Methodological Limitations In The Location Of Underground Objects By Electrical Resistivity

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Electrical resistivity as applied to the field of archaeology is only one approach in the ever-growing family of scientific devices that enable the archaeologist to increase his efficiency in organizing and developing work programs in field projects. The days of the classical site, with hundreds of laborers removing tons of rubble, guided by a handful of experts, are just about over. Increased labor costs in North America and Europe, as well as rising nationalism in other areas of the world, have intensified the need to locate quickly and accurately the objectives of field projects.

Resistivity surveying has been a tool in geological survey projects for over forty years, but it was first applied to archaeology in 1946 (1). Considerable improvements in design and portability have been made in the intervening years and today it is a standard piece of equipment on many projects around the world.

Resistivity surveying essentially is an observation of the conductivity of the ground in specific areas at varying depths. The average resistance pattern will vary widely depending on the type of soil and its moisture content (6). The equipment needs to be versatile enough to handle these variations while at the same time be sensitive enough to detect the presence of an anomaly in any given range. Since there is a direct relationship between soil conductivity and moisture content, an object is indicated when it either retains more moisture than the surrounding area and gives a reading of less resistance, or it excludes moisture, such as a void, or hard solid object, and thereby indicates more resistance. The method has the advantage of being relatively economical and simple to operate, and is not limited or affected by metallic objects or magnetic anomalies.

However, all presently available systems have limitations, and because of this, several types of equipment are frequently used on the same set of problems. The electrical resistivity approach has two such handicaps. Some moisture must be present. This is not a serious limitation for most of South America, Europe, and many parts of Asia and Africa. It works well in eastern North America, and should be usable in most of the plains area and the Northwest. It becomes very limited, however, in areas such as Egypt, Arabia, and in North America's Southwest. Professor Hanfmann of Harvard reported that an M.I.T. team did not obtain satisfactory results at Sardis in Turkey two years ago, but the Lerici Foundation in Rome has received world-wide attention for work done at Tarquinia in Italy on Etruscan tombs (7). No doubt, all remember how Engineer C. M. Lerici developed the technique of using a power-driven auger to drill down into a tomb, insert a periscope with a light attached to the base, and with mirrors, photograph and even televise the contents of the tomb without excavating it. The tombs themselves, however, were located by using electrical resistivity equipment (4). The other limitation of resistivity surveying is the labor involved. Four probes must be inserted into the ground and the depth of the probe penetration must be controlled. The probes must be placed in a nearly straight line at specific intervals, with cables attached to all four probes from the main piece of equipment. In spite of this, the use of a fifth probe, a change-over-switch, transistorized circuit, and skilled operators, up to 300 readings per hour have been made, but this cannot be kept up for extended periods of time (1). This speed approaches that available with a magnetometer, but it is more demanding and tedious.

Let us now examine the recommended set-up for a reading. Since there are, to some degree, natural earth currents measured as direct current, we use an alternating current to eliminate their potential interference. When only two probes are used, the voltage measured between the probes will not only measure the resistance in the ground

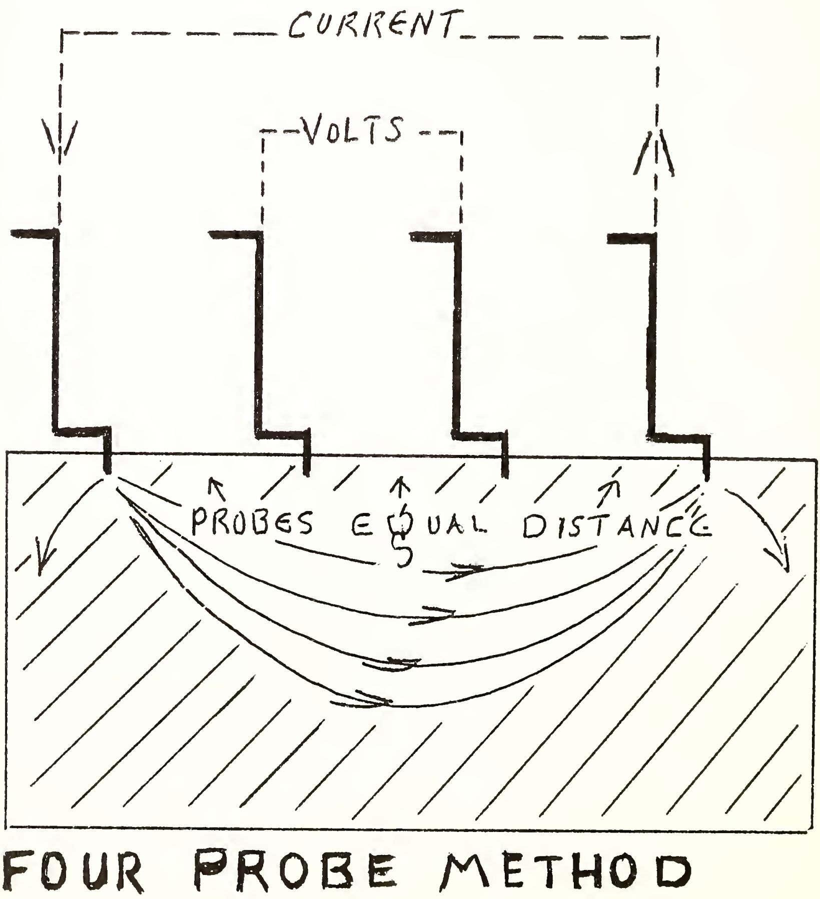

Figure 1. Four probe method.

but will measure the resistance between probe and ground. A loose probe or surface wetness would give false indications. Therefore, the four-probe method is recommended (Fig. 1). An alternating current is sent through the outer probes and, completely independent of these probes, two inner probes measure a voltage that is a very small fraction of the total voltage, but is directly proportional to the current flowing. Thus we have the relation:

Effective resistance (R) equals the voltage across the inner probes divided by the current through the outer probes.

Now when we have the probes equally spaced, the specific resistivity (r), which is what we are after, is related to the effective resistance (R) as follows:

$$r = 2 \pi d R$$

and where (d) is in feet and (R) in ohms, we then have

$$r = 191 \times d \times R \text{ ohm-cm}$$

and it is in these terms that the findings are reported (1).

In order to better acquaint ourselves with electrical resistivity, we decided to build a very simple and inexpensive piece of equipment and to test the basic theory and procedures. Taking a 12-volt auto battery, we drew the direct current through a Radiart Vipower 12-volt, 100-watt inverter, converting it to 60-cycle alternating current, and then on through a 7½-amp, 0-140-volt Powerstat for controlling the current. We applied 100 milliamps of alternating current through the outer probes at 80 volts, but varied the voltage throughout the readings to keep the milliamps constant. We then took our readings off the inner probe voltmeter and calculated the specific resistivity (r).

Professional equipment includes a Null balancing circuit. A calibrated rheostat on the outer probe side is balanced with the voltage developed between the inner probes, and when an anomaly comes into the path of the inner probes, the Null detector is thrown off balance and the variation is recorded. This eliminates calculations.

All four probes should be equally distributed from each other. Their distance is determined by the depth of penetration of the current that the operator wishes. The penetration is 1.5 times the distance between the probes. The penetration of the probe itself into the ground is important. An ideal condition is 1/20th the distance between probes. However, this becomes impracticable when working in one-foot probe separations. As a rule, 3″ probe penetration is necessary. At one-foot probe separations, the error will be approximately 10%. However, with two-foot separations, the error is reduced to approximately 2%. Fortunately, most material will be found below a two-foot depth and the percent error is greatly reduced.

To demonstrate this particular system, a laboratory project was set up. A flat area in Marion County was selected that had not been cultivated for at least ten years. A pit was dug 24″ square and 36″ deep. An empty wooden box (approximately 1000 cu. in.) was placed in the center at the bottom. The first set of readings were set for a four-and-one-half-foot current penetration with no indications of variations. The second set was taken, still over the "known object," for three-foot penetrations with very little variation. The third set was read at the two-and-one-half-foot level and gave an excellent indication in the correct area, which gave nearly a 1000 ohm-cm indicated variation. The fourth set at the one-and-one-half-foot depth exhibited a more erratic pattern, but not as strong or consistent as the actual area of the object. As has been pointed out, at one-foot probe separations, the margins of error are higher due to probe penetrations, and therefore more erratic readings would be expected (Fig. 2). Parallel readings

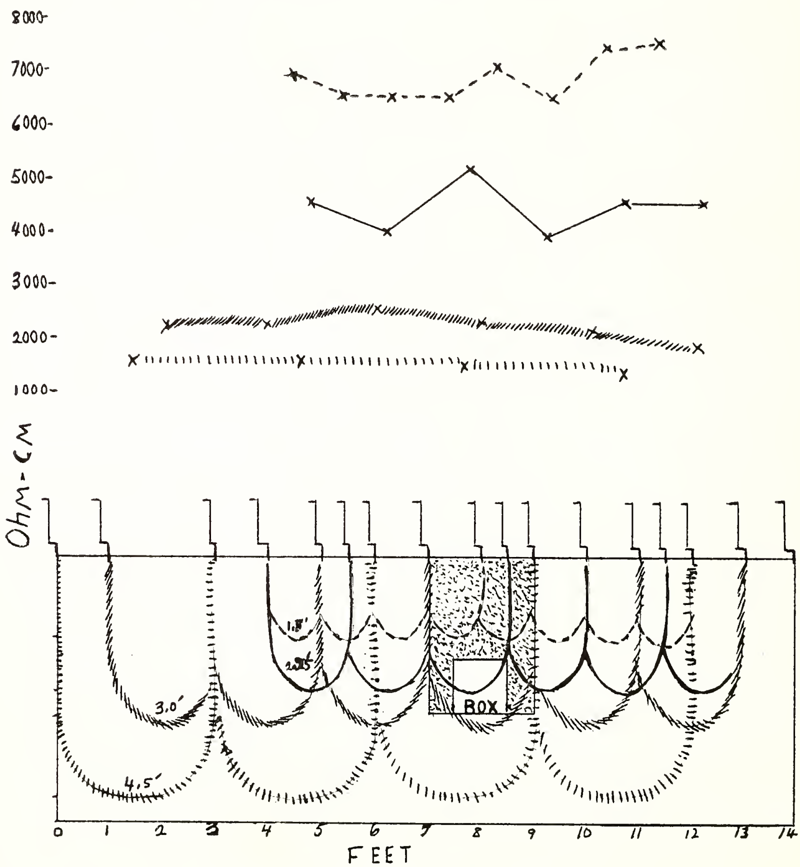

Figure 2. Locating known object.

at constant depth with the first set going through the object and the second set missing the object also showed a nice contrast (Fig. 3). The solid lines were reread one week after the first readings with exactly the same results. The dotted lines indicate readings that were taken over the same area one month later on a day following a light rain. The resistance was lower, but there was reasonably good reproduceability of pattern.

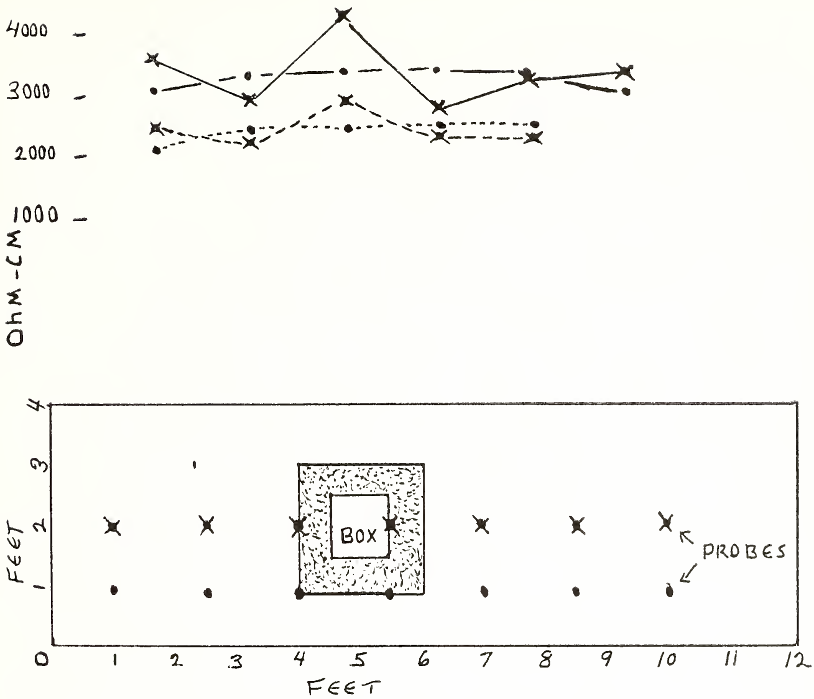

Figure 3. Parallel profile of known object.

There has been little opportunity to field test this equipment. Before the Bowen Site, a late woodland village located at Keystone Avenue and White River just north of Indianapolis, was closed by J. C. Householder last year, some very preliminary resistivity surveying was tried. At that time, the area available was considerably worked over and disturbed by multiple occupation. The object was to find indications of refuse or storage pits. The results were encouraging, but too limited in scope and perhaps too subjective in interpretation to be conclusive. The results did indicate good possibilities with professional equipment on this type of material.

The results obtained in the laboratory project also indicated good future possibilities for testing in this area. On salvage operations where time is short because of highway or building construction, a resistivity survey might be very desirable. On observing a number of burials uncovered and removed at the Bowen Site, it was noted that many of the skulls contained no worked soil and were thus very fragile and subject to damage. It is hoped that with refinements such voids could be detected, and the skulls could be uncovered with much less risk of damage.

Of course, professional equipment is available and should be used on regularly projected sites. The "Geohm," manufactured in Germany, is very dependable and relatively inexpensive. It has been tested extensively in this country by the Applied Science Center of Archaeology, University of Pennsylvania (8). The Martin-Clark Instruments Company of Surry, England, make a more sophisticated instrument which contains the desirable change-over switch that speeds up field readings. It is being used by the Historical Society of Williamsburg, Virginia, among others. The Lerici Foundation in Rome has built a far more complicated instrument, but Elizabeth K. Ralph, Associate Director of ASCA, University of Pennsylvania, reports the "Geohm" as being just as dependable.

As mentioned previously, the resistivity survey method is frequently used with other equipment such as the proton magnetometer (5). The late Dr. Glenn Black was a prime force in inaugurating the use of a proton magnetometer at Angel Mounds near Evansville. Dr. Scollar from Germany has developed a special digital differential proton magnetometer. Elizabeth K. Ralph is now in Southern Italy continuing work in the search for the ancient Greek city of Sybaris, using a Varion Rubidium magnetometer which has many uses (11) and has been used there with excellent results (9). The University of Pennsylvania is also experimenting with a sonic device using a frequency of 600 cycles (2, 8). The author is currently working on equipment using electromagnetic waves in an effort to eliminate the need for probes and at the same time not be limited by metallic interferences. Similar methods are used in geological survey work, but depends on secondary magnetic effects from ore bodies (3).

A new approach currently being investigated is the possibility of locating anomalies by observing, with a sensitive iron core coil, the angle of deflection (resulting from the anomaly) of an alternating current driven into the ground between two widely spaced probes. The alternating current sets up a magnetic field which induces a voltage into the coil. The operator would set the coil in a Null position 2-3 inches above the ground and walk between the probes. The coil would be connected to a portable sub-miniature audio amplifier. As the alternating current is deflected, the Null balance is thrown off which is detected through the audio output of the amplifier (10).

A resistivity survey was made over an area that was known to contain a concrete form approximately 3′ x 5′ x 3′ deep and buried at a probable depth of 4 feet. Its presence was easily picked up on the resistivity profile (Fig. 4). Two probes were then placed at both ends of the survey run (approximately 30′) and 100 milliamps of alternating current was put through the ground at about 80 volts. An iron core coil was then placed in a Null position and the operator walked between the probes. A deflection was indicated by the audio output in the same area indicated by the resistivity profile. The same procedure was repeated over the first experimental area (Fig. 2), but the present coil did not pick up any deflection. A more sensitive coil is planned.

Much work remains to be done, and new doors of knowledge will be opened. Some archaeologists look upon these devices as gimics, while others place great value in them. M. J. Aitken, in his book, Physics and Archaeology, has put it all in its proper perspective. "These techniques reveal the location of certain types of abnormal disturbances

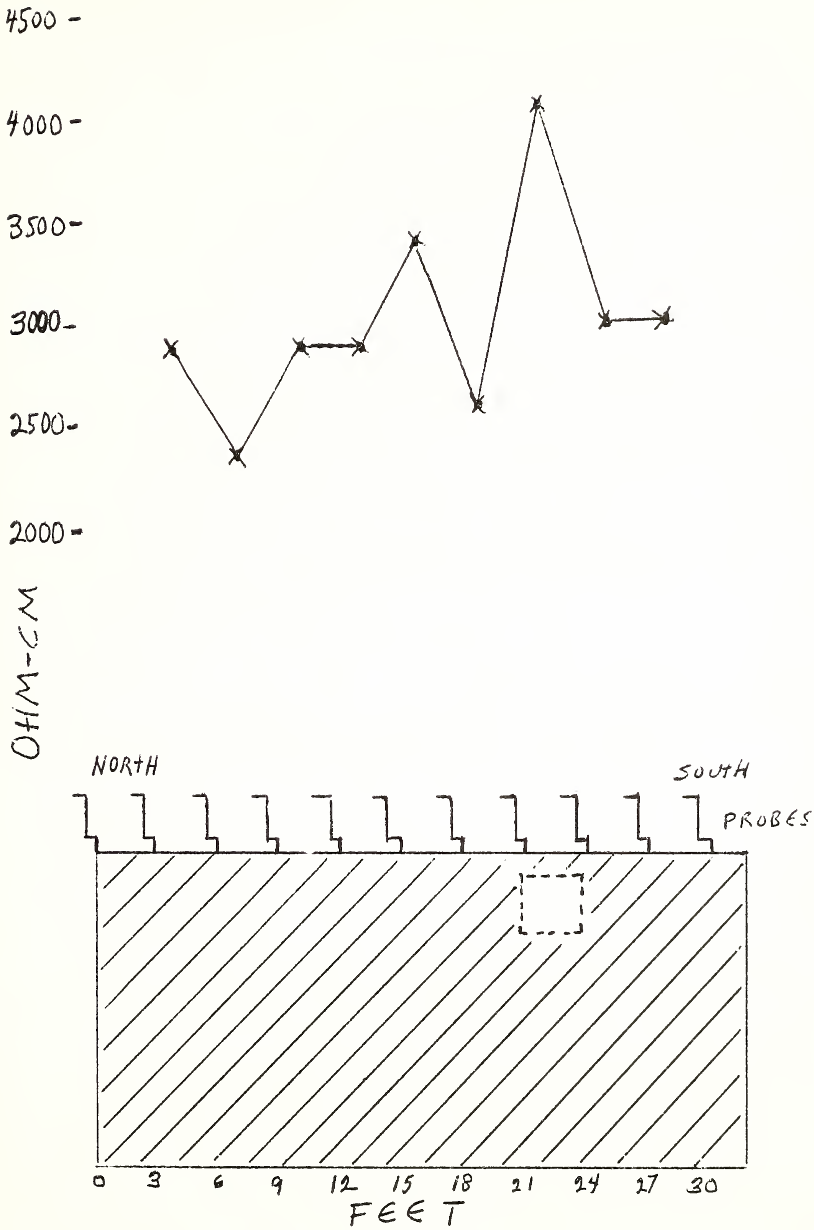

Figure 4. Profile of concrete object.

beneath the surface. They should not be over-estimated; they do not relieve the archeologist of the need to use his spade—but they do suggest the most fruitful spots in which to insert it" (1).

Summary

There is an ever-growing field of scientific devices that are available to the archaeologist today. One of these, Electrical Resistivity, using the four-probe method, is relatively inexpensive and simple to operate. It can be a good useful tool in making more efficient archaeological field work in Indiana as well as in other parts of the world. In measuring the moisture content or the lack of it in the ground, Electrical Resistivity is free from the problems of magnetic interference associated with magnetometers and mine detectors.

A variation of the above method using two very widely spaced probes, high voltage alternating current and an iron core coil with an audio amplifier to detect the angular deflection of the current when confronted with anomalies is also under investigation and shows some promise.

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