5.0 ELECTROMAGNETIC SURVEYING

5.1 Introduction

Magnetic and electromagnetic surveying are considered to be complementary techniques, in that magnetic surveying is used for the detection of ferrous metals, while electromagnetics is used for the detection of ferrous and/or non-ferrous metals.

The EM method provides a rapid means of measuring the relative changes in conductivity between buried metallic objects, subsurface soil and rock, by the induction of an electromagnetic current into the subsurface. A small alternating current passing through a transmitter coil produces a primary, time-varying magnetic field within the ground. Through inductive coupling, the primary magnetic field produces small eddy currents in the subsurface which, in turn, create their own secondary magnetic field (Figure 5-1). The receiver coil senses both the primary and the secondary fields.

Figure 5-1
Electromagnetic Field

Changes in magnitude and phase of the individual currents are sometimes related to the terrain conductivity. Terrain conductivity is a function of the soil or rock type and composition, the porosity and permeability of the subsurface units, the conductivity of the fluids filling the pore spaces, and the presence of buried conductive (metallic) objects. EM methods are very sensitive to subsurface features, such as lateral soil changes due to compaction of backfill, buried metallic objects, and ancient habitation sites.

In general, the following relationships can be used as a guide for determining the effects on conductivity for different objects or geological conditions:

Process/Object	Conductivity
Backfilled excavation	Increase
Mineral rich soil (black sands)	Increase
Salt water	Increase
Clay increase	Increase
Wet soil	Increase
Metallic objects*	Increase/Decrease
Fertilized soil	Increase
Silicification	Decrease

Mineral leached soil Decrease
Soil compaction Decrease

* Note: The shape of a metallic object and its orientation to the EM field will determine if a conductivity increase or decrease will exist. For example, when performing EM surveying parallel to metal pipes, a conductivity high will be evident, while when surveying perpendicular to the same pipes, a conductivity low will be evident.

Utilizing a non-surface contacting transmitter-receiver arrangement, the interaction of the generated circular eddy current loops or electromagnetic field with earthen materials is directly proportional to terrain conductivity within the influence area of the instrument. Conductivity, measured in units of siemens or millimho per meter (mho/m) of material, is the reciprocal of resistivity. Therefore, the information provided by a conductivity survey should in theory produce similar results to that of a resistivity survey. The main advantage of terrain conductivity surveying over that of resistivity surveying is that the instrumentation does not have to be in contact with the ground surface since the EM signal is inductively coupled to the subsurface.

5.2 Limitations

EM measurements taken over an area are an average of all ground conductivities within the depth range of the instrument used. The depth range is a function of the transmitter to receiver coil separation and frequency of the transmitted signal.

Electromagnetic interference from cultural features will be averaged into the measurement. These features, such as

buildings, fences, buried objects and utilities, must be accounted for by maintaining a set distance between the feature and the instrument. EM surveys should not be performed within 15 meters of fences. Field tests will indicate at which distances features will interfere with EM measurements. Areas exhibiting high conductivities, such as clayey soils, may not permit much penetration of the signal due to dissipation of the EM field.

5.3 Instrumentation

Currently available instrumentation consists of two basic types. One type, which is almost always used for forensic investigations, consists of a transmitter coil and a receiving coil mounted together, at a fixed distance apart. The other type of EM instrumentation, primarily used for mineral and groundwater explorations, consists of separate transmitting and receiving coils which can be independently moved to achieve greater separation than fixed coil instruments. The extent or size of the induced electromagnetic field is determined by the coil separations.

Most conductivity equipment incorporates a voltage meter calibrated to read conductivity as a function of an output voltage. The output voltage is, in some cases, linearly proportional to the conductive coupling effects of the subsurface material within the zone of transmitter-receiver influence. A semi-spherical area around the transmitterreceiver coils is investigated, the volume of which is related to the coil separation distance and the orientation of the coils.

Forensic-related conductivity anomalies generally are near the surface, are relatively small, occupy a small volume, and

are probably not very conductive, if they are of a nonmetallic nature. Therefore, equipment must be capable of providing a highly sensitive measurement of a relatively small volume area. To accomplish this, coil spacing must be small, perhaps 1-4 meters in length. A one-meter coil spacing instrument, such as a Geonics EM 38 (Figure 5-2), vertically held at a height of 30 centimeters (cm) above the ground surface, is capable of penetrating approximately 1.5 meters (5 feet) in depth. A larger coil spacing, 3.7 meters, is available in the Geonics EM-31 model, as shown in Figure 5-3. This instrument averages conductivity measurements over a much greater soil volume, to a depth of approximately 6 meters (18 feet).

Figure 5-2
Ground Conductivity Meter, EM 38

Figure 5-3
Ground Conductivity Meter, EM 31

Utilizing a one-meter coil spacing instrument across a site on a one-meter station interval along each line will result in a significant number of measurements. In some investigative cases smaller station spacing may be required, further increasing the number of measurements. To facilitate such data recording, it is recommended that a digital recording device, such as a polycorder (data logger) be employed. The acquired data can be downloaded to a computer upon survey completion.

5.4 Field Procedures

Prior to electromagnetic data collection, the endpoints of each survey line should be staked and marked. The location of these points should be accurately transferred to a base map. Nonmetallic stakes should be used to mark station location in the field. The orientation of the survey lines is not important, as it is in magnetic surveying. An example of a survey grid is shown in Figure 4-6.

Instrument calibration is normally set at the manufacturer's facility and should be checked periodically by the manufacturer. In the field, the instrument operator will normally establish a base line, outside of the grid to be surveyed, to calibrate (finely tune) the instrument based on actual site materials and to ensure proper instrument operation. Measurements along this line should be repeated periodically during the course of surveying. Measurements along this line will give the operator information on the amplitude and spatial changes that will effect EM measurements.

Initial checkout procedures for the instrument involve checking battery condition, zeroing the instrument at its least sensitive scale (typically in units of millimhos/meter), and checking the instrument sensitivity to ensure proper scale readings during the survey. Both the EM-38 and the EM-31 are capable of reading two components of the electromagnetic field, the in-phase and the quadrature phase components. The in-phase component is primarily sensitive to metals, while the quadrature phase is primarily indicative of changes in ground conductivities.

Data acquisition is a straightforward process, similar to magnetic surveys. Measurements can be made along a line on a station-to-station basis or continuously. In fixed-coil (EM-31 or EM-38) surveying, the instrument is kept at a constant height above the ground, and parallel to the ground surface. This will limit interference due to measuring smaller or greater volumes of the subsurface if the instrument is varied in height. The instrument may be maintained in a vertical (coils horizontal) or a horizontal (coils vertical) position. Vertical coil orientations offer, in general, lesser depth penetration than horizontally oriented coils. As a general rule, when using horizontally oriented coils, the depth of penetration is approximately 1-1/2 times the coil separation, and with vertically oriented coils, it is 3/4 of the coil separation.

At each station the instrument should be consistently oriented in the same direction. Taking two readings at each station, perpendicular to each other, will identify lateral changes, if they exist. This is particularly important since a clandestine grave may exhibit a significant measurement variation if the orientation of the instrument is parallel to, or perpendicular to the feature. It is usually more time-efficient

to acquire data with the coils located with one orientation, and then rerun the survey grid with the coils oriented in a direction perpendicular to the initial orientation.

Large negative or positive fluctuations in measurements over a small area may be indicative of highly conductive subsurface materials, possibly related to metallic objects. Some instrument manufacturers recommend determining the effects of nearby cultural features by moving away from a feature until its effects on the measurement are negligible. Besides cultural influences, the operator should be aware of electrical storm activity (spherics), as it may cause meter readings to fluctuate beyond acceptable noise levels. When spherics are a problem the use of a horizontal (vertical coils) coil orientation will minimize their effects.

5.5 Special Considerations

Because fixed coil instruments are very sensitive, it is recommended that instrument operators remove all metal objects from their person prior to performing EM surveys. The operator should be free of objects such as keys, belt buckles, and steel-toed boots.

5.6 Documentation

Similarly to magnetic surveys, all measurements, line numbers, and station locations can be digitally recorded to a data logger. For small scale surveys a written record of line, station, and measurements will suffice. No matter which method of documentation is selected, survey comments should be explained with sufficient detail to aid in the interpretative process. These comments may include location of cultural interference, weather and observed

geologic features. Information obtained during an EM survey can be presented using standardized data sheets (Figure 5-4) when data is not stored in a data logger.

Figure 5-4
EM Field Data Sheet

5.7 Data Reduction

All conductivity values — in millimhos per meter (or millisiemens per meter, mS/m) and in-phase values, in parts per thousand (ppt) — are subsequently plotted on a map and/or computer processed so that their variation over the site can be analyzed.

In most cases very little data reduction is necessary when the primary purpose of the survey is to observe lateral and/or spatial variations rather than absolute conductivity values. Resistivity is obtained by dividing the conductivity by 1000, resulting in unit values of ohm-meters. Usually the resistivity of materials as measured by EM methods is slightly lower than the resistivity of the same materials determined using direct current equipment. This is because the conductivity of a material increases as the frequency of the measuring signal increases.

Generally, a plotted profile or contour map depicting apparent conductivity and in-phase values verses station location is the final data reduction product. For forensic investigations, it is recommended that these plots be produced in the field, by hand or by a computer.

5.8 Data Interpretation

The interpretation of spatial variations in conductivity values is normally a qualitative one. Since the objective of an EM survey is to detect changes from a relatively constant background, both positive (increasing) and negative (decreasing) conductivity can be of significance with respect to a forensic investigation. Conductivity survey results

across sites are often variable. Changes in subsurface moisture content and underground utilities are often the cause. Buried, conductive metals can produce positive or negative anomalies, depending on the shape of the source and its orientation with respect to the EM system coils.

5.9 Data Presentation

The electromagnetic field data is normally presented either in profile form or as iso-conductivity contour maps. When in profile form, the
conductivity value in mS/m is plotted on the y-axis, and the line stations are plotted on the x-axis (Figure 5-5). For inphase data, the ppt value is plotted on the y-axis and the line stations on the x-axis. Iso-conductivity maps and isointensity maps (Figure 5-6) are quite useful in illustrating
features in an area of interest. Computer processing can be used to generate shadow maps and enhance the iso-maps

(Figure 5-7).
WHERE IS IT?
86
Figure 5-5
EM Profile
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87
Figure 5-6
EM Map
WHERE IS IT?
88
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