | |
| **D4** | x | x | x | x | | x |

Control Holes

It is important to note that a number of control holes (one inside the grid (G3) and two outside the grid) were tested during data collection. The disturbed soil of the control holes did not produce any responses for the various depths when tested with the advanced metal detector.

# CHAPTER 7: CONDUCTIVITY METER

## Conductivity Meter Theory

Conductivity refers to the ability of a material to conduct electricity (Dupras et al., 2006; Killam, 2004). The conductivity meter consists of a transmitting coil that emits an electromagnetic wave which produces a primary magnetic field in the ground and a receiving coil that detects the secondary magnetic field formed by a metallic object such as a handgun. The difference between the strength of the two fields is proportional to the conductivity of the weapon or how much faster or slower electromagnetic currents are propagated through the weapon (Dupras et al., 2006; Killam, 2004; Sharma, 1997). Conductivity meters used in archaeological digs or forensic investigations are often built as a portable instrument with both transmitting and receiving coils located within the frame. This type of assemblage is called horizontal loop or slingram method (Dupras et al., 2006; Killam, 2004). This slingram method simply refers to the fact that the transmitting and receiving coils of the conductivity meter move simultaneously (Sharma, 1997).

The conductivity meter provides great advantages to a forensic investigation in that it can detect all types of metallic objects and even some clandestine graves if the backfill exhibits a strong contrast with the environment. It can also be used in all types of terrain (such as a wooded area) and surfaces, and it provides a relatively quick way of surveying a suspect area as the surveyor is able to get a direct reading of the ground conductivity (Dupras et al., 2006; Killam, 2004; Bevan, 1983; Davenport, 2001). However, one disadvantage is that the conductivity meter is extremely sensitive to surrounding large metallic objects, such as fences or underground pipes, and even small metallic items on the surveyor such as keys or a watch. The conductivity meter is also a very expensive piece of equipment that might not be readily available to law enforcement agencies. Finally, the conductivity meter is a complex geophysical tool that requires training before it can be properly operated, unlike more common geophysical technologies such as magnetic locators and metal detectors (Dupras et al., 2006; Killam, 2004).

The conductivity meter used for this research project is a Geonics Limited EM-38RT (Figure 7-1) that measures 1.06m long with a 1m intercoil spacing. Conductivity is measured in one of two ways with this instrument: through an automatic mode that takes readings every second or through a manual mode in which readings are taken by pressing a button at specific locations. Conductivity measurements can also be taken in one of two dipoles or orientations. The vertical dipole (when the instrument is held vertically) is best for detecting differences in conductivity at greater depths while the horizontal dipole (when the instrument is held horizontally) is better suited for conductivity differences near the surface (Reynolds, 2002). The conductivity meter measures ground conductivity using millisiemens per meter (mS/m). There is a direct relationship between conductivity and mS/m; a better conductor will result in a greater value in mS/m (Killam, 2004). However, if the conductivity meter is in close proximity of a very conductive object, the readings can reach negative values. These negative values are caused by the geometry between the metallic objects and the transmitting and receiving coils (Ward, 1990).

### Data Collection Parameters and Processing

Prior to each data collection event, the conductivity meter was calibrated to the soil of the research area in order to accurately detect the anomalies within the grid. Data collection was performed using the conductivity meter on its vertical dipole as it is indicated by the manufacturer's instructions that the vertical dipole is recommended for depths over 40 cm (Geonics Limited, 2006; Clay, 2005). Data were collected over the research area using a 15m (west to east) by 19m (south to north) grid along transects parallel to the 19m axis of the grid (Figure 7-2). All of the data collection was performed by starting at the southern end and traveling north along each of the grid transects (Figure 7-2). Transects were spaced every 25cm and data were recorded along grid transects every 25cm using the manual data collection mode to insure their precision at specific locations along grid transects. While the manufacturer recommends that transects be separated by half the length of the instrument (50cm in the case of the meter-long EM-38 conductivity meter) transects were separated by only 25cm to ensure detection of the smaller targets (Geonics Limited, 2006; Killiam, 2004; Clay, 2005).

Transects for one depth were all collected during the same day to avoid moisture variations in the soil that could have affected the conductivity readings. A full survey of the grid using 25cm transects typically lasted around three hours, including time for preparation of the grid and calibration of the instrument. Measurements were recorded with an Allegro CX Field Computer connected to the conductivity meter (Figure 7-1) using the data acquisition program EM38pro from Geonics Limited. Data files were then transferred from the field computer to a desktop computer for processing using the Geonics Limited software DAT38W. All of the data from each transect was then combined to create an X, Y, and Z file that was converted into a number of different maps. The conductivity measurements represent the Z values that were plotted on the map. The mapping software used for this project was Surfer, Version 8 from Golden Software.

The conductivity data were plotted using contour maps that represent a plan view of the grid data and the software interpolates the spaces between the grid transects. The contour map is a 2-D map using X and Y coordinates, and the contour lines represent points of equal Z value, Z being the conductivity measurement of the targets in question. The contour map also shows the relative slope of the surface through the proximity of the contour lines. Therefore, two close lines will represent a greater slope than two distant lines and indicate a more conductive object. Contour maps are relatively simple given their two-dimensional aspect, but color schemes are used to accurately display the relationship between the different areas on the map. The default program intervals for the spacing between each contour were used with each contour line representing a difference of 0.5 mS/m. The only drawback of the contour map is that it is a composite picture of the ground conductivity and therefore does not provide precise depth information as ground-penetrating radar.

Two contour maps were created for each depth: one consisting of transects every 25cm (Figure 7-2) a second consisting of transects every 50cm (Figure 7-3). Contour maps showing the conductivity readings when using 50cm transects were created from the readings obtained in the 25cm transects survey by only plotting every other transect. Overlay maps were also created for each depth to determine which anomalies were produced by weapons and which ones were produced naturally by the soil. In addition, a weapon was classified as being detected if an anomaly was present at the location of the burial marker and the strength of the anomaly contained at least two continuous circular or semi-circular contour lines. The anomalies produced by the detected weapon were classified as either a *strong* or *slight* anomaly based on the number of circular or semi-circular contour lines present. The presence of four or more continuous contour lines indicated a *strong* anomaly and was considered a definite hit, while two or three contour lines were considered a *slight* or weak anomaly and a probable hit. The difference between definite and probable hits has direct consequences on forensic searches.

Areas where definite hits are detected will be the first areas to be investigated during a search followed by the probable hits if the *strong* anomalies did not reveal any weapon. Data analysis included determining whether each firearm, miscellaneous metal, and blunt and sharp force weapon was detected at each depth when using transect interval spacing of 25cm and 50cm transects .

Figure 7-1. Data collection using the Geonics Limited EM-38RT conductivity meter in the vertical dipole along a grid line at the research site.

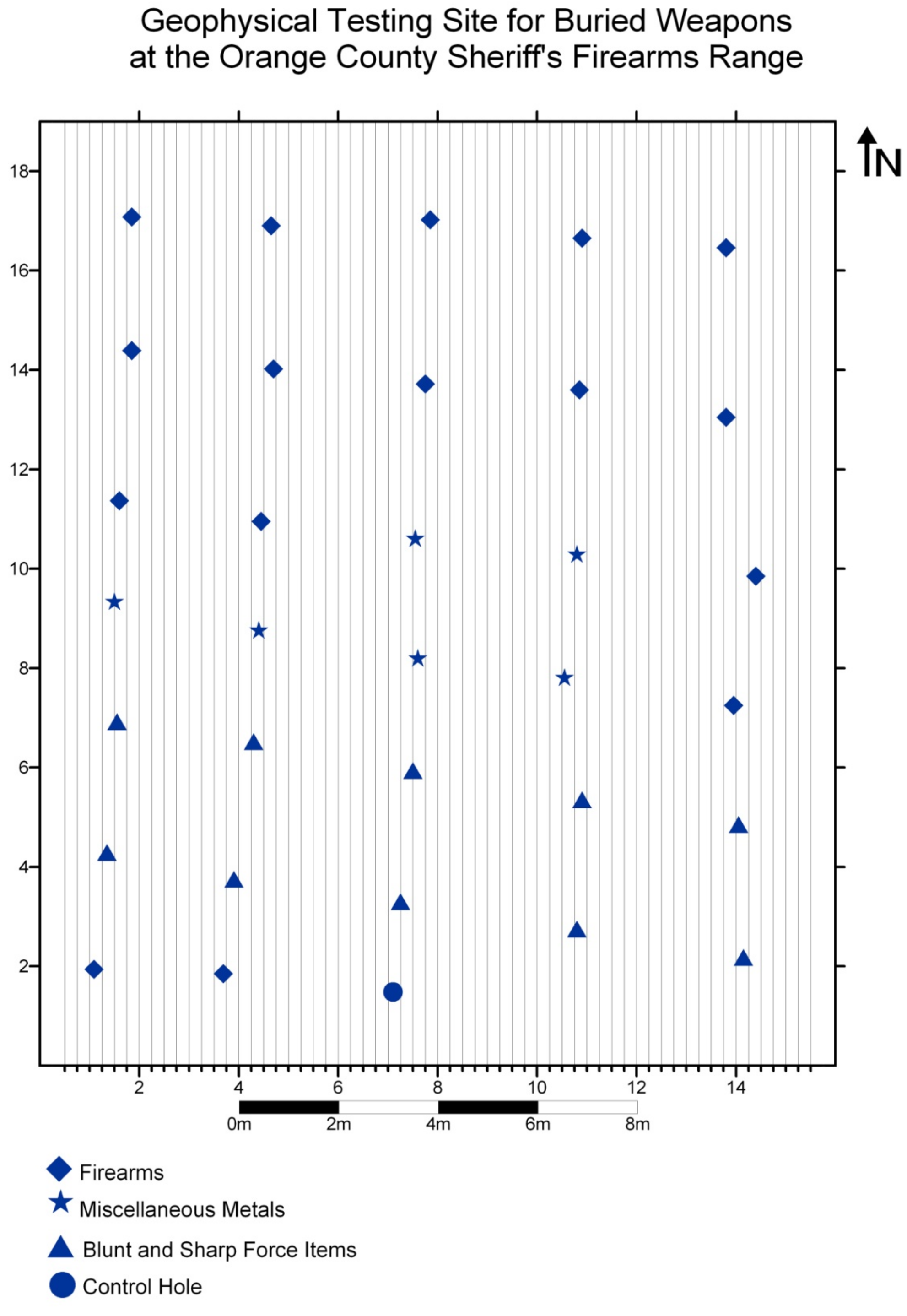

Figure 7-2. Data collected and mapped along grid transects every 25cm

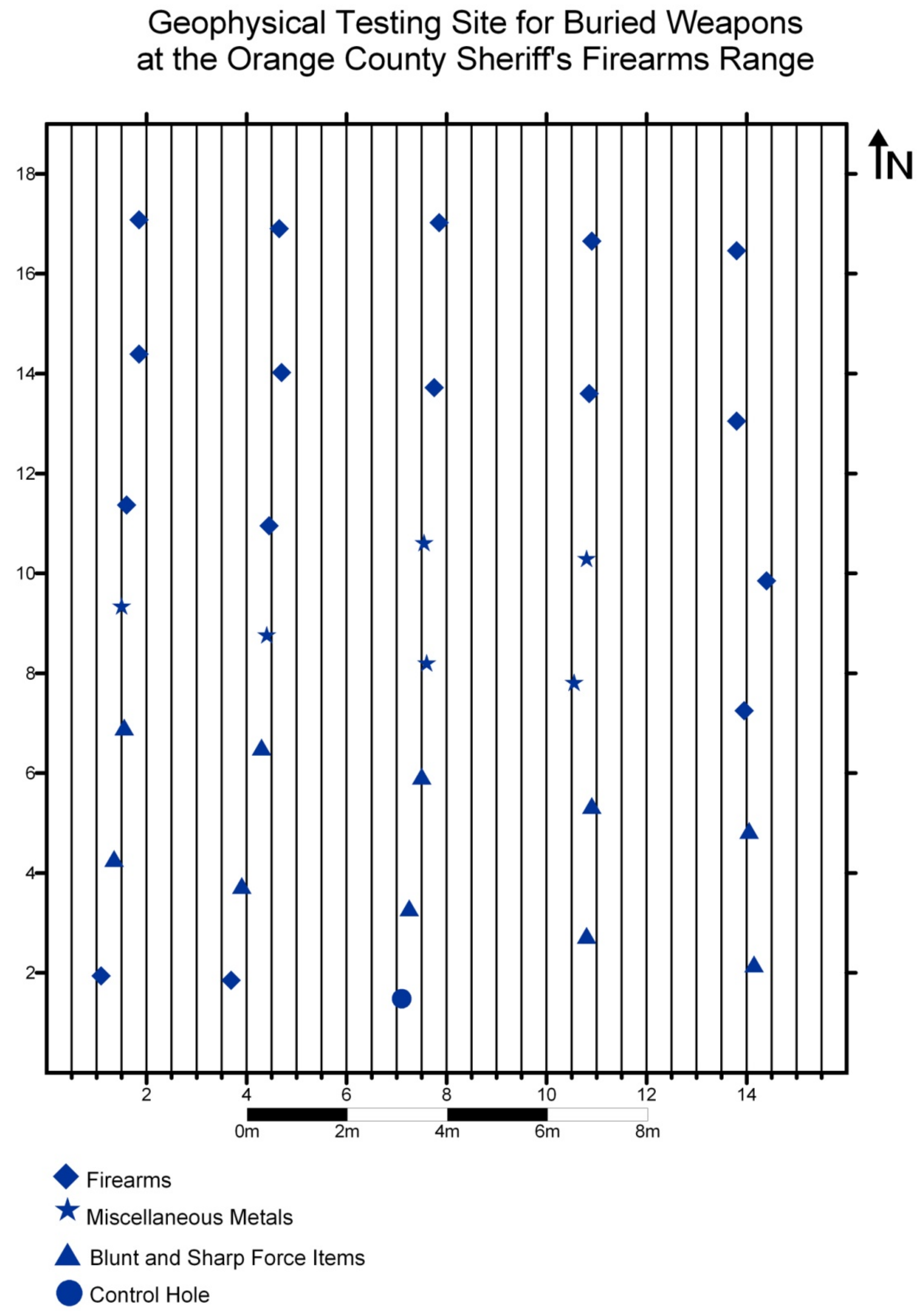

Figure 7-3. Data mapped along grid transects every 50cm

## Results

The data collection started at a depth of 45-50cm with the conductivity meter because data collection had already been ongoing with a number of the other geophysical tools by the time the conductivity meter was included. The delay of the conductivity meter was due to purchasing the equipment through the grant and then training with the equipment before it was included with the data collection. The metallic weapons were reburied 5cm deeper following each data set and once all objects were undetected, the weapons were reburied at the shallow depths that had already been done prior to the purchase of the conductivity meter. The conductivity data for each data collection depth is presented as a Surfer topographic conductivity map with either 25cm or 50 cm transects, and then a second map of each is provided with an overlay of the location of the weapons (Figures 7-4 to 7-7; see appendix A for the additional conductivity maps).

### Firearms

Data analysis of the conductivity readings using 25cm transects showed that all 16 firearms were detected with *strong* anomalies to a depth of at least 25-30cm (Figure 7-8). The deepest detected weapon was the Smith & Wesson 5906 (A4) down to 65-70cm, followed by the Remington 870 (G1), the Norinko AK (C5), and the Smith & Wesson Model 686 (B3) at 60-65cm. The Ruger P89 (G2) and the Mossberg Model 500A (D5) were both detected down to 55-60cm, while the Glock Model 19 (A5) was detected down to 50-55cm. The Colt Commander (B5) was detected down to 45-50cm. Thus, half of the firearms were still strongly detected at a depth of a half-meter by the conductivity meter (Figure 7-8). Interestingly, the eight firearms that were detected were also the eight largest, which confirms the effect of size on the depth of detection by the conductivity meter. The Smith & Wesson Model 37 (C1) was detected down to 40-45cm, followed by the Hi-Point Model C (A3), the North American Arms Mini-Magnum (B1), and the Jennings Bryco 59 (B2) down to 35-40cm. The Raven Arms MP-25 (A2) and the RG Industries RG23 (C2) were detected down to 30-35cm and finally, the Davis Derringer (A1) and the Lorcin L380 (B4) were detected down to 25-30cm.

When comparing the 50cm transect data to the 25cm transect data, there are a number of differences in maximum depth of detection for *strong* anomalies produced by firearms (Figure 7-9). Five firearms were detected 5cm shallower when analyzed with 50cm transect contour maps compared to 25cm transect maps: the Colt Commander (B5), the Lorcin L380 (B4), the Jennings Bryco 59 (B2), the North American Arms Mini-Magnum (B1), and the Davis Derringer (A5). Two firearms were detected 10cm shallower when analyzed with 50cm transect contour maps compared to 25cm transect maps: the Smith & Wesson 686 (B3) and the Smith & Wesson 5906 (A4). Finally, two firearms, the Ruger P89 (G2) and the Glock Model 19 (A5) were detected 15cm shallower when analyzed with 50cm transect contour maps compared to 25cm transect maps.

## Miscellaneous Weapons

Data analysis of the conductivity readings using 25cm transects showed that all 10 miscellaneous weapons were detected with *strong* anomalies down to depth of at least 15-20cm (Figure 7-10). The machete (E5) was the deepest weapon detected, down to 55-60cm. The prybar (E3), the mallet (E4) and the claw hammer (F4) were all detected down to 45-50cm, while the sword (F5) and the baton (F1) were detected down to 40-45cm. The Buck knife (E2) and the scissors (E1) were detected down to 30-35cm and 35-40cm, respectively. Finally, the Phillip's head screwdriver (F2) was detected down to 20-25cm followed by the brass knuckles (F3) down to 15-20cm.

When comparing the 50cm transect data to the 25cm transect data, there are a few differences in maximum depth of detection for *strong* anomalies produced by miscellaneous weapons (Figure 7-11). The mallet (E4) was detected 5cm deeper when analyzed with 50cm transect contour maps compared to 25cm transect maps. The prybar (E3) was detected 5cm shallower when analyzed with 50cm transect contour maps compared to 25cm transect maps. Finally, the brass knuckles (F3) were not detected using the 50cm transects data.

### Scrap Metals

Data analysis of the conductivity readings using 25cm transects showed that all six scrap metals were detected with *strong* anomalies down to a depth of at least 25-30cm (Figure 7-12). The rusty iron pipe (D2) and the solid iron pipe (C4) were both detected the deepest down to a depth of 45-50cm. The rebar (D4) was detected down to 40-45cm, while the hollow copper pipe (D1), the aluminum edging (C3), and the solid aluminum pipe (D3) were all detected the shallowest a depth of 25-30cm.

Data collection with the conductivity meter using 50cm transects indicated identical depth detection results for the six scrap metals compared to those obtained using 25cm transects.

## Control Hole

It is important to note that a control hole located within the survey grid was tested during data collection. The one control hole within the grid (G3) never produced any anomalies when using the conductivity meter (Figures 7-4 to 7-7 and Figures A1 to A60).

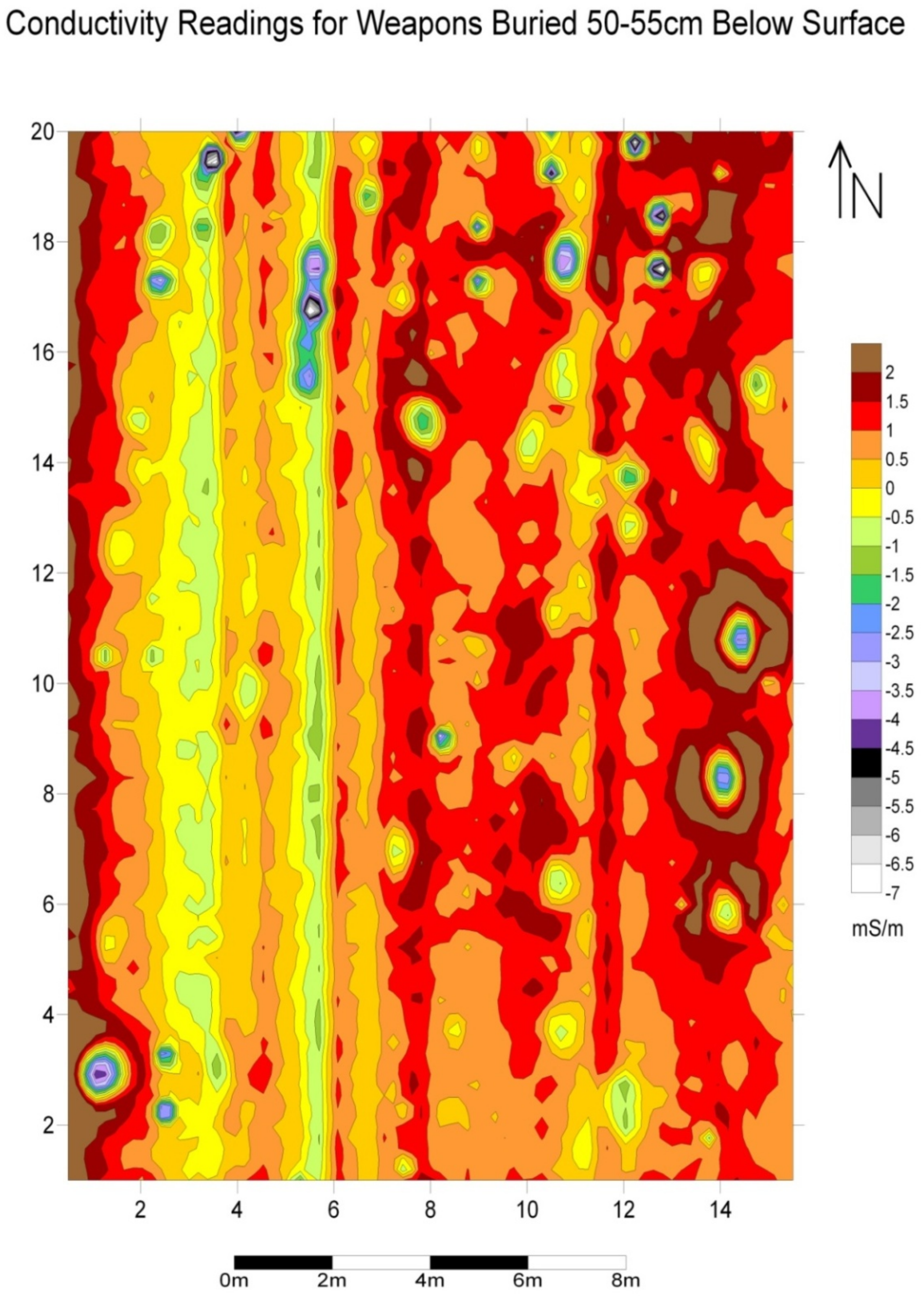

Figure 7-4. Conductivity map for weapons buried between 50-55cm and mapped using 25cm transects

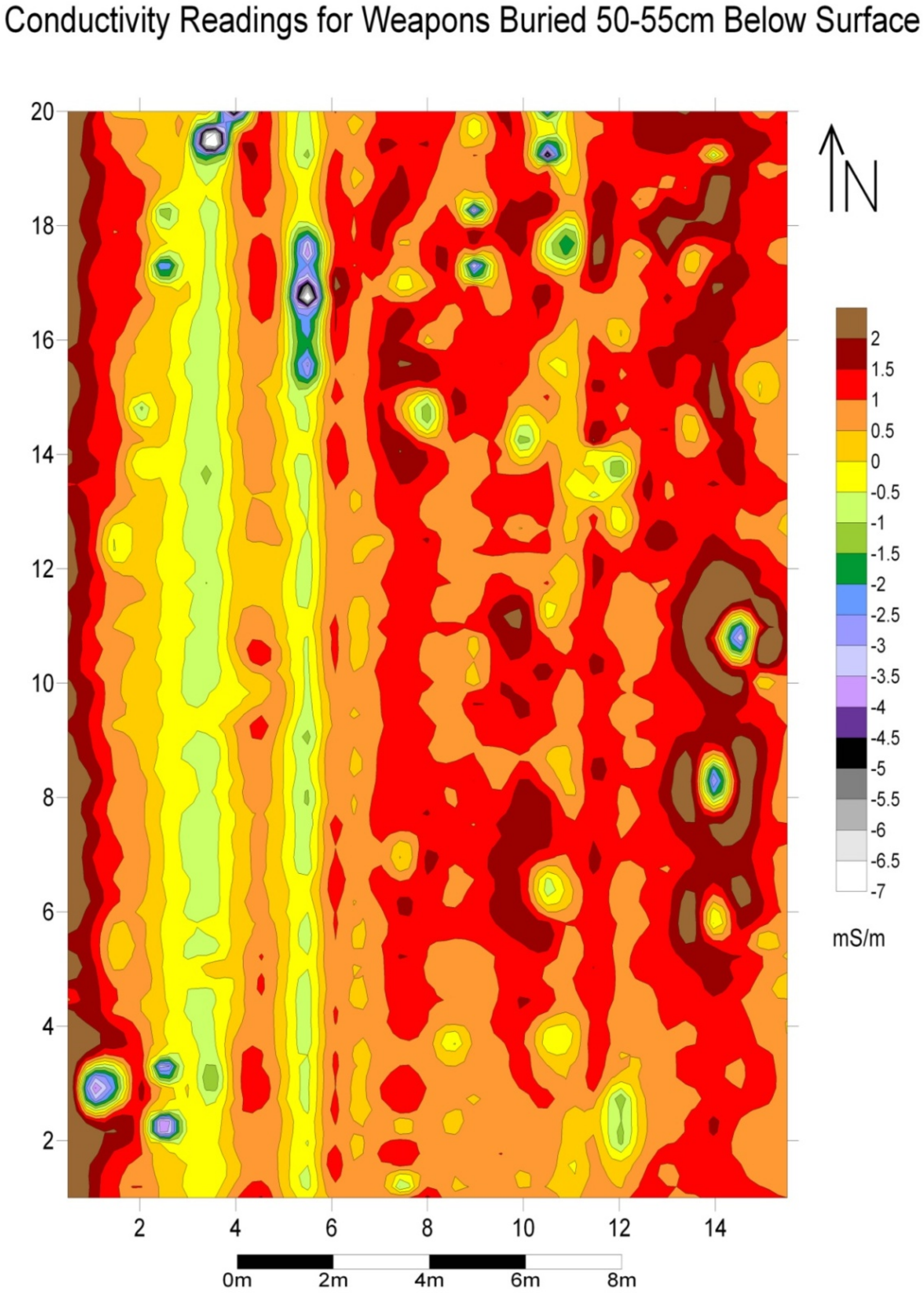

Figure 7-5. Conductivity map for weapons buried between 50-55cm and mapped using 50cm transects

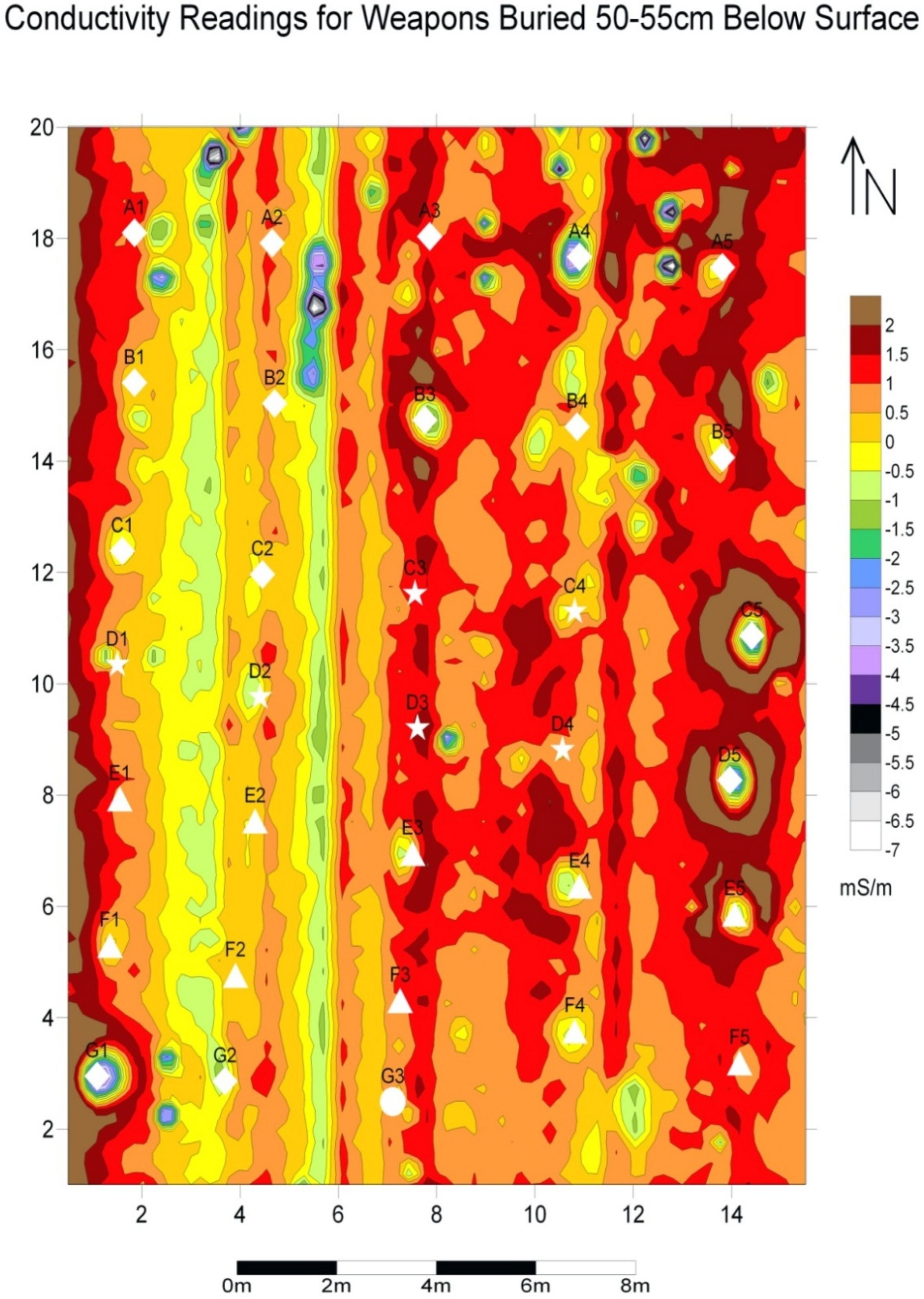
Conductivity Readings for Weapons Buried 50-55cm Below Surface

Figure 7-6. Research grid overlay with conductivity map for weapons buried between 50-55cm and mapped using 25cm transects

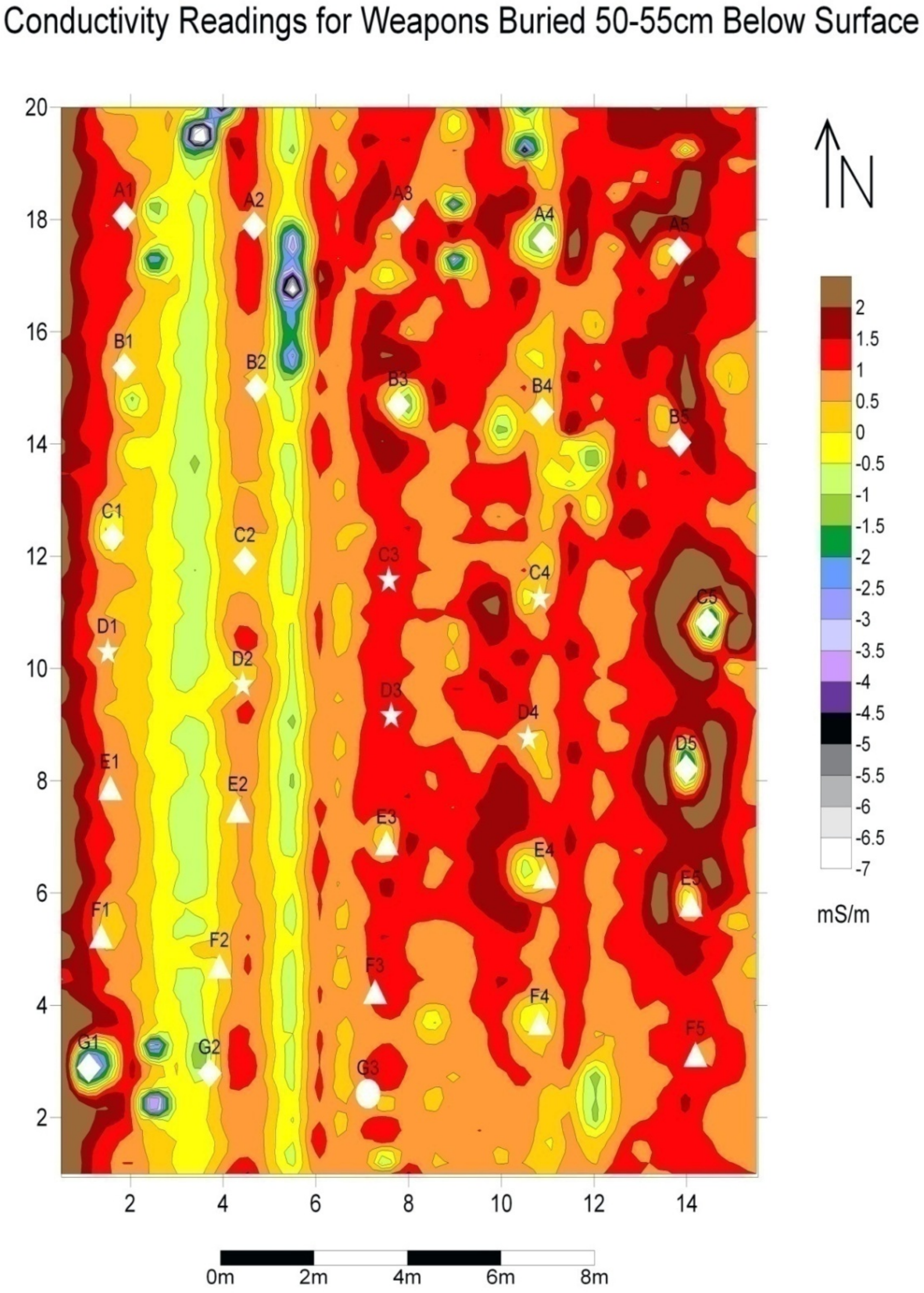

Figure 7-7. Research grid overlay with conductivity map for weapons buried between 50-55cm and mapped using 50cm transects

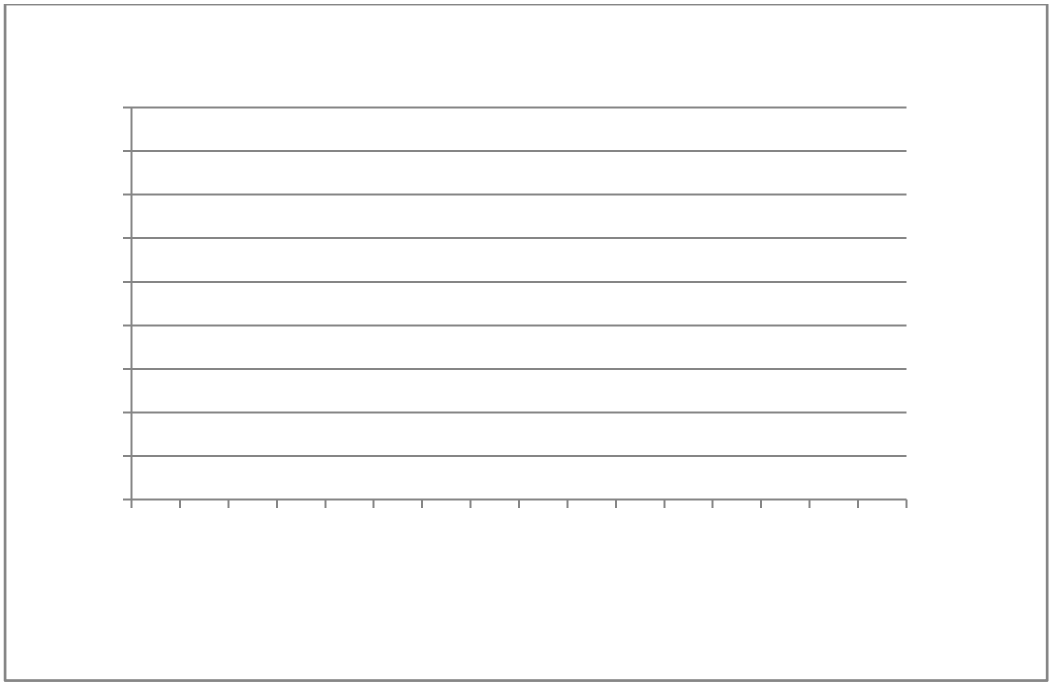

Figure 7-8. Summary of results for firearm detection with 25cm transects.

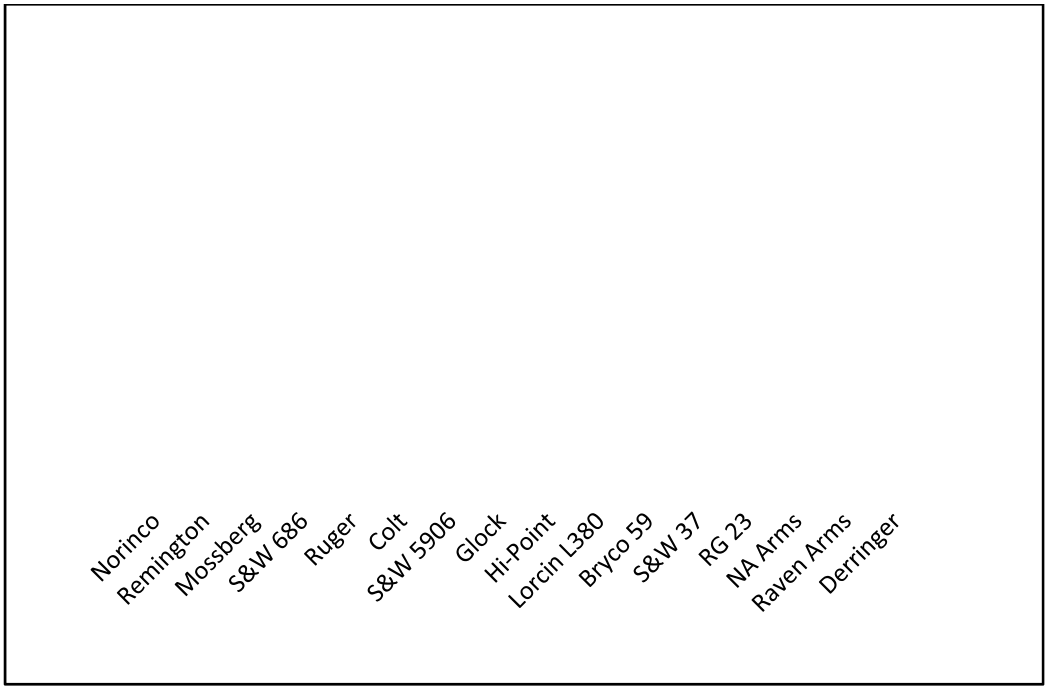

Figure 7-9. Summary of results for firearm detection with 50cm transects.

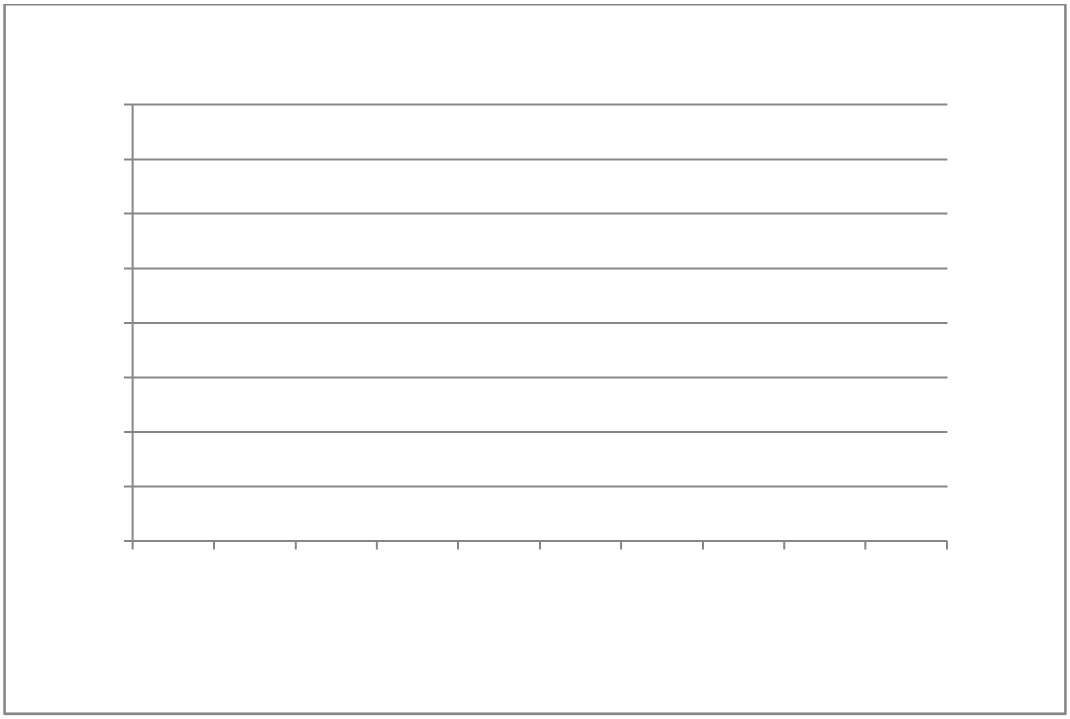

Figure 7-10. Summary of results for miscellaneous weapon detection with 25cm transects.

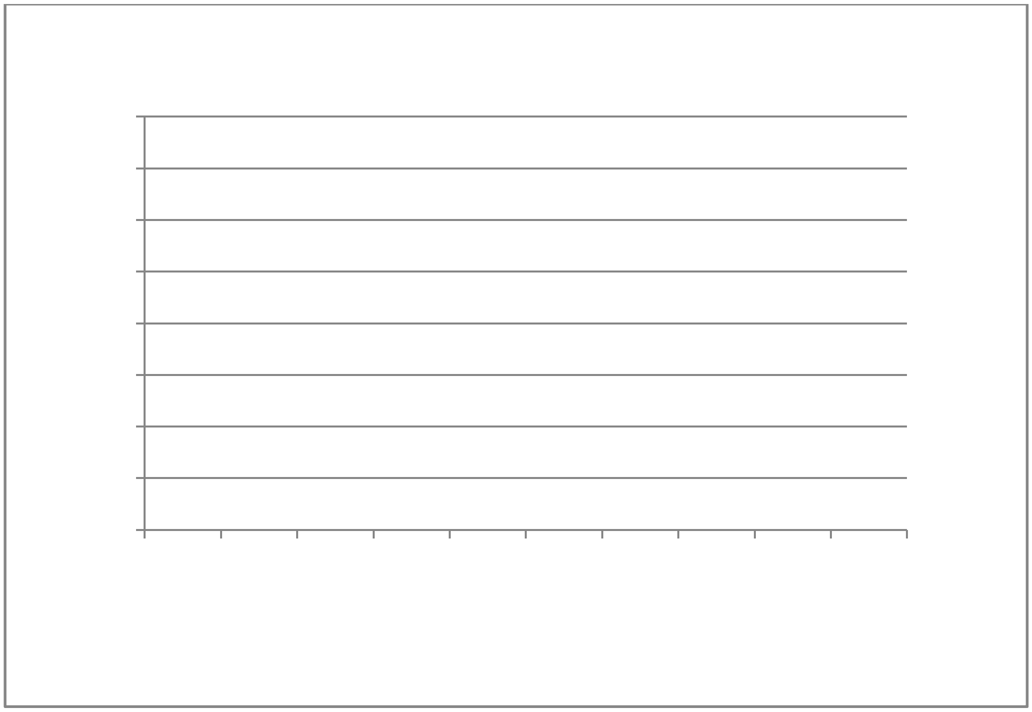

Figure 7-11. Summary of results for miscellaneous weapon detection with 50cm transects.

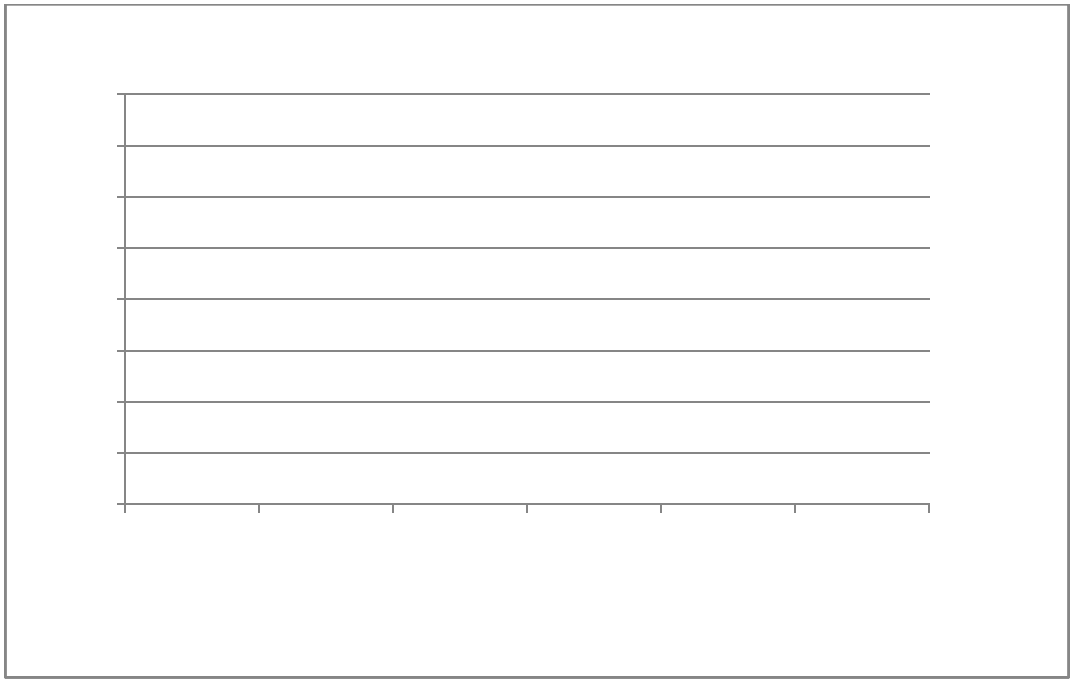

Figure 7-12. Summary of results for scrap metal detection with 25cm transects.

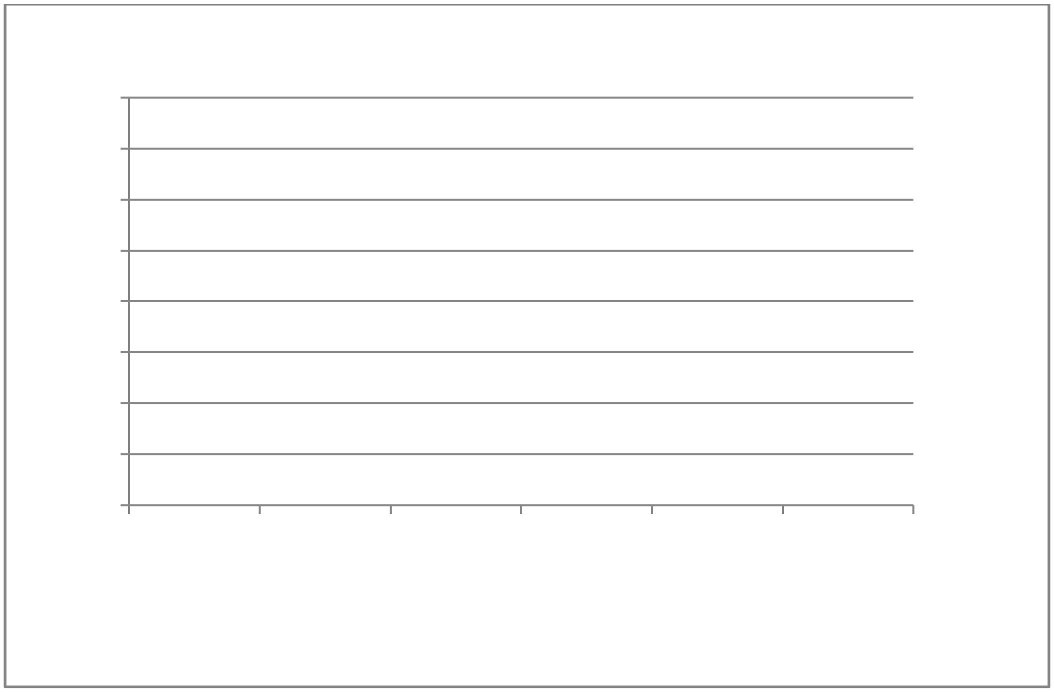

Figure 7-13. Summary of results for scrap metal detection with 50cm transects.

# CHAPTER 8: GPR

## GPR Theory

Ground-penetrating radar is an electromagnetic tool that emits continuous electromagnetic pulses of short duration which propagate from the transmitting unit in the antenna downward into the ground. With the placement of the antenna on the ground, the signal penetrates into the subsurface, and will be reflected, refracted, and scattered as it encounters materials of contrasting electrical properties that include differing soil features, voids, moisture, and metallic differences. The receiving portion of the antenna records the returning signal and sends it back to the control unit along a different line located within the cable. The control unit formats the reflected signal for immediate display on a video monitor. The data can also be downloaded to an external computer for processing and analysis. One of the great advantages of the GPR is that it provides great resolution because the data is displayed on the monitor for immediate assessment in the field. However, there are a number of drawbacks to using GPR. The equipment is very expensive compared to metal detectors, specialized training is required to operate the equipment, the data may require processing, and the data requires interpretation from an experienced technician. Furthermore, GPR works best with optimal soil and site conditions such as dry, sandy soils and clear and flat site conditions.

The GPR system that was used for this project is a MALA RAMAC X3M with 800- and 500-MHz antennae that were integrated into a cart and pushed over the survey area. The unit consisted of a control unit mounted to the top of the antenna, a monitor with a hard drive for data storage, and a survey wheel which is integrated into the cart. Depth of investigation and vertical resolution are two important considerations when choosing the appropriate antenna. A decrease in antenna frequency (e.g., 250-MHz) will increase the depth of investigation while decreasing the vertical resolution of the subsurface. The 500-MHz, or similar frequency, antenna provides an excellent compromise between depth of viewing and vertical resolution and is a common type used for archaeological and forensic applications (Schultz, 2007; Schultz et al., 2006). Conversely, an increase in antenna frequency (e.g., 900-MHz) will decrease the depth of investigation while increasing the vertical resolving capabilities of subsurface objects. Depending on the subsurface and size of forensic targets in question, a higher frequency antenna may detect multiple false anomalies or clutter (produced from pipes, roots, stumps, garbage, rocks, differences in moisture content, etc.) making it impossible to discern the target in question. It is important to note that the antenna generally transmits a cone-shaped electromagnetic wave directly below the antenna when it is placed in the standard position. Therefore, the antenna must be pulled directly over forensic targets for target detection.

Figure 8-1. MALA RAMAC X3M with GPR unit with 500-MHz antenna integrated into a cart

## Data Collection Parameters and Processing

Data were collected over the research area using a 15m (west to east) by 19m (south to north) grid along gridlines oriented along the 19m axis of the grid (Figure 8-2). All of the data collection was performed along the same direction starting at the southern end of the grid and traveling north (Figure 8-2). It is usually good practice to collect all transects in the same direction rather than alternating directions. Next, gridline transects were spaced every 10cm to ensure detection of small weapons. Transects for each depth were all collected during the same day to avoid significant variations in the soil, such as the moisture level, that could have affected the quality of the GPR readings. Next, gridline transects were taken directly over the five rows of buried items. Rows 1 and 2 consisted of seven buried items, row 3 consisted of six buried items and a control hole, and rows 4 and 5 consisted of six buried items (Figure 8-3).

Finally, the last component of this research consisted of processing and presenting the GPR data. Initially, GPR-SLICE was used for the data processing. However, data processing issues with small subsurface anomaly identification resulted in using REFLEXW, version 4.5, GPR software. The first step was to process the data using a variety of steps. The next step was to create radargrams or transects of the five rows. Third, all of the transects (radargrams) were welded together to create a 3-D cube. The first presentation of GPR data is to generate 2-D time slices, or Z-slices, that are planview representations of the grid data at different depths. The different colors represent different amplitudes. An option is provided to change the colorform to utilize a variety of colors that best highlight the targets in question. Fourth, fence diagrams were created from the 3-D model that incorporated a Z-slice and a Y-slice (radargram).

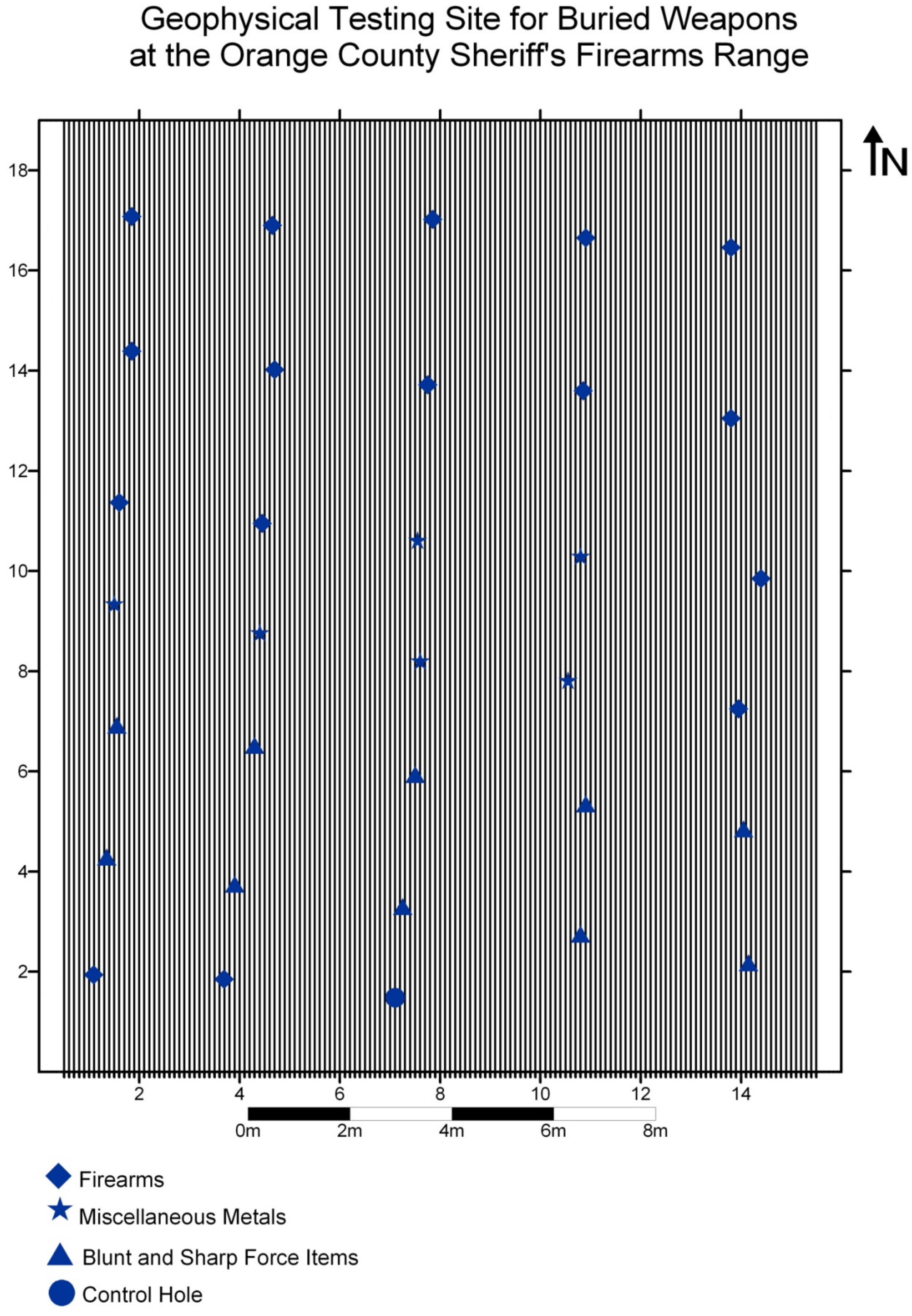

Figure 8-2. Grid line transects collected every 10cm

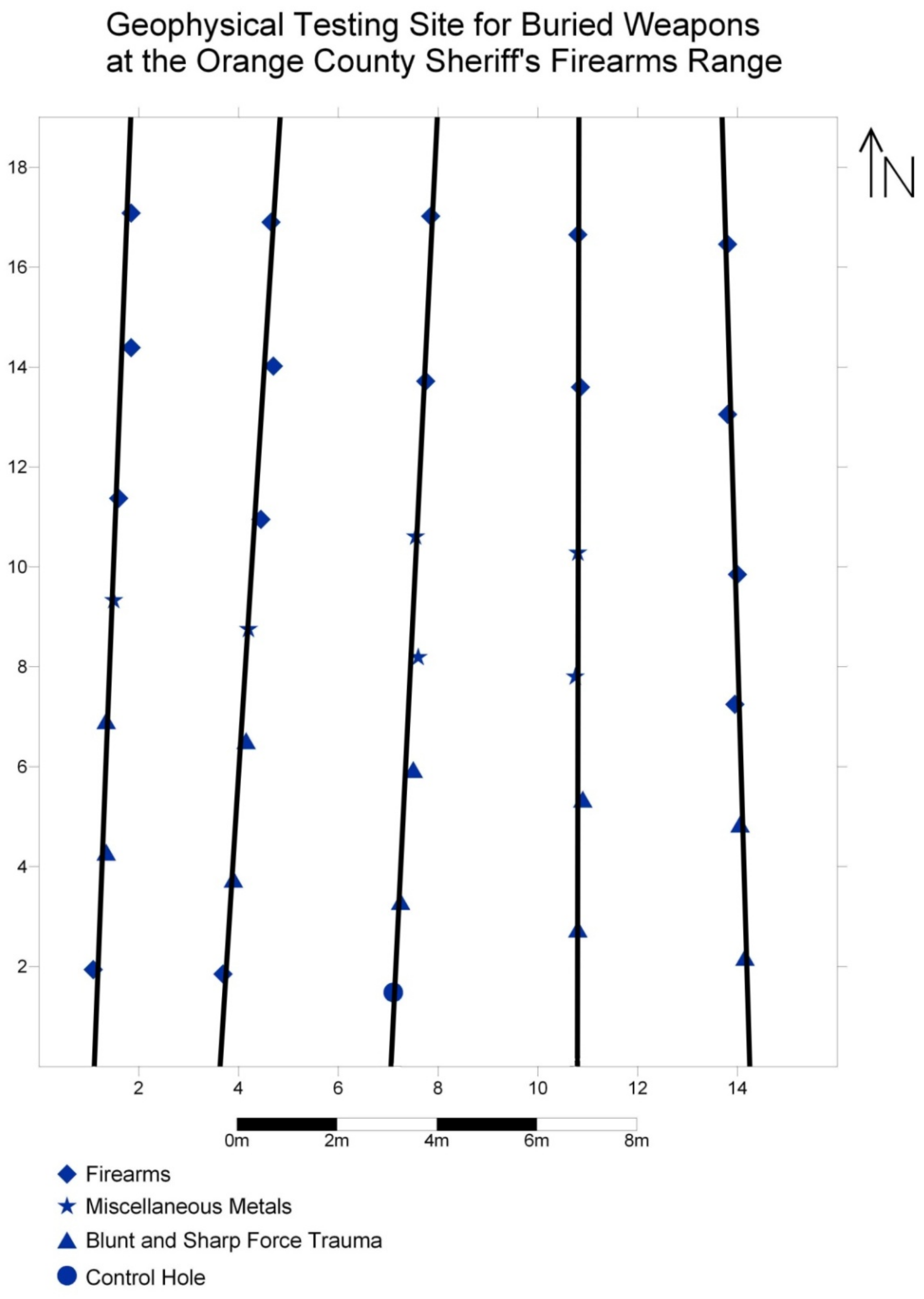

Figure 8-3. Five gridline transects collected directly over each forensic target with row 1 designated as the most western row and row 5 as the most eastern row

## Results

The GPR results will only focus on describing the data or GPR imagery and what can be learned from the data. Detection of the various weapons using GPR was variable for the different depths tested. The most favorable results were seen when the weapons were buried between 60-65cm because the data were collected when flooding was not an issue at the site. This chapter will only focus on describing the 60-65cm depth because increased moisture at the research site from flooding produced poor GPR imagery for many of the tested depths.

The various image options for presentation of the GPR data provided multiple views to discern the forensic targets. Figure 8-4 is a GPR radargram of row 3 taken with a 500-MHz antenna at a depth of 60-65cm. On the radargram, right left to represents length and top to bottom represents depth. Markers on the top of GPR profiles represent the location of the buried weapons. The one feature that stands out in Figure 8-4 is a row of six hyperbolic anomalies attributed to the brass knuckles (F3), the prybar (E3), the solid aluminum pipe (D3), the aluminum edging (C3), the Smith & Wesson Model 686 (B3), and the Hi-Point Model C (A3). The hyperbolic anomaly is the most striking feature noted when a single item is detected in the soil subsurface. The buried item is located at the apex of the anomaly and the tails or extensions of the hyperbola are artifacts of the wide angle of the transmitted beam. In addition, above the hyperbolic anomaly it may be possible to discern the soil disturbance (see arrow at top of page above G3 in Figure 8-4). The control hole in the grid (G3) was important to show that the disturbed soil in the hole was not producing the hyperbolic anomaly.

When the GPR imagery is compared between the 500-MHz (Figure 8-4) and 800-MHz antenna (Figure 8-5) for row 3 at 60-65cm, there are obvious detection differences. Overall, the hyperbolic anomalies were clearly demarcated on the imagery for the 500-MHz (Figure 8-4).

Refer to Appendix B for the 800- MHz and 500-MHz radargrams of the rows 1 to 5 that were collected when the targets were buried at 60-65cm. Conversely, the hyperbolic anomalies were poorly demarcated on the imagery for the 800-MHz (Figure 8-5).

With the incorporation of the Z-slices from the 3-D model, additional data were provided. Two Z-slices were found to be useful for analysis. The first Z-slice was a cut through the 3-D model near the ground surface. The second Z-slice was a deeper cut through the 3-D model at the depth of hyperbolic anomalies. The top Z-slice of the 500-MHz data (Figure 8-6A) clearly detected the disturbed soil of the top portion of all holes that were dug within the grid including the control hole (G3). When comparing the Z-slices of the 500-MHz data (Figure 8-6A) with those of the 800-MHz data (Figure 8-7A) there was much better demarcation of the disturbed soil of the burial holes with the 500-MHz data. Overall, there was poor detection of the burial holes using the 800-MHz data compared to the 500-MHz data. Furthermore, when the deeper 500 MHz Z-slice (Figure 8-6B) was compared to the corresponding Z-slice of the 800-MHz data (Figure 8-7B), the 500-MHz data once again provided increased demarcation of the weapons. For example, all of the buried weapons were detected on the deeper Z-slice. The circles and linear lines most likely represent the hyperbolic anomalies produced by the buried weapons. Conversely, there were no weapons detected when viewing the Z-slice for the 800-MHz (Figure 8-7B).

The next and most comprehensive level of GPR data analysis is to construct a fence diagram, which is a composite image of a Z-slice and a Y-slice. The fence diagram was useful to show how the detected soil disturbance on the top Z-slice corresponded with the hyperbolic anomaly of the radargram. For example, Figure 8-8 is a fence diagram of row 5 using the 500-MHz antenna. The particular Y-slice through the 3-D model shows four hyperbolic anomalies from a number of large firearms and weapons (F5, E5, D5 and C5). The Y-slice is oriented through the Z-slice to show how the four hyperbolic anomalies were located directly below the disturbed soil.

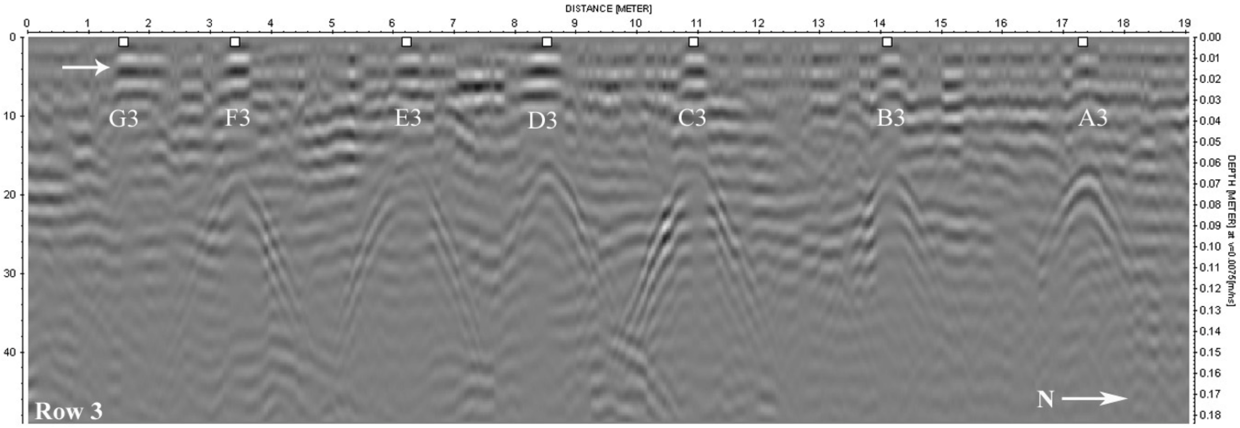

Figure 8-4. GPR radargram using 500-MHz antenna of row 3 taken at a depth of 60-65cm showing hyperbolic anomalies attributed to the brass knuckles (F3), the prybar (E3), the solid aluminum pipe (D3), aluminum edging (C3), Smith & Wesson Model 686 (B3), and the Hi-Point Model C (A3). Note the control hole (G3) without a hyperbolic anomaly.

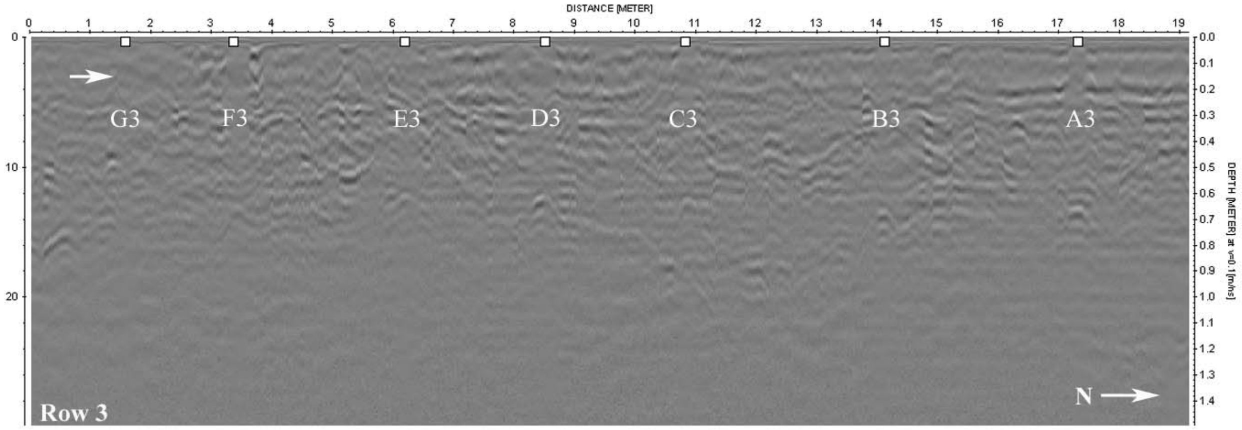

Figure 8-5. GPR radargram using 800-MHz antenna of row 3 taken at a depth of 60-65cm showing hyperbolic anomalies attributed to the brass knuckles (F3), the prybar (E3), the solid aluminum pipe (D3), aluminum edging (C3), Smith & Wesson Model 686 (B3), and the Hi-Point Model C (A3). Note the control hole (G3) without a hyperbolic anomaly.

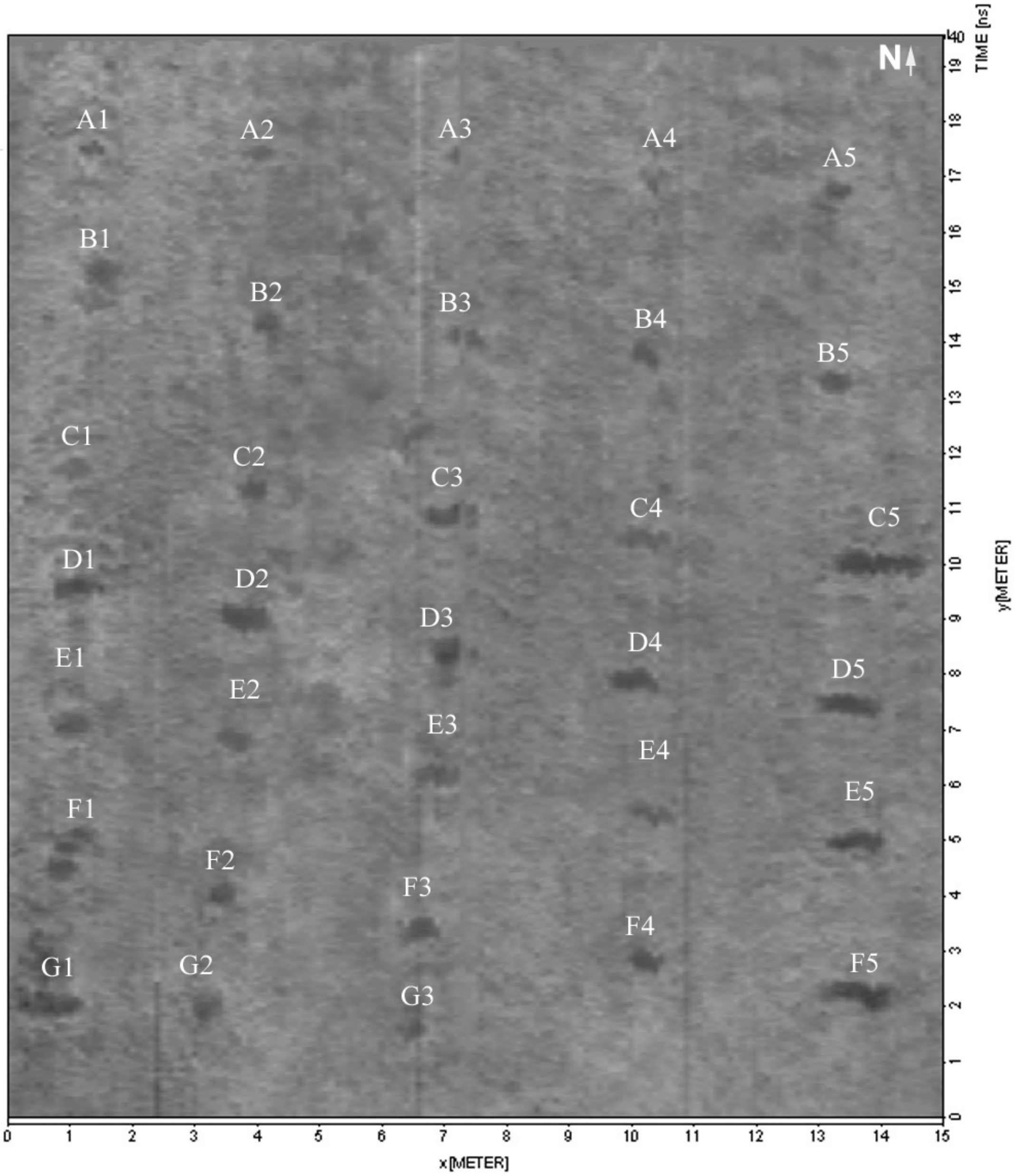

Figure 8-6A. GPR Z-slice using 500-MHz antenna when the weapons were buried at a depth of 60-65cm showing soil disturbances of the holes near the ground surface.

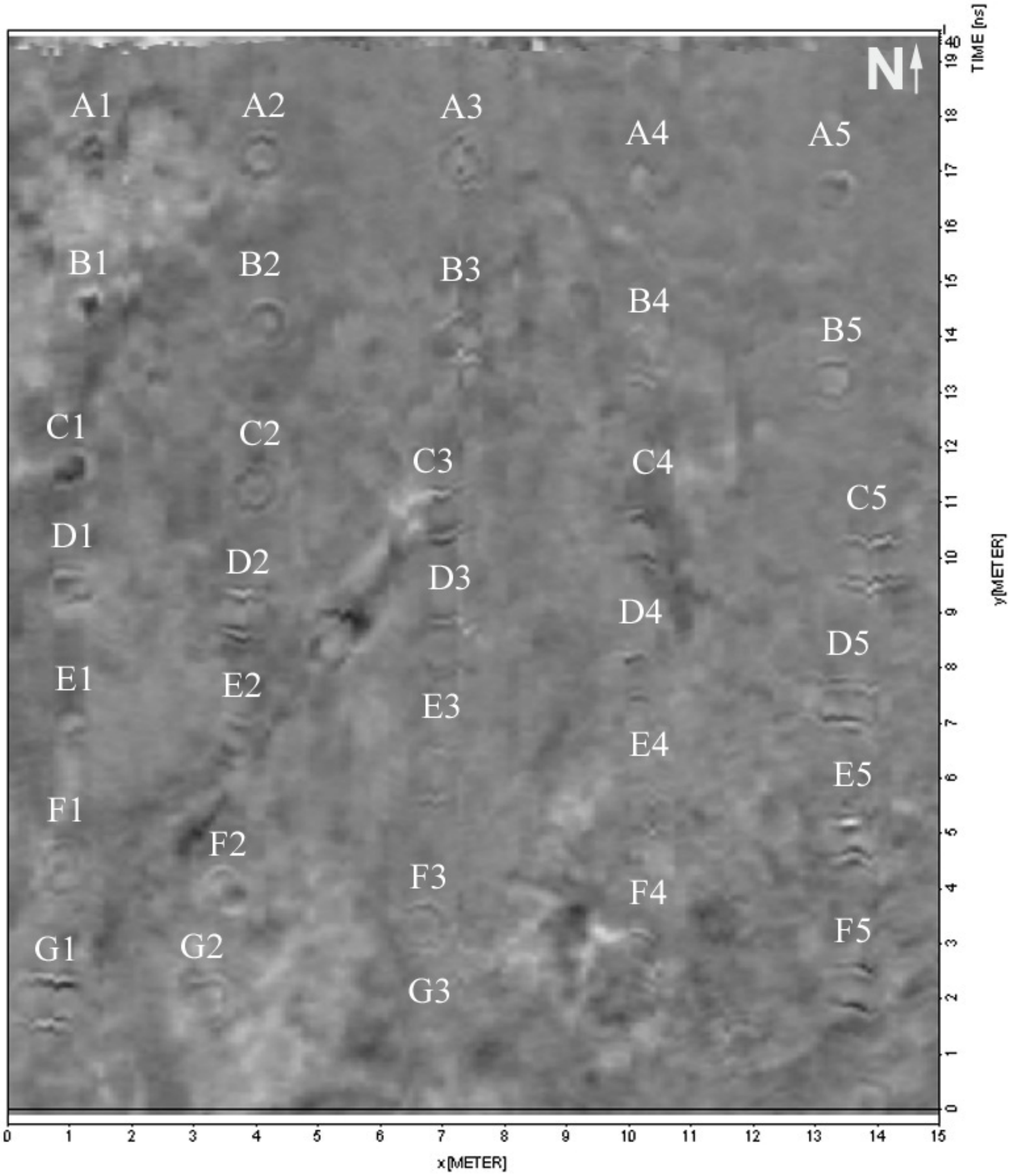

Figure 8-6B. GPR Z-slice using 500-MHz antenna when the burial depth of the weapons was at 60-65cm showing anomalous detection of numerous targets.

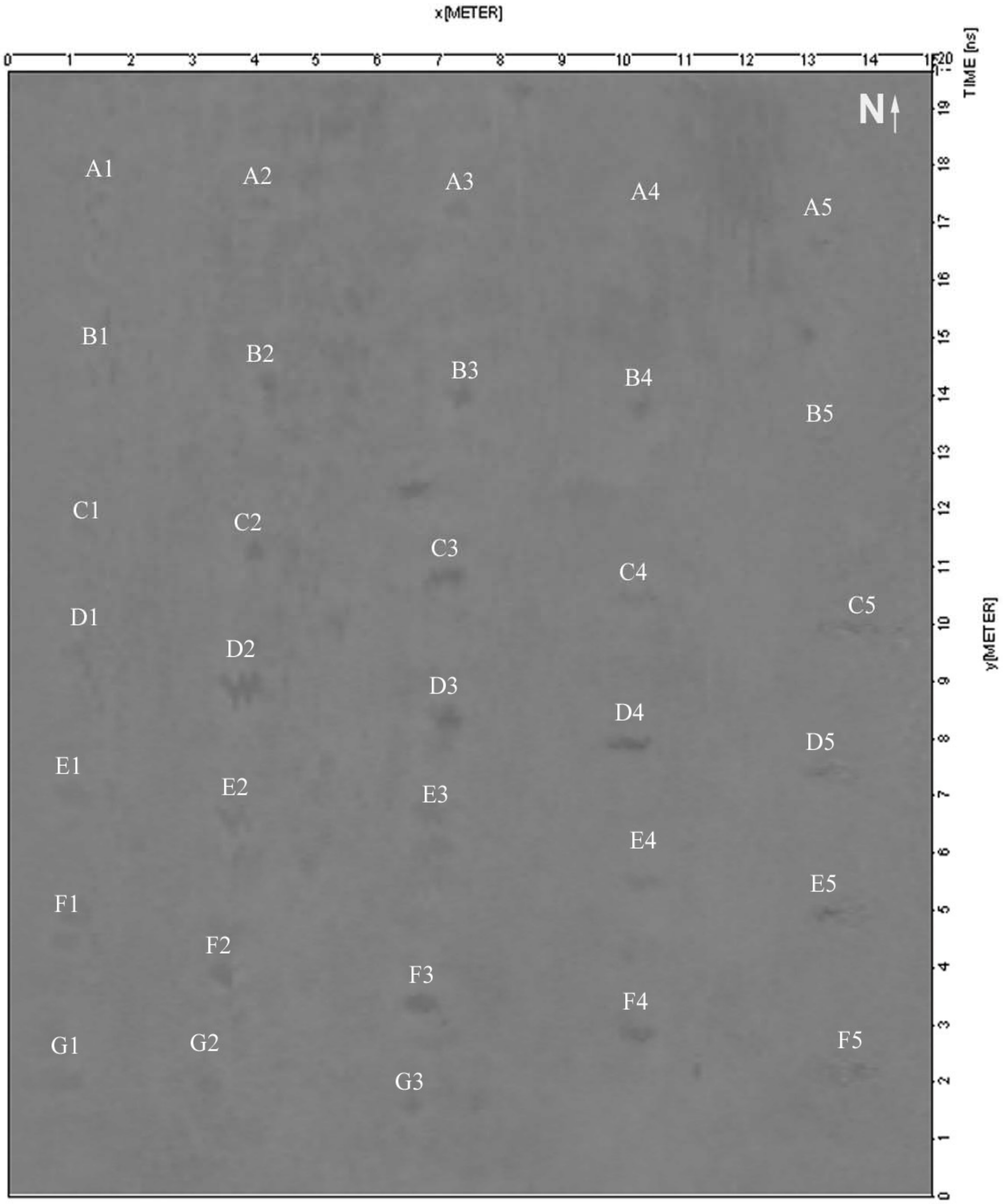

Figure 8-7A. GPR Z-slice using 800-MHz antenna taken when the weapons were buried at a depth of 60-65cm showing a number of soil disturbances for the holes near the ground surface.

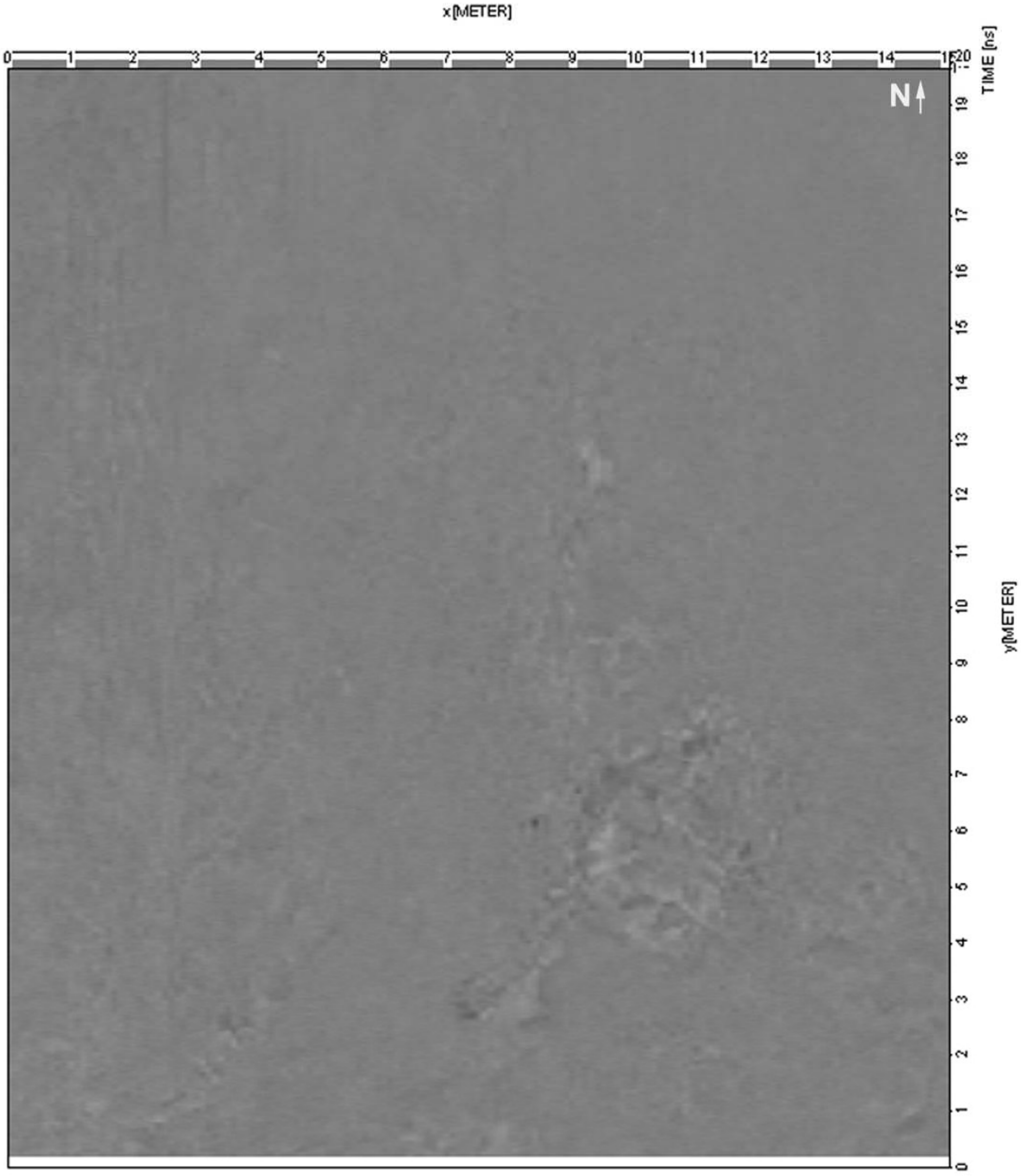

Figure 8-7B. GPR Z-slice using the 800-MHz antenna when the burial depth of the weapons was at 60-65cm showing no anomalous detection of targets.

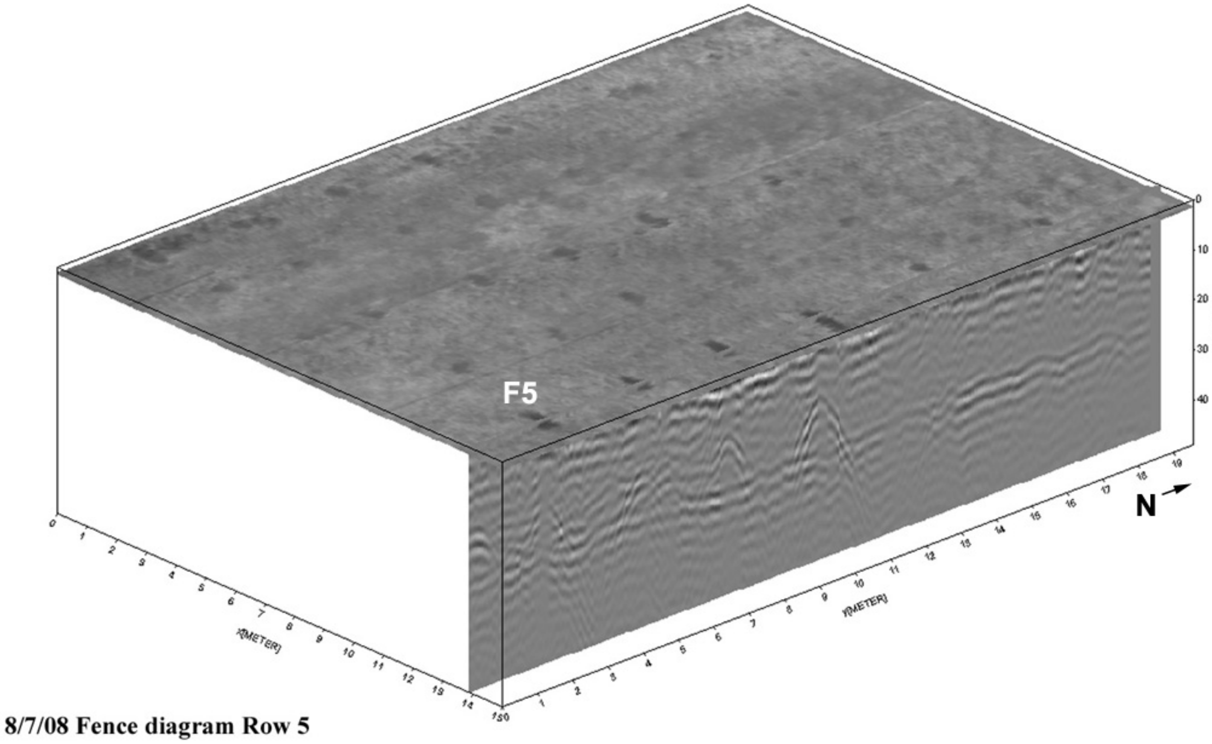

Figure 8-8. Fence diagram of row 5 using the 500-MHz antenna that was collected when the weapons were buried at a depth of 60-65cm

# CHAPTER 9: DISCUSSION, SEARCH GUIDELINES, & CONCLUSIONS

## Discussion

The first issue to consider when performing a search for a buried weapon is which geophysical tool should be used. First, the geophysical equipment can be separated into two groups: the easy to operate and less expensive equipment (metal detectors and magnetic locator) and the more expensive units (conductivity meter and GPR) that require operator training and experience. Both the magnetic locator and the all-metal detector proved to be easy to use with little training, and would therefore be suitable for law enforcement officials and forensic investigators with little or no prior experience with geophysical technologies. Most questions that arose concerning operation could generally be answered using the owner's manuals and in-field adjustments were easy to perform. The advanced metal detector proved to require more training than the all-metal detector, due in part to the discrimination function, but the results demonstrated that the discrimination capability was not useful because the majority of firearms and miscellaneous weapons were composed in part or completely of steel. Therefore, it was not possible to accurately distinguish one steel object from another based on the discrimination feature of the advanced metal detector.

Discussed below are only those results that generated an audible response of *strong*, as it is the most easily discernable response. *Slight* audible responses take more in-depth operator experience to tune one's ear to. Tables 9-1 to 9-6 summarize and compare the results for the all-metal detector using both settings, the magnetic locator using both settings, the advanced metal detector using both coils, and the conductivity meter using 25cm transects. For each metallic object, the geophysical instrument offering the best depth of detection was bolded. The GPR results were not included in these tables because maximum depth of detection of the forensic targets was not determined using the GPR.

Several aspects of the forensic targets were seen to affect detection: depth, metal composition, and size. It is important to note that a number of control holes (two outside the grid and one inside the grid) were tested during data collection. The disturbed soil of the control holes did not produce any audible responses for the various depths when tested with the magnetic locator, all-metal detector, and advanced metal detector.

In terms of detection, all of the firearms including the Glock Model 19 contained enough metal to be detected with the all-metal detector down to a depth of at least 10-15cm using the Normal/Medium setting (Table 9-1) and only considering audible responses classified as *strong*. When examining the effect of depth on the detection of forensic targets, there were several patterns which became apparent. While the metal composition of the items was not a factor for detection using the all-metal detector, there was a depth detection limit at 30-35cm for all of the items tested including the firearms, miscellaneous weapons, and the scrap metals using the Normal/Medium setting (Tables 9-1 to 9-3). In contrast, while the magnetic locator was able to detect five firearms at a greater depth than the all-metal detector using the Normal/Medium setting, four were detected at the same depth, and seven were detected at a shallower depth or not detected at all (Table 9-1). Overall, the magnetic locator performed better at detecting the larger firearms at deeper depths, while the all-metal detector performed better at detecting smaller firearms. Once High settings were incorporated, the array of firearms detected was roughly the same between the two tools; however, the magnetic locator was still able to detect the larger targets at greater depths (Table 9-4). For example, four firearms were detected at depths greater than 50cm with the magnetic locator compared to only one with the all-metal detector.

Furthermore, while no miscellaneous weapons or scrap metals were detected at a depth greater than 45cm using the all-metal detector, three miscellaneous weapons and one scrap metal were detected deeper than 45cm using the magnetic locator using the Normal/Medium setting (Tables 9-2 and 9-3). Once again, the magnetic locator appears to have a greater depth of detection for a number of items using both the Normal/Medium and High settings.

There were a few advantages in using the advanced metal detector. When using either the standard or large size coil, the advanced metal detector detected the medium to small firearms at the deepest depths compared to the magnetic locator and the all-metal detector. Also, the three iron scrap metals (C4, D2, and D4) were not detected using the advanced metal detector because the factory preset for the Iron Mask is designed not to detect iron objects because they generally represent trash metals.

One striking result concerning the advanced metal detector with the large coil was the detection of the smallest firearms. The advanced metal detector had the deepest detection for the smallest firearms in comparison to the all-metal detector, the magnetic locator, and the conductivity meter (Tables 9-1 and 9-4). Another issue to consider was whether a larger search coil should be used to increase depth of detection with a metal detector. Theoretically, the large search coil from the advanced metal detector should penetrate the ground deeper than the medium coil and provide better results at greater depths. This research confirmed that the larger coil provided equal or greater detection depths for a majority (30 out of 32) of the targets in comparison to the medium coil (Figures 6-8 to 6-10). However, it should be noted that the two coils actually displayed the same depth of detection for 22 of the 32 weapons (Figures 6-8 to 6-10). There was an advantage detecting the largest weapons at deeper depths using the large coil. On the other hand, the depths of detection were very similar between the two coils for the medium and smaller sized weapons. Both coils may therefore be valuable in real-life forensic searches in which law enforcement is looking for a buried metallic weapon. However, if the weapon being searched for is large, a large coil may provide the best depths of detection.

*Table 9-1: Maximum depth of detection (cm) for firearms comparing the all-metal detector and magnetic locator on Normal/Medium setting, the advanced metal detector with the medium coil, and the conductivty meter using 25cm transects when only audible responses classified as strong are considered.*

| Firearms | All-Metal Detector | Magnetic Locator | Advanced Metal Detector | Conductivity Meter |
|---|---|---|---|---|
| Norinco | 25-30 | 45-50 | 20-25 | **55-60** |
| Remington | 30-35 | 50-55 | 40-45 | **60-65** |
| Mossberg | 25-30 | 25-30 | 35-40 | **60-65** |
| S&W 686 | 20-25 | 15-20 | 40-45 | **60-65** |
| Ruger | 20-25 | 15-20 | 35-40 | **55-60** |
| Colt | 25-30 | 40-45 | **45-50** | **45-50** |
| S&W 5906 | 20-25 | 20-25 | 45-50 | **65-70** |
| Glock | 15-20 | 15-20 | No Detection | **50-55** |
| Hi-Point | 15-20 | 15-20 | **35-40** | **35-40** |
| Lorcin L380 | 15-20 | No Detection | **35-40** | 25-30 |
| Bryco 59 | 15-20 | 10-15 | **45-50** | 35-40 |
| S&W 37 | 15-20 | 20-25 | 30-35 | **40-45** |
| RG 23 | 15-20 | 0-5 | **40-45** | 30-35 |
| NA Arms | 10-15 | 15-20 | No Detection | **35-40** |
| Raven Arms | 15-20 | No Detection | **35-40** | 30-35 |
| Derringer | 10-15 | 5-10 | **40-45** | 25-30 |

*Table 9-2: Maximum depth of detection (cm) for miscellaneous weapons (blunt and sharp edge) comparing the all-metal detector and magnetic locator on Normal/Medium setting, the advanced metal detector with the medium coil, and the conductivty meter using 25cm transects when only audible responses classified as strong are considered.*

| Miscellaneous Weapons | All-Metal Detector | Magnetic Locator | Advanced Metal Detector | Conductivity Meter |
|---|---|---|---|---|
| Sword | 20-25 | 15-20 | 30-35 | **40-45** |
| Machete | 20-25 | 0-5 | 40-45 | **55-60** |
| Mallet | 20-25 | 15-20 | 30-35 | **45-50** |
| Claw Hammer | 25-30 | **60-65** | 55-60 | 45-50 |
| Prybar | 15-20 | 15-20 | 25-30 | **45-50** |
| Screwdriver | 5-10 | **70-75** | No Detection | 20-25 |
| Baton | 20-25 | 15-20 | No Detection | **40-45** |
| Buck Knife | 10-15 | 25-30 | 25-30 | **30-35** |
| Scissors | 10-15 | **60-65** | 35-40 | 35-40 |
| Brass Knuckles | 10-15 | No Detection | **35-40** | 15-20 |

*Table 9-3: Maximum depth of detection (cm) for scrap metals comparing the all-metal detector and magnetic locator on Normal/Medium setting, the advanced metal detector with the medium coil, and the conductivty meter using 25cm transects when only audible responses classified as strong are considered.*

| Scrap Metals | All-Metal Detector | Magnetic Locator | Advanced Metal Detector | Conductivity Meter |
|---|---|---|---|---|
| Hollow Copper | 10-15 | No Detection | **25-30** | **25-30** |
| Rebar | 15-20 | 15-20 | No Detection | **40-45** |
| Rusty Iron | 25-30 | **55-60** | No Detection | 45-50 |
| Aluminum Edging | 15-20 | No Detection | **40-45** | 25-30 |
| Solid Iron | 25-30 | 40-45 | No Detection | **45-50** |
| Solid Aluminum | 10-15 | No Detection | **30-35** | 25-30 |

*Table 9-4: Maximum depth of detection (cm) for firearms comparing the all-metal detector and magnetic locator on High setting, the advanced metal detector with the large coil, and the conductivty meter using 25cm transects when only audible responses classified as strong are considered.*

| Firearms | All-Metal Detector | Magnetic Locator | Advanced Metal Detector | Conductivity Meter |
|---|---|---|---|---|
| Norinco | 45-50 | **70-75** | 40-45 | 55-60 |
| Remington | 50-55 | **70-75** | 50-55 | 60-65 |
| Mossberg | 40-45 | 55-60 | 40-45 | **60-65** |
| S&W 686 | 35-40 | 30-35 | 40-45 | **60-65** |
| Ruger | 35-40 | 40-45 | 40-45 | **55-60** |
| Colt | 35-40 | **55-60** | 45-50 | 45-50 |
| S&W 5906 | 35-40 | 35-40 | 45-50 | **65-70** |
| Glock | 30-35 | 30-35 | No Detection | **50-55** |
| Hi-Point | **35-40** | 25-30 | **35-40** | **35-40** |
| LorcinL380 | 30-35 | 5-10 | **35-40** | 25-30 |
| Bryco 59 | 35-40 | 30-35 | **45-50** | 35-40 |
| S&W 37 | 30-35 | 30-35 | 30-35 | **40-45** |
| RG 23 | 30-35 | 10-15 | **45-50** | 30-35 |
| NA Arms | 25-30 | 25-30 | No Detection | **35-40** |
| Raven Arms | 25-30 | 5-10 | **35-40** | 30-35 |
| Derringer | 25-30 | 20-25 | **30-35** | 25-30 |

*Table 9-5: Maximum depth of detection (cm) for miscellaneous weapons (blunt and sharp edge) comparing the all-metal detector and magnetic locator on High setting, the advanced metal detector with the large coil, and the conductivty meter using 25cm transects when only audible responses classified as strong are considered.*

| Miscellaneous Weapons | All-Metal Detector | Magnetic Locator | Advanced Metal Detector | Conductivity Meter |
|---|---|---|---|---|
| Sword | 35-40 | **40-45** | 30-35 | **40-45** |
| Machete | 35-40 | 25-30 | 40-45 | **55-60** |
| Mallet | 35-40 | 20-25 | 35-40 | **45-50** |
| Claw Hammer | 40-45 | **50-55** | **50-55** | 45-50 |
| Prybar | 30-35 | 25-30 | 40-45 | **45-50** |
| Screwdriver | 15-20 | **80-85** | No Detection | 20-25 |
| Baton | 30-35 | 25-30 | No Detection | **40-45** |
| Buck Knife | 25-30 | **35-40** | 25-30 | 30-35 |
| Scissors | 25-30 | **60-65** | 35-40 | 35-40 |
| Brass Knuckles | 25-30 | No Detection | **35-40** | 15-20 |

*Table 9-6: Maximum depth of detection (cm) for scrap metals comparing the all-metal detector and magnetic locator on High setting, and the advanced metal detector with the large coil, and the conductivty meter using 25cm transects when only audible responses classified as strong are considered.*

| Scrap Metals | All-Metal Detector | Magnetic Locator | Advanced Metal Detector | Conductivity Meter |
|---|---|---|---|---|
| Hollow Copper | 25-30 | No Detection | **30-35** | 25-30 |
| Rebar | 30-35 | 25-30 | No Detection | **40-45** |
| Rusty Iron | 40-45 | **65-70** | No Detection | 45-50 |
| Aluminum Edging | 30-35 | No Detection | **40-45** | 25-30 |
| Solid Iron | 40-45 | **55-60** | No Detection | 45-50 |
| Solid Aluminum | 20-25 | No Detection | **30-35** | 25-30 |

As expected, metal composition was an issue using the magnetic locator. The magnetic locator is designed to detect ferrous metals and ignore non-ferrous metals. The most striking instances where metal composition was a factor with detection of firearms using the magnetic locator included the Lorcin L380 (B4) and Raven Arms MP-25 (A2). Both of these weapons were only detected down to 5-10cm using the High setting. Although these are two of the smallest weapons, it is not surprising that there was shallow detection based on the metallic materials comprising the weapons. The Lorcin L380 (B4) is comprised of an aluminum frame and magazine. The Raven Arms MP-25 (A2) is primarily comprised of a zinc alloy with an aluminum clip. Zinc is classified as a diamagnetic alloy that weakly repels magnetic fields, and aluminum objects are not supposed to be detected by the magnetic locator. Conversely, the Jennings Bryco 59 (B2), which is also comprised of a zinc alloy, was detected much deeper than the Raven Arms MP-25 (A2) at 30-35cm because the clip is made out of steel. Also, while the frame for the RG Industries RG23 (C2) is comprised of aluminum, the weapons were detected deeper than the Lorcin L380 (B4) and the Raven Arms MP-25 (A2) at 30-35cm because the barrel and cylinder are comprised of steel.

The reduced detection of items comprised of non-ferrous materials is further demonstrated by a number of other items that were tested. For example, the two pieces of aluminum scrap metal (C3 and D3) and the hollow copper pipe (D1) were not detected with the magnetic locator on either the Medium or High settings. Furthermore, the brass knuckles (F3) were not detected with a *strong* hit using either the Medium or High settings.

At the request of one of the reviewers of the concept paper, we tested a number of weapons buried in a plastic PVC pipe. The largest PVC pipe available at the local home improvement store was 4 inches in diameter. Due to the small diameter of the PVC pipe, only the smallest handguns were able to fit within the pipe. A firearm was placed in a small section of PVC pipe and two rubber ends were placed over the open ends of the pipe to ensure that the weapon would be secured within the pipe when buried. We tested three small handguns (the Raven arms MP-25 (A2), the North American Arms Mini Magnum (B1), and the RG Industries RG23 (C2) with the all-metal detector, the magnetic locator, and the advanced metal detector. As expected, the results of all three geophysical instruments showed that the maximum depths of detection did not change when the weapons were placed within the buried plastic PVC pipe.

Compared to the all-metal detector, magnetic locator, and the advanced metal detector the conductivity meter and the GPR are more expensive and require expert training before they can be operated. The conductivity meter demonstrated good depths of detection and was able to detect all weapons, unlike the magnetic locator and the advanced metal detector, down to a depth of at least15-20cm, slightly deeper than the all-metal detector. In addition to being able to detect all types of metals, the greatest advantage of the conductivity meter is the superior depths of detection, especially with the larger weapons. Thirteen of the 32 weapons were still detected at a depth of 45-50cm compared to nine for the magnetic locator on high setting, six for advanced metal detector with the large coil, and two for the all-metal detector on high setting. The study showed that the conductivity meter was especially useful in detecting firearms and miscellaneous weapons. The conductivity meter provided the best depth of detection for half of the 16 firearms and half of the ten blunt and sharp edged weapons when compared to the all-metal detector and magnetic locator on High setting and the advanced metal detector with the large coil. Although the conductivity meter demonstrated good detection of the scrap metals, it only detected one of the scrap metals deeper than the other geophysical tools (Table 9-6). This is probably due to the relatively smaller size of these targets and it has already been mentioned that the conductivity meter is best suited for detection of larger metallic objects.

The transect interval is another variable that needs to be addressed if one is using a conductivity meter to perform a forensic search. When using the 25cm interval spacing, there was always at least an equal or a greater number of weapons detected at the same depth compared to the 50cm intervals. The difference was the greatest at the 50-55cm depth where five more weapons were detected using 25cm intervals compared to the 50cm intervals. On the other hand, an equal amount of weapons was detected at depths of 35-40cm, 40-45cm, 65-70cm, and every depth below 30cm. It is also important to note that the weapons that displayed different detection patterns from one transect interval to the other were usually the small weapons. As expected, the results for larger weapons such as the shotguns and the rifle were not affected as much by changing the transect interval. Overall, the conductivity meter proved to be a valuable tool for forensic searches, especially when searching for larger metallic objects or objects that are believed to be buried at greater depths.

Next, it is important consider the utility of the GPR. The research has shown that the 500-MHz antenna was a better option to use than the 800-MHz antenna for weapons searches in this type of environment. The 800-MHz highlighted too much of the subsurface resulting in difficulty discerning the actual forensic targets. This research utilized transects spacing of 10cm which clearly highlighted both the small and large weapons. However, a survey utilizing 10cm spacing takes a considerable amount of time to perform. The survey performed for this research project generally took at least 3 hours of field work, not including setting up the grid. For a real life scenario, it would not be feasible to collect transects with this spacing for a large search area if the forensic target was a small sized handgun; a magnetic locator or an all-metal detector would provide better options for small-sized weapons.

The various image options to present the GPR data provided multiple views to discern the forensic targets. The control hole in the grid (G3) was important to show that the disturbed soil in the hole was not producing the hyperbolic anomaly. The detection of the various weapons was discernable when using the radargrams or 2-D time slices as a hyperbolic anomaly that may contain a soil disturbance directly above the buried object. An advantage of the radargram is that general depth information is provided which helps investigators know how deep they need to excavate or invasively test areas of interest. With the incorporation of the Z-slices from the 3-D model, additional data are provided. For example, the Z-slices near the ground surface detected the disturbed soil of the holes. Then, in a number of instances, a Z-slice slightly deeper than the depth of the weapon was able to discern the tails of the hyperbolic anomalies. Furthermore, the fence diagrams incorporated the visual data by showing that an object (hyperbolic anomaly on the Y-slice) was buried directly below the soil disturbance on the Z-slice. Another advantage of the GPR over the rest of the geophysical tools is depth of penetration. There were depth detection limits to all of the geophysical tools. However, based on the depth of penetration of the radargrams, the GPR would be able to detect a larger weapon such as a rifle or a shotgun at depths deeper than a meter with appropriate site conditions (flat ground surface, little brush and trees, little metal debris, soil conductivity, etc.).

There are a number of advantages for using conductivity over GPR for buried weapons searches. Conductivity provides a general size of the target based on the size and intensity of the anomaly. There is less processing of the data needed to produce a conductivity map than to produce the various GPR imagery views. A conductivity map provides a quick way to produce a visual image of the subsurface that cannot be created from a magnetic locator or a metal detector. Another advantage of the conductivity meter over GPR concerns site conditions. Site conditions where conductivity can be used include wooded areas and uneven terrain where GPR data interpretation becomes more challenging. Furthermore, GPR will respond to many subsurface features such as tree roots. All of the hits result in clutter on the GPR imagery that makes it difficult to distinguish the actual target from the false anomalies. Conversely, fewer items in the subsurface, such as tree roots, interfere with the conductivity readings, resulting in less false anomalies on a conductivity map. In addition, if the research site is littered with metallic debris, a conductivity meter may be an option because the operator will be able to ignore many of the small items that may be detected by the other geophysical tools with readings on the digital display.

There are two disadvantages when using the conductivity meter. First, depth information is not as accurate as with the GPR and the image is a composite of the conductivity for the entire subsurface that is measured by the conductivity meter. Second, the maximum depth of detection for the buried items when using the 25cm transects was limited to less than a meter for the largest items tested, and many of the medium size and all of the small size objects were not detected below 45-50cm. This problem was expected as the manufacturer states that the conductivity meter, on its vertical dipole, reaches maximum sensitivity at a depth of 40cm and decreases beyond that (Geonics Limited, 2006). In ideal soils, where the conductivity of the soil stays uniform with increasing depth, the effective depth of exploration can reach at least 1m. Unfortunately, the soil at the field site was not uniform and thus, the maximum depth of exploration of the instrument was 75cm. The spacing of the transmitter and receiver, the operating frequency, and the orientation of the coils determine depth of detection for a conductivity meter. Other longer, more expensive, and less portable conductivity meter units can provide information on depths greater than those tested. One of the best uses of the EM-38 conductivity meter for forensics is looking for lateral changes in conductivity related to larger excavations, and not depth of the anomaly, that are associated with clandestine burials. It is also recommended that both conductivity and inphase, or magnetic susceptibility, readings be recorded at the same time during the survey. In our case, the research focused on conductivity readings because the conductivity meter model used in the research did not allow for both readings to be recorded simultaneously. The EM-38 model that is available from Geonics Limited records conductivity and inphase simultaneously.

## Search Guidelines

### Guidelines for Choosing a Geophysical Tool

This research has shown that there are a number of options available when trying to choose which geophysical tool to use on a forensic search based on the target in question. In many instances, weapons are at a shallow depth because they have been hastily discarded.

First, materials must be considered. All of the detectors can be used for items made of steel. However, if the item in question is made of aluminum zinc, copper, or brass the magnetic locator should not be used. Second, the size of the target must be considered. If the target in question is a small metallic object buried shallower than 20-25cm, then an all-metal detector or a magnetic locator should be used. If the item is larger, then all of the detectors can be used.

Third, depth at which the target is buried must be considered. Any of the geophysical tools can be used for shallow targets buried shallower than 50cm. If the target is buried greater than 50cm and less than 75cm, the magnetic locator or the conductivity meter are options. For large objects that may be buried at a depth of at least 1m, GPR or a conductivity meter designed to detect smaller objects at deeper depths would be options.

Fourth, there are many site conditions to consider. Water-saturated ground conditions present a problem for all detectors except the magnetic locator when searching for a buried metallic object. However, a little moisture in the ground can sometimes highlight the disturbances present in the soil as anomalies. If the target is in a wooded area or if the ground surface is not flat, GPR may not be the best option, but the conductivity meter can be used along with the all-metal detector and magnetic locator. If a search is being conducted in a small backyard, many of the geophysical tools can be considered. However, if there is a large metal fence or other relatively large metal features (e.g., swingset) in close proximity to the survey area, the investigator needs to know the location of these features with respect to the instrument so the effect can be taken into account during the interpretation. The GPR is the primary option for weapons searches involving buried weapons that may be placed under a cement slab or blacktop. For example, if a suspected weapon is buried under the cement slab of a house or garage, a GPR survey can be performed to highlight specific areas for limited invasive testing through the cement. A conductivity meter can also be used for this type of search. However, if there is any metal in the concrete, the metal may interfere with the anomaly created by the actual target.

Fifth, the size of the search area must also be considered when planning the search. If the search area is very large, such as many acres, a grid search should be used with multiple operators using either all-metal detectors or magnetic locators. The conductivity meter and GPR are better suited for smaller search areas because the time-consuming tasks involved with data collection and data processing are not always conducive to the time constraints involved with a forensic search.

## Guidelines Prior to the Search

Forensic professionals should start the search for a buried weapon by gathering all possible information regarding the suspected target including size, metal composition, and a possible burial depth. All forensic personnel involved with using the geophysical search equipment must be trained prior to using the equipment in the field during an actual search. Also, if multiple metal detectors are used during a search, all of the detectors must be configured to the same settings to ensure the consistency of results. If a weapon similar to the weapon in question is available prior to the search, geophysical testing of the weapon should be performed prior to the field survey by burying the weapon at 10cm intervals to determine the optimum instrument settings for that investigation. If enough time has elapsed for the search area to have changed since the weapon in question was hidden or discarded, aerials of the search area from the burial period should be sought to help plan the search. It is also important to note that preparations for the search should focus on either defining a manageable area to search or dividing up larger search areas and starting with the most likely area first. In addition, if it is possible to have the underground utilities and pipes marked in the search area prior to the search, this can help to avoid searching and checking false targets.

## Guidelines During the Search

In the field, a grid should be constructed over the search area with transects of 1m. Next, a basic all-metal detector or magnetic locator should be used to survey the area. While both tools will detect most trash metals, the magnetic locator should ignore trash metal such as aluminum, copper and brass. However, if the weapon in question is composed of brass or aluminum, then an all-metal detector must be used. Also, although it is recommend that the tool be operated on a High setting, too much interference from cultural objects or buried utilities in the vicinity may restrict the use of a magnetic locator on the High setting. There should be one operator per geophysical tool for the entire search, and it is a good idea to have someone assisting the geophysical operator so they can place flags or markers on the ground to indicate the location of the hits. The assistant should follow the geophysical operator along the grid transects. The geophysical operator must swing the geophysical tool so there is overlapping coverage between adjacent rows or transects for complete coverage of the search area. Once the geophysical operator has a hit, the operator should discern the size and center of the hit by utilizing an X pattern with a metal detector or magnetic locator. Once the center and size of the hit is determined, the assistant should place a flag at the location of all hits with a plastic stake (metal is not recommended as the detectors will hit on any metal in the search area) and designate the hit as either *slight* or *strong*. If a large-sized hit is noted by the operator, multiple flags can be placed in the ground delineating the size of the buried target. Once the survey is completed, the operator needs to prioritize which anomalies to investigate further by excavating. It may be possible for the operator to first rule out a number of hits based on the context of the site or buried utilities. Producing a map of the site that indicates all of the features is invaluable at the data interpretation phase when prioritizing anomalies for investigation.

## Conclusions

The controlled setting of this research allowed for consistent testing, providing dependable results which can be easily replicated by investigators during real-world search scenarios. A number of issues to consider when choosing which geophysical tool to use include materials of the target, depth of the target, size of the target, size of the search area, and site conditions. Clearly, these results show that when law enforcement is searching for a buried metallic weapon, there are a number of options to choose from. The simplest, easiest, and quickest options include an all-metal detector and a magnetic locator. When site conditions allow, the search should incorporate a High setting to reach deeper depths. Even though these detectors may be advertised as simple to use, training is still a must for all forensic personnel involved in the search. Finally, when performing a search, a grid should be used in order to ensure the coverage is adequate.

# CHAPTER 10: REFERENCES

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# APPENDIX A

## Conductivity Maps

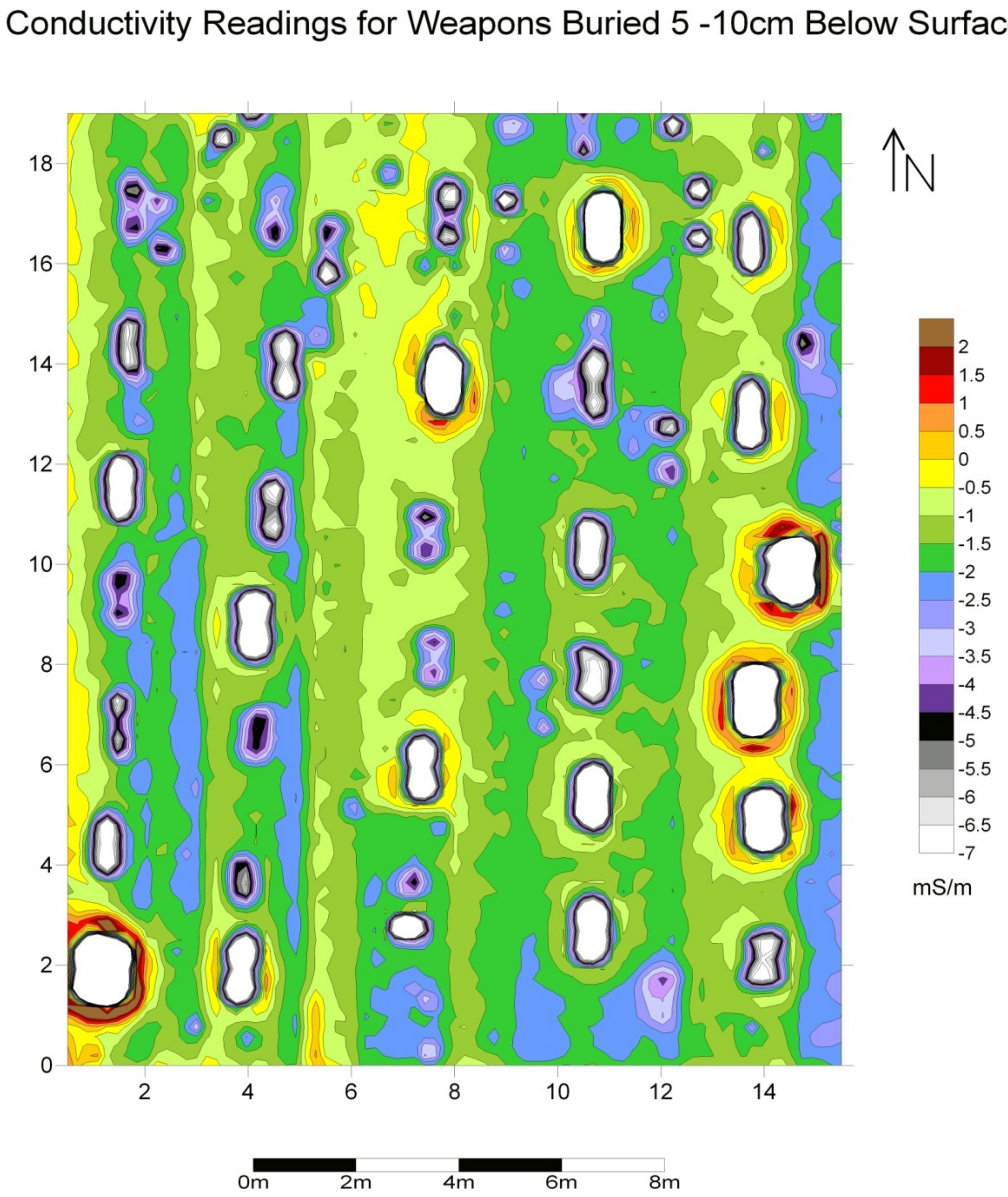
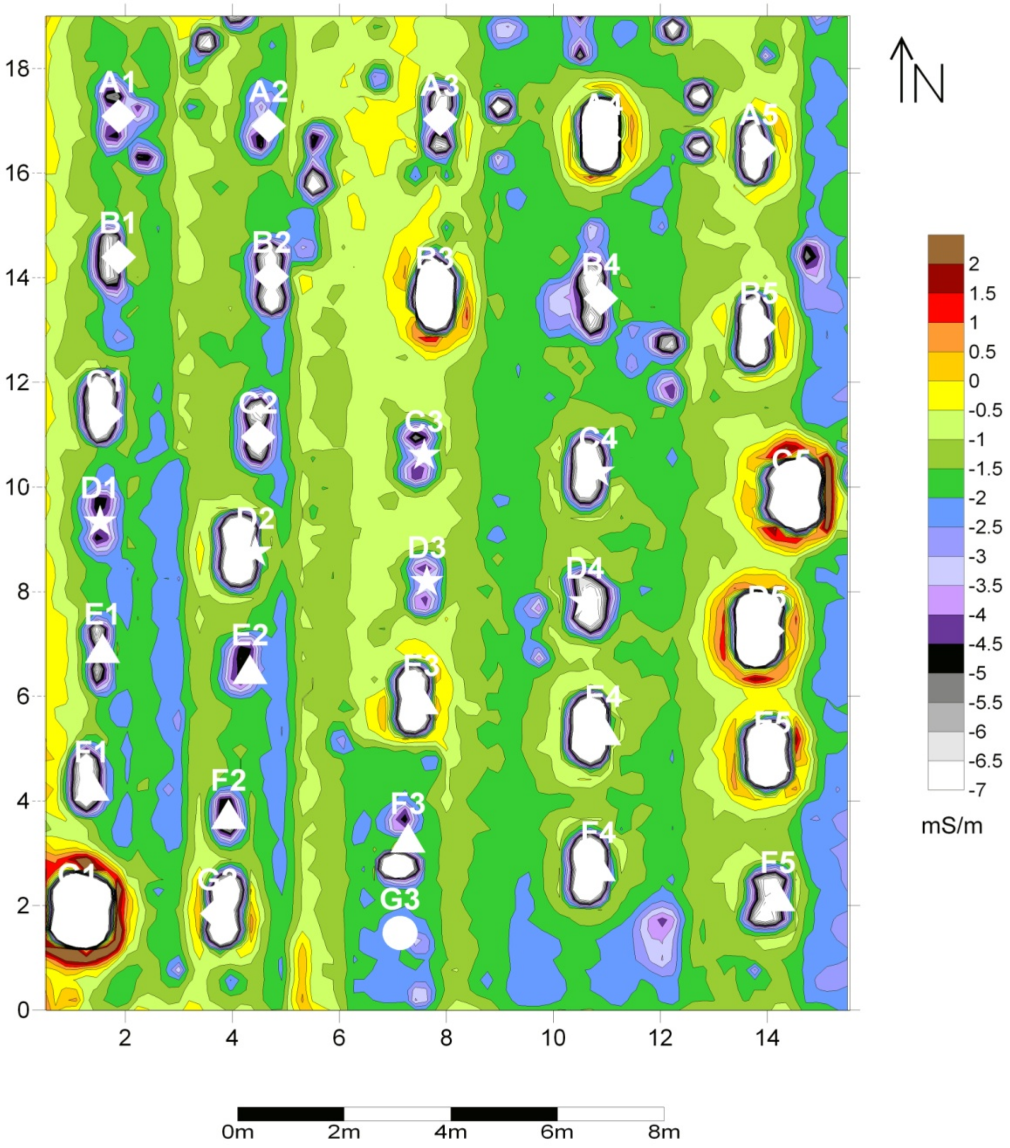


Figure A-1. Conductivity map with weapons buried between 5-10cm and mapped with 25cm transects.



Conductivity Readings for Weapons Buried 5 -10cm Below Surface

Figure A-2. Overlay of research grid on conductivity map with weapons buried between 5-10cm and mapped with 25cm transects.

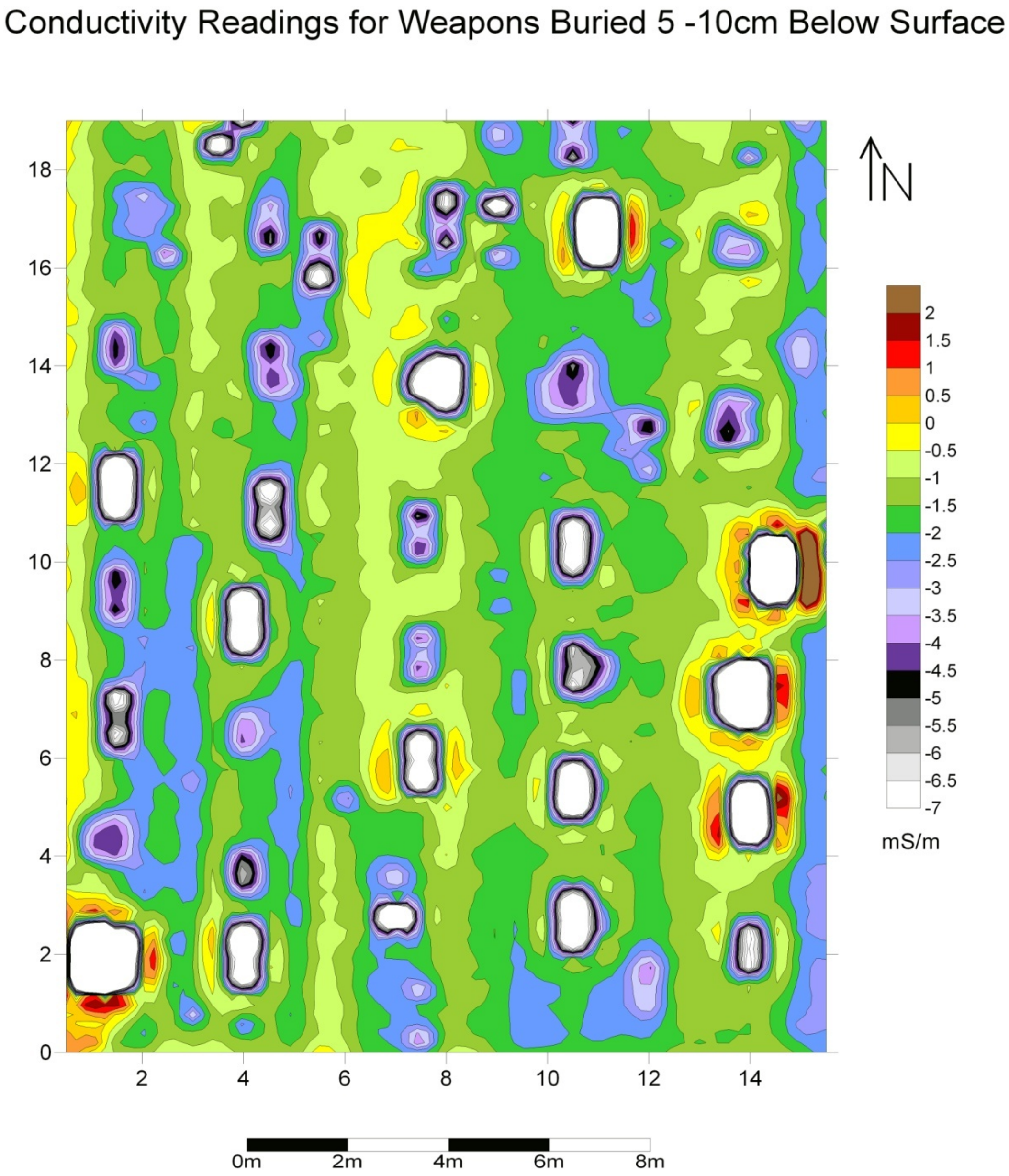


Figure A-3. Conductivity map with weapons buried between 5-10cm and mapped with 50cm transects.

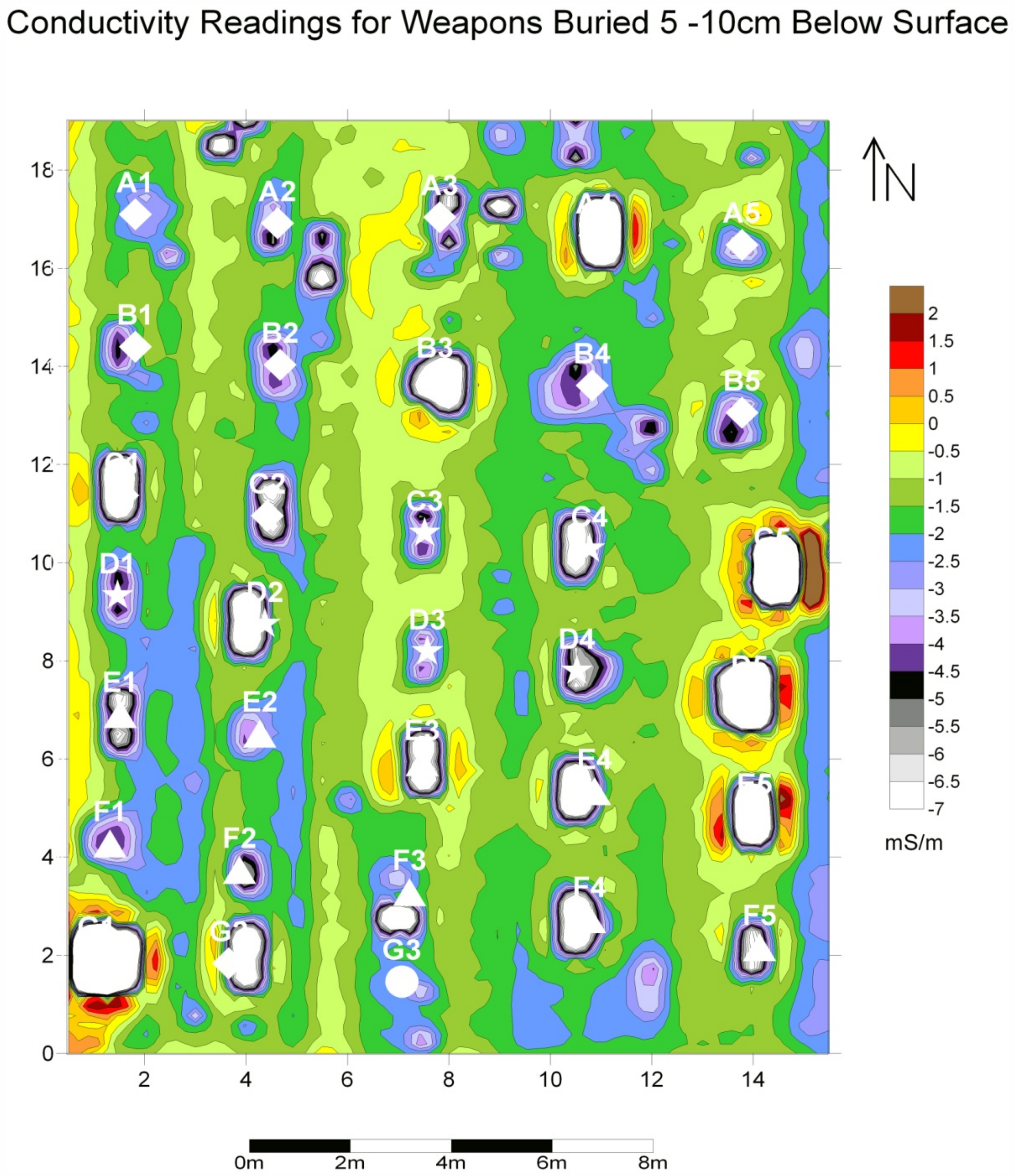

Conductivity Readings for Weapons Buried 5 -10cm Below Surface

Figure A-4. Overlay of research grid on conductivity map with weapons buried between 5-10cm and mapped with 50cm transects.

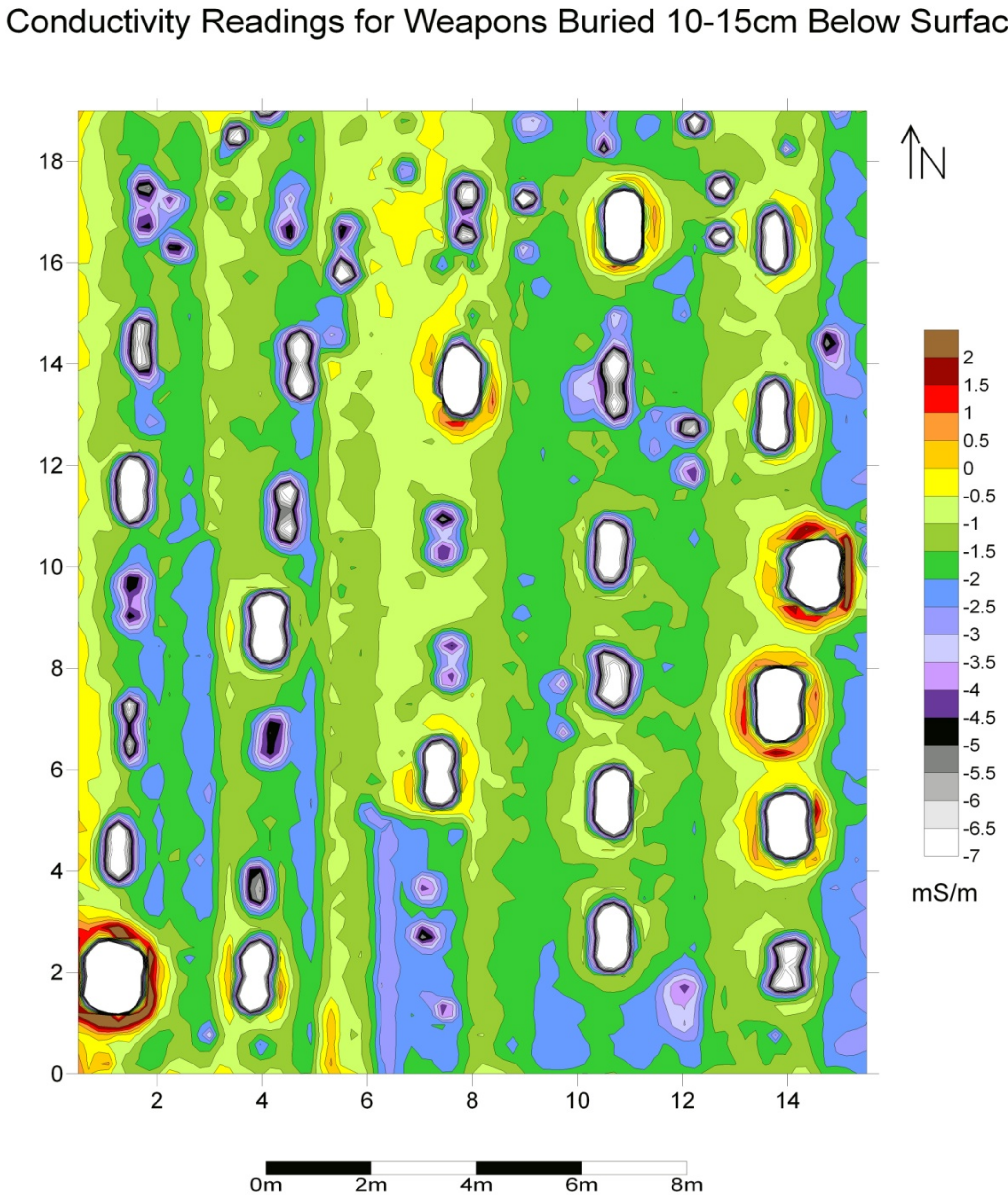

Conductivity Readings for Weapons Buried 10-15cm Below Surface

Figure A-5. Conductivity map with weapons buried between 10-15cm and mapped with 25cm transects.

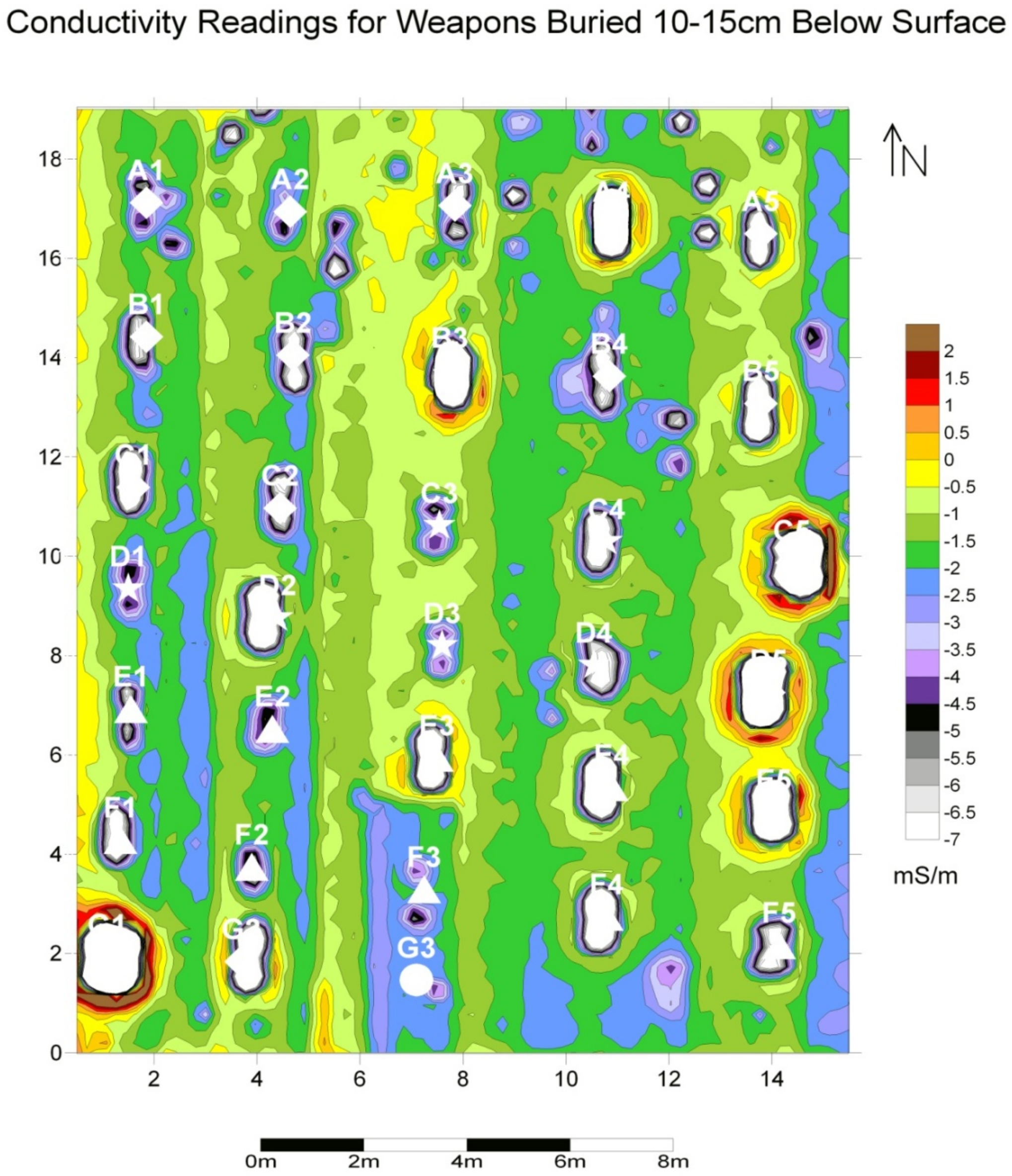


Figure A-6. Overlay of research grid on conductivity map with weapons buried between 10-15cm and mapped with 25cm transects.

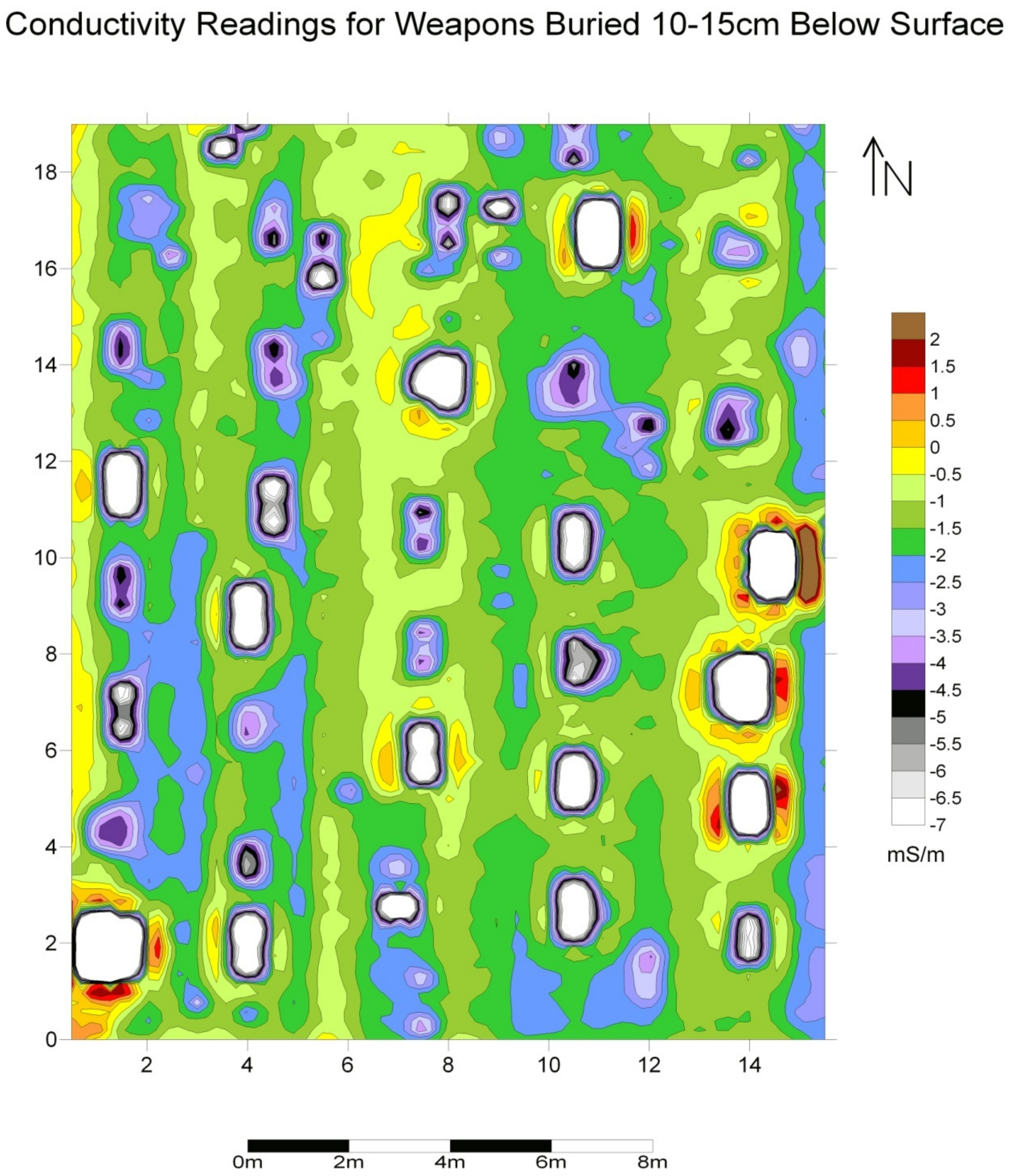


Figure A-7. Conductivity map with weapons buried between 10-15cm and mapped with 50cm transects.

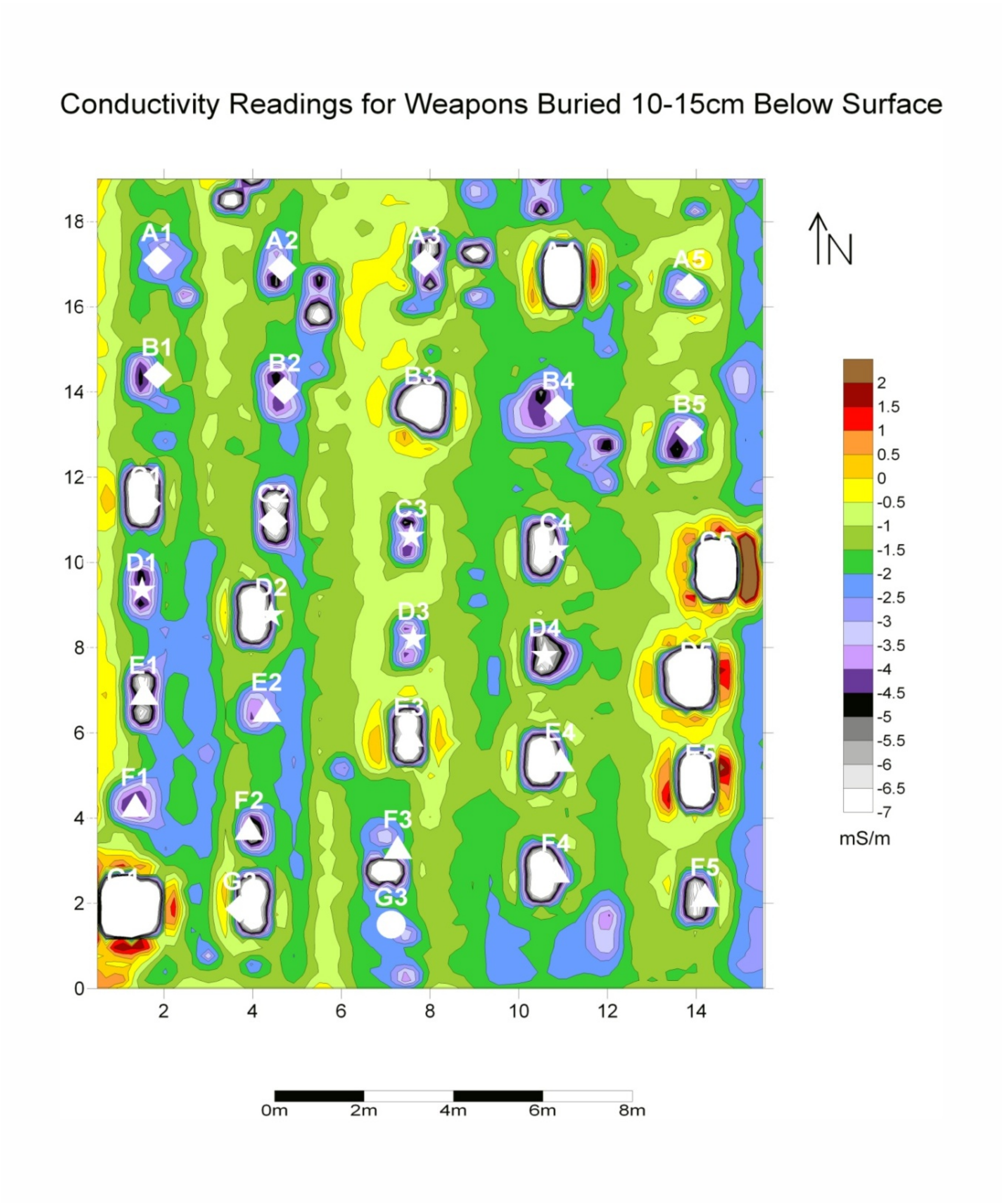


Figure A-8. Overlay of research grid on conductivity map with weapons buried between 10-15cm and mapped with 50cm transects.

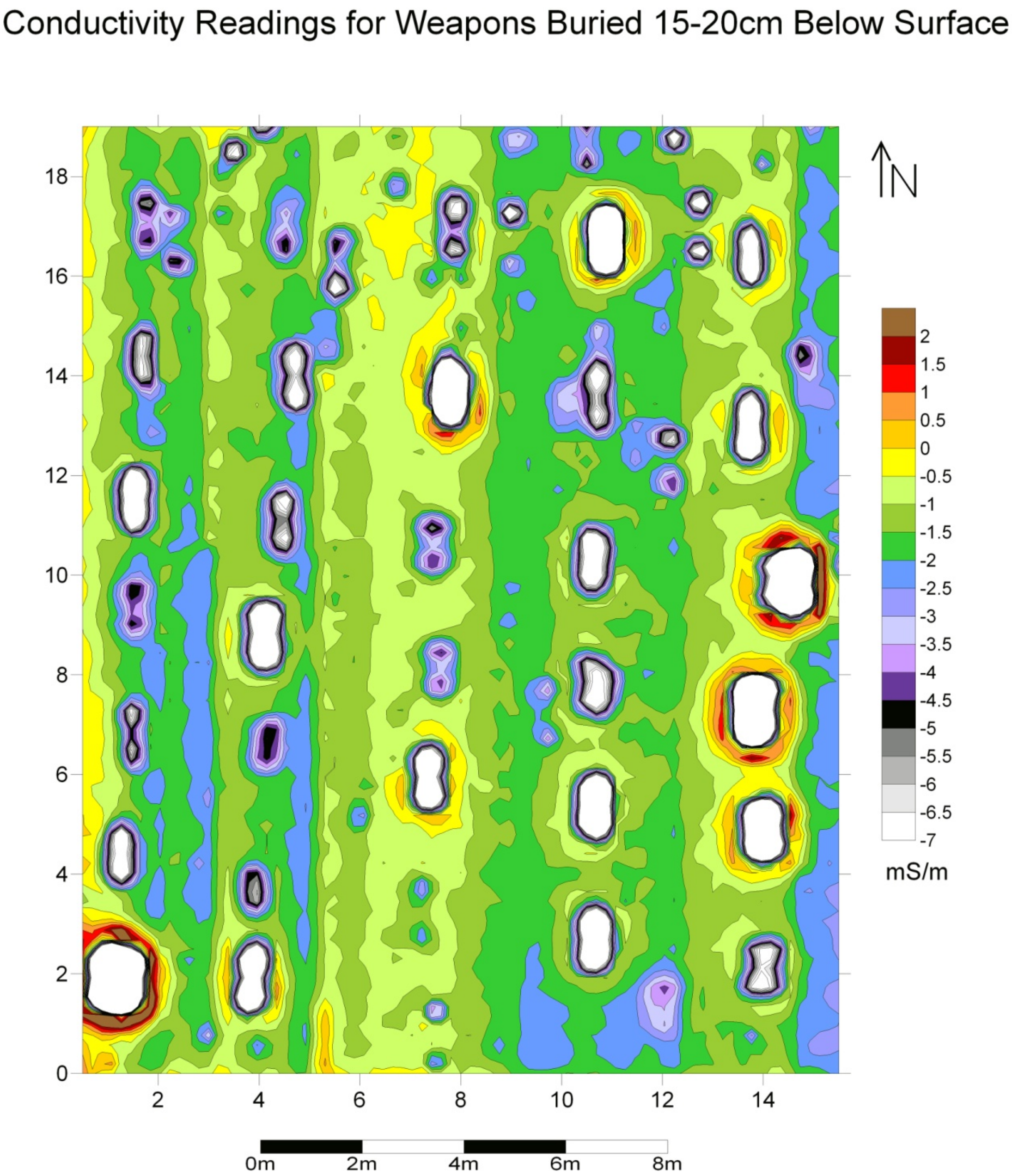
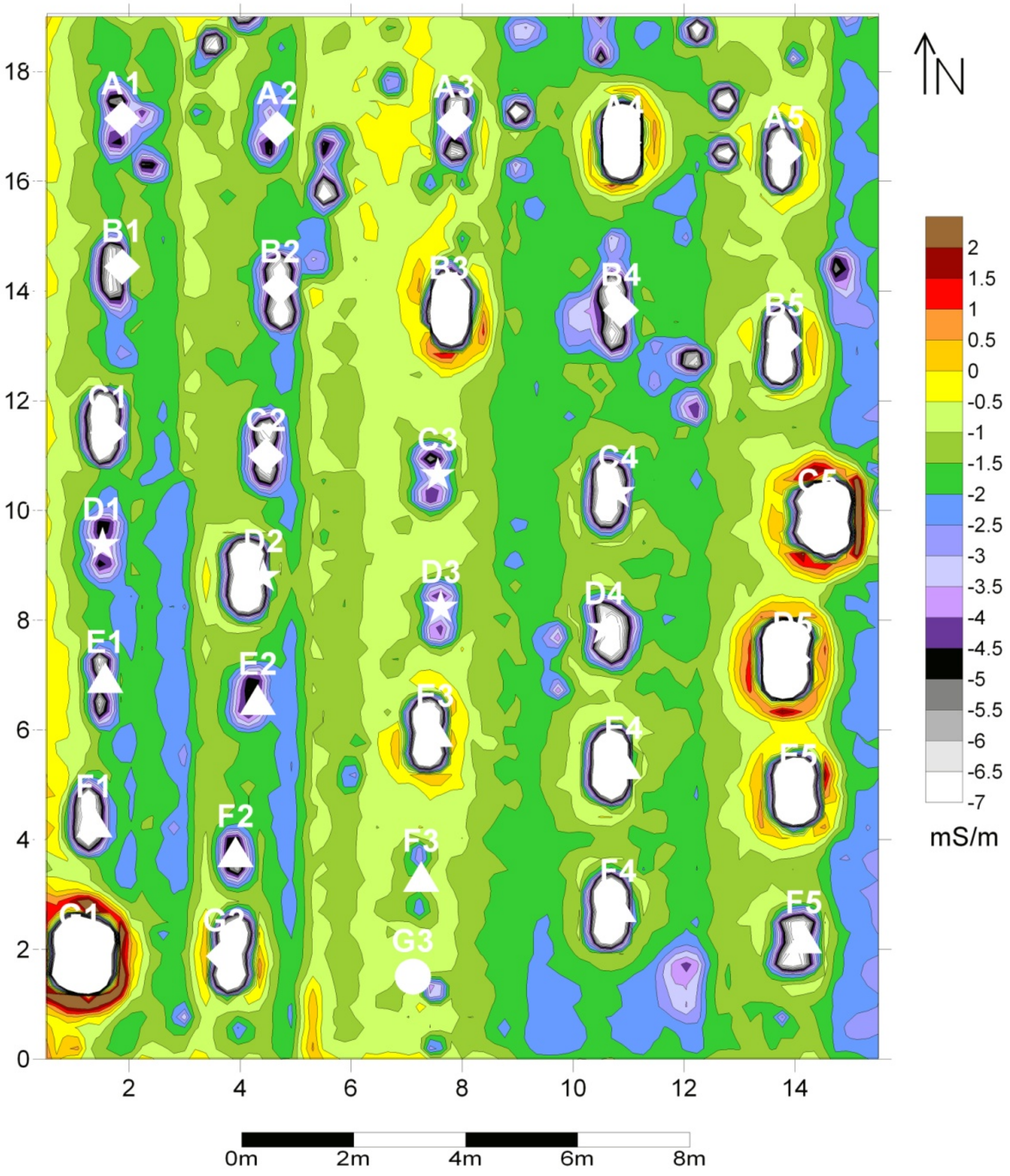


Figure A-9. Conductivity map with weapons buried between 15-20cm and mapped with 25cm transects.



Conductivity Readings for Weapons Buried 15-20cm Below Surface

Figure A-10. Overlay of research grid on conductivity map with weapons buried between 15-20cm and mapped with 25cm transects.

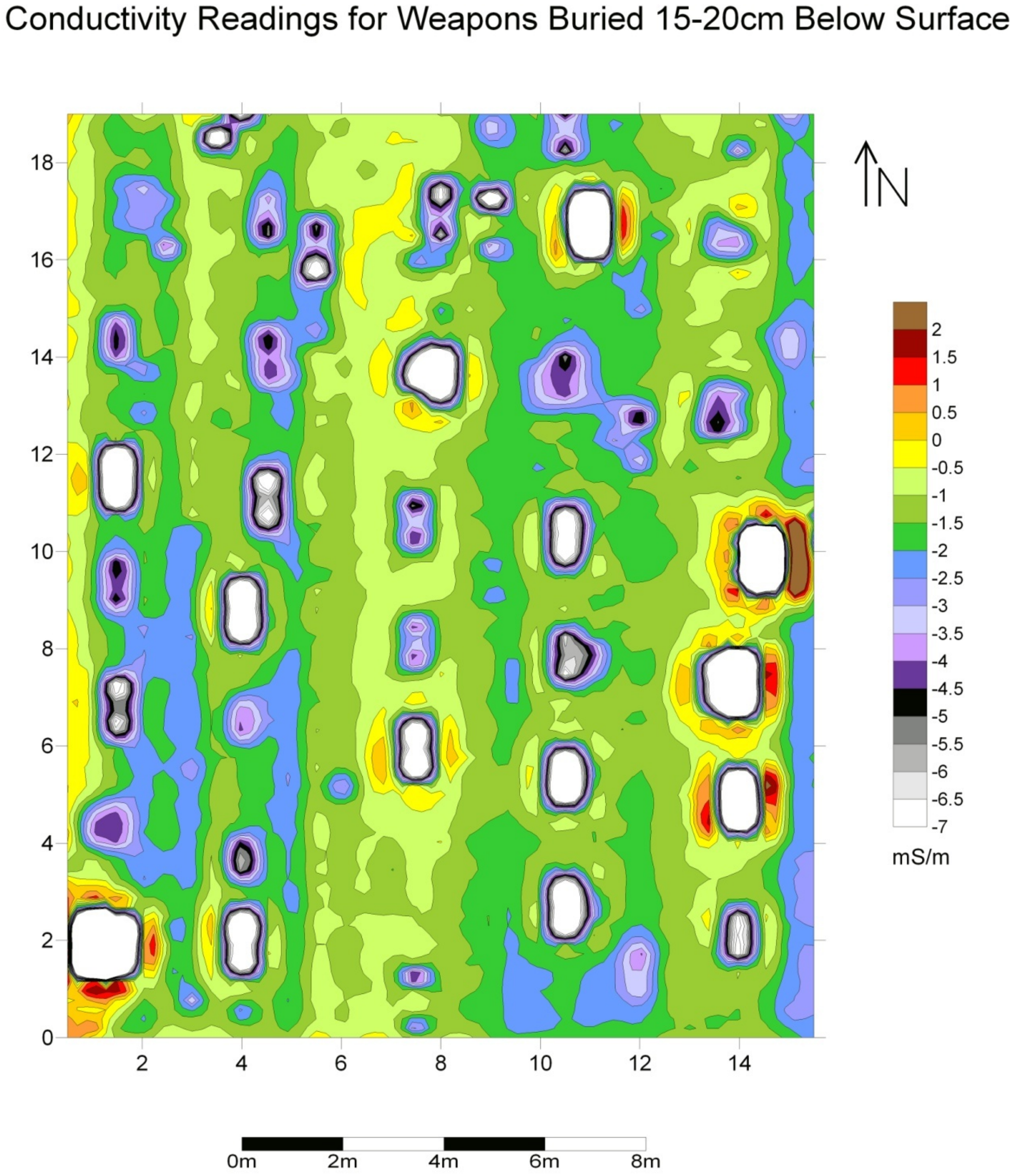


Figure A-11. Conductivity map with weapons buried between 15-20cm and mapped with 50cm transects.

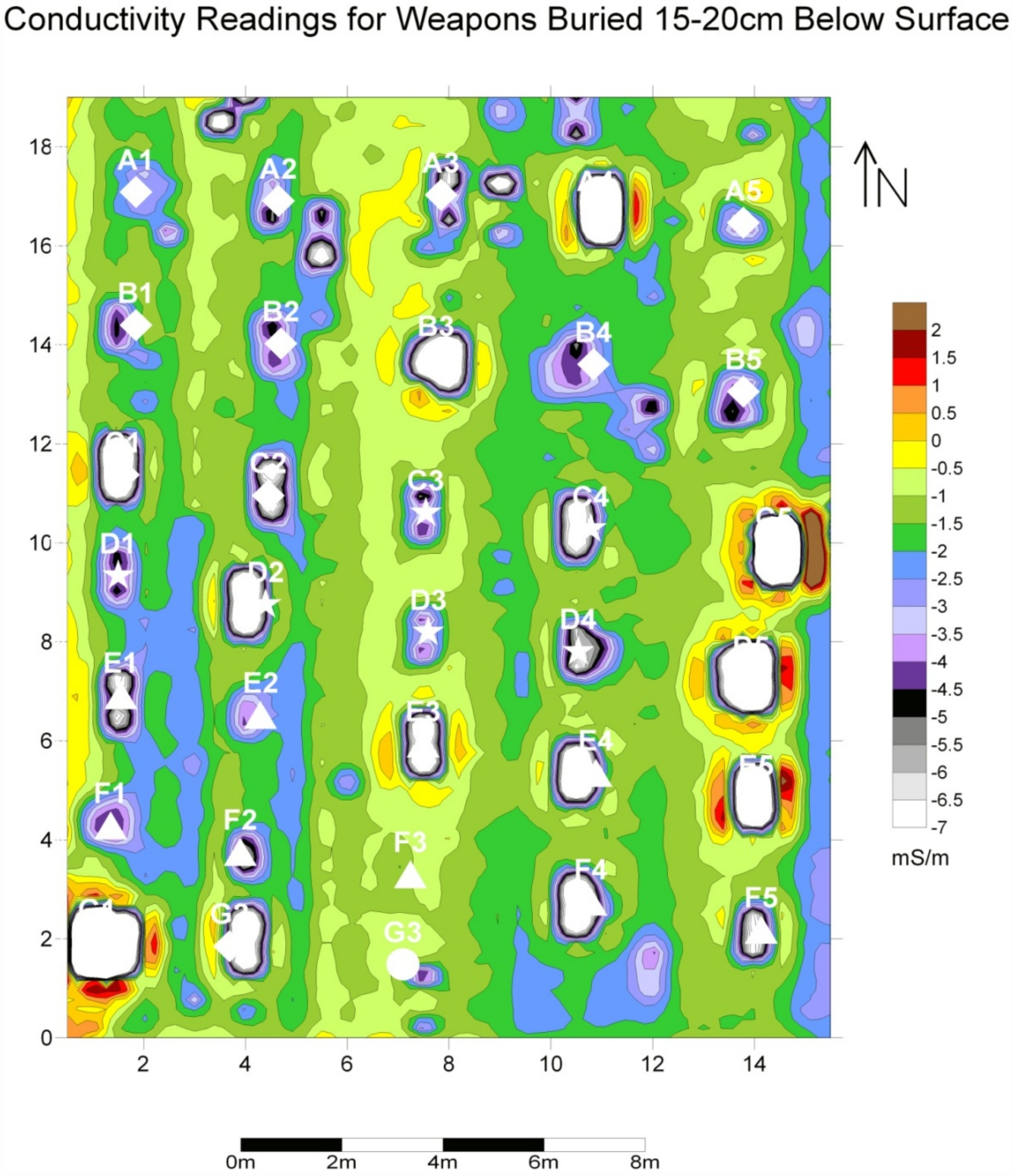


Figure A-12. Overlay of research grid on conductivity map with weapons buried between 15-20cm and mapped with 50cm transects.

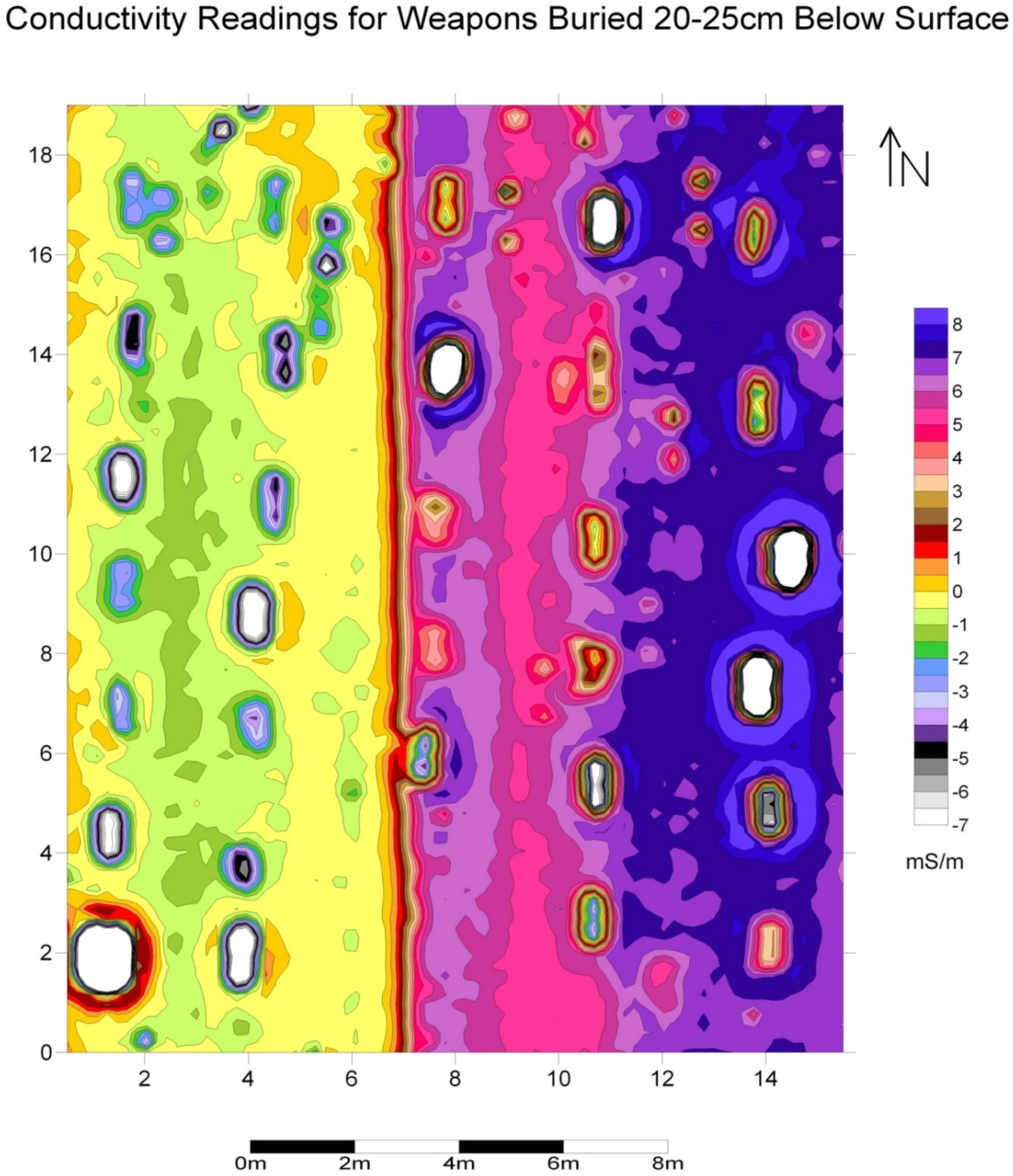


Figure A-13. Conductivity map with weapons buried between 20-25cm and mapped with 25cm transects.

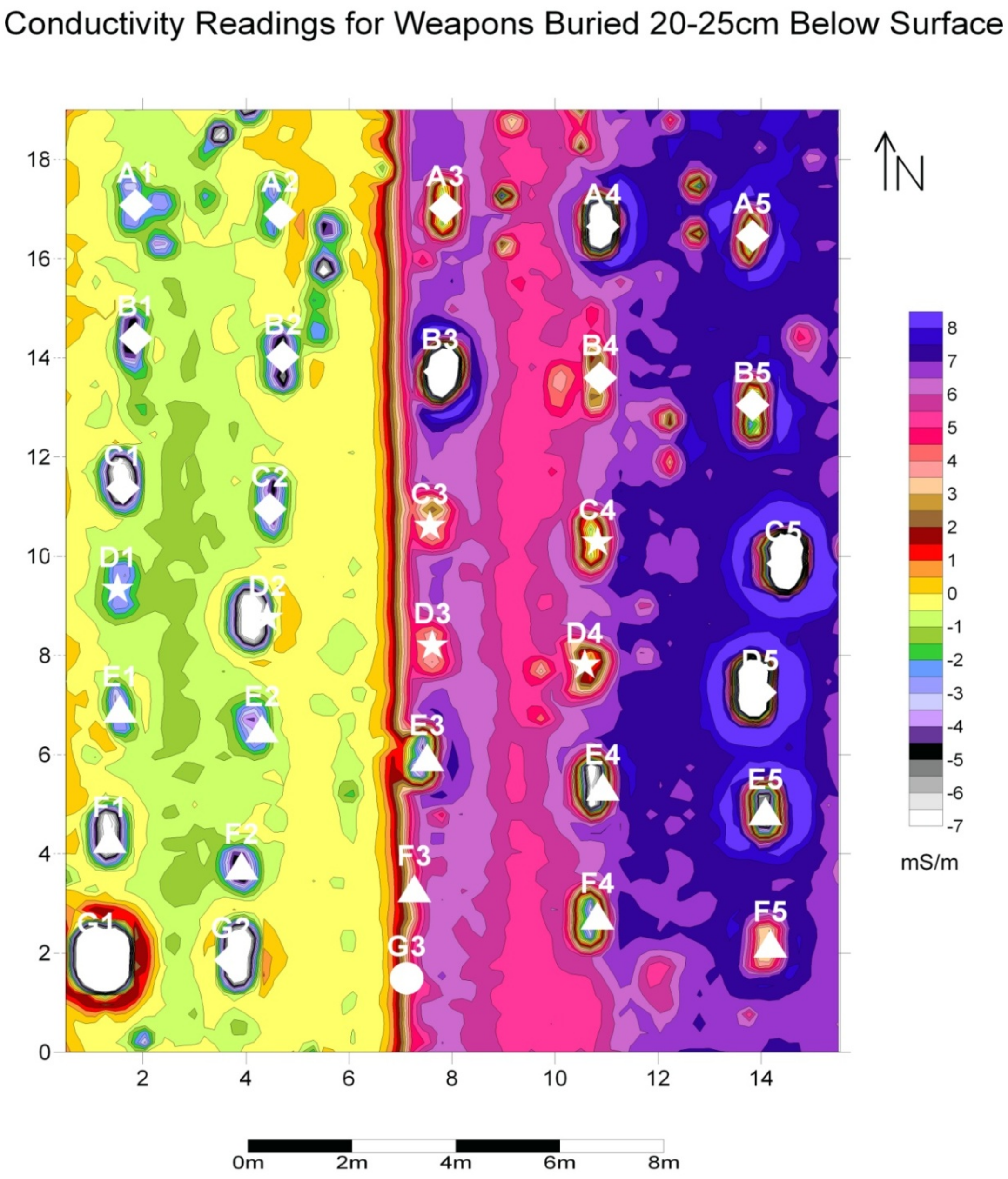


Figure A-14. Overlay of research grid on conductivity map with weapons buried between 20-25cm and mapped with 25cm transects.

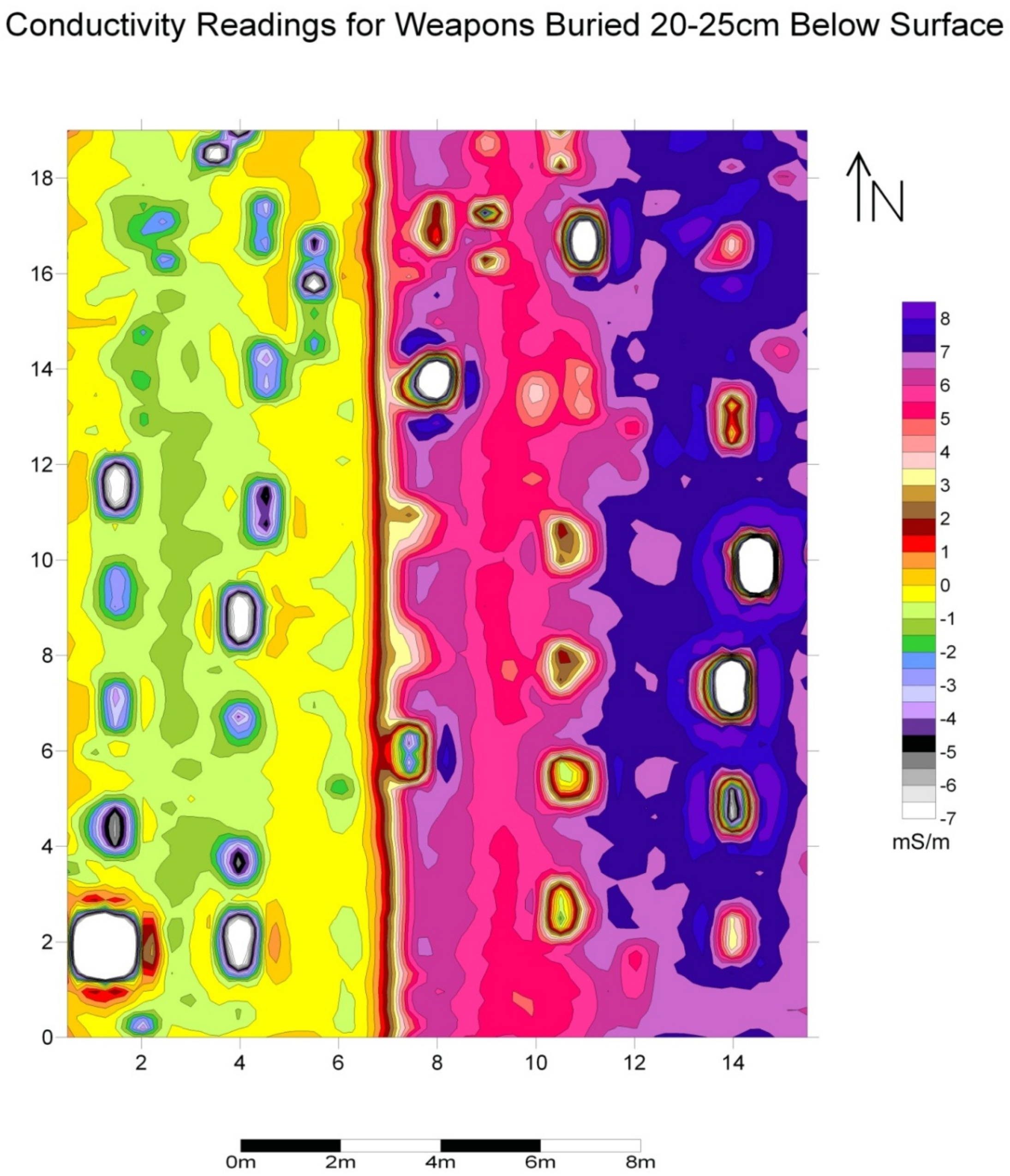


Figure A-15. Conductivity map with weapons buried between 20-25cm and mapped with 50cm transects.

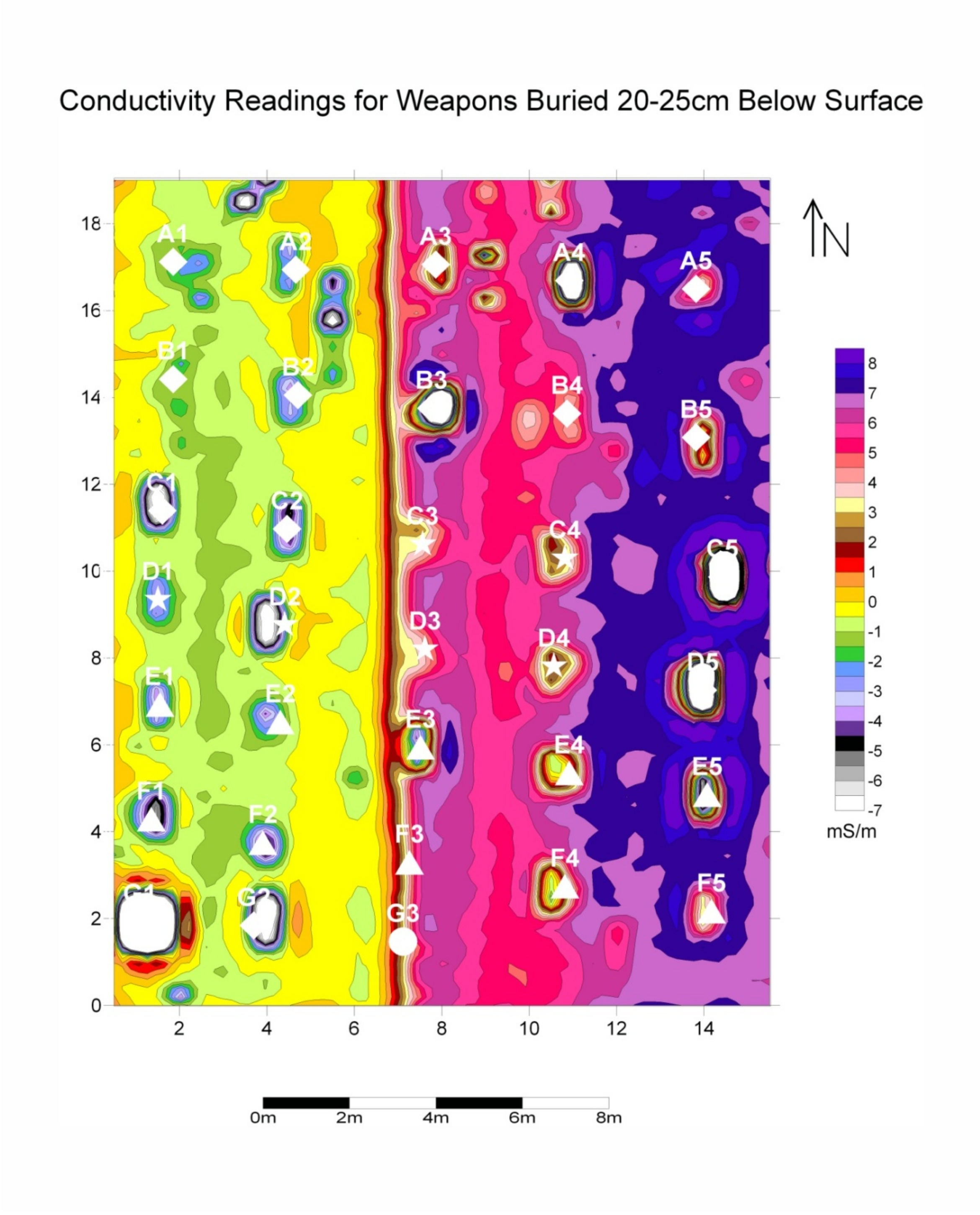


Figure A-16. Overlay of research grid on conductivity map with weapons buried between 20-25cm and mapped with 50cm transects.

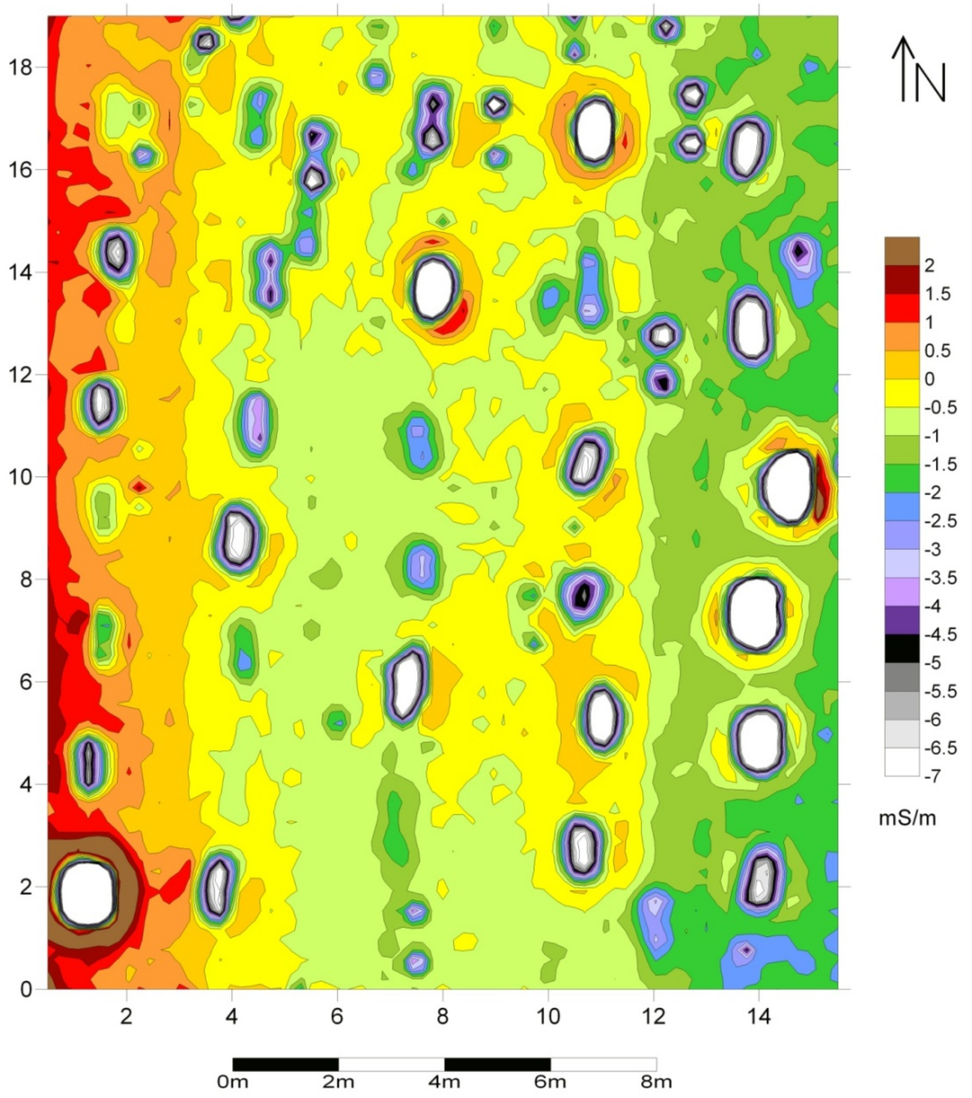

Conductivity Readings for Weapons Buried 25-30cm Below Surface

Figure A-17. Conductivity map with weapons buried between 25-30cm and mapped with 25cm transects.

Conductivity Readings for Weapons Buried 25-30cm Below Surface

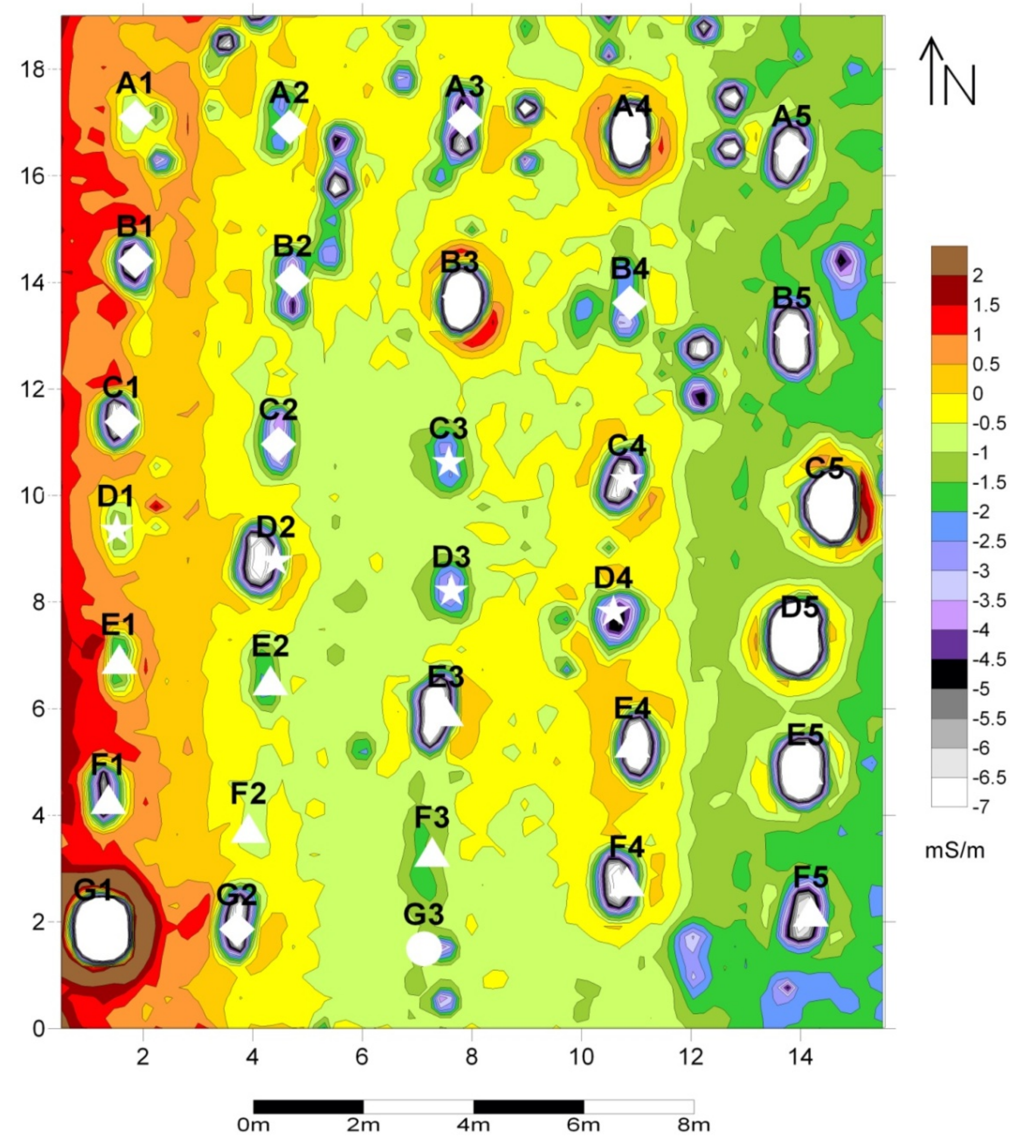


Figure A-18. Overlay of research grid on conductivity map with weapons buried between 25-30cm and mapped with 25cm transects.

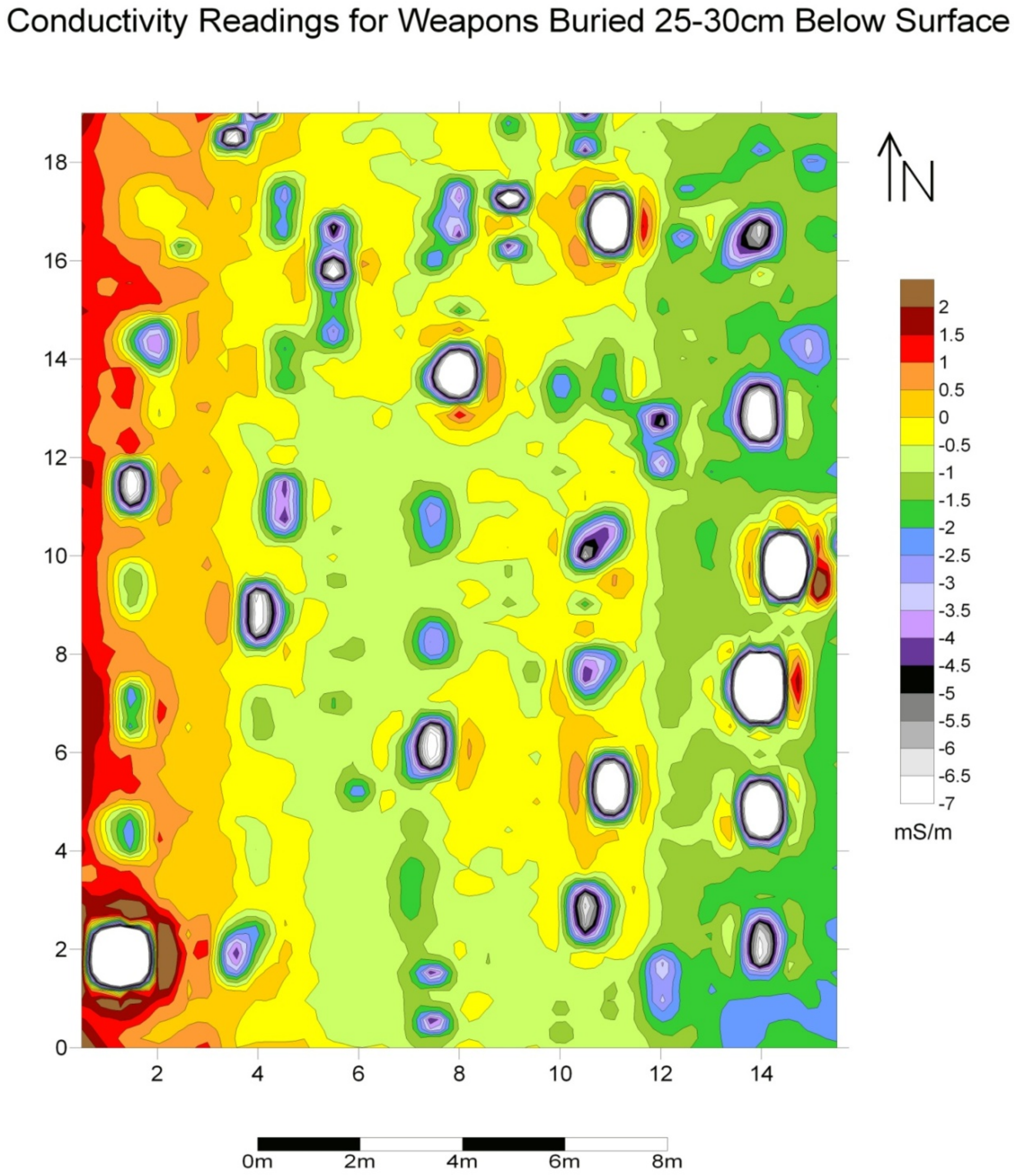


Figure A-19. Conductivity map with weapons buried between 25-30cm and mapped with 50cm transects.

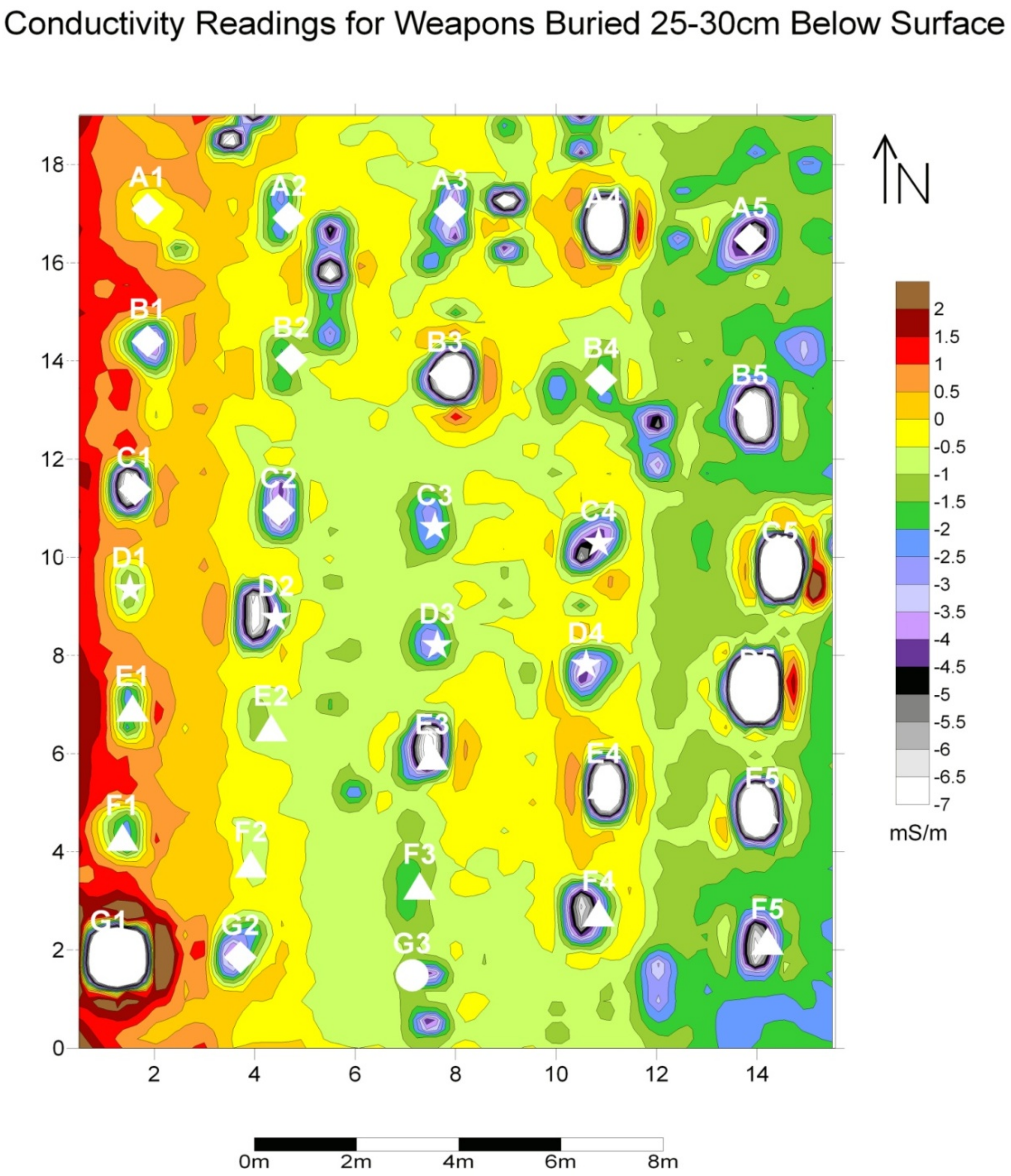


Figure A-20. Overlay of research grid on conductivity map with weapons buried between 25-30cm and mapped with 50cm transects.

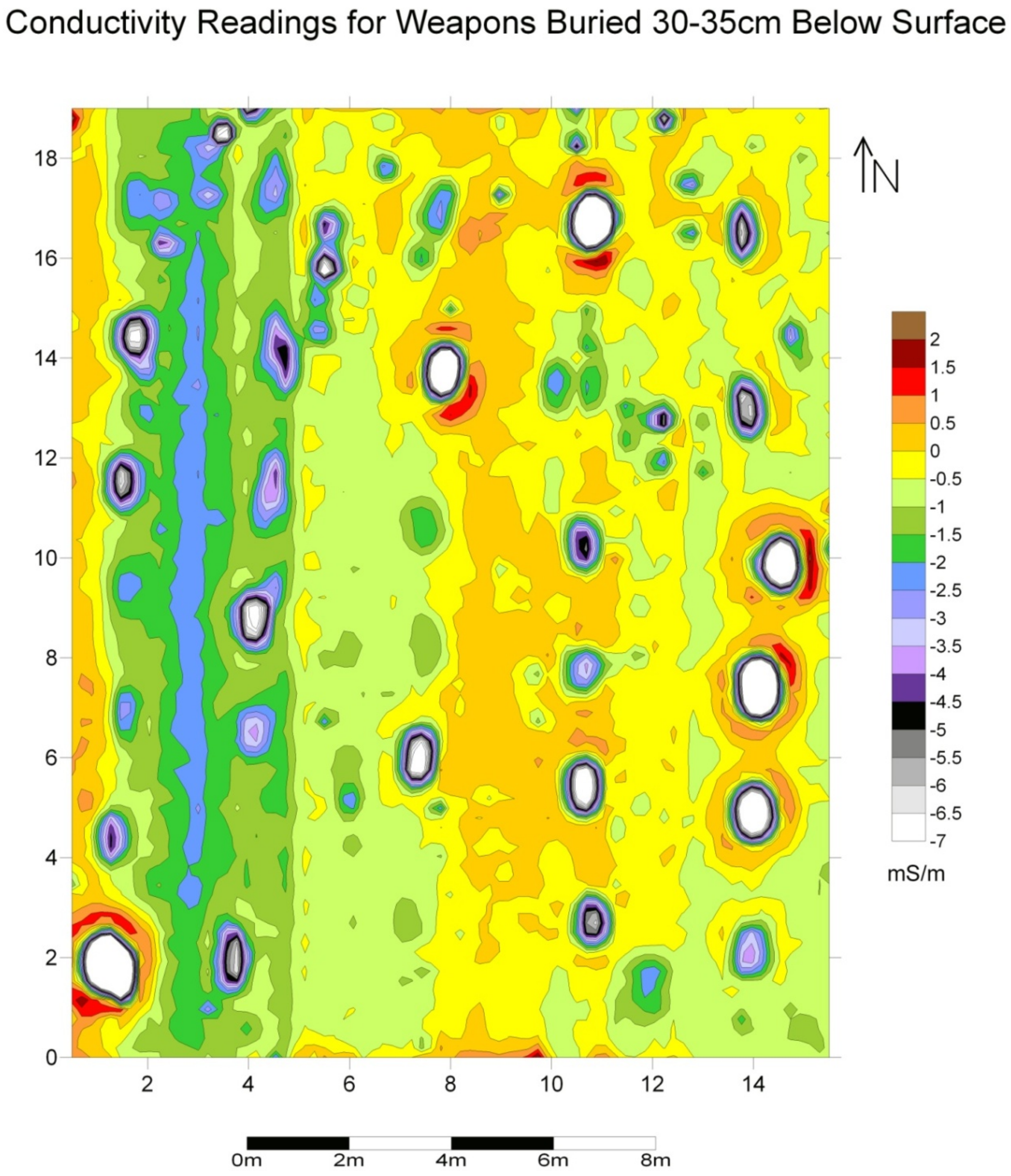


Figure A-21. Conductivity map with weapons buried between 30-35cm and mapped with 25cm transects.

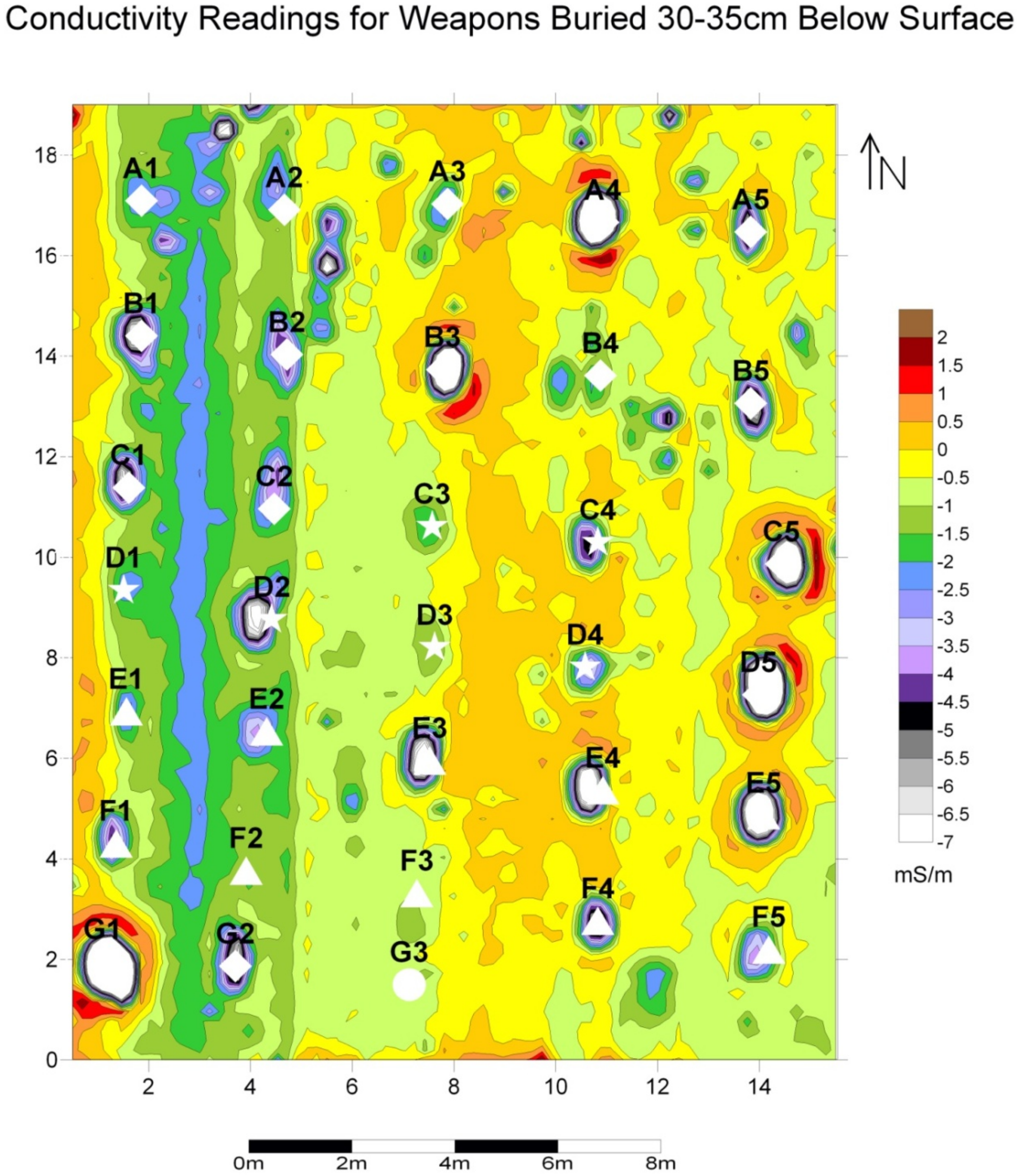


Figure A-22. Overlay of research grid on conductivity map with weapons buried between 30-35cm and mapped with 25cm transects.

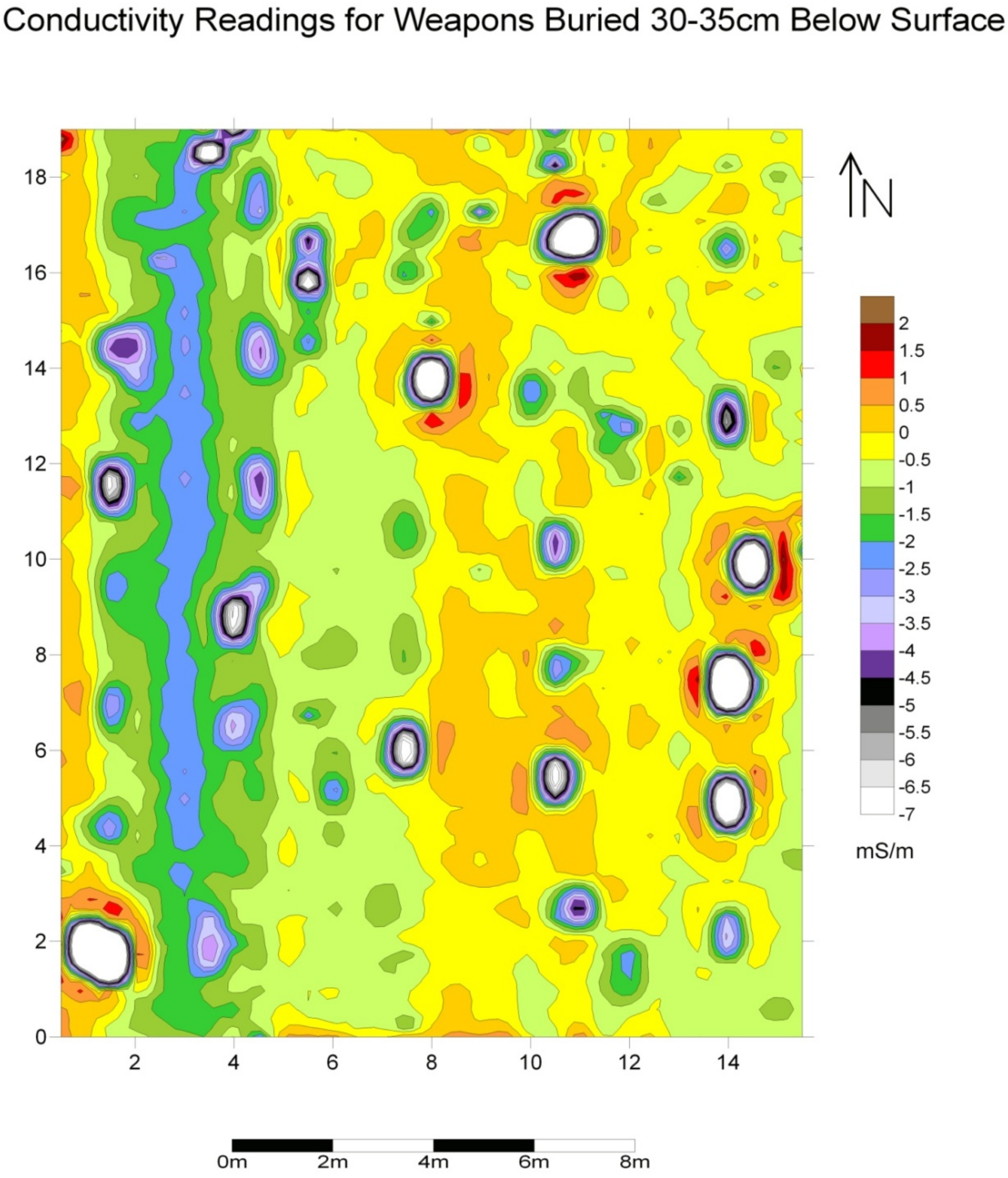


Figure A-23. Conductivity map with weapons buried between 30-35cm and mapped with 50cm transects.

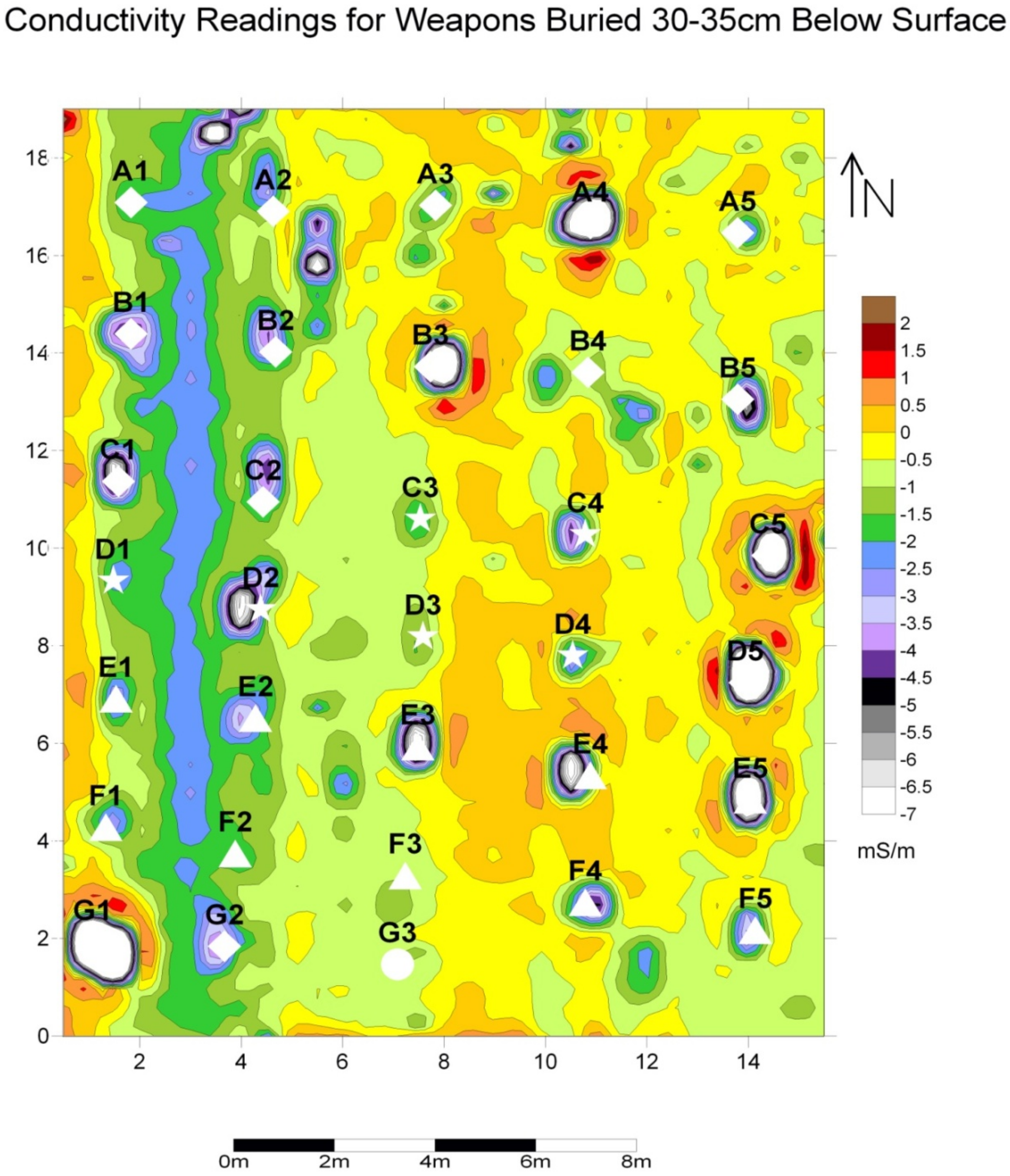


Figure A-24. Overlay of research grid on conductivity map with weapons buried between 30-35cm and mapped with 50cm transects.

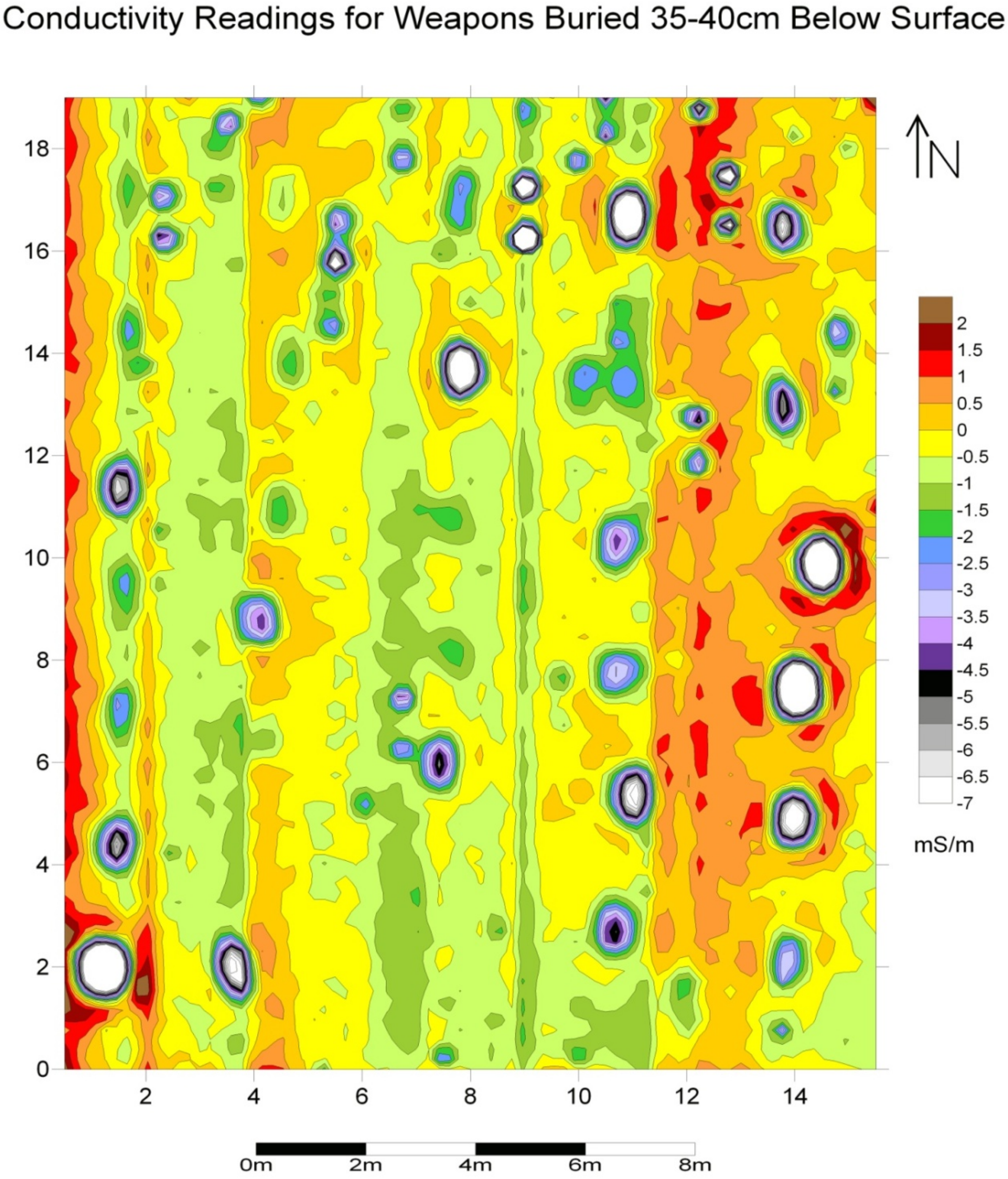


Figure A-25. Conductivity map with weapons buried between 35-40cm and mapped with 25cm transects.

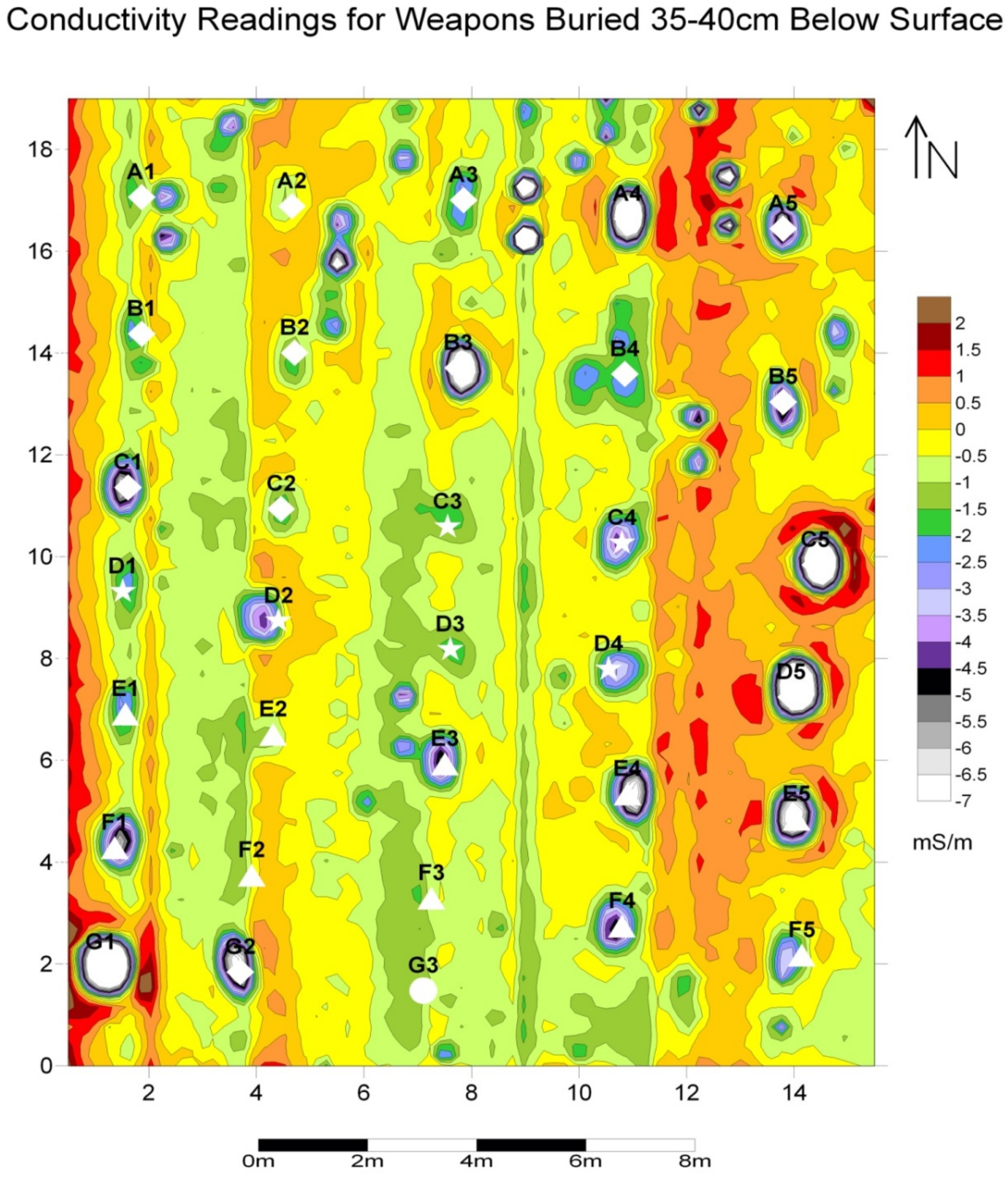


Figure A-26. Overlay of research grid on conductivity map with weapons buried between 35-40cm and mapped with 25cm transects.

Conductivity Readings for Weapons Buried 35-40cm Below Surface

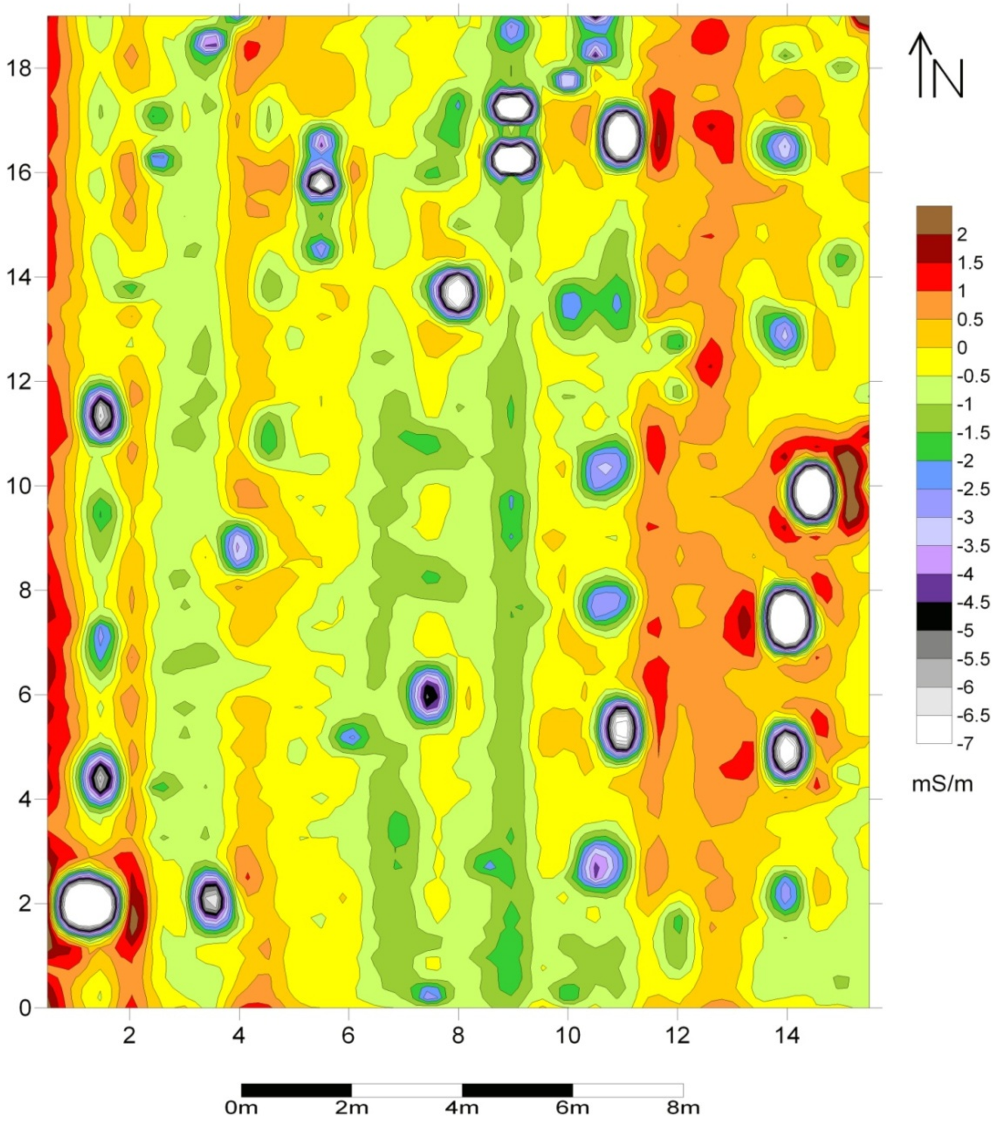


Figure A-27. Conductivity map with weapons buried between 35-40cm and mapped with 50cm transects.

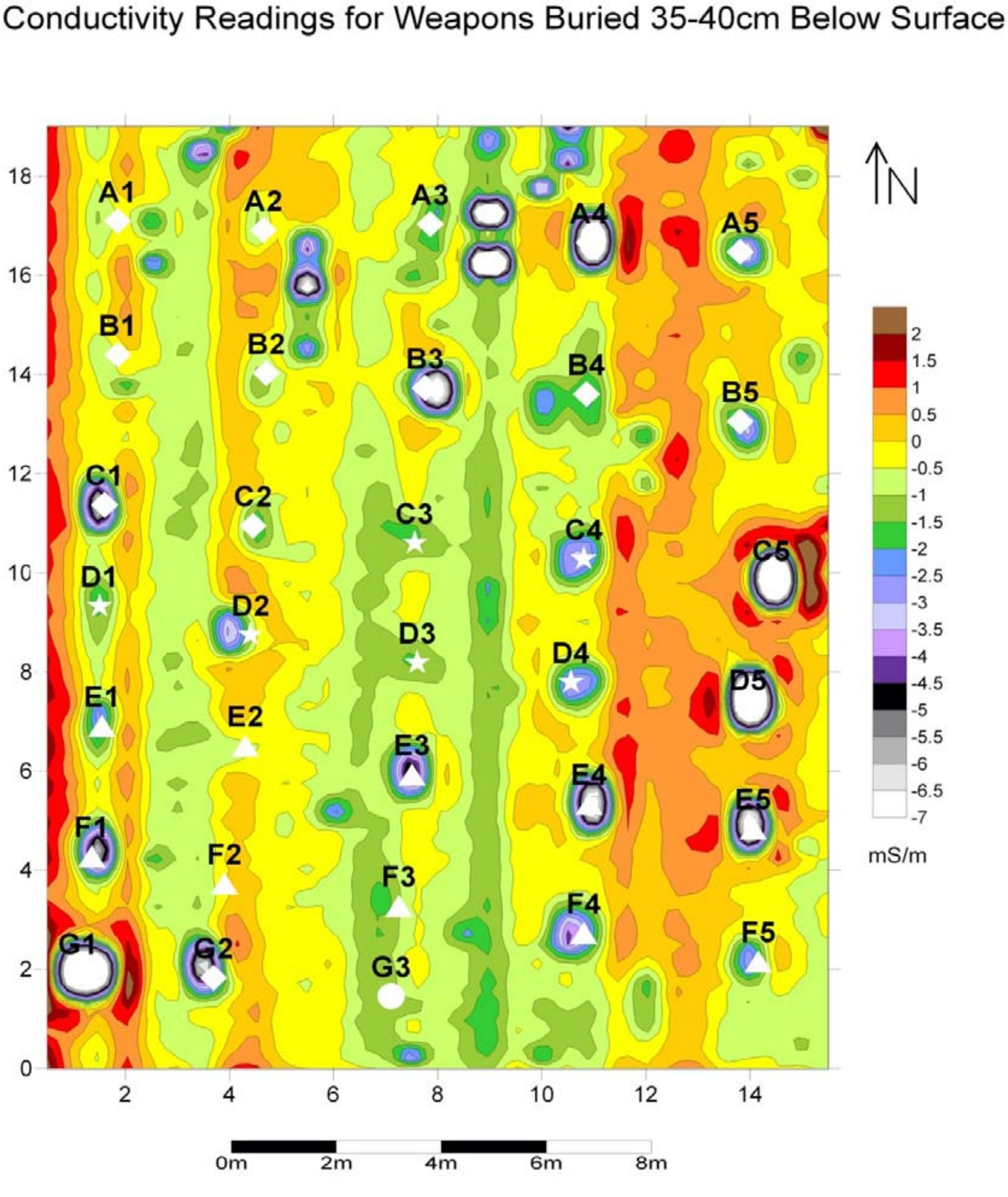


Figure A-28. Overlay of research grid on conductivity map with weapons buried between 35-40cm and mapped with 50cm transects.

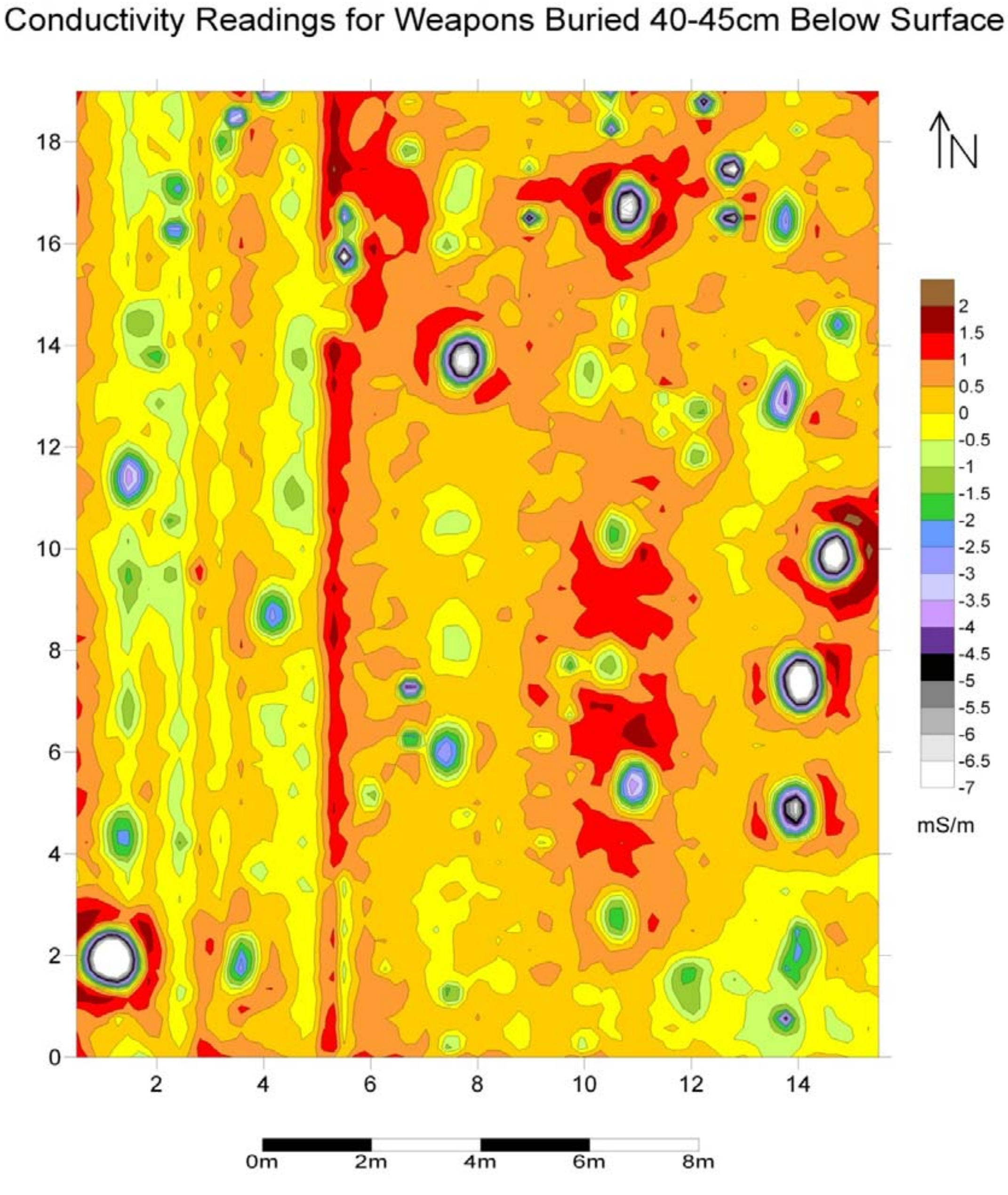


Figure A-29. Conductivity map with weapons buried between 40-45cm and mapped with 25cm transects.

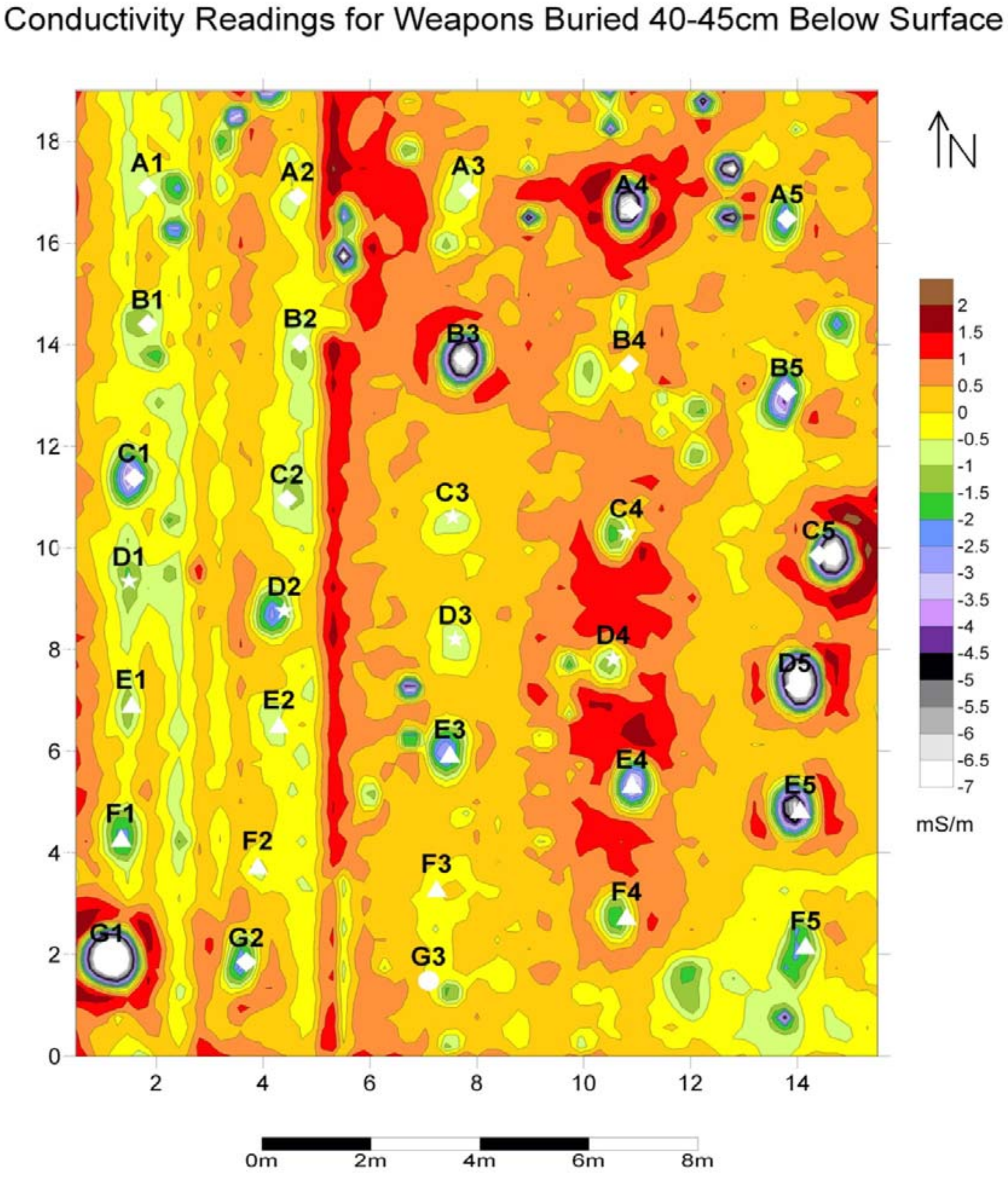
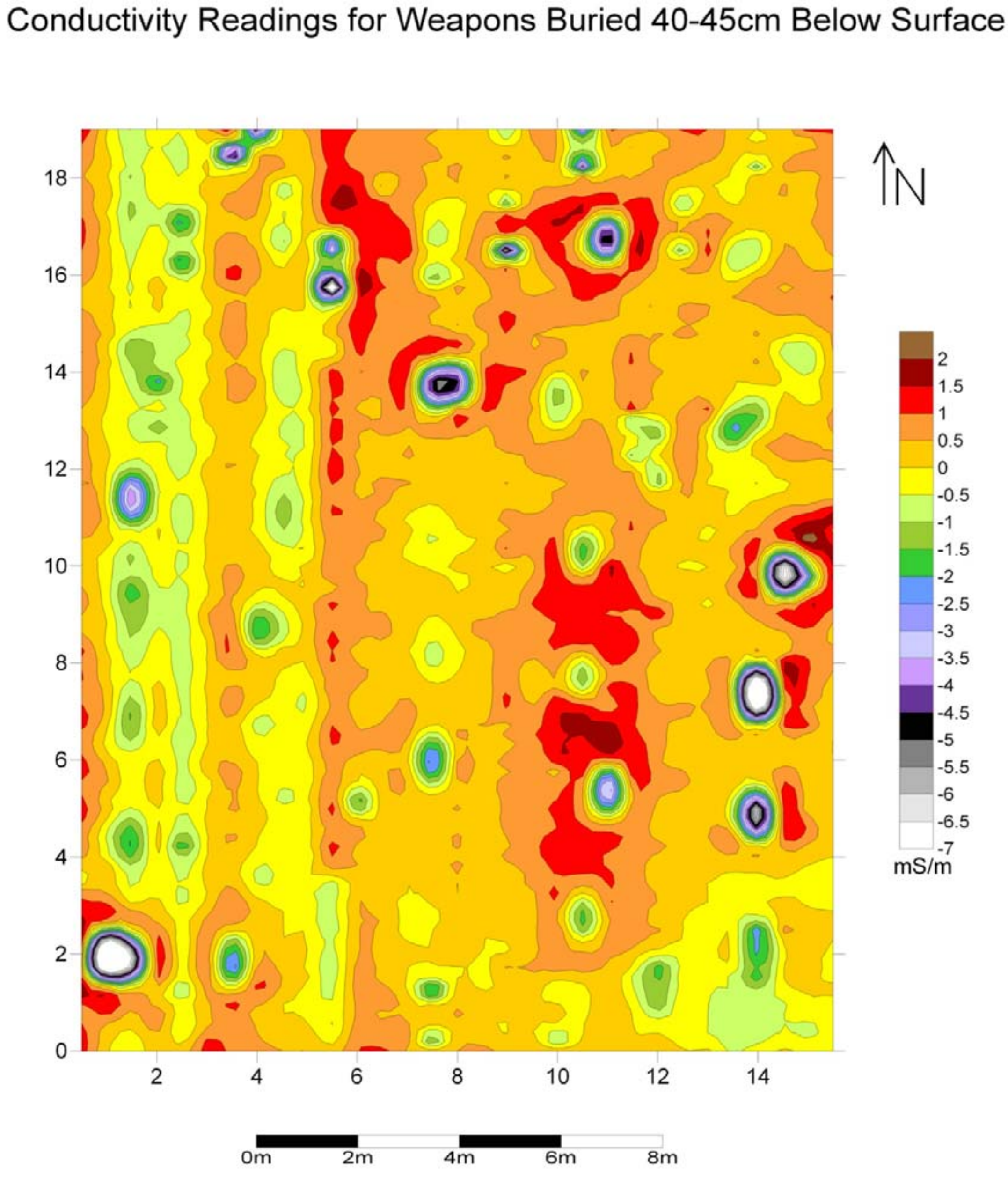


Figure A-30. Overlay of research grid on conductivity map with weapons buried between 40-45cm and mapped with 25cm transects.



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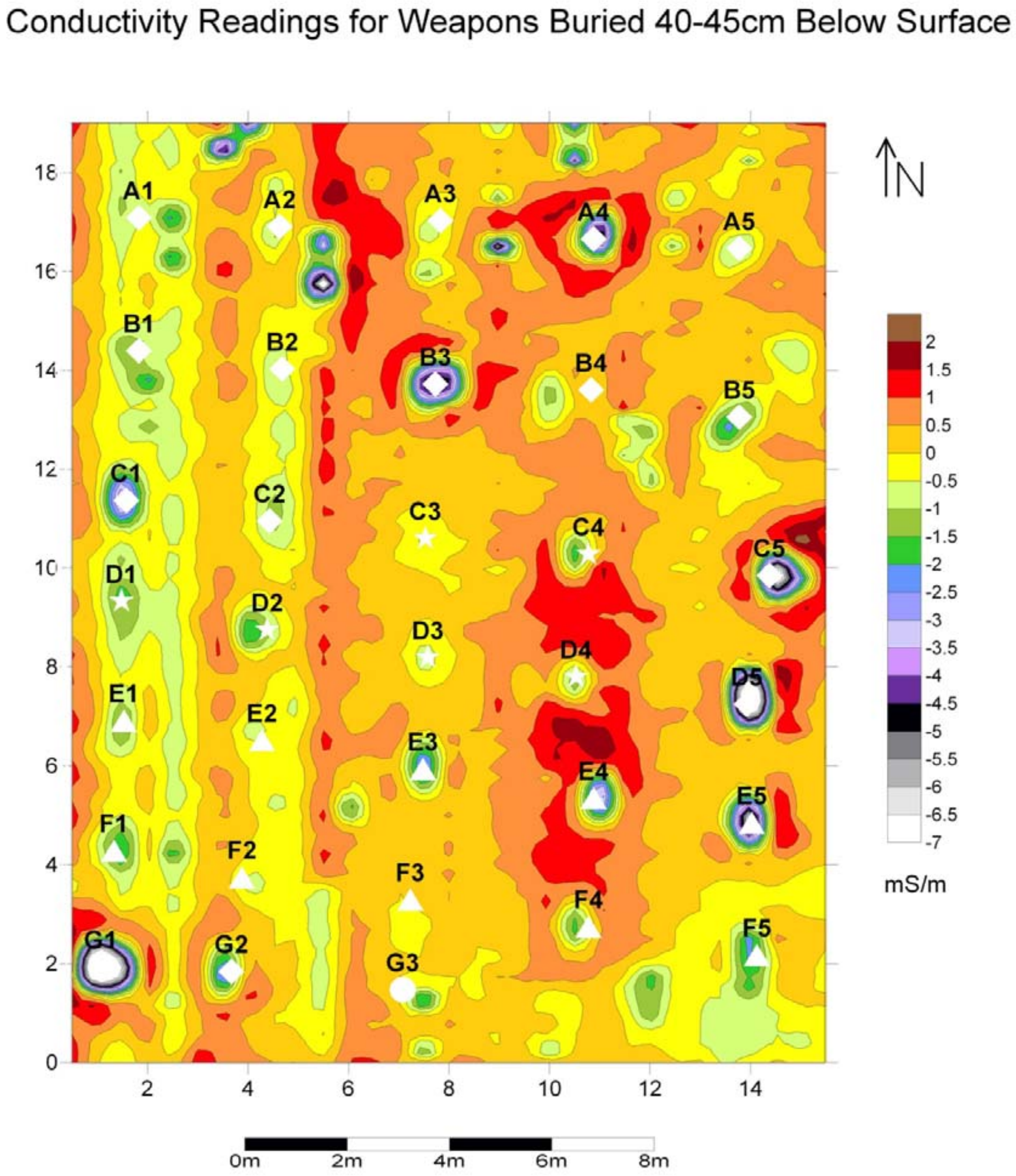

Figure A-32. Overlay of research grid on conductivity map with weapons buried between 40-45cm and mapped with 50cm transects.

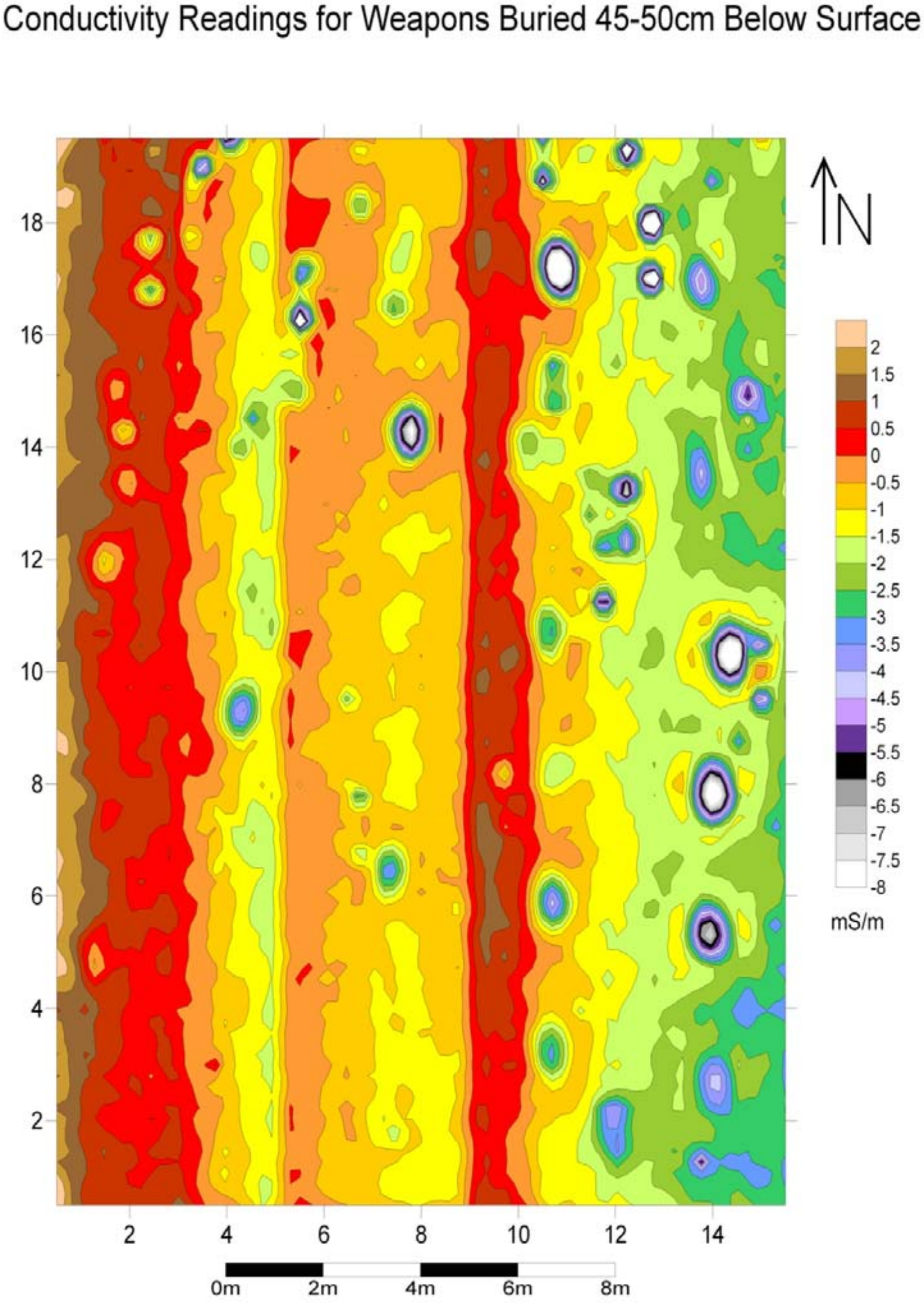

Figure A-33. Conductivity map with weapons buried between 45-50cm and mapped with 25cm transects.

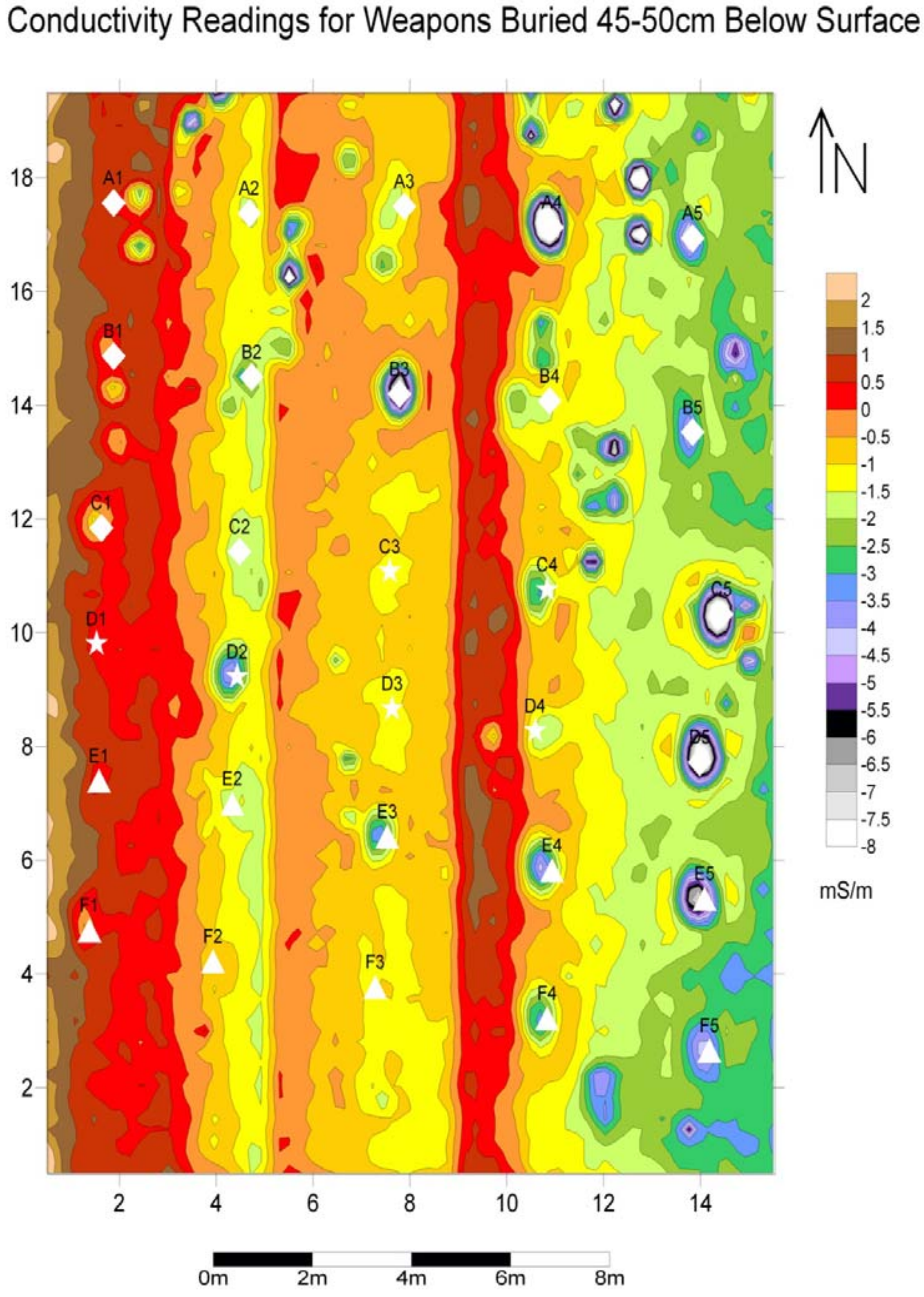

Figure A-34. Overlay of research grid on conductivity map with weapons buried between 45-50cm and mapped with 25cm transects.

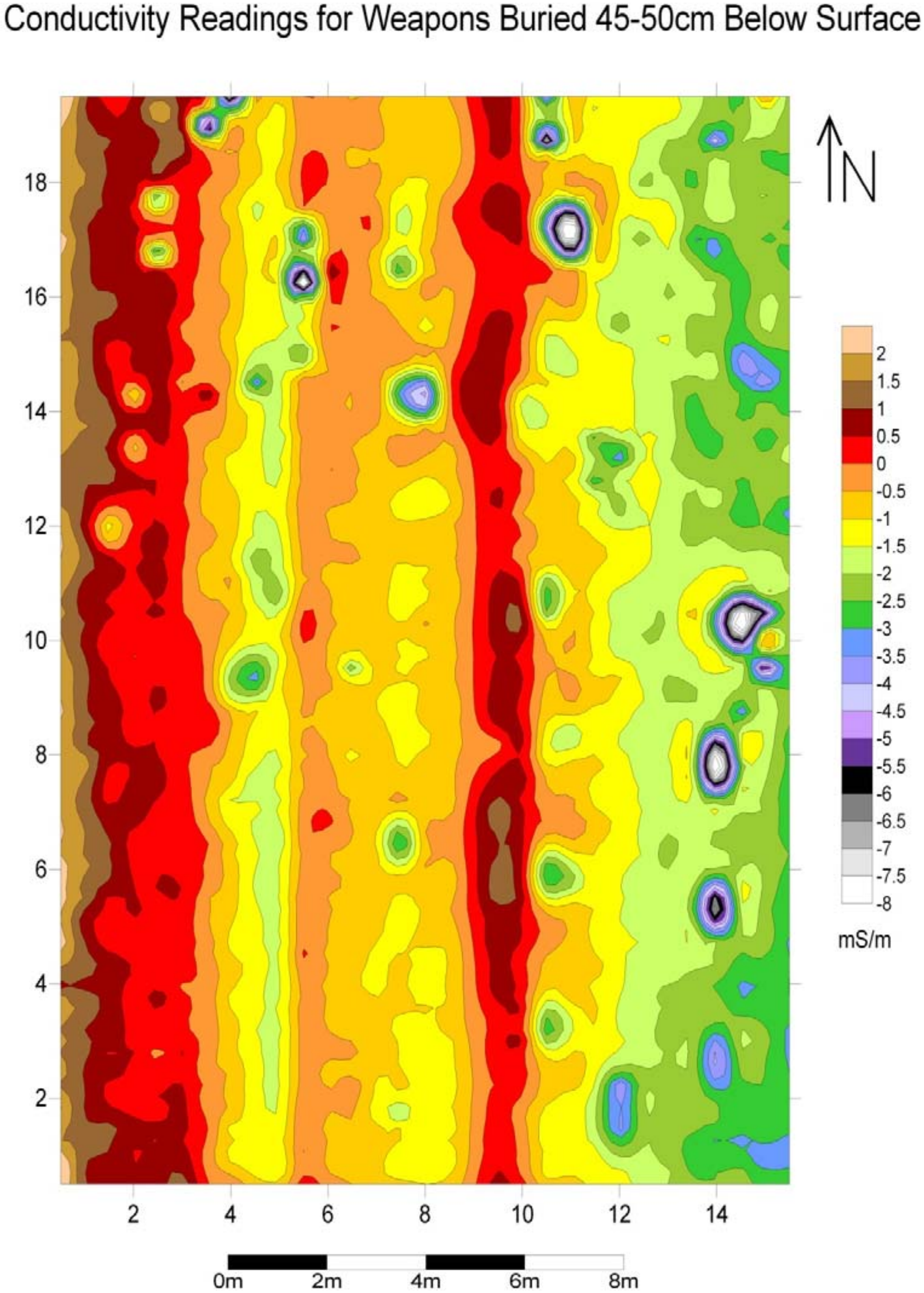

Figure A-35. Conductivity map with weapons buried between 45-50cm and mapped with 50cm transects.

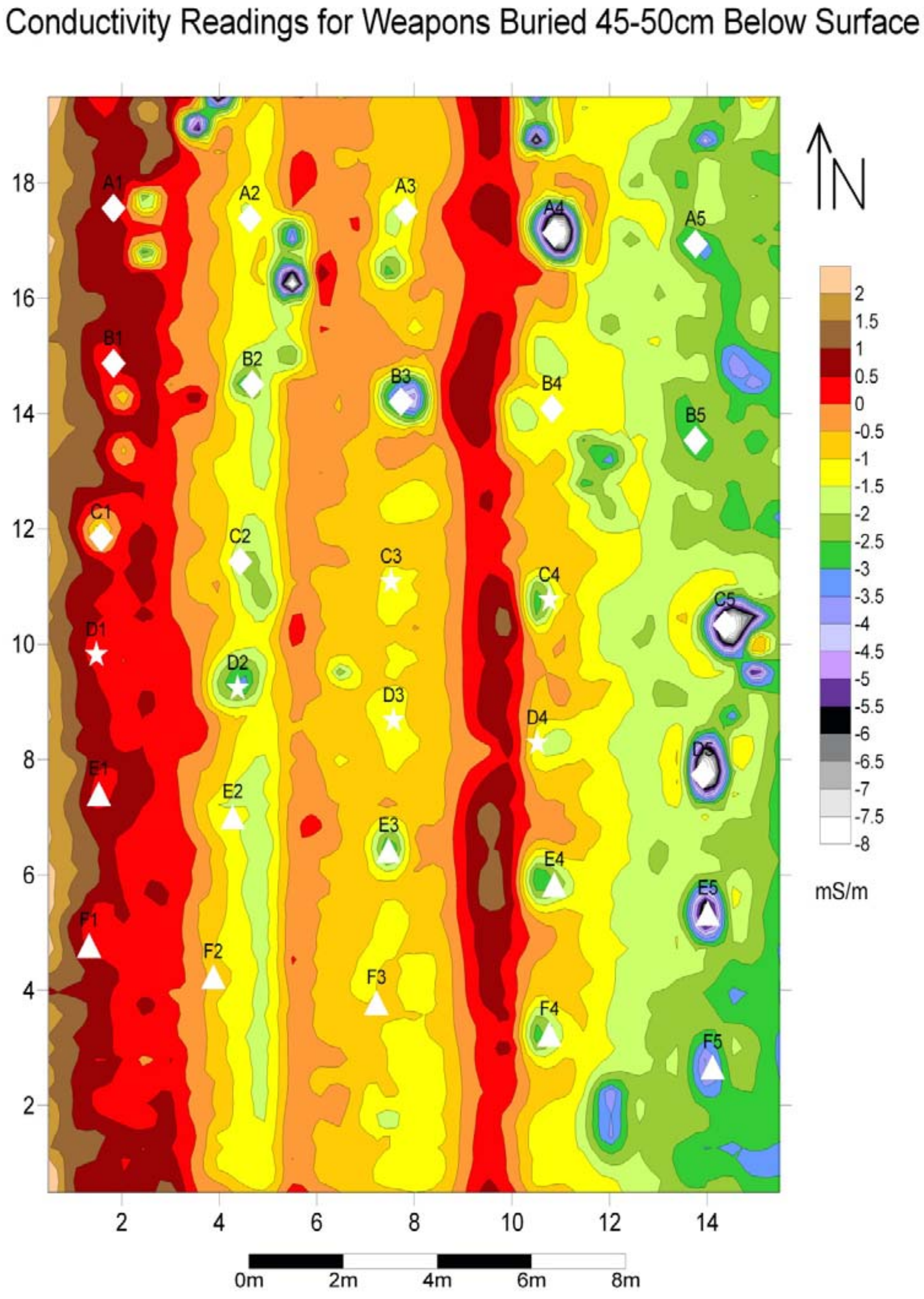

Figure A-36. Overlay of research grid on conductivity map with weapons buried between 45-50cm and mapped with 50cm transects.

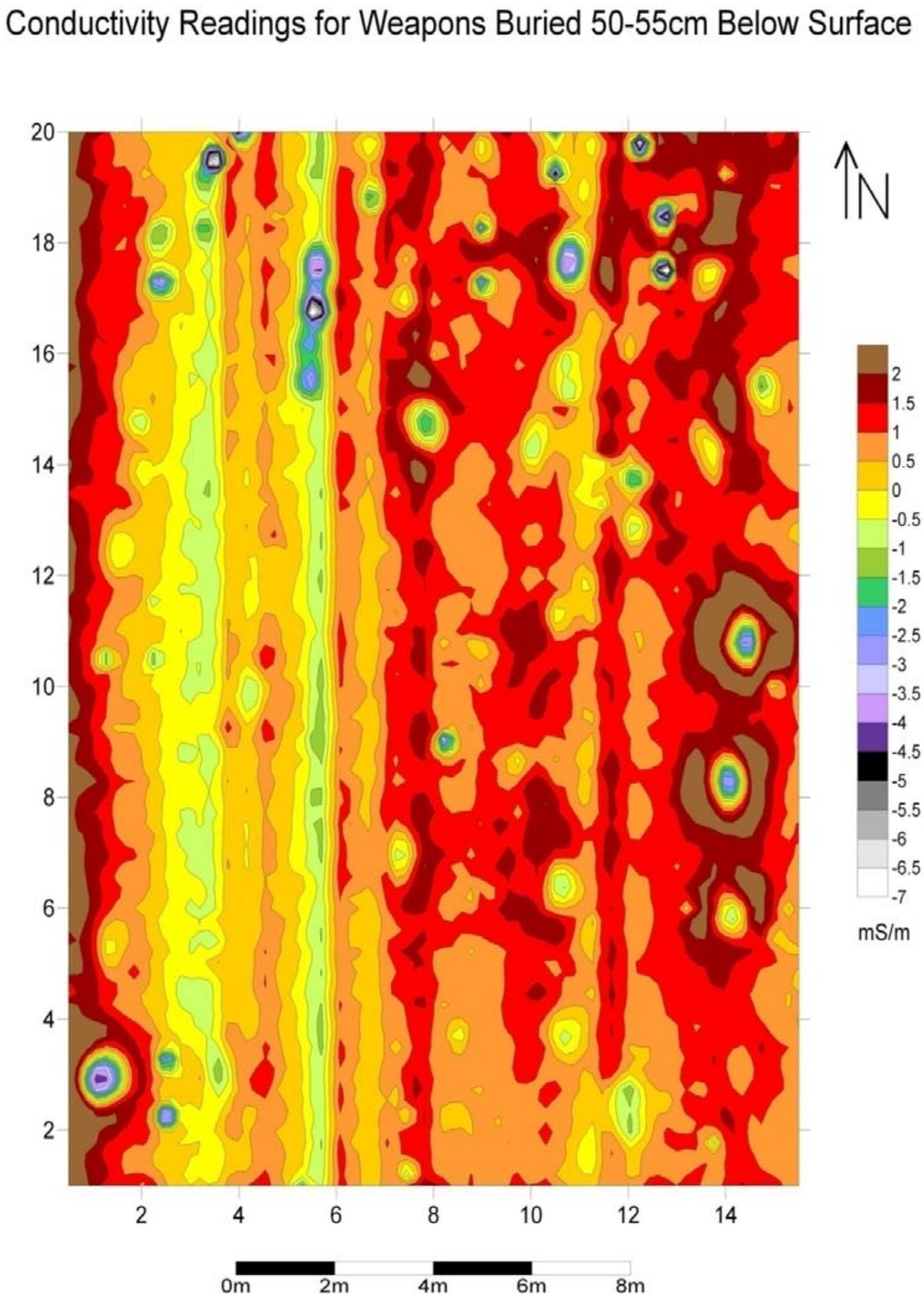
Conductivity Readings for Weapons Buried 50-55cm Below Surface

Figure A-37. Conductivity map with weapons buried between 50-55cm and mapped with 25cm transects.

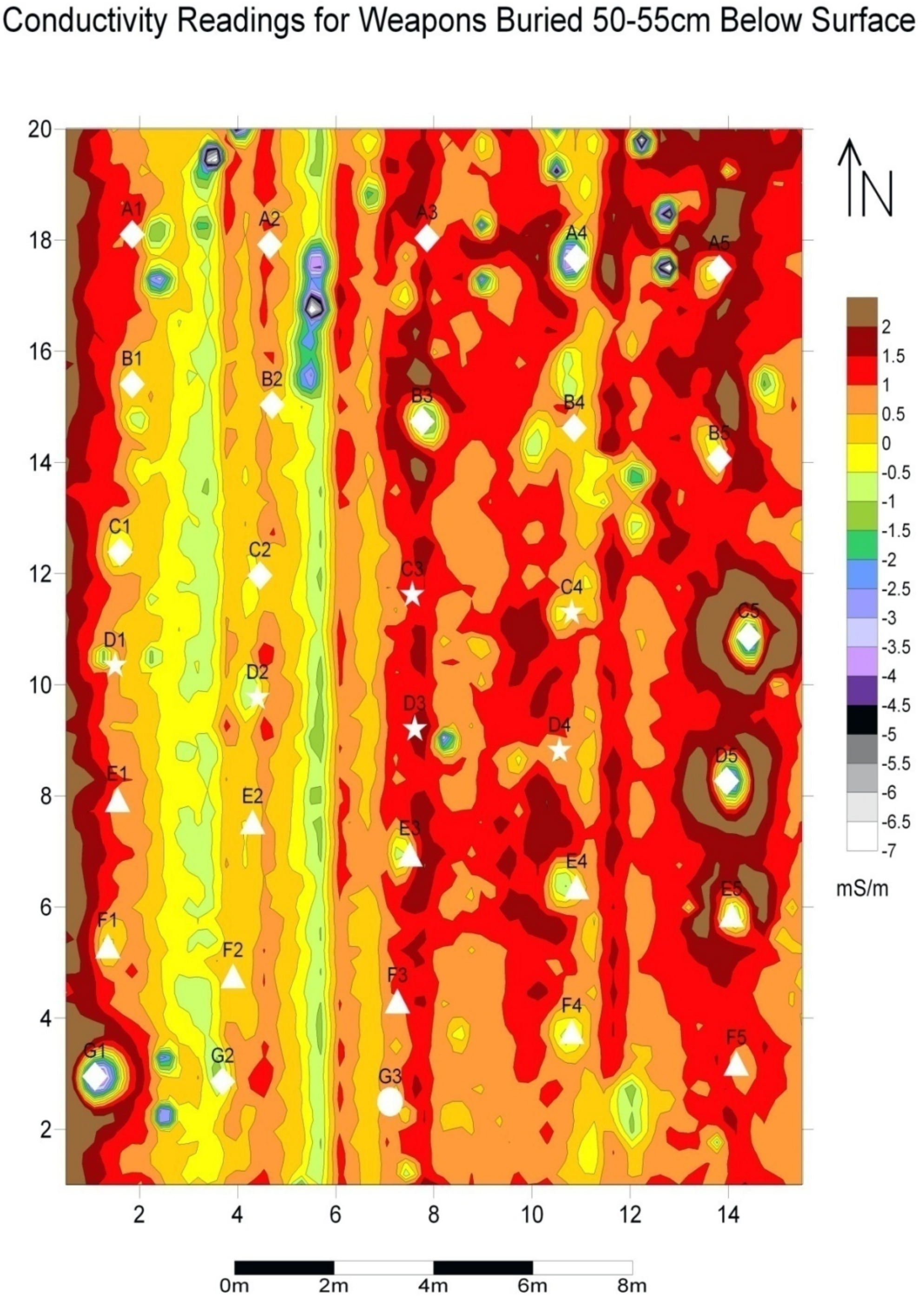
Conductivity Readings for Weapons Buried 50-55cm Below Surface

Figure A-38. Overlay of research grid on conductivity map with weapons buried between 50-55cm and mapped with 25cm transects.

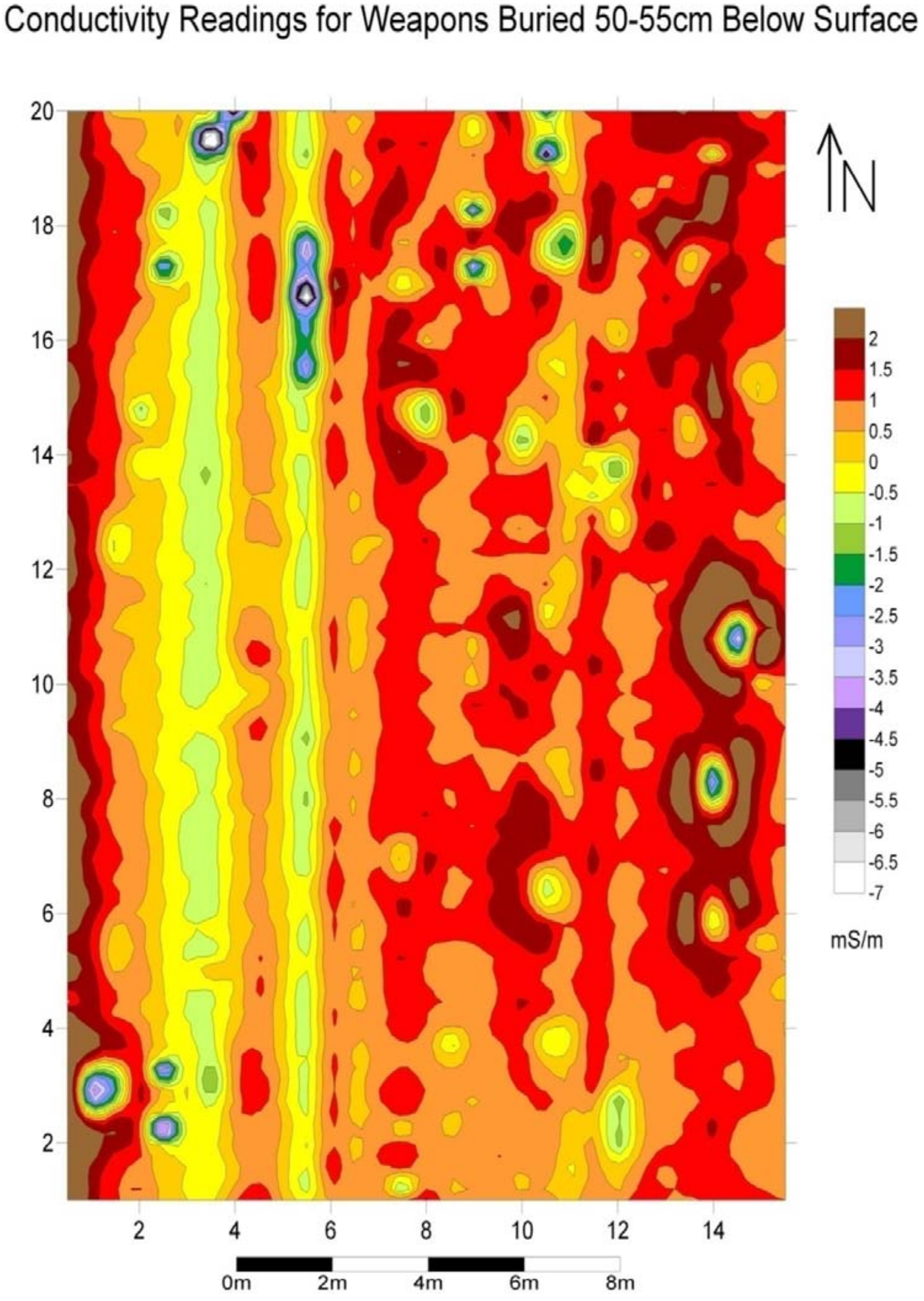

Figure A-39. Conductivity map with weapons buried between 50-55cm and mapped with 50cm transects.

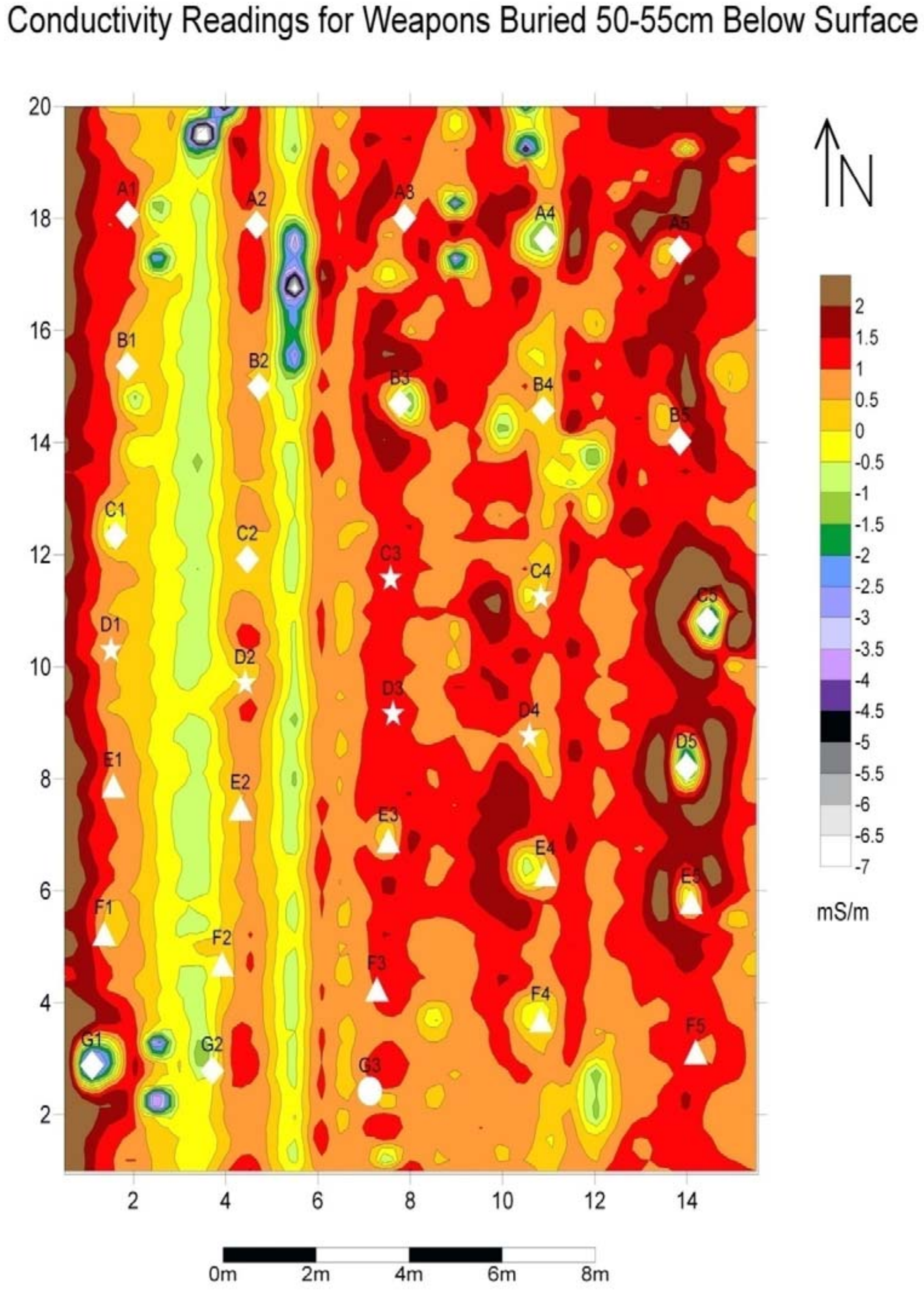

Figure A-40. Overlay of research grid on conductivity map with weapons buried between 50-55cm and mapped with 50cm transects.

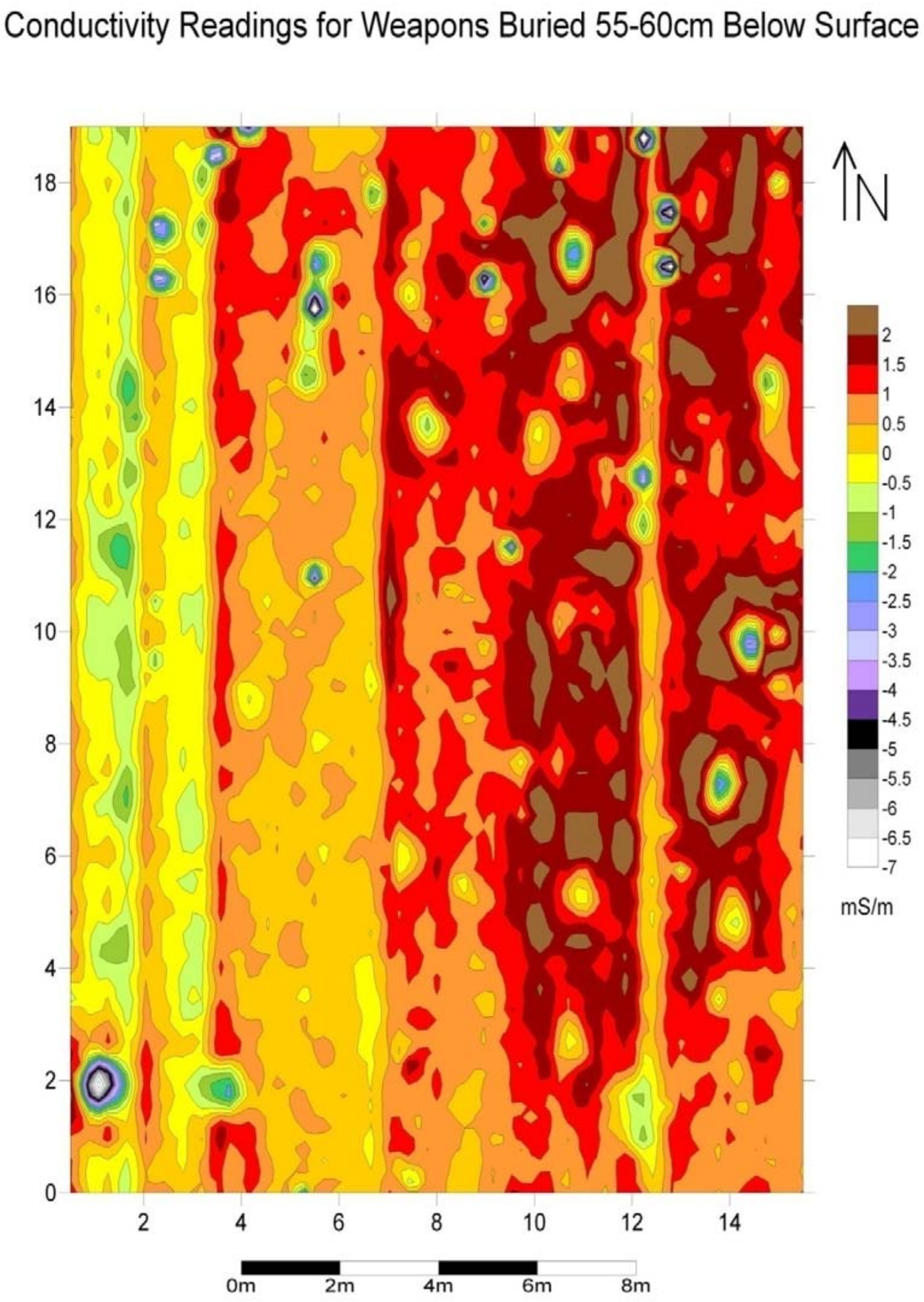
Conductivity Readings for Weapons Buried 55-60cm Below Surface

Figure A-41. Conductivity map with weapons buried between 55-60cm and mapped with 25cm transects.

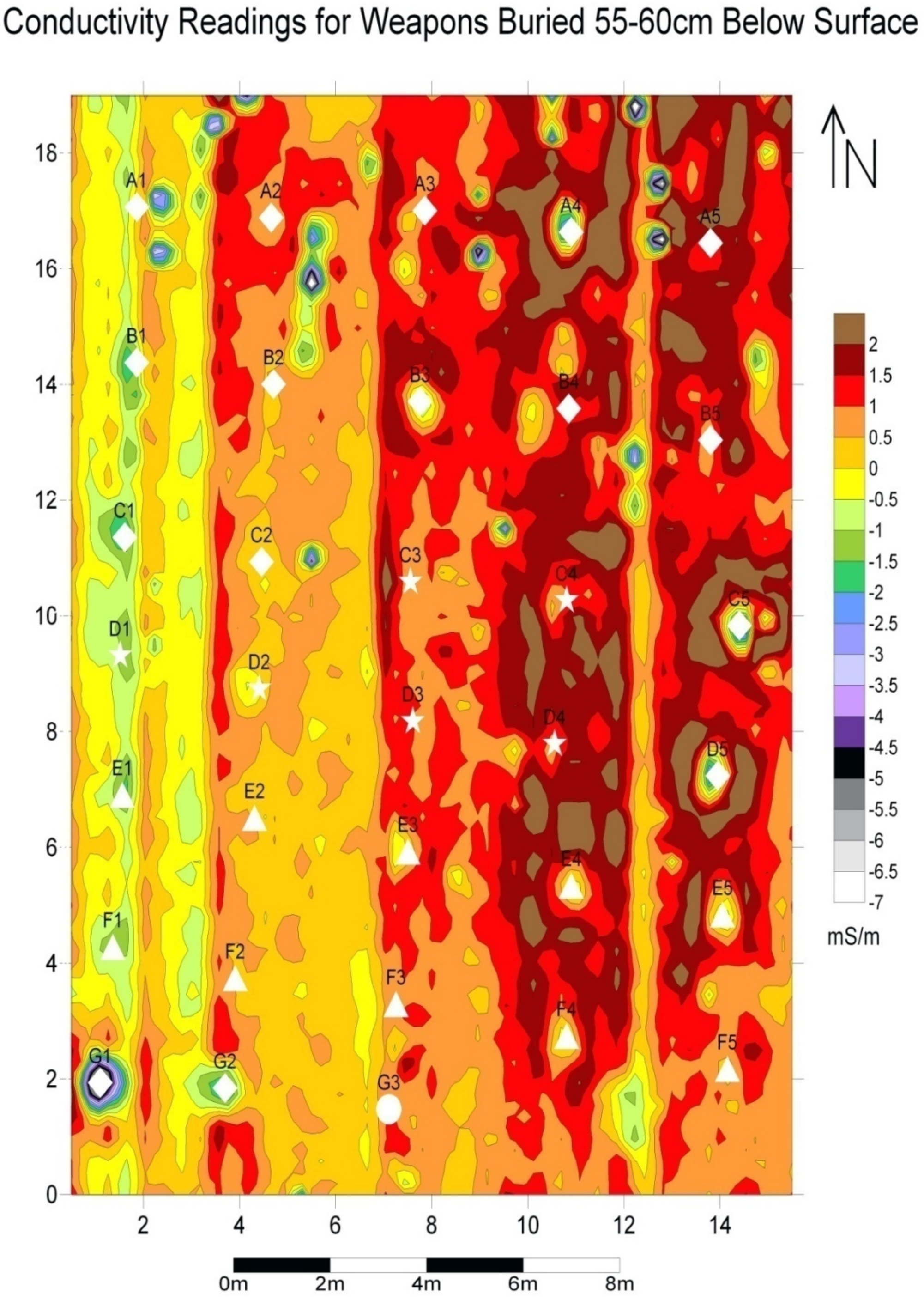

Figure A-42. Overlay of research grid on conductivity map with weapons buried between 55-60cm and mapped with 25cm transects.

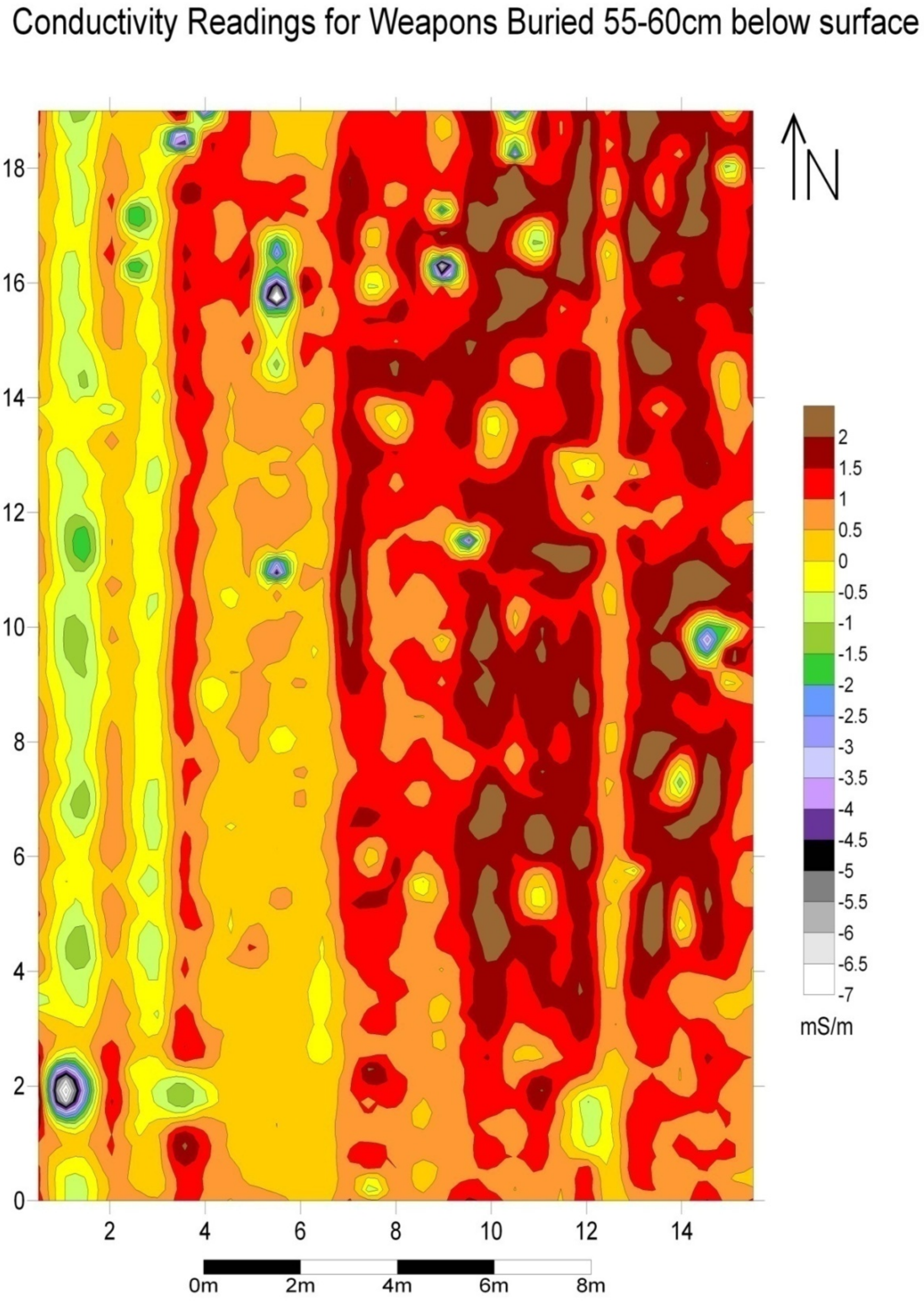

Figure A-43. Conductivity map with weapons buried between 55-60cm and mapped with 50cm transects.

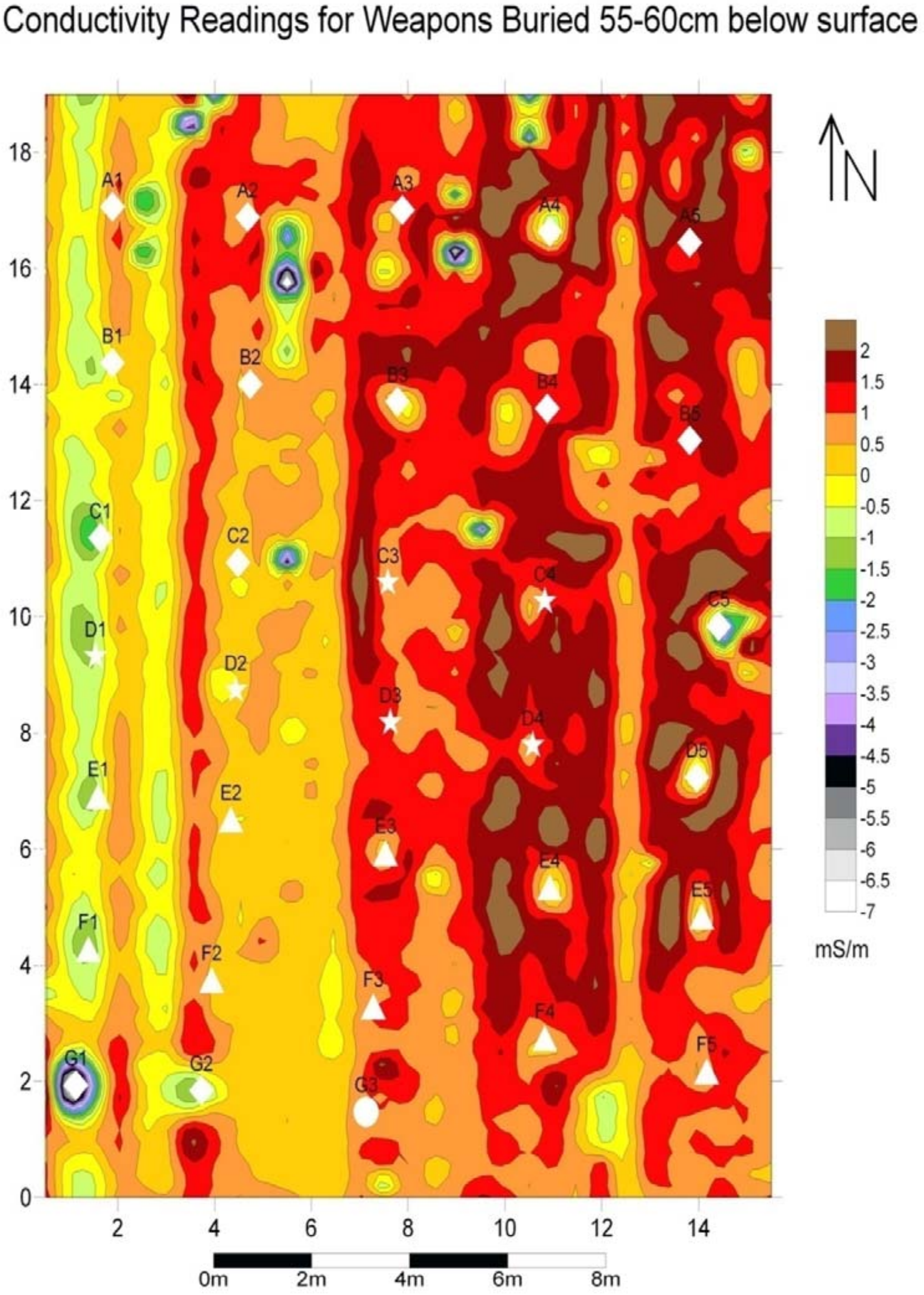

Figure A-44. Overlay of research grid on conductivity map with weapons buried between 55-60cm and mapped with 50cm transects.

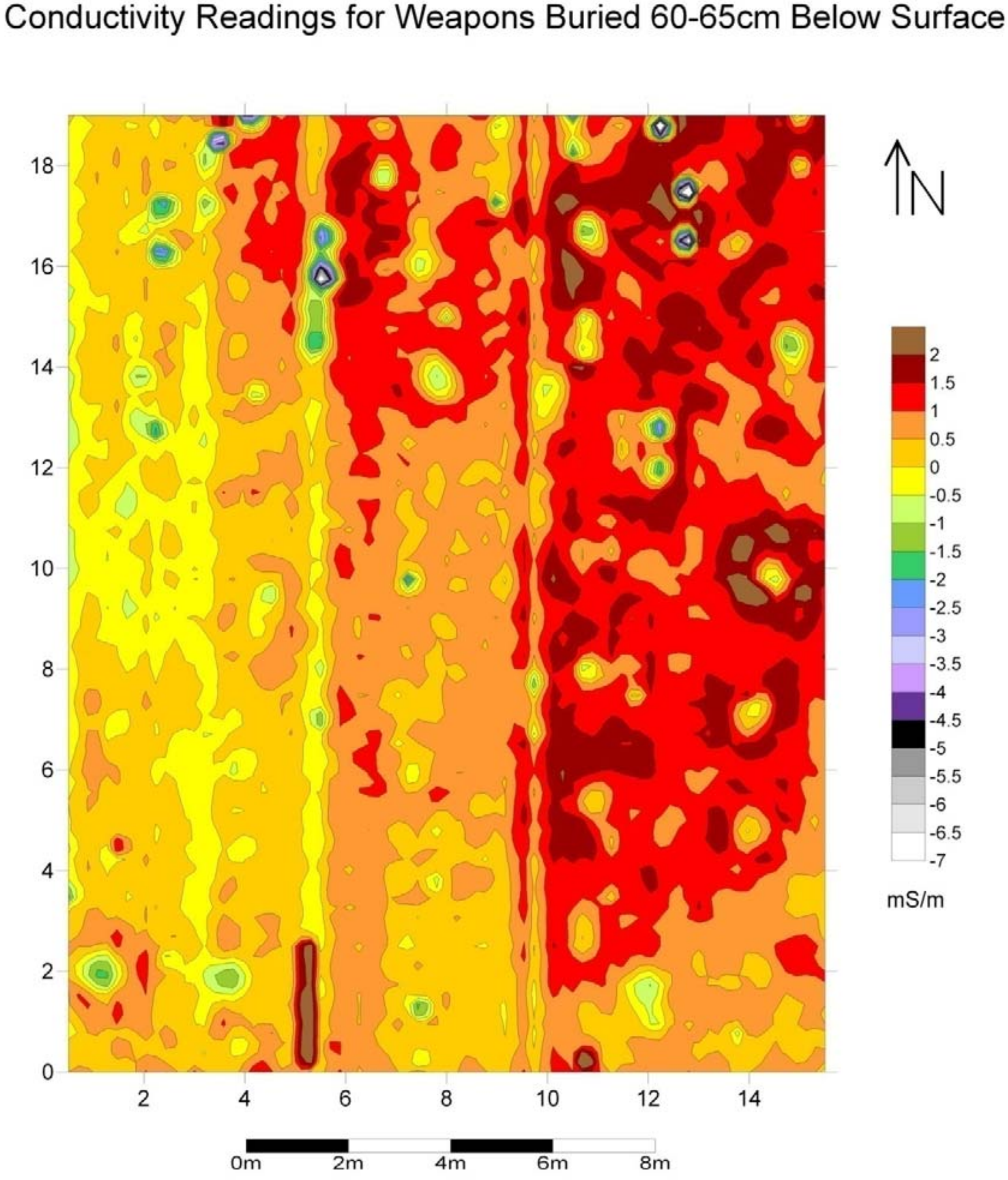

Figure A-45. Conductivity map with weapons buried between 60-65cm and mapped with 25cm transects.

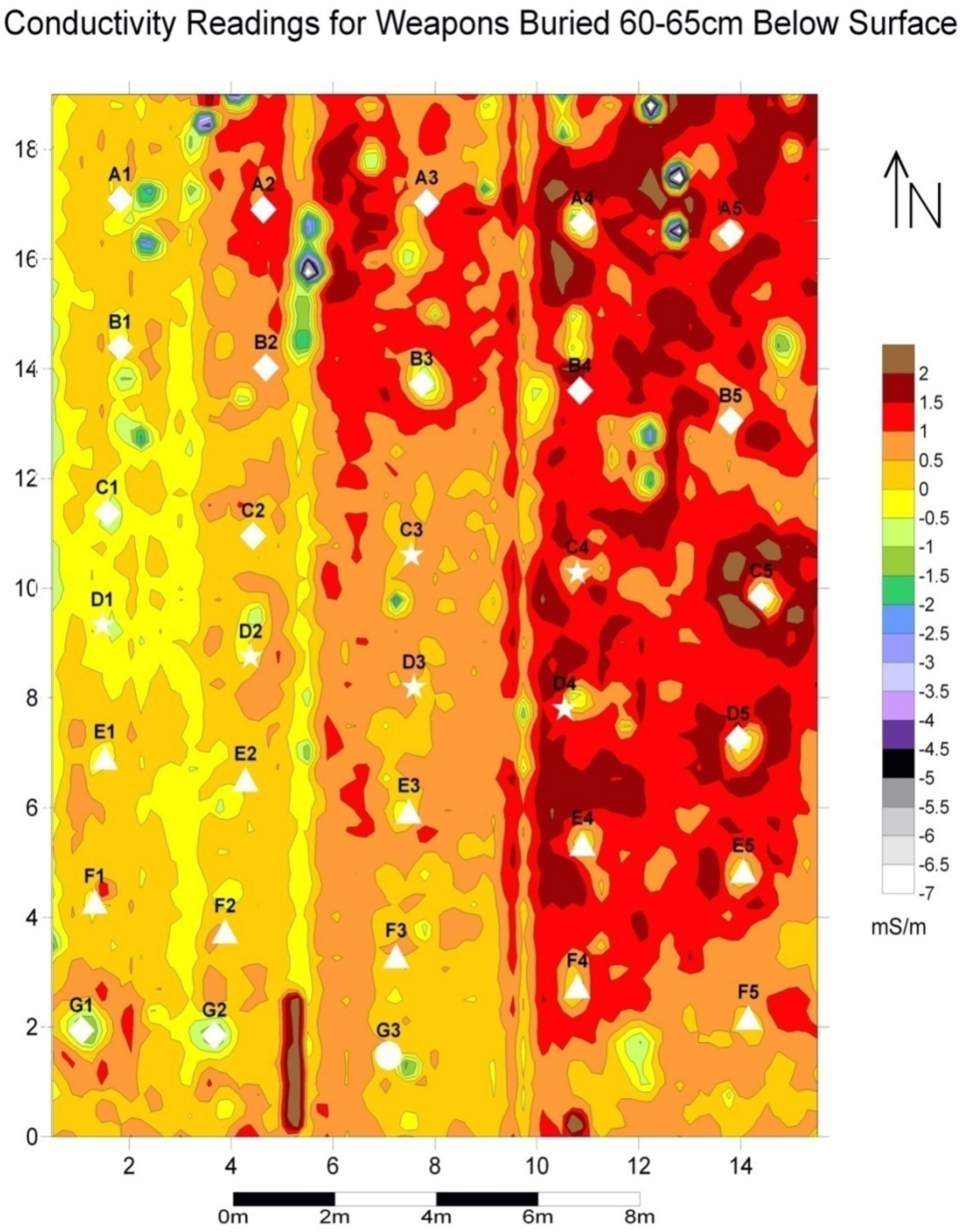

Figure A-46. Overlay of research grid on conductivity map with weapons buried between 60-65cm and mapped with 25cm transects.

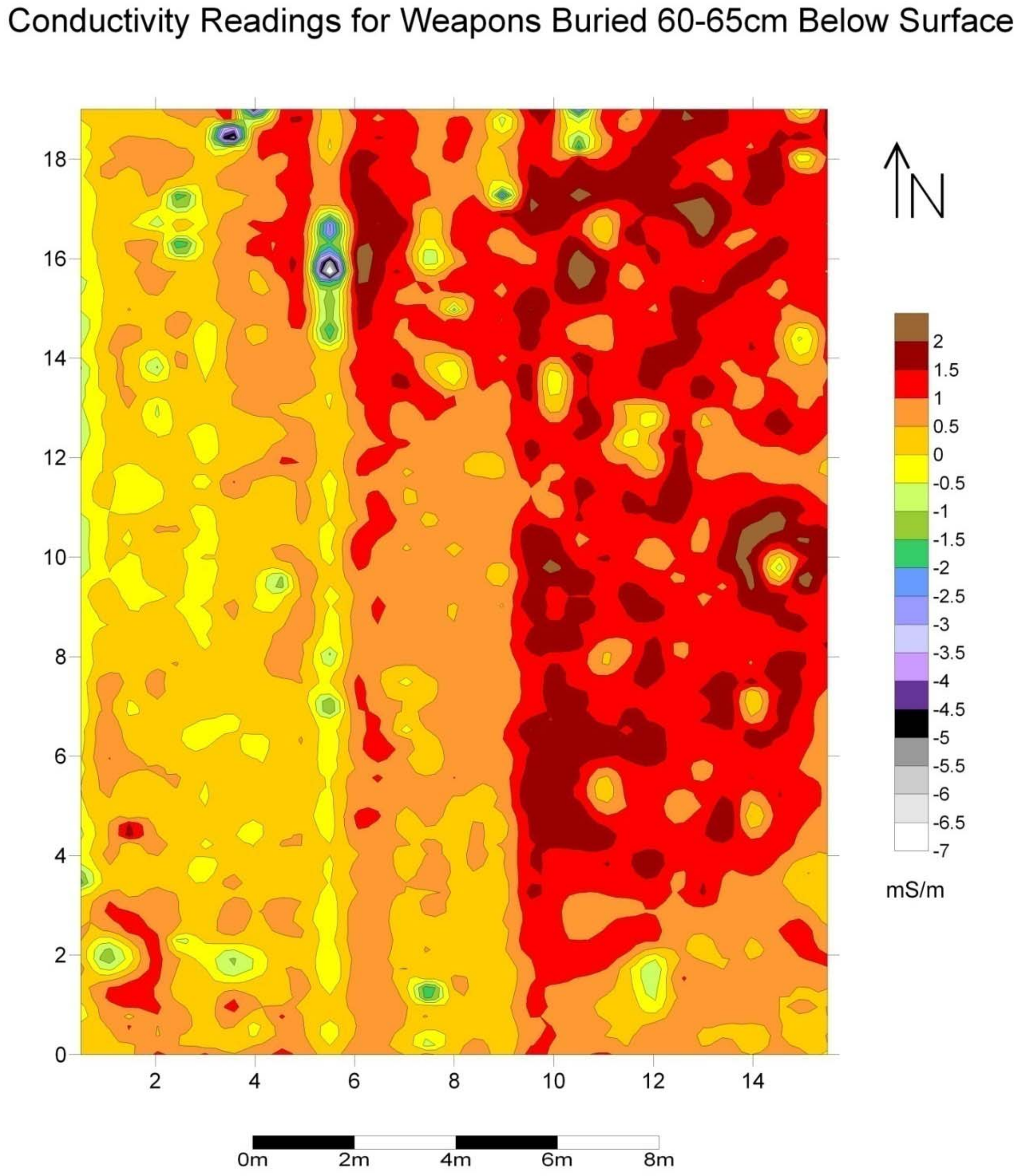

Figure A-47. Conductivity map with weapons buried between 60-65cm and mapped with 50cm transects.

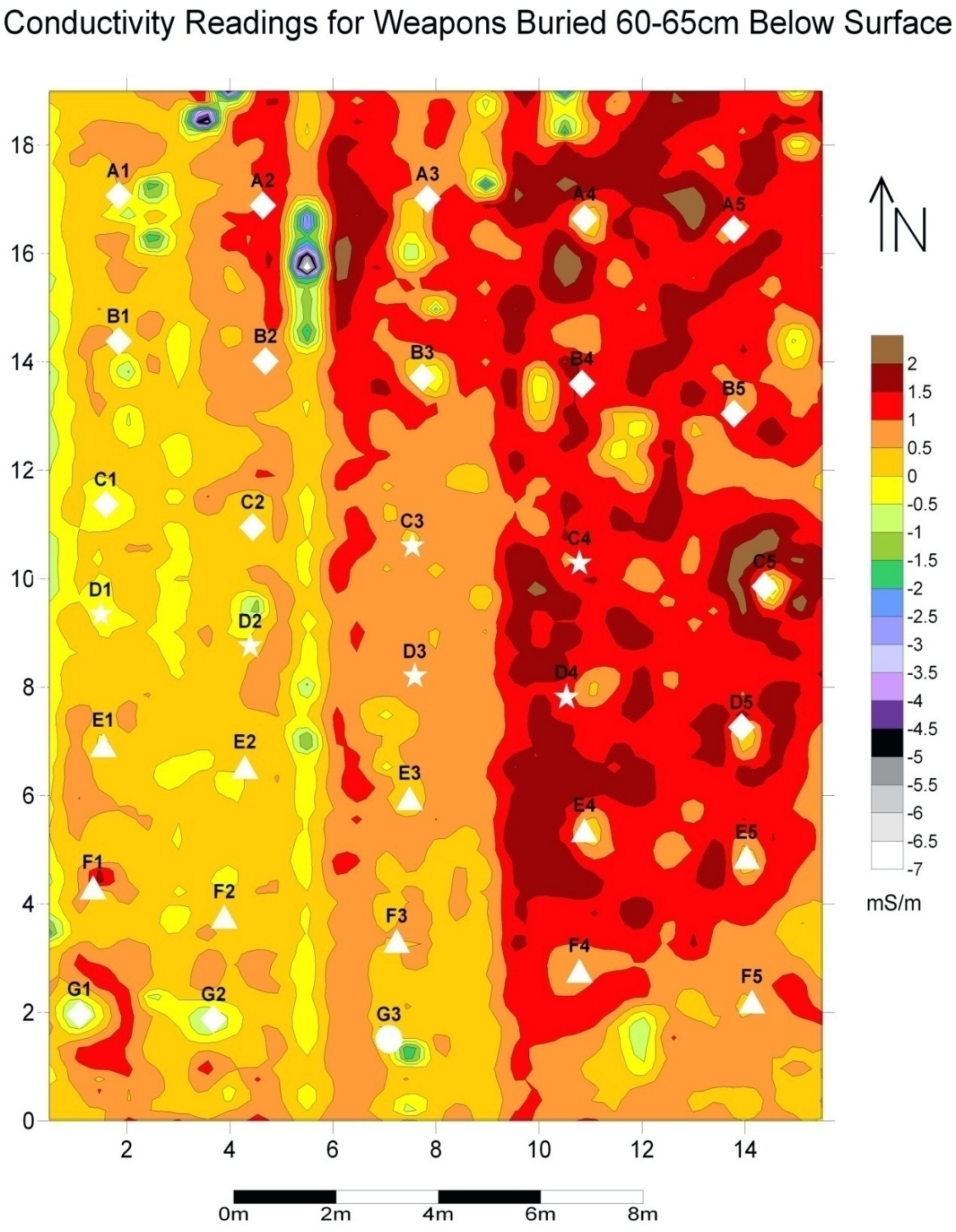

Figure A-48. Overlay of research grid on conductivity map with weapons buried between 60-65cm and mapped with 50cm transects.

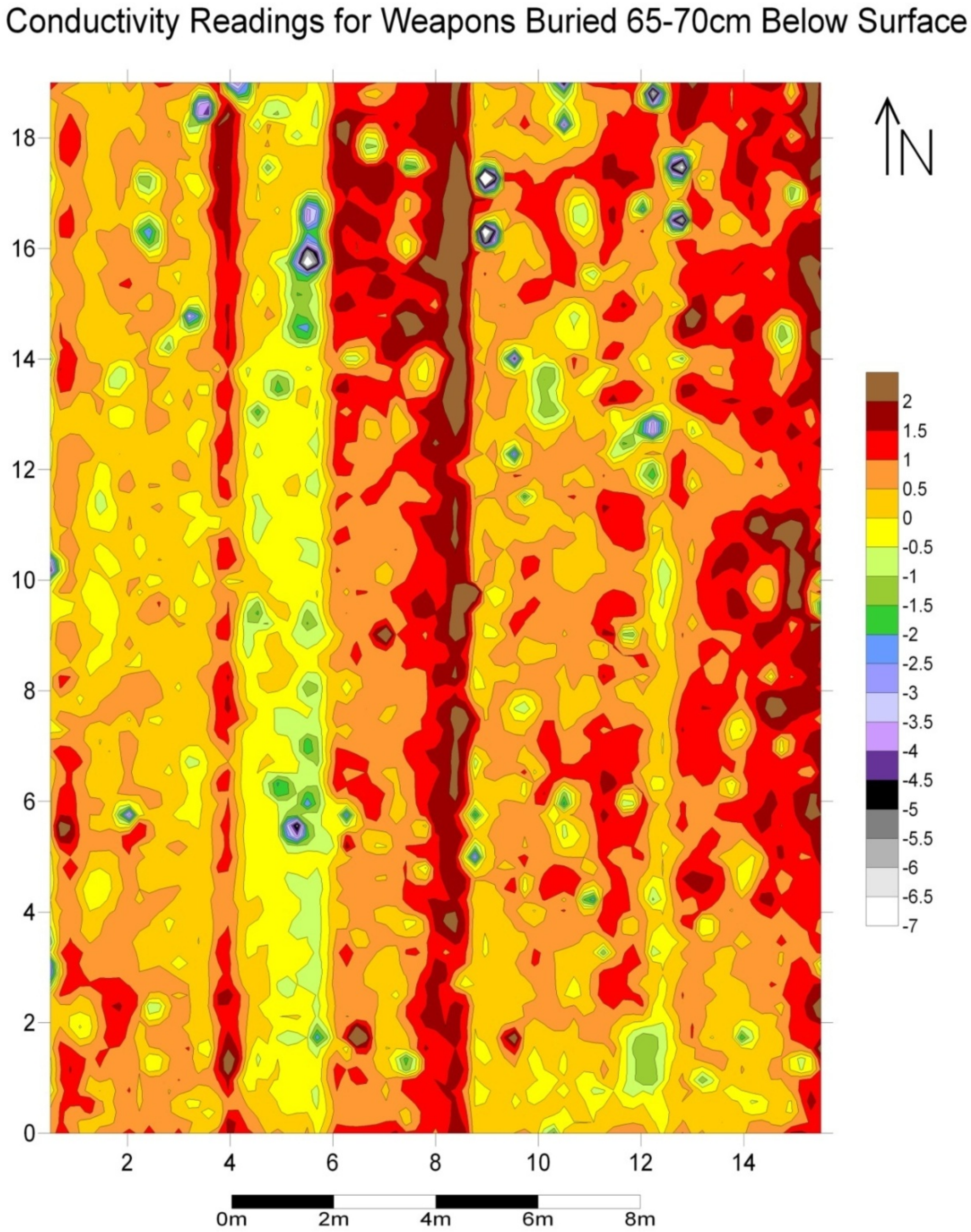

Figure A-49. Conductivity map with weapons buried between 65-70cm and mapped with 25cm transects.

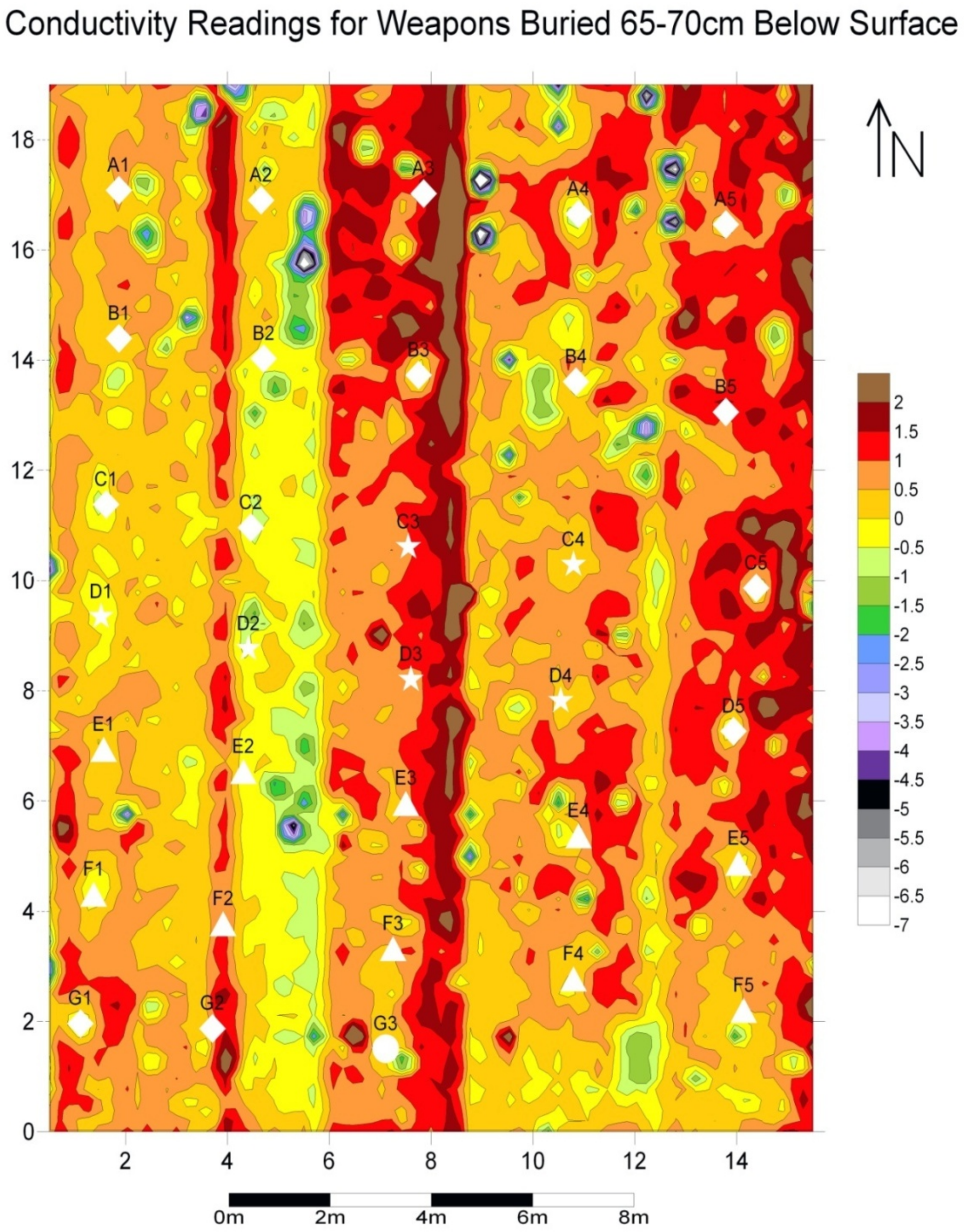

Figure A-50. Overlay of research grid on conductivity map with weapons buried between 65-70cm and mapped with 25cm transects.

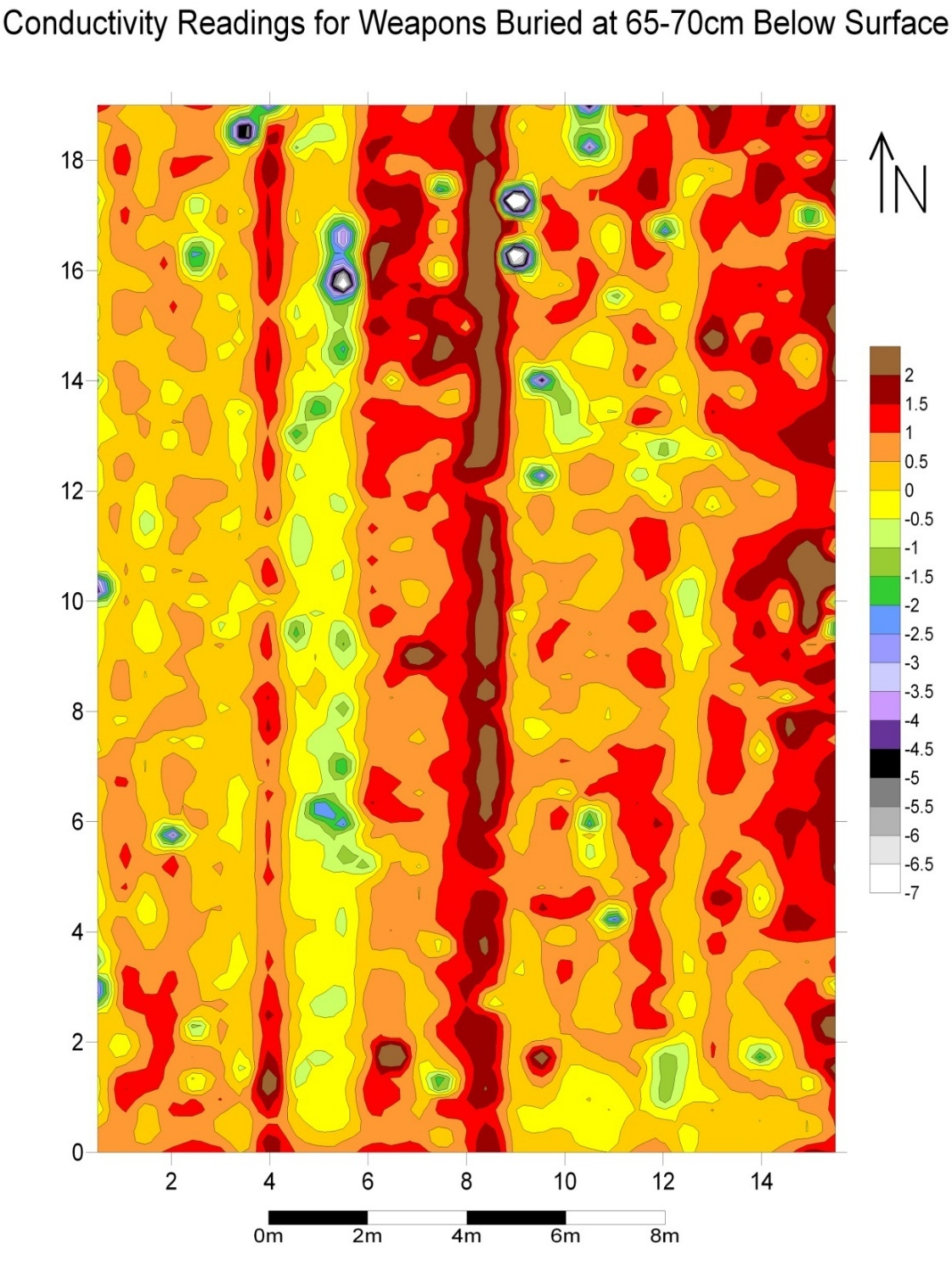

Figure A-51. Conductivity map with weapons buried between 65-70cm and mapped with 50cm transects.

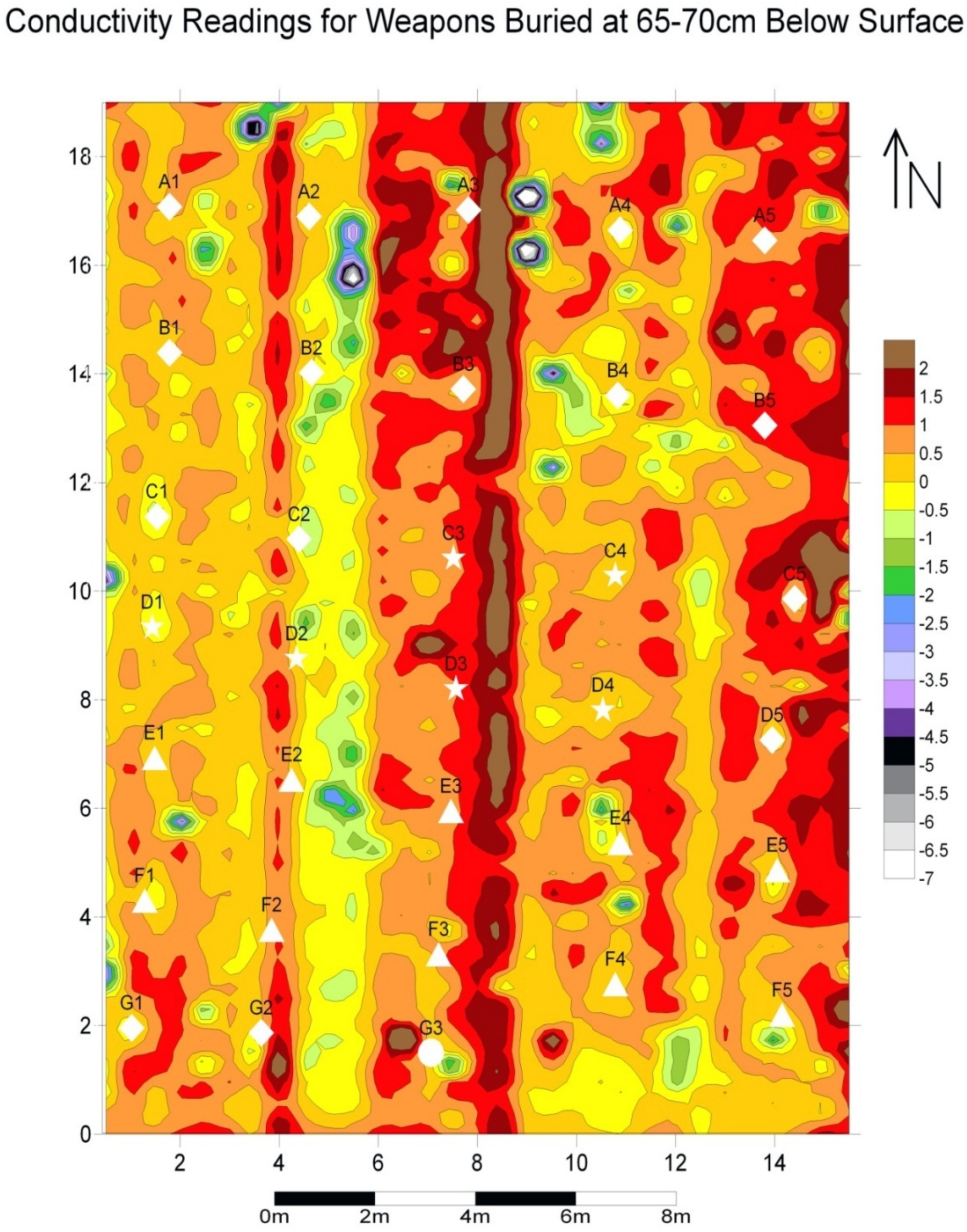

Figure A-52. Overlay of research grid on conductivity map with weapons buried between 65-70cm and mapped with 50cm transects.

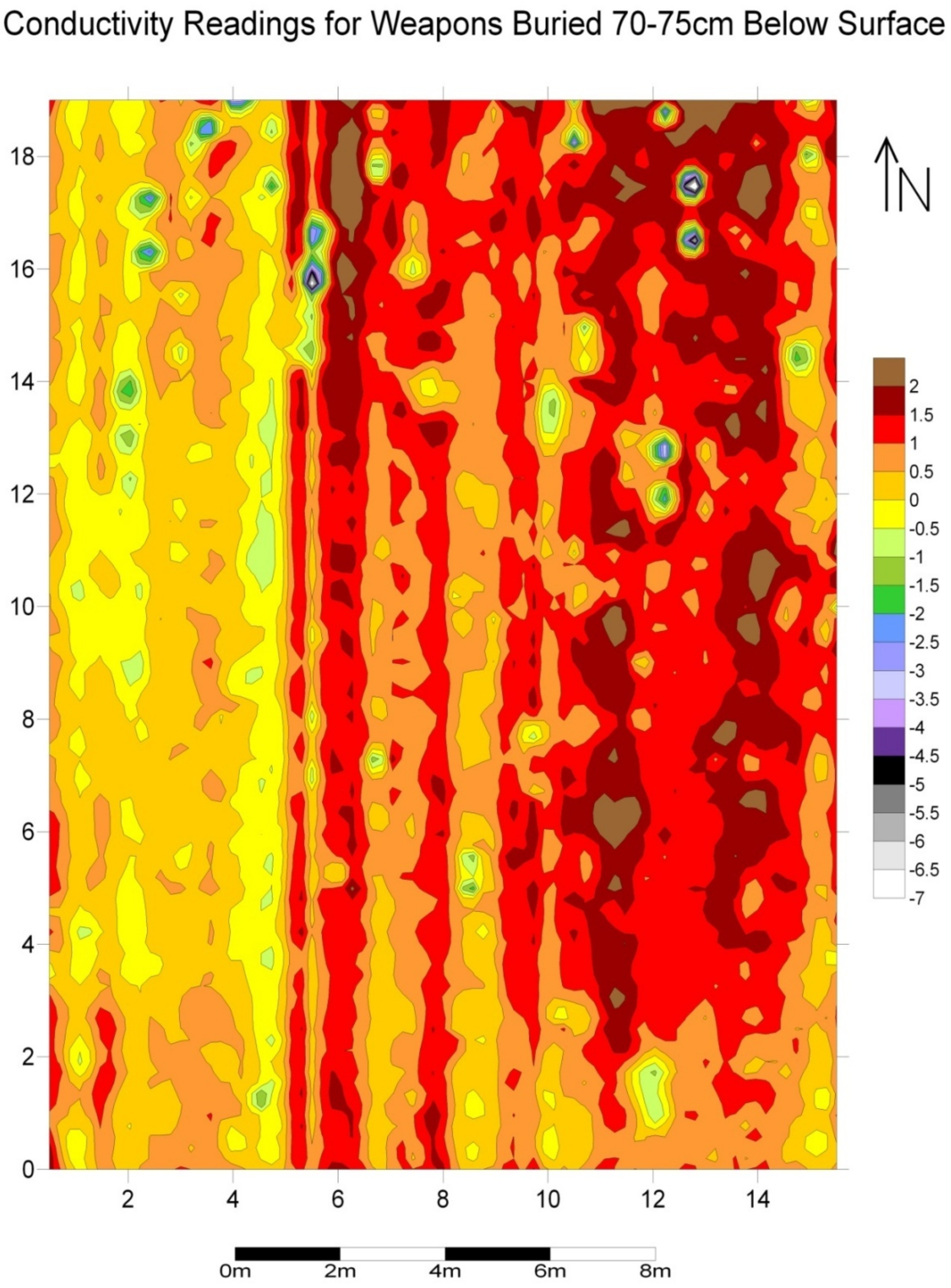

Figure A-53. Conductivity map with weapons buried between 70-75cm and mapped with 25cm transects.

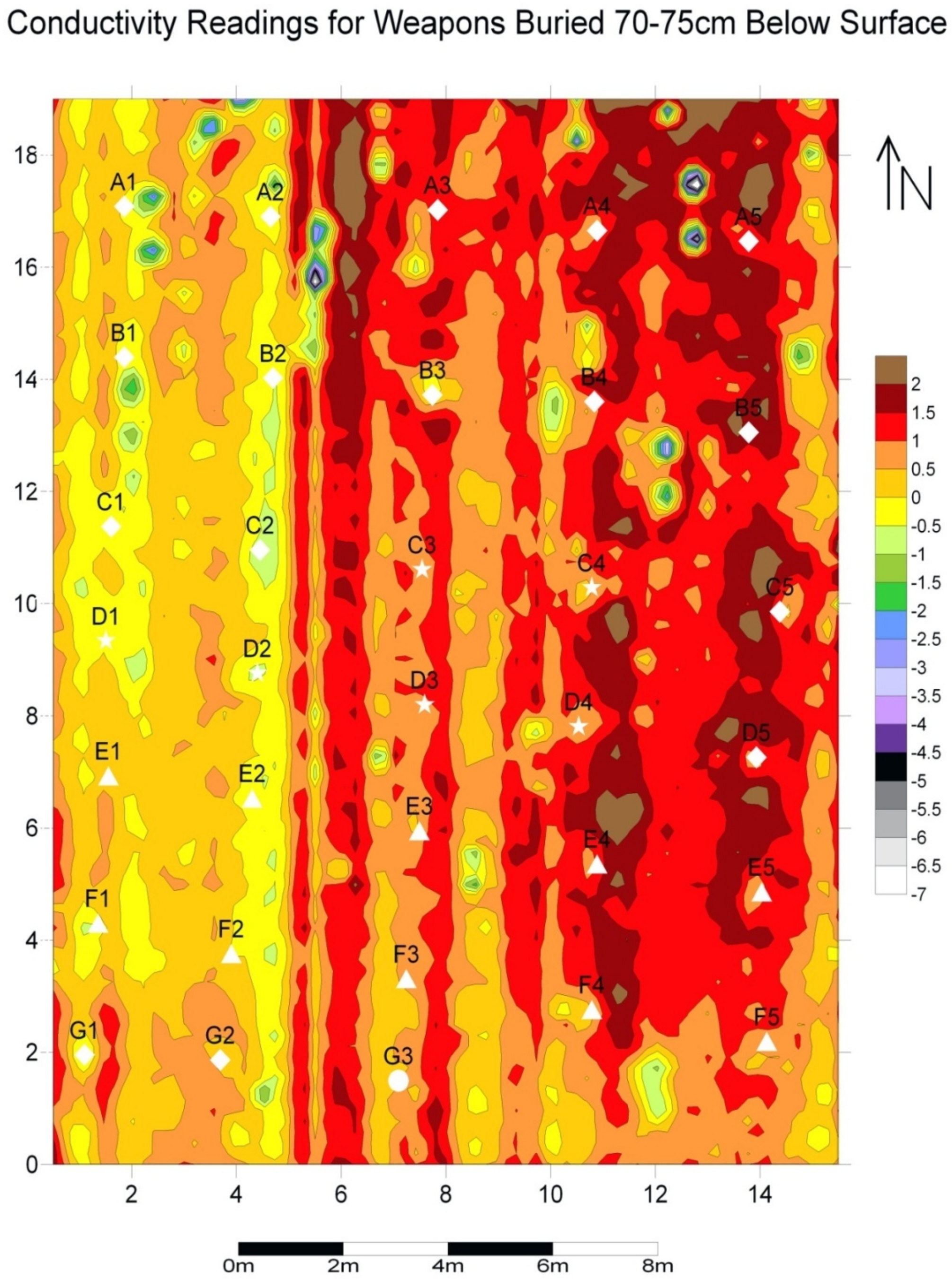

Figure A-54. Overlay of research grid on conductivity map with weapons buried between 70-75cm and mapped with 25cm transects.

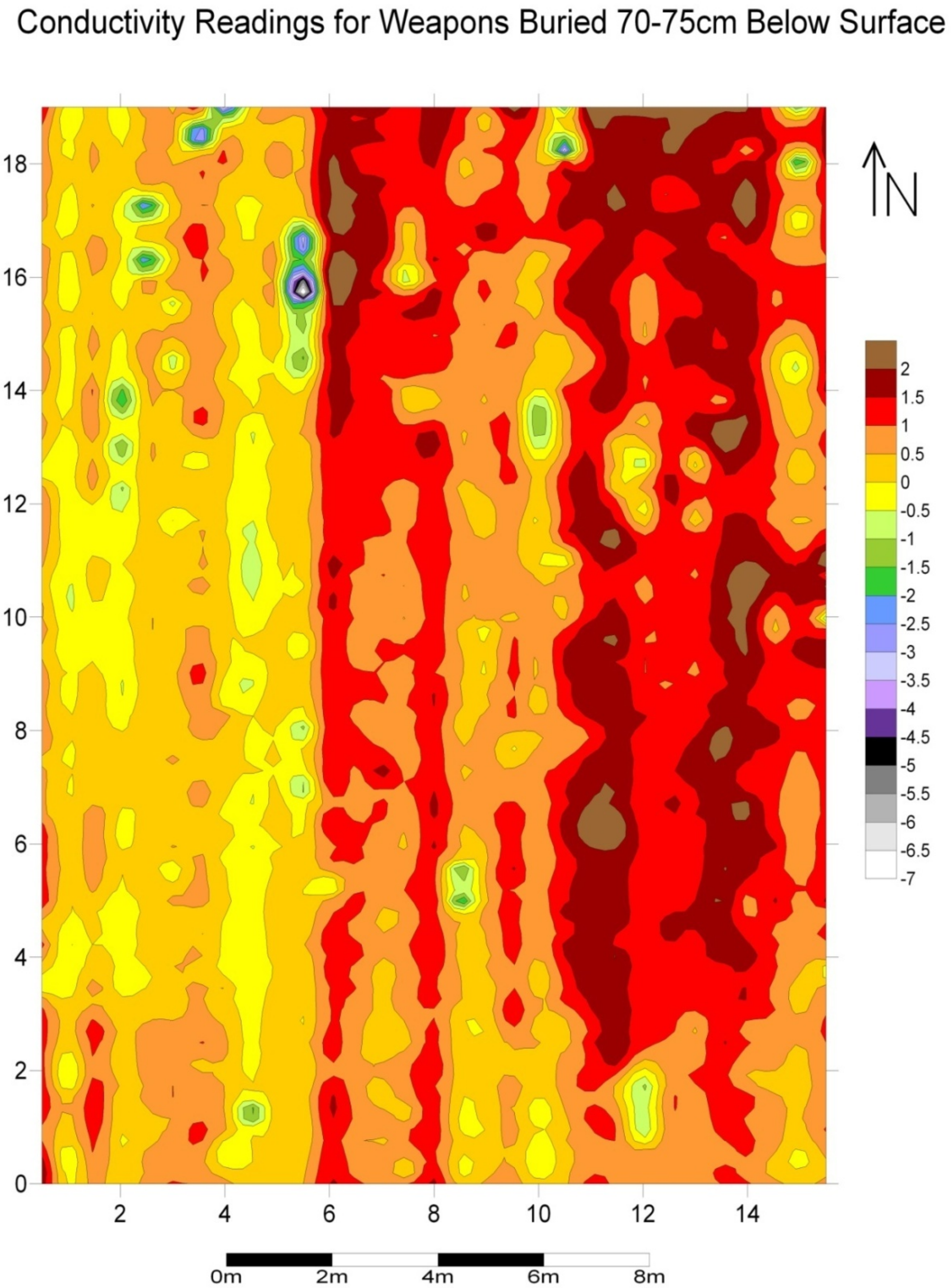

Figure A-55. Conductivity map with weapons buried between 70-75cm and mapped with 50cm transects.

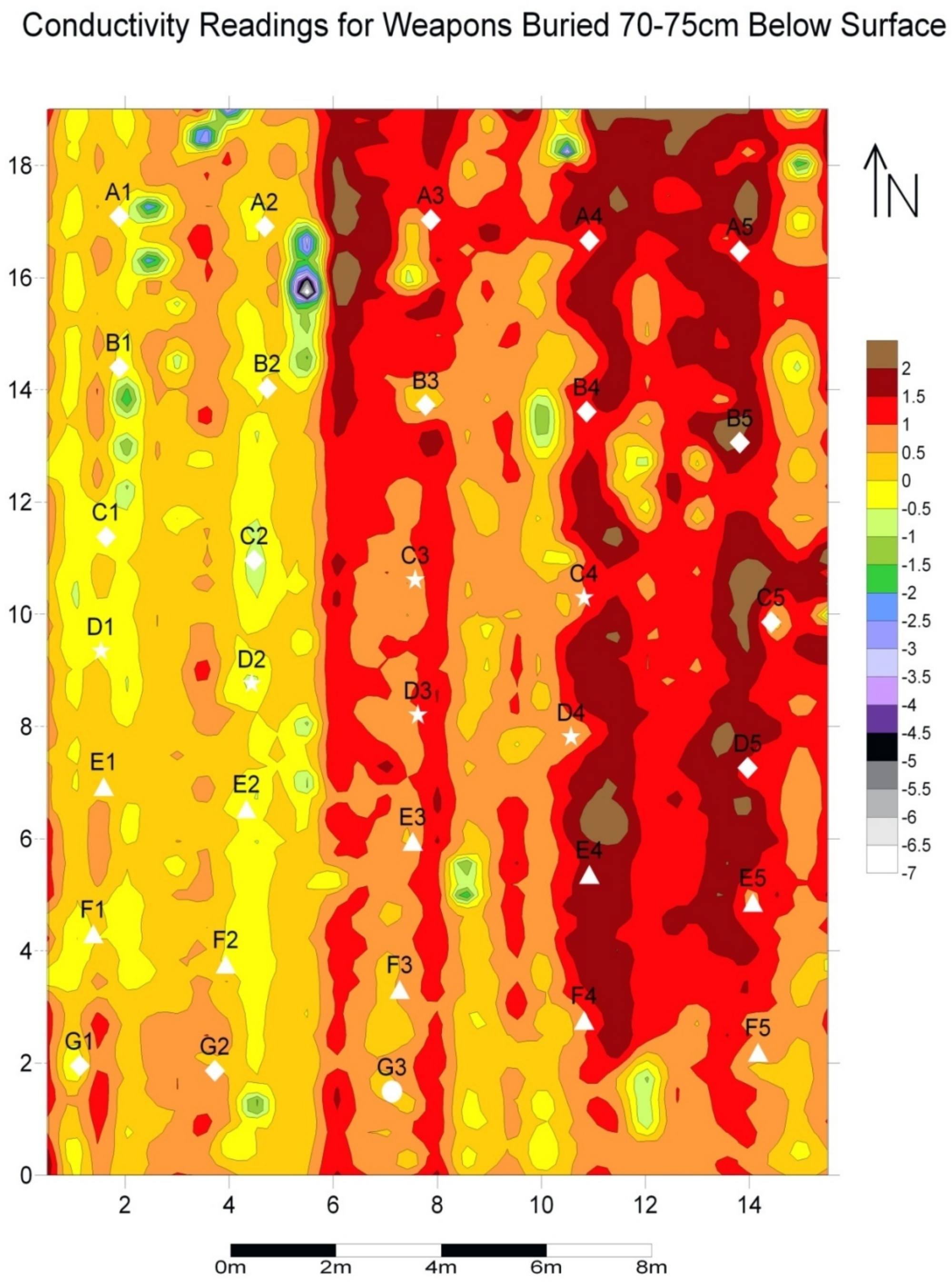

Figure A-56. Overlay of research grid on conductivity map with weapons buried between 70-75cm and mapped with 50cm transects.

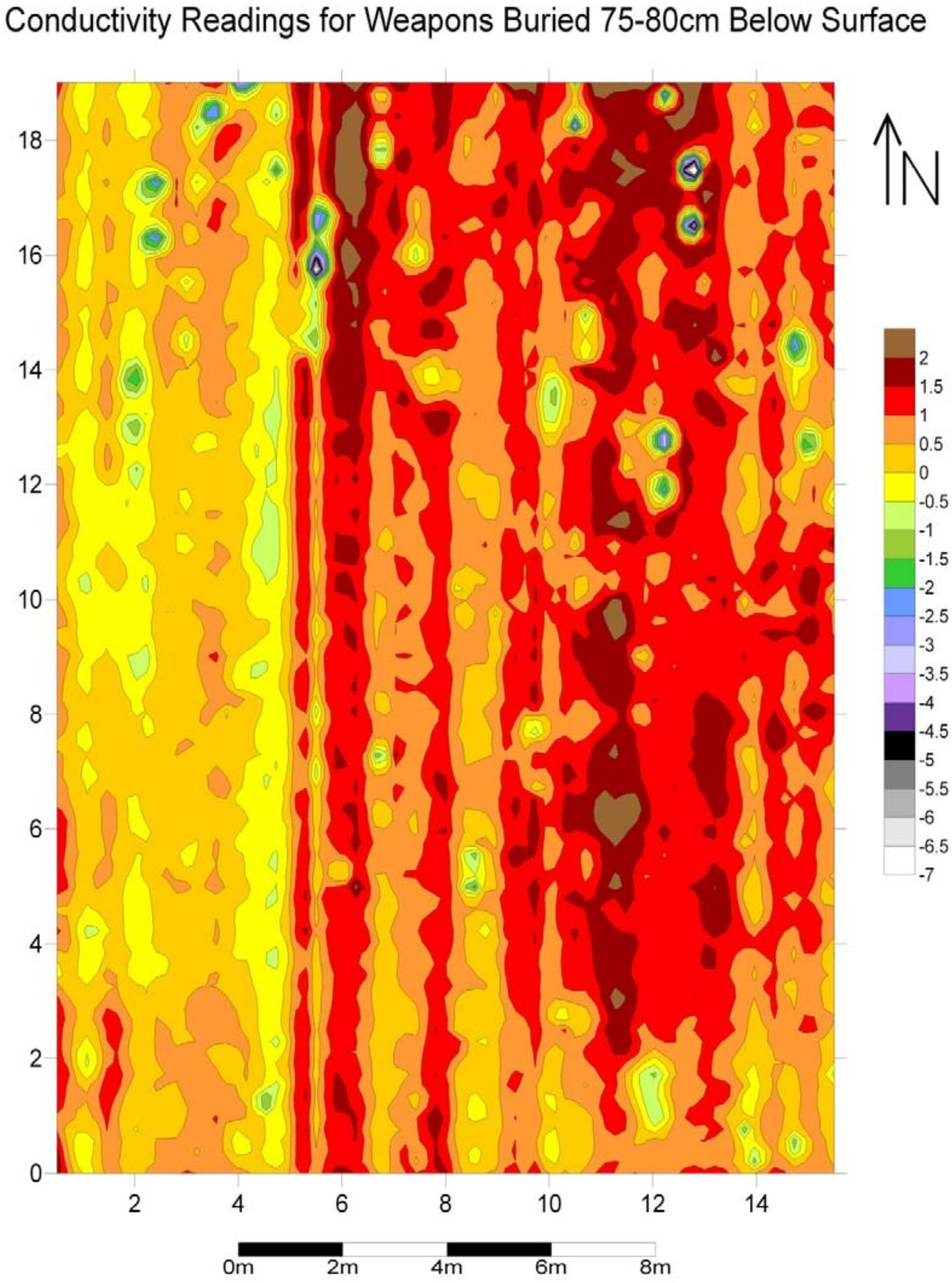

Figure A-57. Conductivity map with weapons buried between 75-80cm and mapped with 25cm transects.

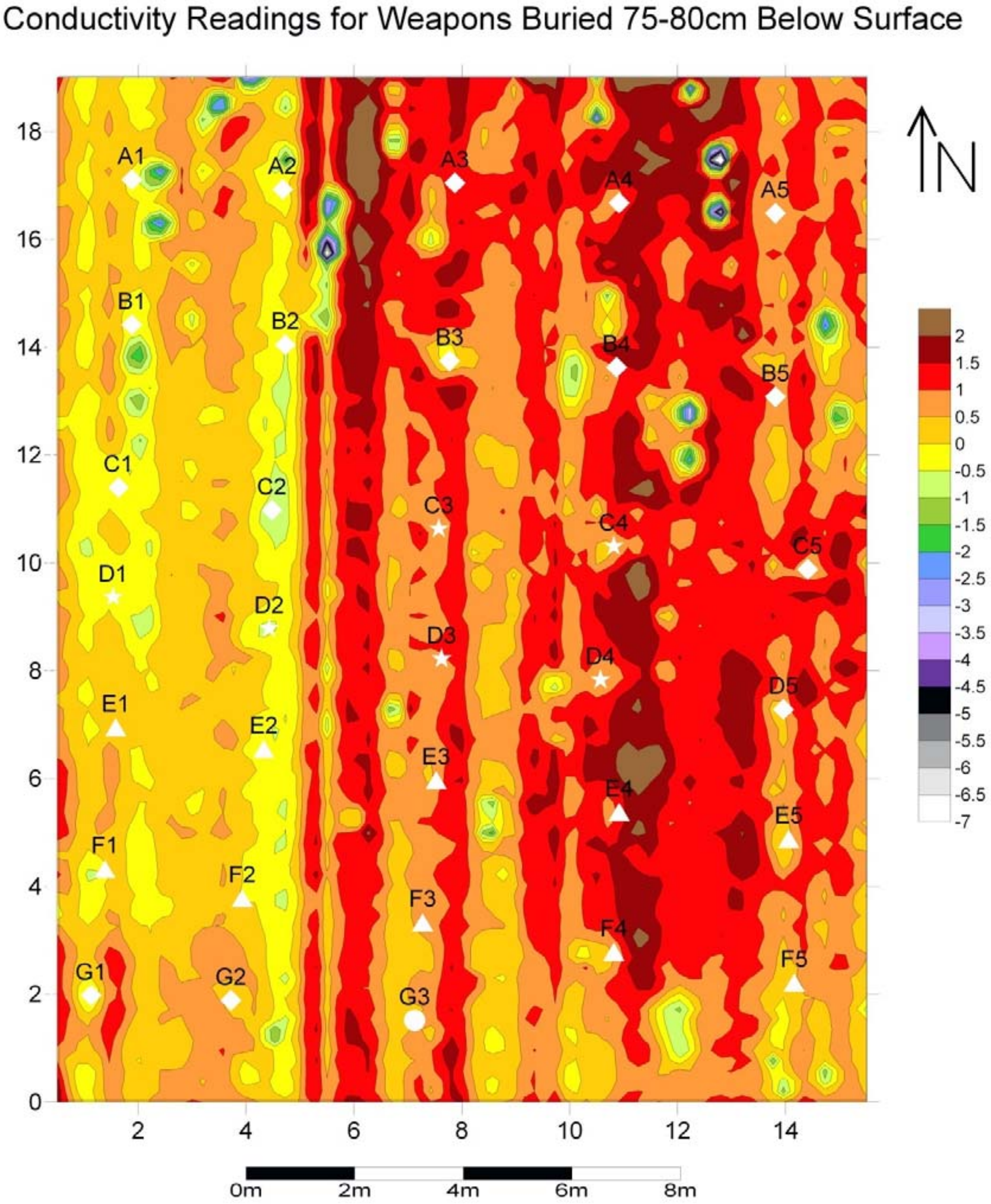

Figure A-58. Overlay of research grid on conductivity map with weapons buried between 75-80cm and mapped with 25cm transects.

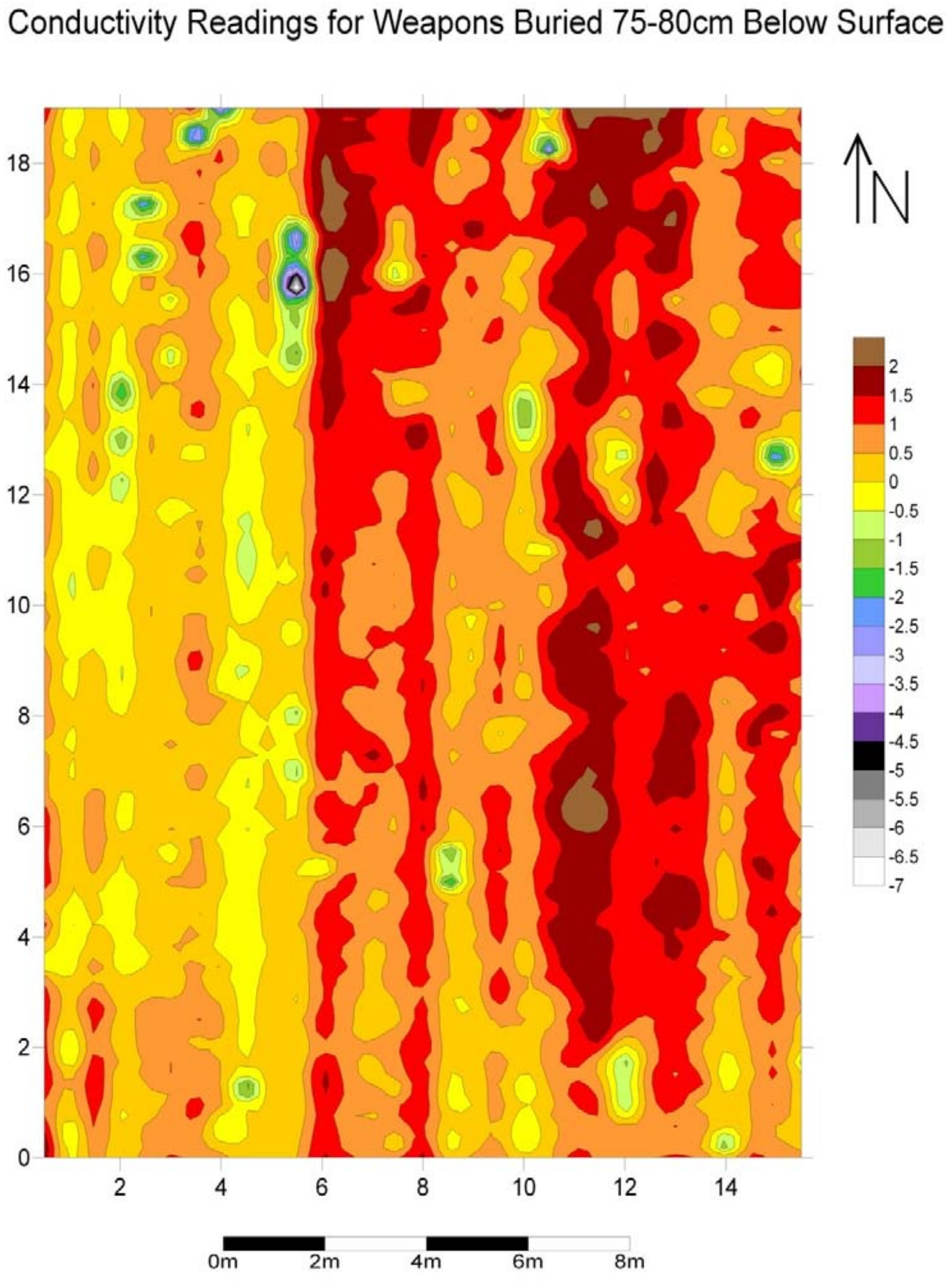

Figure A-59. Conductivity map with weapons buried between 75-80cm and mapped with 50cm transects.

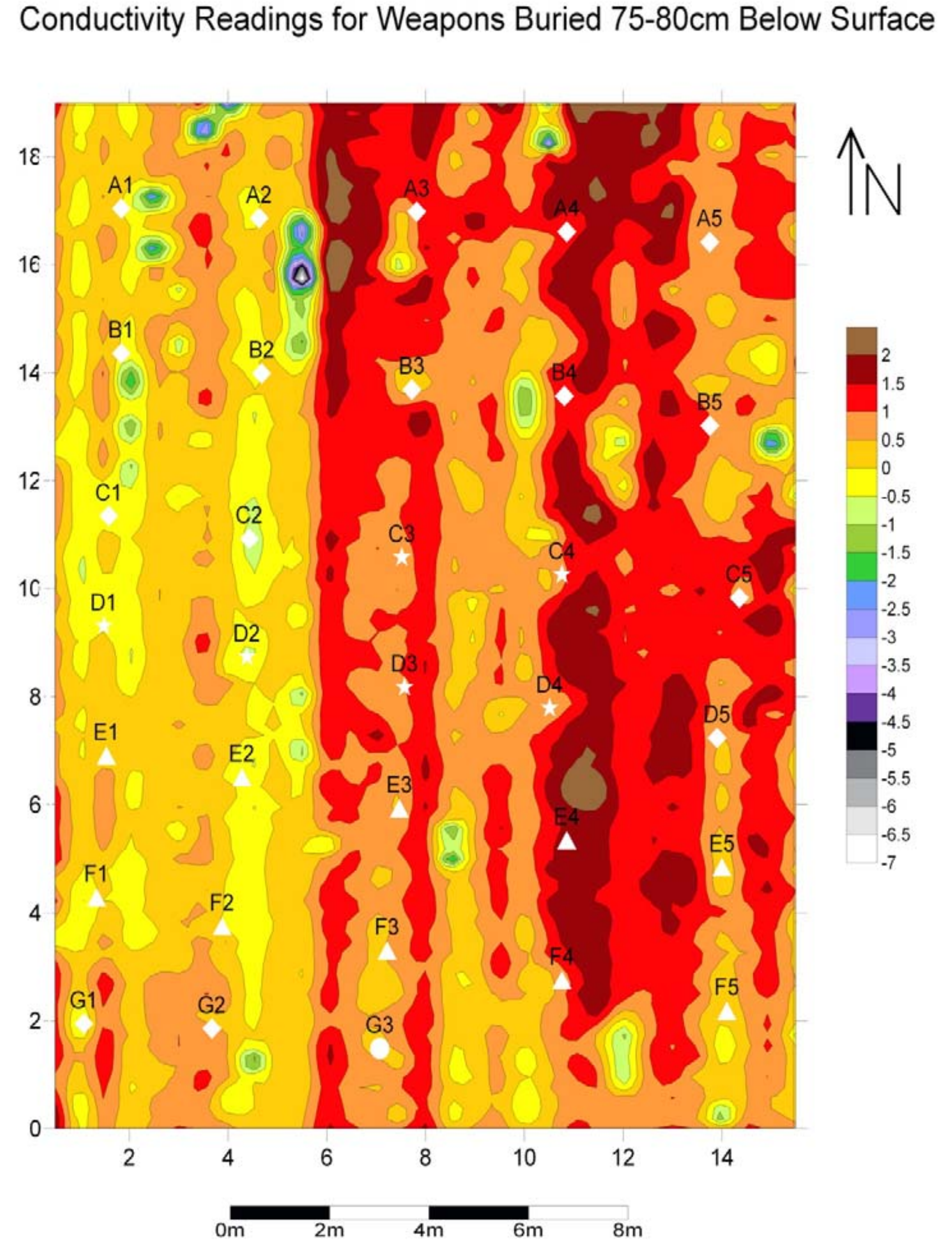

Figure A-60. Overlay of research grid on conductivity map with weapons buried between 75-80cm and mapped with 50cm transects.

# APPENDIX B

## GPR Radargrams

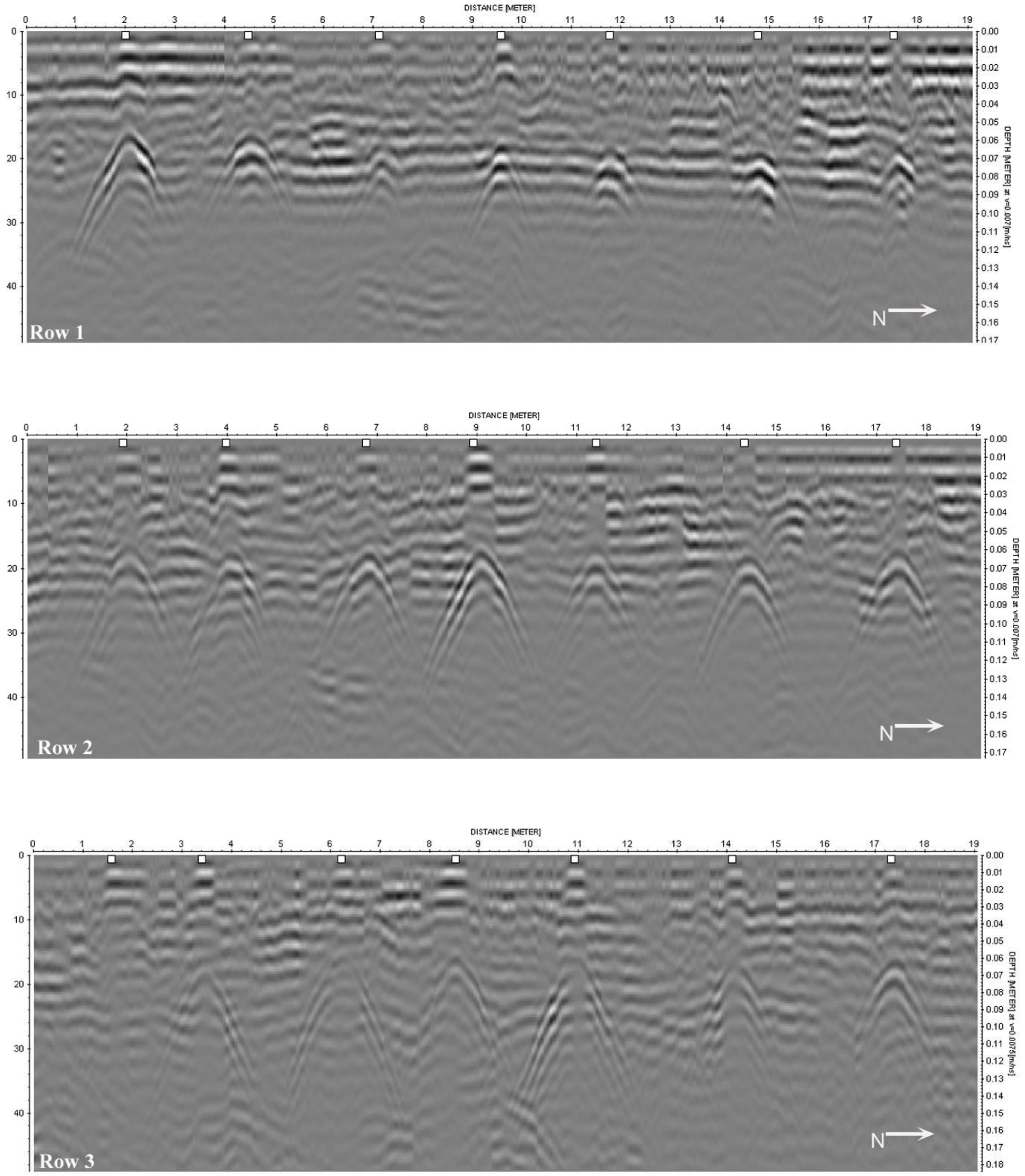

Figure B-1. Radargrams for rows 1, 2, and 3 collected with the 500-MHz antenna when the weapons were buried at a depth of 60-65cm.

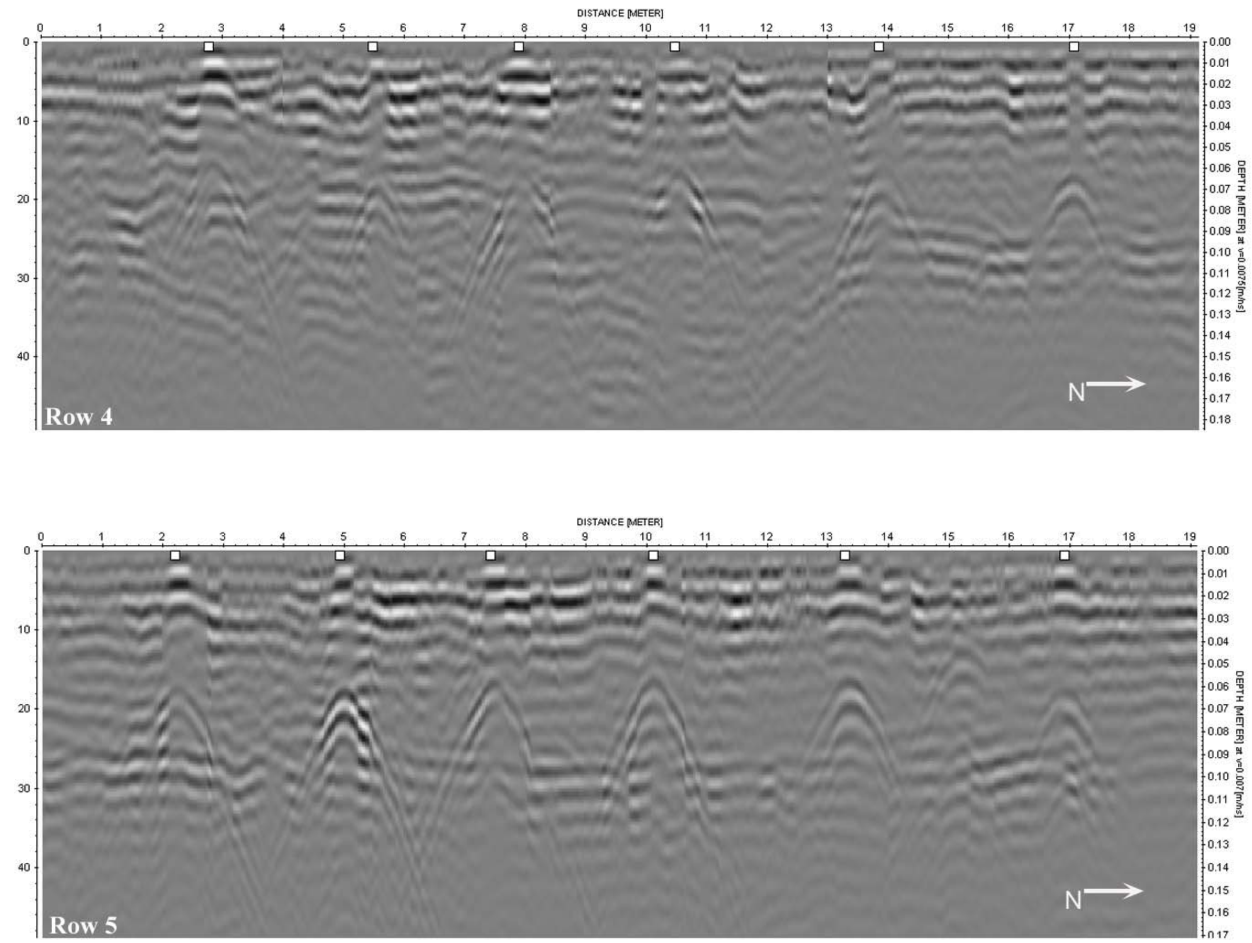

Figure B-1 continued. Radargrams for rows 4 and 5 collected with the 500-MHz antenna when the weapons were buried at a depth of 60-65cm.

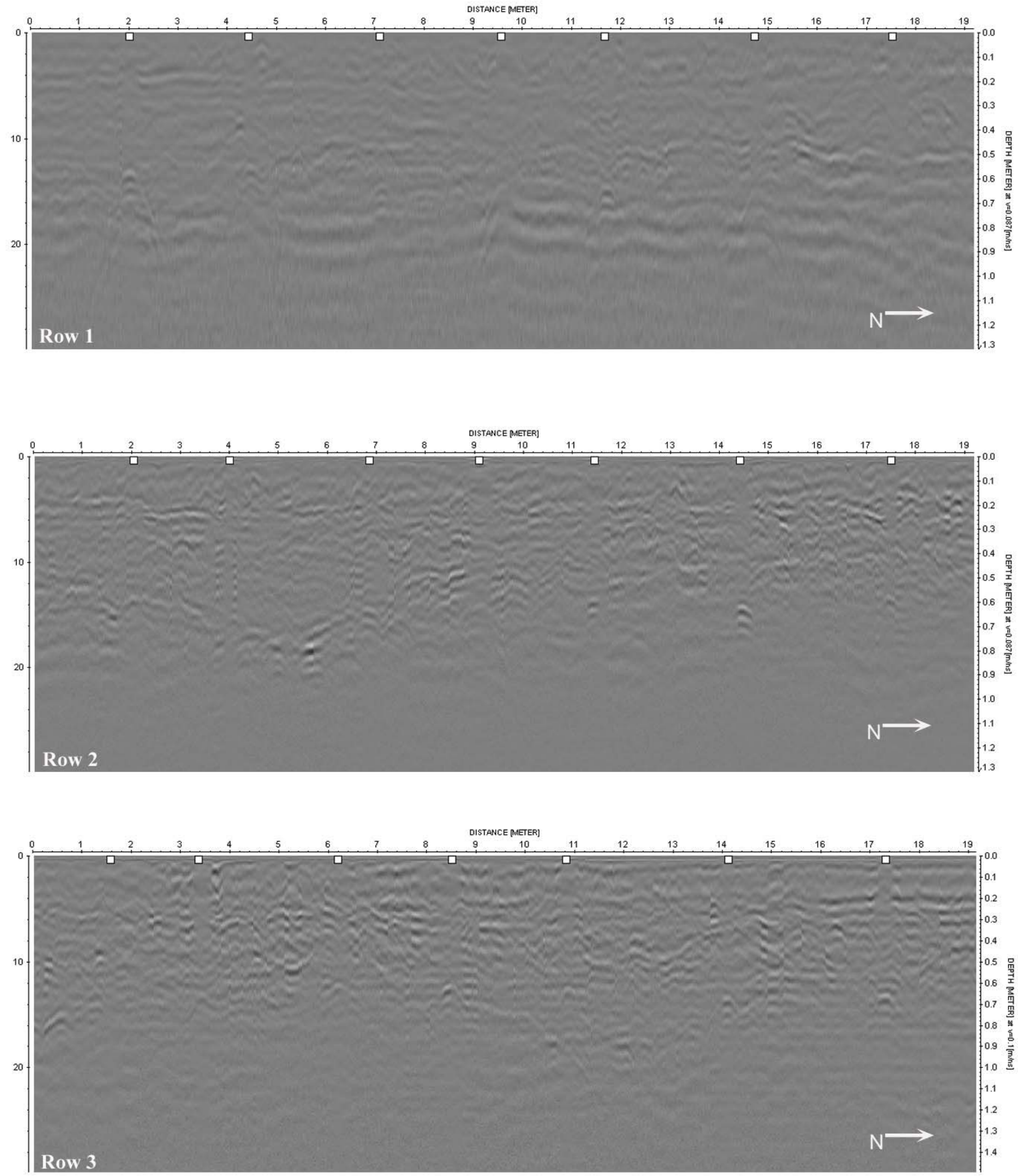

Figure B-2. Radargrams for rows 1, 2, and 3 collected with the 800-MHz antenna when the weapons were buried at a depth of 60-65cm.

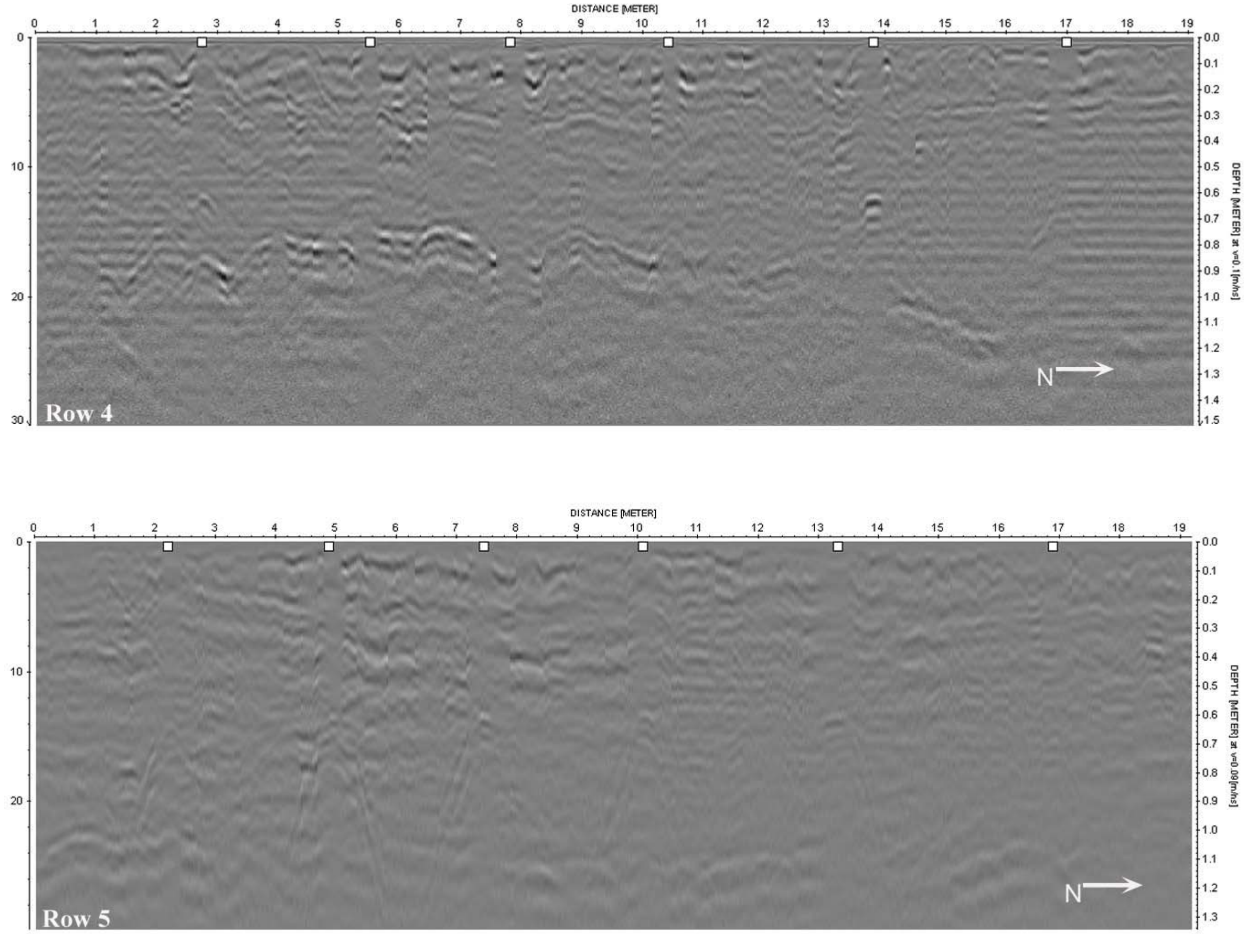

Figure B-2 continued. Radargrams for rows 4 and 5 collected with the 800-MHz antenna when the weapons were buried at a depth of 60-65cm.