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Canadian Archaeological Association
Association canadienne d'archéologie

Resistivity Survey

Recommended Data Collection Procedures for Locating Unmarked Graves

Introduction

Electrical resistivity techniques have long been used in archaeological and forensic contexts. Like other geophysical methods, this technique can produce both maps and profiles of an archaeological site, highlighting possible features or structures. It measures the ability of the Earth's near-surface to resist an electrical current moving through it.

A wide variety of instruments are available with different ways of surveying, however, the core principles remain the same. The method works by sending electric current, generated from a battery, into the ground via metal electrodes. The computer/meter measures the voltage between any two electrodes and then calcululates the resistance in Ω m between these two electrodes. Once a measurement has been made from many electrodes, the specialist interprets the shape, character, and depth of any observed anomalies and determines whether or not they could be related to possible archaeological features. For example, metal objects conduct electricity well and can produce low resistivity values if they are large enough. Characteristics such as ground composition, porosity, fluid saturation, and fluid chemistry also affect resistivity. In other words, the technique will register changes in subsurface deposits based on how resistive or non-resistive they are to the passage of electrical current.

Resistivity surveys have been used to locate graves in cemeteries. Why is resistivity a useful technique for locating unmarked graves? This technique is very good at identifying voids (which have high resistivity due to the presence of air) as well as changes in sediment compaction and moisture levels (increasing or decreasing resistance respectively). It is also well suited for high clay/conductive soils (environments that GPR often finds challenging). In cemeteries, some authors have found that high resistivity values denote grave shafts, while low resistivity values within graves may indicate metal (such as coffin plates or hardware). It is clear that graves may be represented by many different characteristics in resistivity data, so it is important to adapt the search and interpretation methods accordingly. In the following document, we present some key points to consider in resistivity surveys.

Like the other techniques presented by the *CAA Working Group on Unmarked Graves (https://canadianarchaeology.com/caa/resources-indigenous-communities-considering-investigating-unmarked-graves)*, it is important to remember that resistivity surveys locate changes in the physical properties of the subsurface that could be related to cultural and natural disturbance events (**not the objects themselves**). Therefore, interpreting this type of data requires caution, discretion and expertise.

1) Planning

There are two main types of resistivity survey: (1) area survey that maps a large area with a focus on a particular depth range and (2) electrical resistivity tomography (ERT) that images a vertical transect through the earth along a profile (Figures 1 and 2). Both methods have advantages / disadvantages and the cost / time required can be different. In Europe, resistivity area surveying is quite popular and conducted with a rotating two- or four- metal electrode cart system with fixed electrode widths. Such devices cover larger areas quickly but largely produce area maps and have limited ability to document variation in subsurface properties across a range of depths (Figures 2 and 3). Conversely, ERT systems take longer and are more stationary. They require the operator to place a line or grid of metal electrodes and allow the computer to calculate the ground resistance over a period of time. Once those calculations are done, these electrodes are removed from the ground and planted at the next survey location (this can be done in a grid with consistent intervals). While relatively slow, ERT can produce both maps of sites, and also detailed profiles of the subsurface, with variable depths/resolutions depending on the electrode spacing (Figures 1 and 3). Both techniques have been shown to be able to identify graves under reasonable conditions.

Figure 1. Geophysical survey in progress. Profiling ERT equipment pictured in the foreground with IRIS Syscal Junior Switch-48 resistivity meter, marine battery, metal electrodes and cable. 48 electrodes were spaced 0.5 m apart spanning a profile of 23.5 m. Six 23.5 m profiles, spaced 1 m apart, were collected at a known cemetery. Dipole-dipole and Wenner electrode arrays were used to collect the resistivity profiles. In the background are different GPR systems. Image taken as part of a project in southern Ontario (https://doi.org/10.1007/s41636-020-00251-7).

Figure 2. Geophysical survey in progress. The Geoscan RM15 configured in twin probe array. Two pairs of probes are used. The first “mobile” pair are attached to the frame and are moved systematically across a survey area to take measurements. The second “remote” pair, which record the background resistance, are out of picture at the end of the 30 m orange cable. The beam holding the two probes at the bottom of the frame can be modified to take up to 9 probes, allowing vertical profile measurements and the production of pseudo-sections.

When planning for a resistivity survey, it is important to remember that the depth and resolution of the data collected is determined by the spacing of the electrodes. The more widely spaced the electrodes, the deeper the electric current can propagate through the subsurface. However, widely spaced electrodes result in lower spatial resolution. The maximum data resolution is directly equivalent to the minimum electrode spacing. For ERT surveys, widely spaced electrodes also result in more area being covered per line (perhaps decreasing the time necessary to survey a site). Additionally, there are different electrode configurations (which electrodes are sending and receiving the current) that will result in different types of data collected. As a result of all these factors, many authors recommend shorter electrode spacing (~25 cm) to get as clear and detailed a profile/map of potential graves and grave shafts as possible. Regardless of this variation in data collection, how you design your survey will depend largely on the equipment you have available.

It is also important to remember that resistivity is helpful in cases where other geophysical techniques (such as GPR) fail. Notably, resistivity is a reliable technique in high clay/saline environments and in areas with lots of obstructions and vegetation (*environments that typically prohibit GPR*). However, the technique is not effective in dry environments (where GPR excels). While resistivity will not replace GPR as the 'go-to' technique for locating graves (given its extensive setup and operating time), it remains a great addition to unmarked grave projects and an important technique in certain environments.

2) Data Collection Protocols

Data collecting protocols will vary significantly depending on the methodology and instrument used. In ERT surveys (Figure 3), electrode placement and how current is transmitted between them has a significant impact on the resolution and sensitivity of the data collected. Common electrode configurations/geometries include Wenner, Schlumberger, pole-dipole, dipole-dipole, pole-pole, and gradient, all of which can be used for ERT/ profiling (Figure 4). Interested readers can learn about the different configurations using this open source link (Surveys — GPG 0.0.1 documentation (geosci.xyz)). Dipole-dipole is used extensively for shallow geophysical work, such as archaeology. Area survey systems (Figure 2) on the other hand often have limited profiling capabilities, and thus have limited options for electrode configuration. Which configuration you use is determined by: the location and characteristics of your target, field/environmental constraints on laying electrodes, and the practical limitations of your specific equipment. If you are borrowing resistivity equipment from geophysics departments in North America, the equipment will likely be ERT/ profiling equipment.

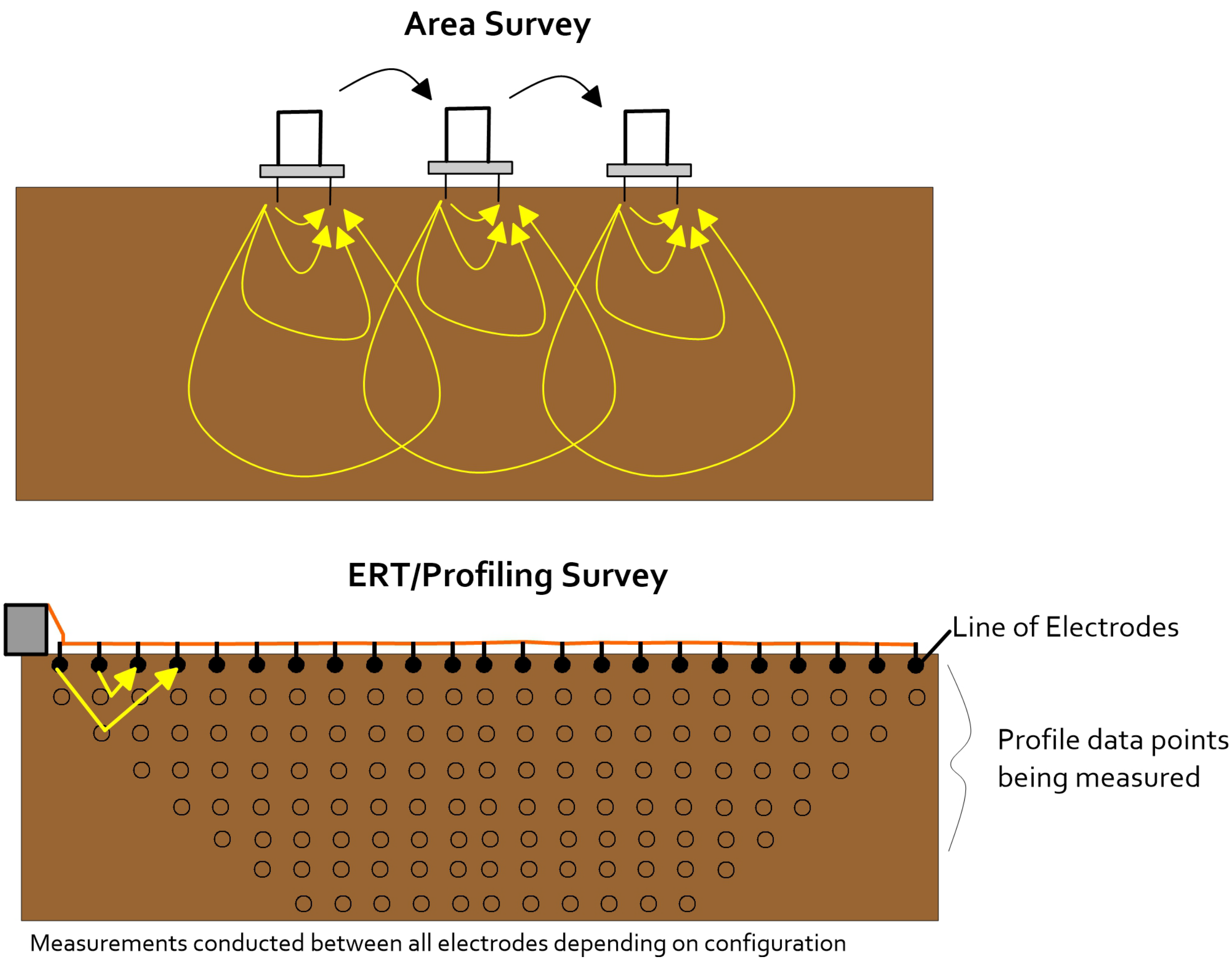

Figure 3. Schematic diagram of how both area surveys and ERT survey the subsurface. *Top:* Area surveys (also see Figure 2) send and receive electrical current from a fixed frame. Repeated measurements are taken by physically moving the frame to a new location to record the new data points. *Bottom:* Profiling surveys (also see Figure 1) send and receive electrical current from many electrodes that are manually placed along the ground's surface. The resistivity meter will send electrical current in various patterns between the electrodes to record a profile with many data points (o). This diagram shows the initial readings of a dipole-dipole ERT survey. To collect another profile, the entire system has to be removed and replaced at a new location. Figure by Liam Wadsworth.

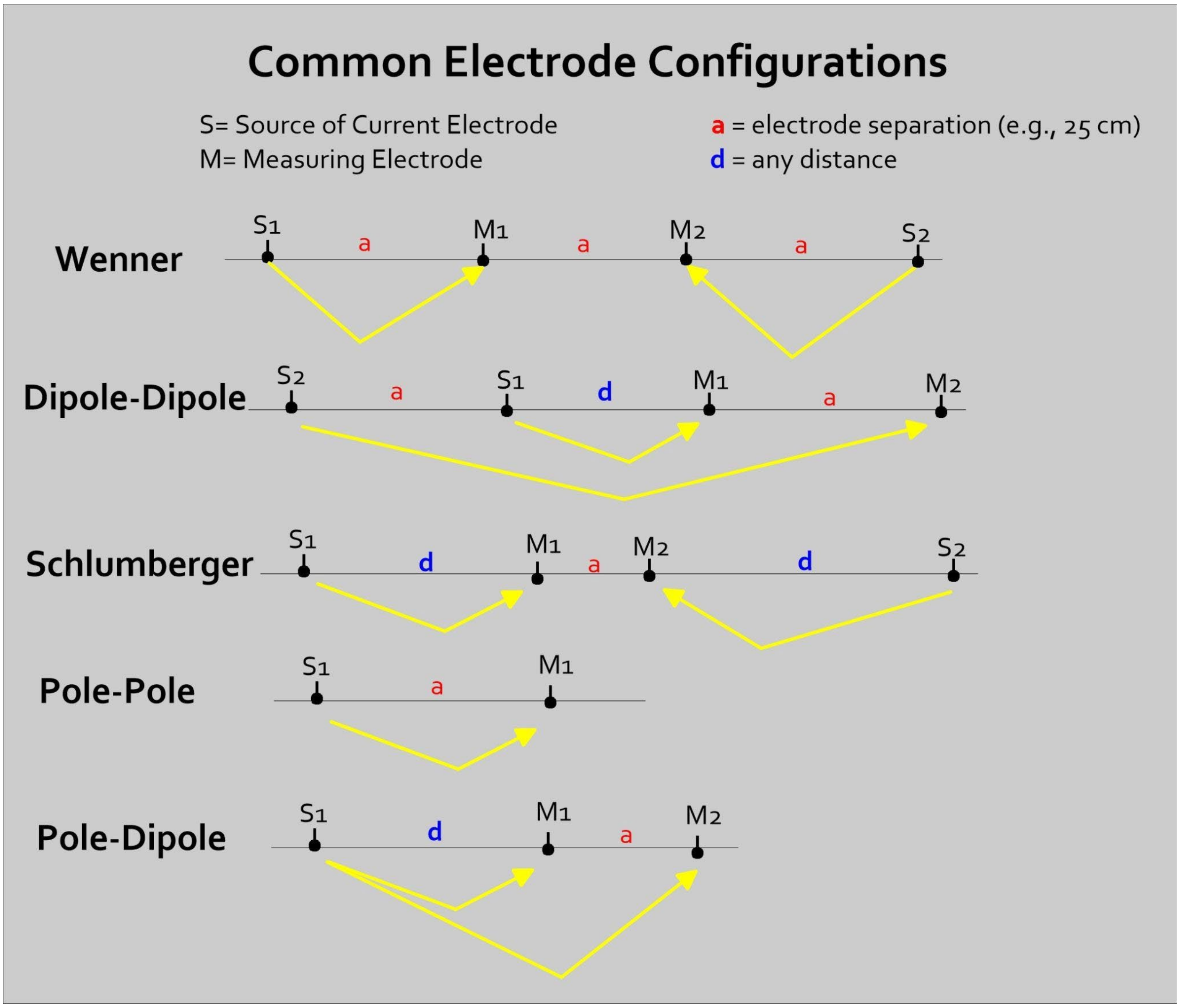

Figure 4. Common electrode arrays/configurations. Yellow lines denote the electrical current that transmits between a source and measurement electrode. The different patterns produce different types of resistivity surveys, some are better for profiling. Diagram remade from the open source textbook, Geophysics for Practicing Geoscientists (https://gpg.geosci.xyz/).

For ERT surveys, multiple electrodes are set up in an equidistant straight line across the ground. Often these are centered above the area or feature of interest. Depending on how many electrodes you have available, it is best to space them at either 25 cm (ideal) or 50 cm (acceptable) intervals. Each of these electrodes is connected to a cable that connects to the resistivity meter. The meter is pre-programmed with different electrode arrays that run resistivity tests between the electrodes. It’s important that the cables, electrodes, and meter are not touched or changed until it has finished its calculations. You may need to improve the initial contact resistance between the electrode and the ground by moistening the insertion point around your electrodes with water. You can also collect 3-D resistivity data by spacing electrodes in a grid pattern, or collecting individual resistivity lines in a grid pattern. This is done much the same way you collect individual profiles. After you collect an individual line, you must manually move each electrode a certain distance to the next profile. This is a time-consuming process, and again it is best to limit the space between your profiles. In an ideal world, if you spaced each electrode 25 cm apart, and each profile 25 cm apart, you would collect very high resolution data that could be used to identify potential graves. However, given that often it's only possible to get a few profiles done in a day, you may wish to increase this distance to 50 cm or a meter (this will of course result in worse resolution and possibly miss graves).

For area surveys, grids are established over the area of investigation in much the same way as for GPR survey. For the Geoscan RM15 two pairs of probes are used, usually configured in a twin probe array. The first “mobile” pair of probes are attached to a frame and are moved systematically across a survey area (Figure 2). Also connected to the frame (by a 30m cable) is a second “remote” pair of probes that are left in a stationary position to record background resistance. Data points are collected by inserting probes into the ground at regular points along transects marked by tapes. To identify graves, we recommend taking readings every 25 cm along traverses spaced 25 cm apart. Transects can be walked bi-directionally (e.g back and forth) as long as the instrument is left in the same orientation. This shortens the time needed to survey, though it is still relatively slow compared to other techniques. We estimate that it takes approximately 2 hours to survey a 20m by 20m area at this resolution. This process can be speeded up by connecting more probes to the mobile frame, though the resulting instrument is often clumsy to use and only works in ideal field conditions.

Whether ERT or area surveys are carried out, once all of your data is collected, it is time to process the data so it can be interpreted by specialists.

3) Data processing, interpretation and presentation

Once the resistivity survey is completed, the data needs to be processed in computer software that generates plots and profiles for interpretation and presentation (Figure 5). File outputs are often xyz files in ASCII format. Like other geophysical techniques, data processing is usually undertaken to reduce noise and improve interpretability. Data can be presented and processed in 1-D, 2-D or 3D forms. To transform resistivity data into 2-D profiles (and then plot into 3-D grids), the data must undergo a process called *inversion*. Most commercially available inversion software (such as Res2DInv) will automatically calculate the best resistivity model possible for the electrode configuration with minimum user input. Once this is done, processed resistivity data can be gridded and visualized in different software options such as Surfer or a GIS.

Resistivity survey data is often difficult to interpret. While more robust than other forms of geophysical data, it is often more challenging to interpret than GPR data. As a result, interpretations should be made by trained professionals, and step-by-step explanations of the different processes and logic models applied to the data should be outlined. For example, grave shafts/pits may have low resistance when their pores are filled with fluid and sediments are less compacted. However, if the structure of the grave is intact, or a coffin is present, graves may appear as highly resistant because of void space. In reality, there are different markers for a grave in resistivity data, therefore (as always) it is best to include additional (and different) remote sensing data and community information to inform interpretations.

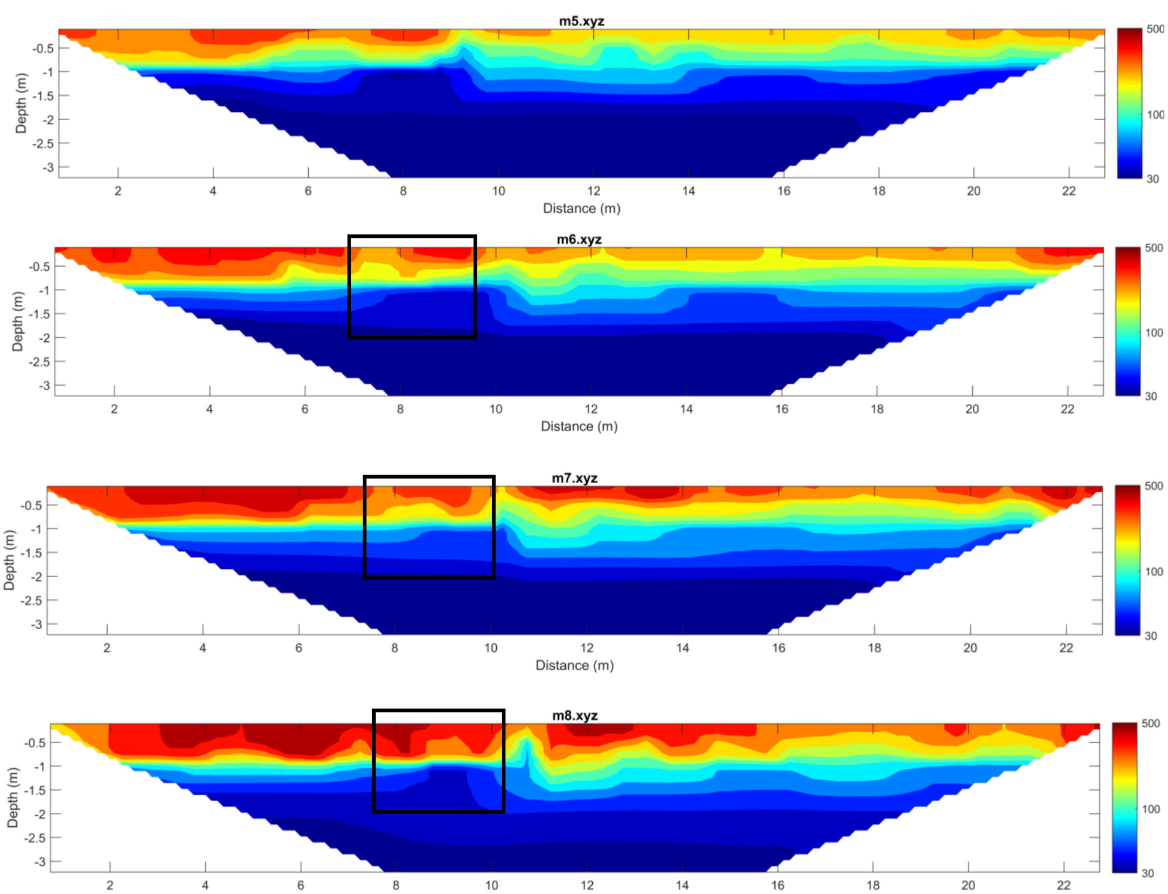

Figure 5: Four 24 m resistivity (ERT) profiles spaced one meter apart following inversion. Highlighted is an identified grave in the profile spanning 2 m (or 3 profiles) that shows a range of Ω m values and a rectangular shape. This specific feature was also surveyed with GPR and the

two datasets both suggested a grave was located at this location. This figure was taken from Wadsworth et al. 2020: https://doi.org/10.1007/s41636-020-00251-7).

The final report should include:

• Copies of unprocessed raw data should be included with the report for archiving.

• A brief site description indicating underlying soil types and geology, ground conditions and vegetation, description of built architecture, previous disturbance including previous archaeological investigations and known underground services that might impact the results.

• Photographs, if appropriate, of each survey area showing the ground conditions.

• The survey methodology should provide a description of the instrumentation used and indicate the line and electrode separation, electrode configuration, sampling interval, and the resulting effective spatial resolution achieved.

• A map showing the location of survey grids in relation to other features at the site.

• All location maps must be geo-referenced and annotated with the geographic coordinate system and projection used in order that the location of the grids can be re-established by a third party.

• Plots of minimally processed or raw data should be included prior to or in comparison with the presentation of final processed (and/or inversion) plots.

• All data processing steps should be described in full and their effects on the data highlighted.

• Anomalies resulting from data collection errors that cannot be removed through data processing should be described and distinguished from other responses.

• The interpretation should distinguish anthropogenic from natural features identified in the data.

• Depth estimates of features should be included with inversion ERT data.

• Colour Scales should be appropriate and highly visible. Plots should include a north arrow, range bar including appropriate values and units, and be presented in and include an appropriate scale for interpretation.

• Interpreted plans indicating all features of interest should be included alongside the data plots.

• Anomalies of interest should be identified with a unique identifier on the plots, and described in full to indicate shape and signal amplitude. This might best be achieved in a table rather than a long descriptive narrative.

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