95

GEOPHYSICAL SURVEY IN THE COTZUMALGUAPA REGION: RESULTS OF THE VI CENTRAL AMERICAN SCHOOL OF APPLIED GEOPHYSICS

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The VI School of Applied Geophysics for Central America was held in Guatemala from May 5 to17, 2003, under the direction of Louis Pastor and Richard Vanhoeserlande, with the participation of a group of French professors, physicists and Central American students. Previously, similar schools were held in Nicaragua (1995), Costa Rica (1997), Honduras (2000), El Salvador (2001) and Panama (2002). The one held in Guatemala was focused on the applications to archaeology, just like the schools conducted in Honduras (Copan) and Panama (Panama Viejo).

The importance of geophysics applied to archaeology lies mainly in the advantage that it allows for time saving avoiding unnecessary excavations and destructions and orienting future explorations. According to the interests of the archaeologists working in Central America, it was decided that the school was to take place at El Baul, located in the south zone (boca costa region) of Guatemala in the department of Escuintla, and that it was to be complemented with theoretical courses taught in Antigua Guatemala.

The Acropolis of El Baul is located 4 km north of the modern city of Santa Lucía Cotzumalguapa, at an altitude of 550 m and on a slight slope that descends to the Pacific Ocean, approximately 50 km to the south. The San Francisco River runs at the east of the site, along a small ravine. The geological context is of the volcanic type with abundant lava outcrops. The site is located several kilometers away from the Fuego volcano, which is part a volcanic range that crosses the south portion of Guatemala and which has maintained a permanent activity, depositing a large amount of sediments in the region and on the prehispanic structures. These deposits obstruct the reconnaissance of the archaeological structures, making it even more necessary to use geophysical techniques. Presently, the fertile zone of El Baul is being farmed with sugar cane, and the lands are owned by the company

El Baul, S.A. The south part of the acropolis was destroyed with the construction of Colonia Maya (Santa Lucía Cotzumalguapa), in 1997.

The archaeological site was part of a large prehispanic settlement, in the Late Classic period (600-1000 AD), of around 10 km^2 and denominated the “Nuclear Zone of Cotzumalguapa” by Chinchilla (1996, 1997). Further to El Baul, this ancient city included the groups of monumental architecture known as Bilbao and El Castillo. The spatial distribution of the area was reinforced with a system of paved causeways and bridges, and their main structures were made of dirt and lined with selected stones.

Over 200 monumental sculptures were found in the area. Most of them feature the Cotzumalguapa style that flourished in the Late Classic period. The field works in the area were carried out by Thompson (1948), Parsons (1967-1969), and Chinchilla (1996). The investigations revealed that Cotzumalguapa was one of the major centers of political power and cultural innovation in southern Mesoamerica during the Classic period. Nonetheless, the significance of activity in that period should not put in a second place the important Preclassic vestiges in the area, among which Monument 1 of El Baul should be mentioned, a stela with one of the most ancient calendaric inscriptions known in Mesoamerica, dated to 36 AD.

During the School of Applied Geophysics, surveys were completed in three sectors located in the surroundings of the Acropolis of El Baul. Electric, magnetic and electromagnetic methods were used. Each one of these sectors was given a colloquial name, as follows:

- Site of Las Vacas, with an area of 50 x 60 m, located approximately 150 m west of the northern portion of the Acropolis, in a grazing field adjacent to Colonia Maya, at the east side of the road that leads to the mill of Los Tarros. Excavations conducted there in 1997 revealed a residential group with structures located around a paved patio. These structures include stone benches, and in one case, walls and steps lined with stones.

- Site of the Ballgame, located 100 m west of Las Vacas, in a sugar cane plantation located at the west side of the road to Los Tarros. Excavations conducted in 1998 revealed the presence of a Ballgame. In 1997, Lawrence Conyers, a geophysicist of the University of Denver, conducted a survey with a geo-radar in that sector (Chinchilla 2002).

- Site of La Ceiba, with dimensions of 50 m x 80 m, located some 500 m north of the Acropolis. The surveys and surface collections previously conducted in this sector revealed the presence of dense settlements. Moreover, excavations conducted in 2002 confirmed that this sector was communicated with the Acropolis through the Eisen and Thompson causeways (Chinchilla and Carpio 2003).

This paper presents the results of the application of geophysical methods in each one of these sectors, following a summarized explanation of the principles involved in each one of the methods used. In the case of Las Vacas and the Ballgame, the results are contrasted with the observations derived from the archaeological excavations. These results are the basis for discussing the perspectives that geophysical methods offer to Guatemalan archaeology.

THEORY OF THE METHODS OF GEOPHYSICAL SURVEY

Etymologically speaking, geophysics is a scientific discipline devoted to the study of the physical properties of Earth. It can be divided in two parts: Pure Geophysics, which concentrates on the study of gravity, magnetism, electricity and electric conductivity, and terrestrial seismology; and Applied Geophysics, which is consecrated to the application of Pure Geophysics.

Applied Geophysics, whose purpose is to make use of physical concepts in the study of the superficial part of the earth's crust, constitutes a powerful tool fit to be exploited in favour of archaeology. The geophysical surveyor focuses his full attention on the broad space-time variations of certain physical parameters of the soil, such as resistivity and electric conductivity, among others. The representation of these variations on a map and its subsequent interpretation allow for making inferences on the absence or presence of archaeological structures in the subsoil.

The geophysical methods may be classified as passive methods (associated with a natural field), and active methods (associated with an artificial field). The exciter field (active or passive) will be modified by the physical properties of the environment. If the values in certain points of this field are measured, they will provide an idea on the variations of the physical properties of the soil.

METHODS OF GEOELECTRICAL SURVEY

The measures of superficial resistivity (ρ *a*) are the basis of the survey methods of continuous direct current which consist in introducing a continuous electric current of a known density between two electrodes, and to measure the difference in potential between two others. This parameter translates the difficulty with which an electric current can cross a given volume of soil. All the materials have the property of allowing the passing of electrical charges; if they do it easily, they are conductors, and if they don't, they are resistors. If a soil is too dry or rocky, the value of resistivity will be high, but whenever a soil is humid or salty, resistivity will be low.

Historically, this method is the most ancient one for archaeological survey. The average parameter is the apparent resistivity of the soil.

The method is based on two fundamental laws:

a) The law of conservation of the spatial charge

$$\nabla \bullet J = -\frac{\partial q}{\partial t} \quad (1)$$

b) the Ohm's law

$$J = \sigma E \quad (2)$$

With vector J representing a density of current (A/m^2), q is the density of space charge (C/m^3), t is time, σ is the electric conductivity. On the other hand, E, the electric field vector, is defined as the gradient of the electrical potential.

The Ohm's law is valid in isotropic means only, inasmuch as for an un-isotropic means, conductivity could not be considered as a scalar but as a symmetric tensor of a secondary order. But, considering the first case with a stationary regime, the density of the space charge will be constant and the law of conservation of the space charge is simplified. Then, by using the two fundamental laws, we come to the following equation:

$$\nabla^2 V = 0 \quad (3)$$

This is known as the "Laplace equation". This equation, applied in spherical coordinates to the study of a semi-space formed by a homogeneous and isotropic terrain whose surface presumes a specific charge (the current electrode at the point in consideration), with a reference in infinite and following a mathematical treatment (Cantos 1987), produces the below equation of electrical potential:

$$V = \frac{I\rho}{2\pi}\frac{1}{r} \quad (4)$$

The elements monitored in a geoelectrical survey are the injected current and the separation between the four electrodes: two for measurements, denoted as M and N (wherefrom the voltage difference ΔV is obtained); and two of electrical injection A and B, as shown in Figure 1. The objective is a measurement of electrical resistivity ρ, obtained further to introducing the geometric parameters of the position of the electrodes in the equation (4), which leads to:

$$\rho = \left[\frac{2\pi}{\left(\frac{1}{AM}-\frac{1}{BM}\right)-\left(\frac{1}{AN}-\frac{1}{BN}\right)}\right]*\left(\frac{\Delta V}{I}\right) \quad (5)$$

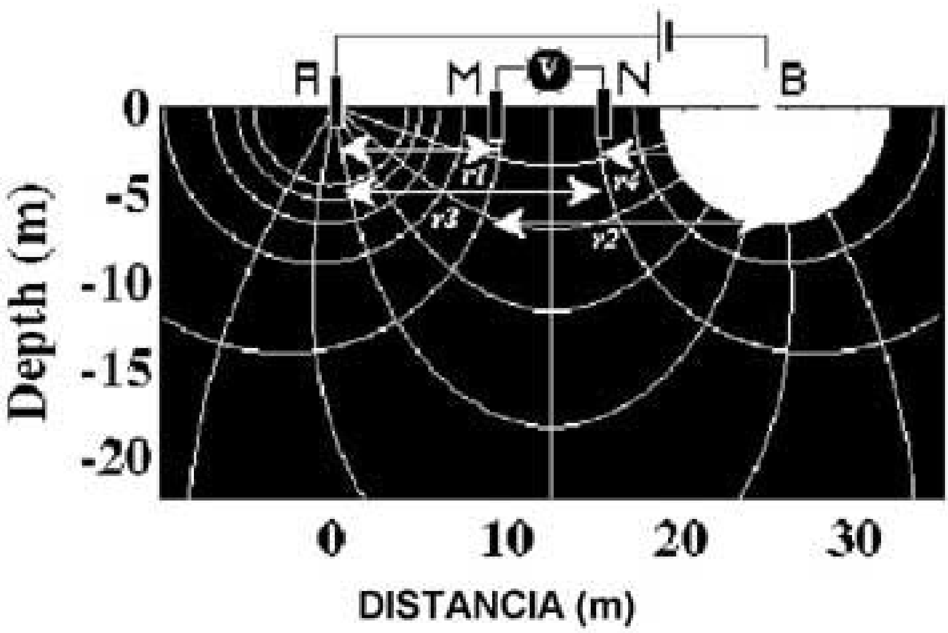

Figure 1. Some results.

The first term of the expression is called geometric factor *k*, which is a function that depends on the type of device used (Figure 1). For the Wenner device, the configuration is similar to that of Figure 1, with an identical separation between the electrodes AM, MN and NB, whose value *α* remains constant, in a way that the equation (5), with its corresponding geometric factor, becomes:

$$\rho = 2a\pi \frac{\Delta V}{I} \quad (6)$$

On the other hand, for the Schlumberger device, the configuration of Figure 1 establishes symmetry as of a point of origin at the center of the arrangement: electrodes M and N are separated a 2*l* distance, and electrodes A and B are separated a 2*L* distance. The resulting equation is:

$$\rho = \frac{\pi\left(L^2 - l^2\right)}{2l}\frac{\Delta V}{I} \quad (7)$$

Finally, the configuration of the dipole-dipole device (Figure 2) produces the equation:

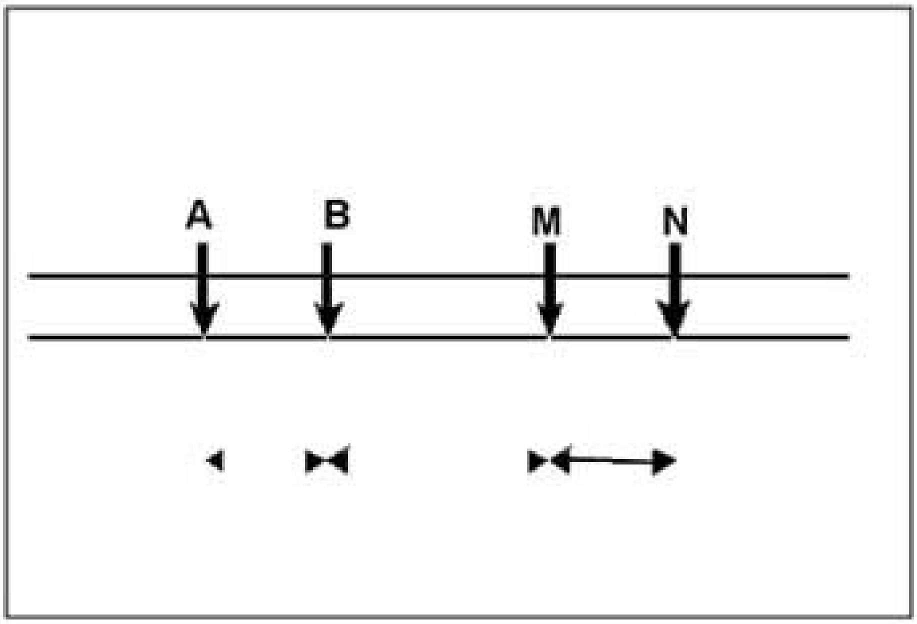

Figure 2. Some results.

$$\rho = n\pi(n+1)(n+2)a\frac{\Delta V}{I} \quad (8)$$

METHOD OF GEOMAGNETIC SURVEY

The comprehension of the behaviour of soil magnetism allows for the use of new survey tools at archaeological sites. The space variations of the geomagnetic field or "magnetic anomalies" are caused by the variations in the amount of magnetic materials distributed in the soil, or by objects that contain a certain amount of iron. Such anomalies may be measured by means of a protonic precession magnetometer, which depends on the free precession frequency of the protons polarized in a normal direction to the direction of the Earth field. Whenever the polarized field changes, protons precess near the Earth field at an angular speed ω known as the Larmor frequency, represented by the equation:

$$\omega = \gamma_p B \quad (9)$$

Where the constant Y_p is the radio magnetic turn of the proton, a known value, and *B* is the value of the magnetic field.

In practice, magnetic oxides are the main component parts responsible for the magnetism observed. Figure 3 shows a sketch of the magnetic field corresponding to a structure in the subsoil.

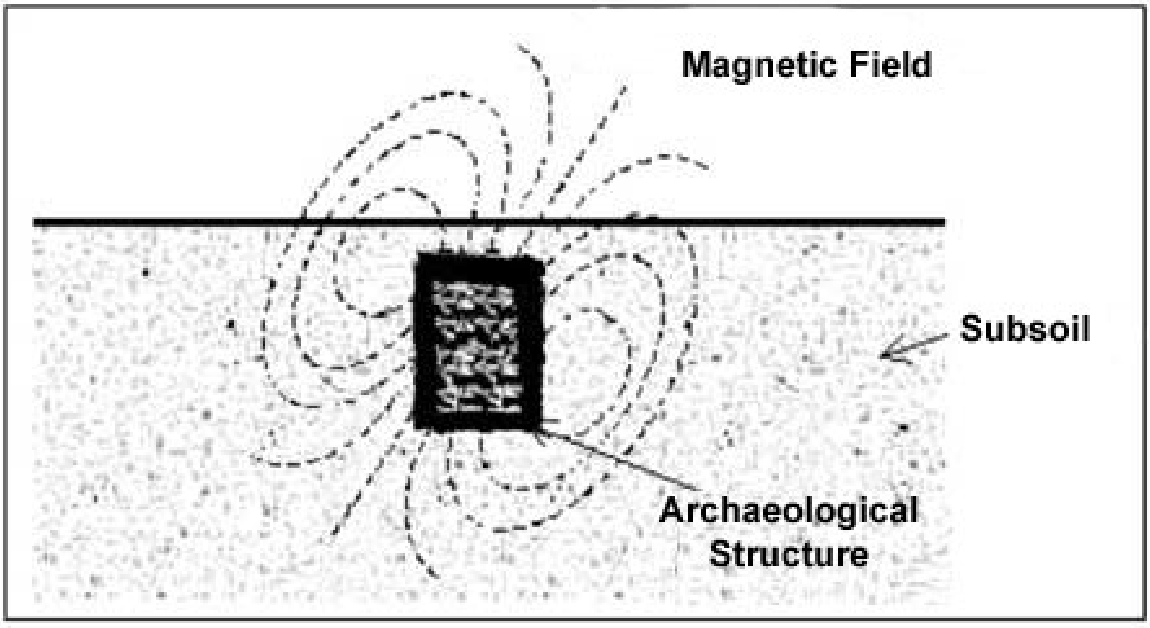

Figure 3. Some results.

METHOD OF ELECTROMAGNETIC SURVEY

The electromagnetic systems, also known as SCM (Soil Conductivity Meter), may measure in a very accurate manner the electric conductivity of the soil, which is the opposite of electrical resistivity and is expressed in miliSiemens per meter (mS/m). The theoretical foundation of these systems is based on the emission of a magnetic field by means of a coil (as an antenna), that broadcasts in the air and then, in the volume of the subsoil close to the vertical of the coil. This magnetic field induces electrical currents in the subsoil, in the more conductive parts and in the buried metals (Figure 4). These induced currents create a secondary magnetic field which may be detected with a second receiver coil. The basic principles of the method are the Biot-Savart law and the relation obtained through mutual inductance.

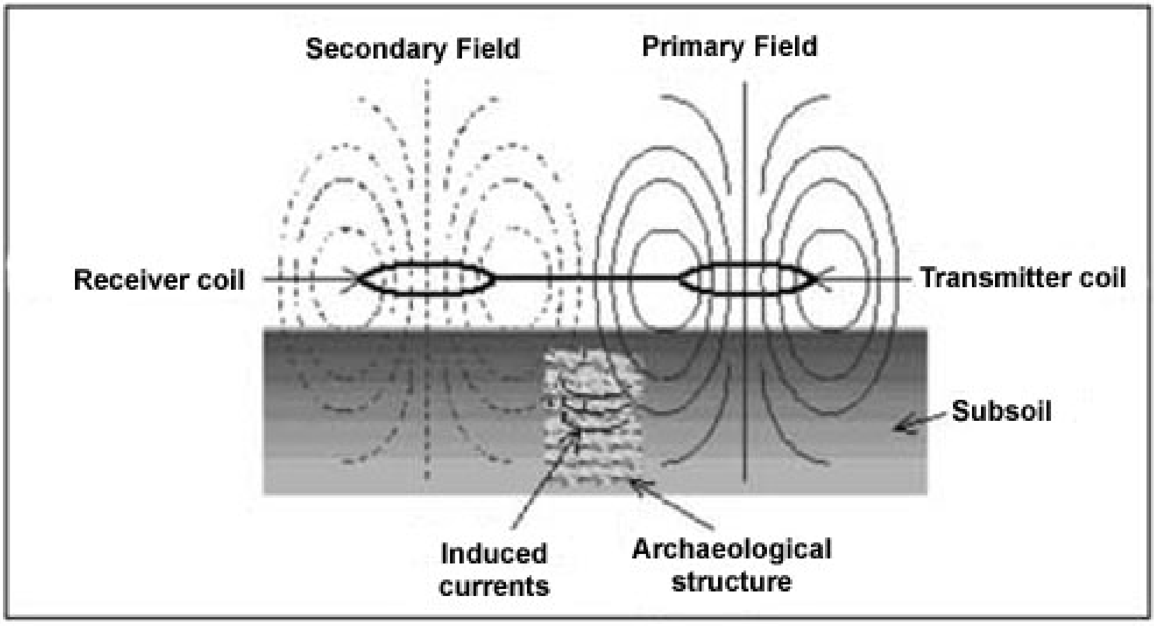

Figure 4. Some results.

PRESENTATION AND ANALYSIS OF RESULTS

With the purpose of gathering information about places with the potential of having buried pre-Columbian structures, the subsoil of the three zones selected at El Baul was tested, applying the different geophysical techniques examined in the previous section. The inversion of the data was accomplished using the Surfer 8 software. We are now presenting the results of the geophysical survey.

LAS VACAS

At this site, the geophysical survey was accomplished to verify whether the structures found previously could be detected through the geophysical methods described, and whether these showed the continuation of them or of other new ones in the still unexcavated area.

Through the geomagnetic survey, a non-regular zone was defined with a separation of 1.0 m between profiles, using a cesium magnetometer. The system was set to obtain 10 measures per second and to make an interpolation of 0.20 m along the profile.

The geomagnetic map obtained is shown in Figure 5, where a number of discontinuities are observed, because the survey was conducted by stages, throughout several days and by different operators, as part of the workshops of the School for Applied Geophysics. Nonetheless, some alignments (full line) can be observed, which could be related to the habitational structures mentioned earlier, not too deeply buried. The magnetic anomalies shown in Figure 5 suggest as well several secondary alignments within the main structure. In addition, there is evidence of other isolated anomalies that may be the result of the presence of some scattered ferric material not too deeply buried, in a way that they are not of archaeological interest.

The main anomalies are satisfactorily consistent with the results of the previous excavations, as they coincide with the localization of the already known structures, or either, with their orientation (broken line).

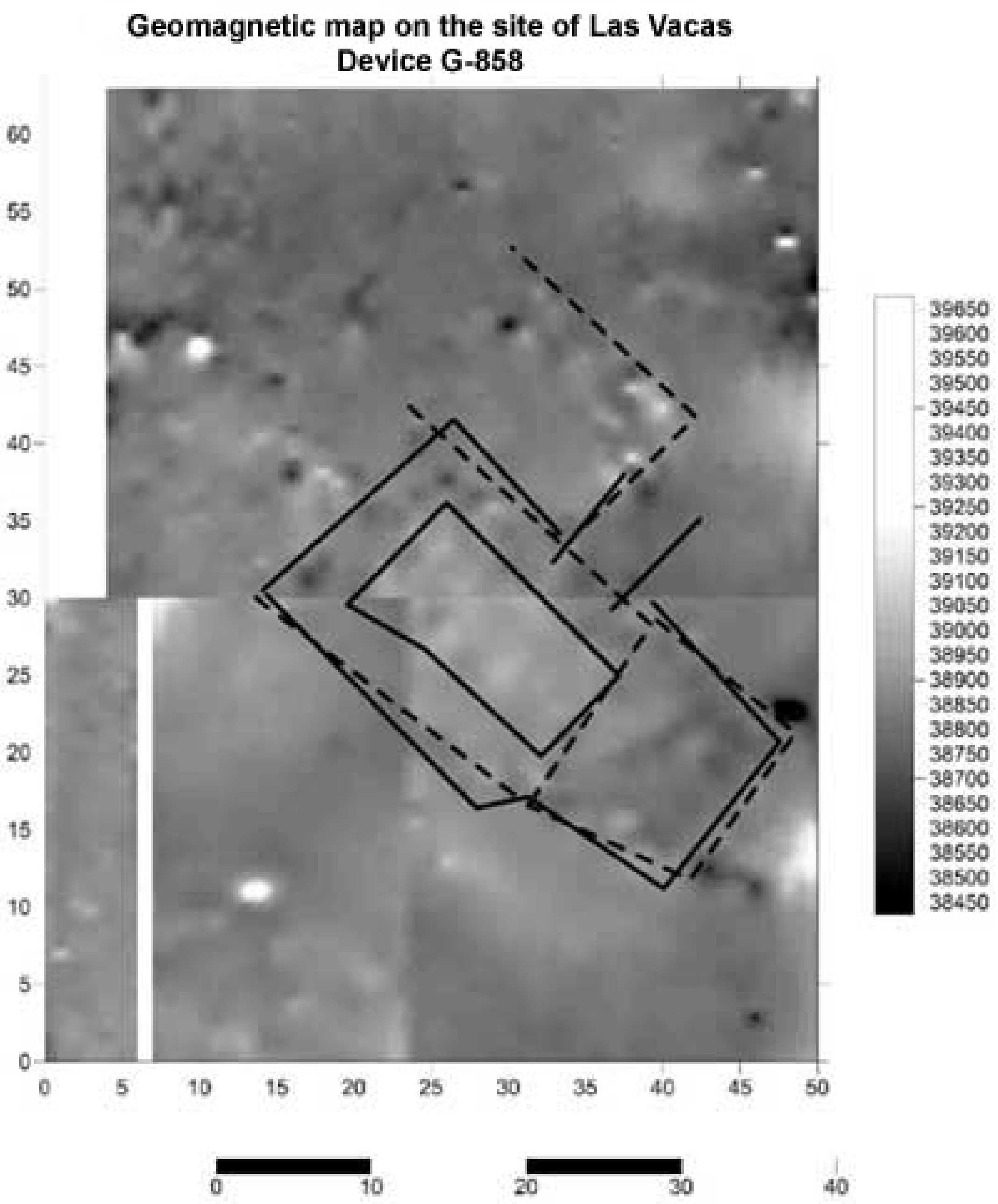

Figure 5. Geomagnetic map of Las Vacas.

On the same site, and surveying only one fraction of the area, a proton precession magnetometer was used. The geomagnetic map obtained (Figure 6) shows strong coincidences with the cesium magnetometer map (Figure 5). The interesting alignments (full line) are also coincident with the orientation of the already known structures (broken line).

For the geoelectrical survey, a dipole-dipole device was used, with a measurement frequency of 2.0 m and a separation of 2.0 m between profiles. The map of apparent resistivity obtained is shown in Figure 7. There are very evident anomalies that indicate an alignment of material of a high apparent resistivity (full line), coincident with the expected orientation of the structures, closely related with the geomagnetic anomalies previously shown. A superimposition with the geomagnetic maps will show a clear correspondence between the alignment patterns of the anomalies (note the similarities with the geomagnetic map obtained with the protonic precession magnetometer in Figure 6).

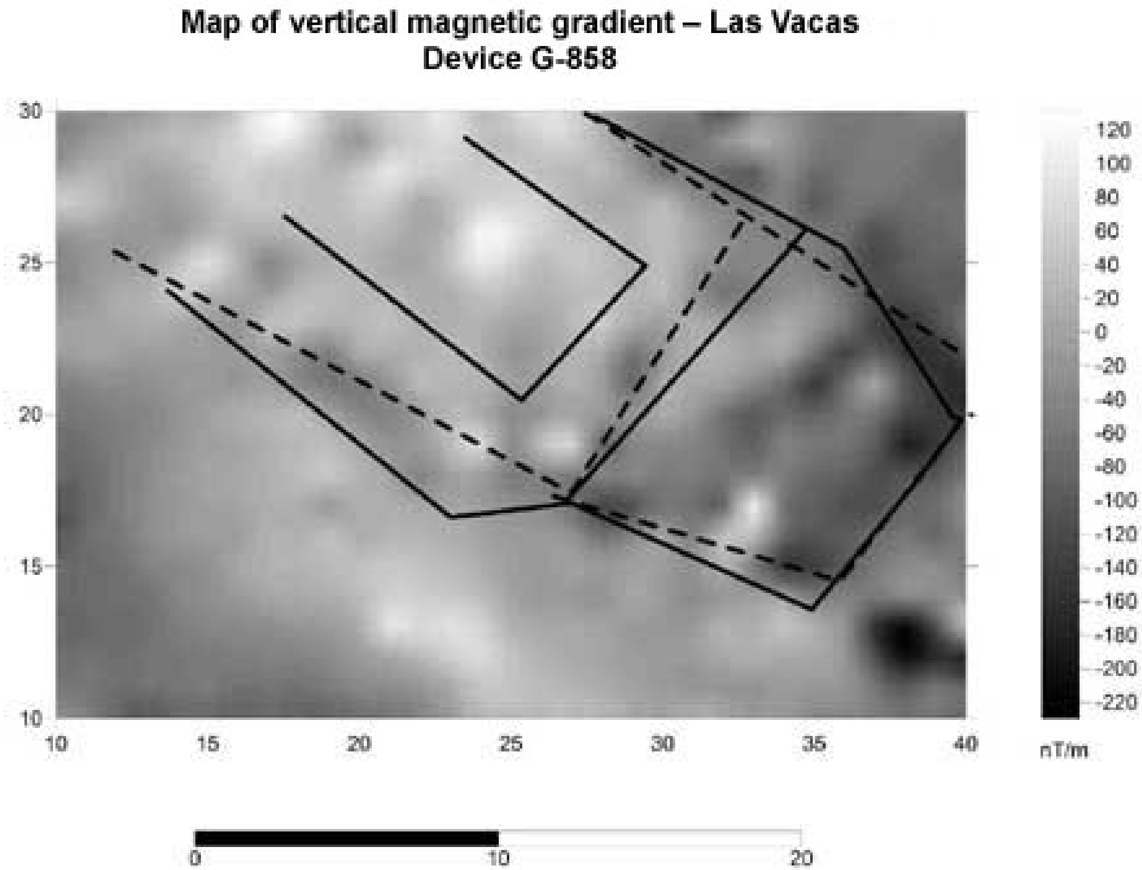

Figure 6. Map of vertical magnetic gradient – Las Vacas.

All these results confirm the presence of archaeological structures buried a few meters deep in the area.

THE BALLGAME

Here, magnetic, electromagnetic and electrical surveys were conducted to establish anomalies that could reveal the presence of other structures aligned with those already found, that were a part of the original complex. However, the results generated by the electromagnetic method proved clearly affected by the irregularity of the ground caused by agricultural activities, and therefore were not included.

For the geomagnetic survey of this area we used a cesium steam magnetometer with a separation of 1.0 m between the profiles. The geomagnetic map obtained is shown in Figure 8, with three evident anomalies, A, B, and C. The polygons A and B show two large groups with heavy magnetic anomalies hard to interpret, which could be related to the structures that integrate the Ballgame. An archaeological survey needs to be conducted, so as to have their nature defined. The pattern of alignment in anomaly B corresponds to that of the structures already found. Besides, anomaly C is peculiar for not being co-linear with the direction of the survey and could also be associated with the Ballgame.

For the electrical survey we used a dipole-dipole device, with a measuring frequency of 2.0 m and a separation of 2.0 m between profiles.

The results of the cartography are shown in Figure 9 where it is possible to observe three interesting anomalies, A, B, and C, which indicate zones of a high apparent resistivity that could have some relation with the magnetic anomalies of the site (Figure 8).

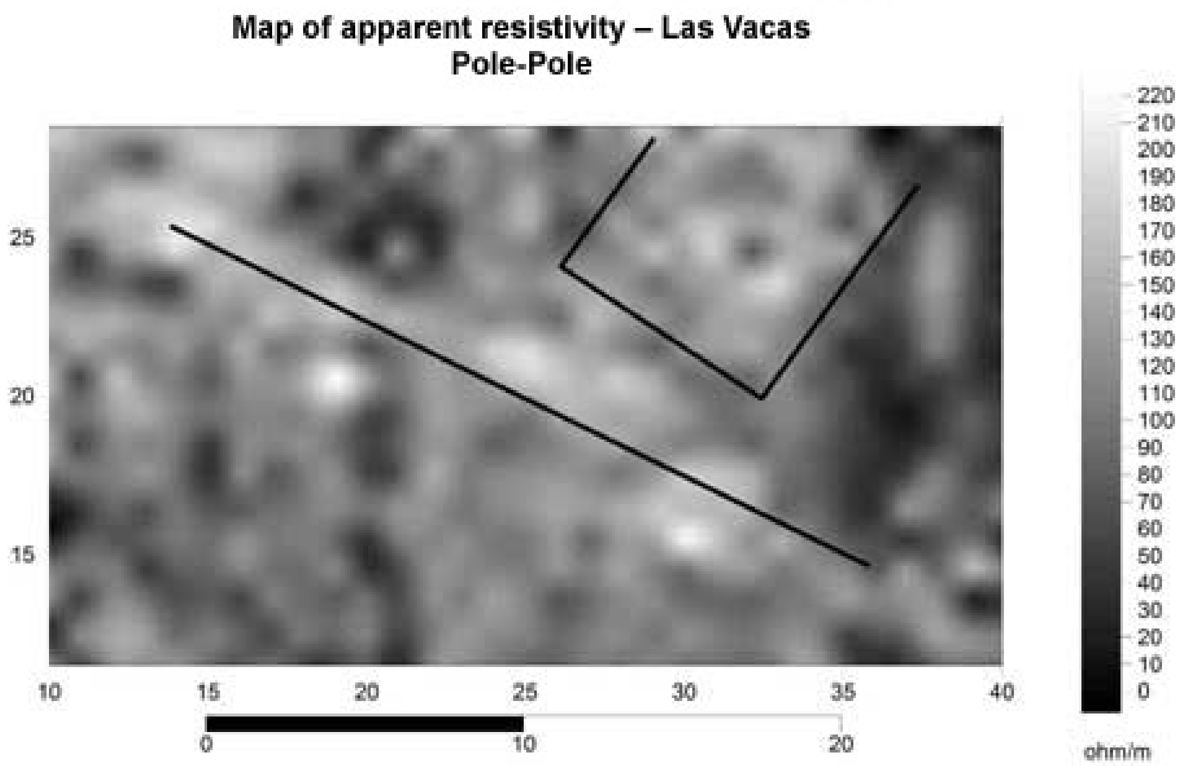

Figure 7. Map of apparent resistivity – Las Vacas.

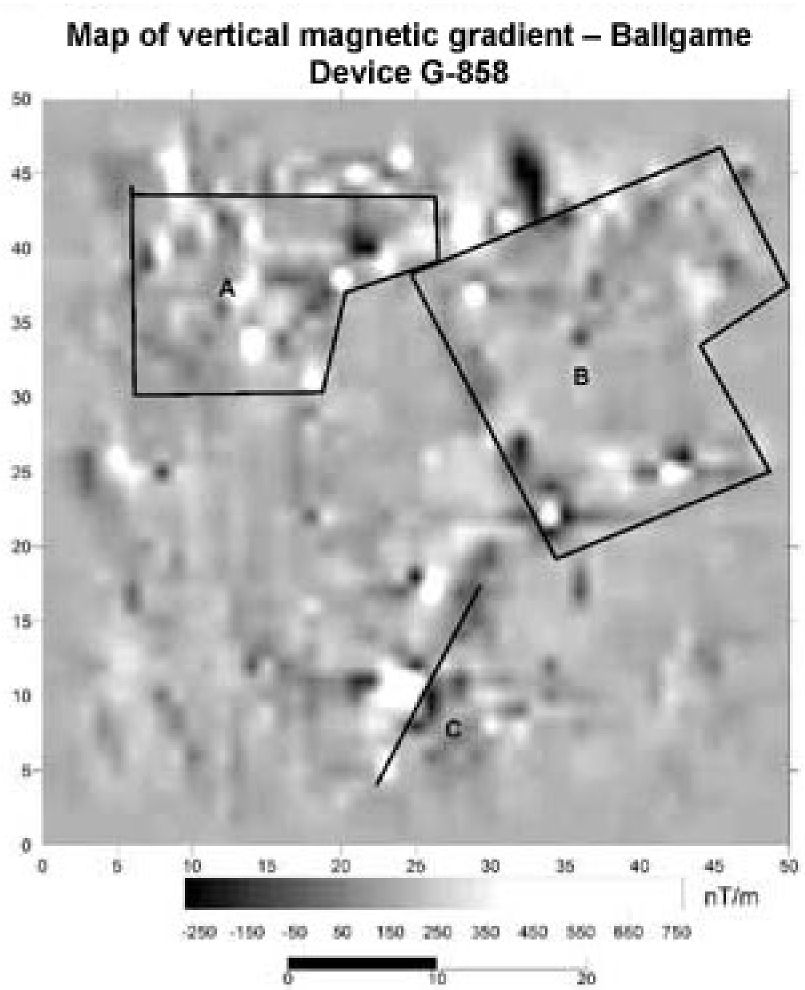

Figure 8. Map of vertical magnetic gradient – Ballgame.

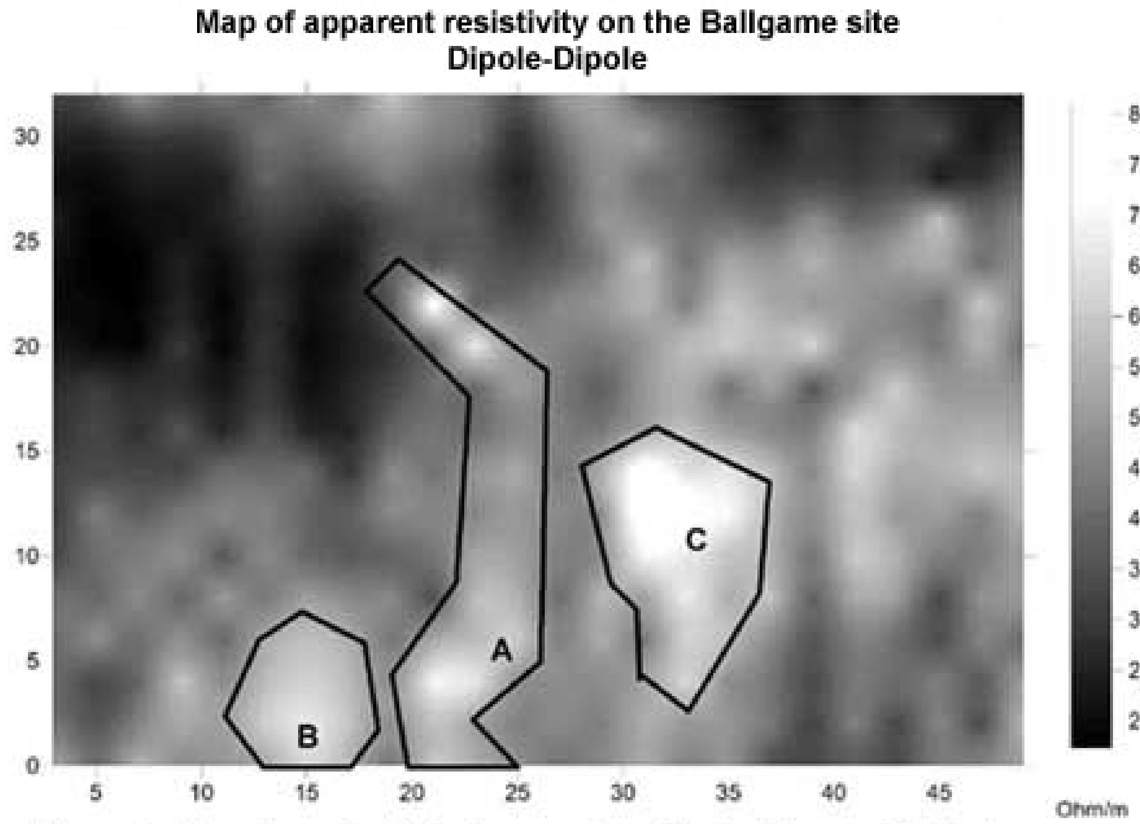

Figure 9. Map of apparent resistivity – Ballgame.

LA CEIBA

In this zone the technique of geomagnetic survey was applied, to define the anomalies that could have a relation with the presence of some archaeological structured not too deeply buried, to orientate the carrying out of further excavations. Several work sessions were conducted using a frequency of 10 measurements per second and a distance of 1.0 m between profiles.

The results of the survey are shown in the map of Figure 10, which reveals very heavy anomalies in the vertical magnetic gradient, highlighted with the full line.

The specific geomagnetic anomalies may be attributed to the presence of small dispersed igneous rocks, in a way that its geomagnetic response is superimposed to the response of the possible buried archaeological structures. Nevertheless, anomalies A, B, C, and D are very strong, and their geometry could correspond to archaeological structures not too deeply buried, as their orientation is consistent with the one anticipated, according to the known structures of the other zones (broken line). On the other hand, the alignment of anomalies E and F is interesting, as they could be a part of a residential group.

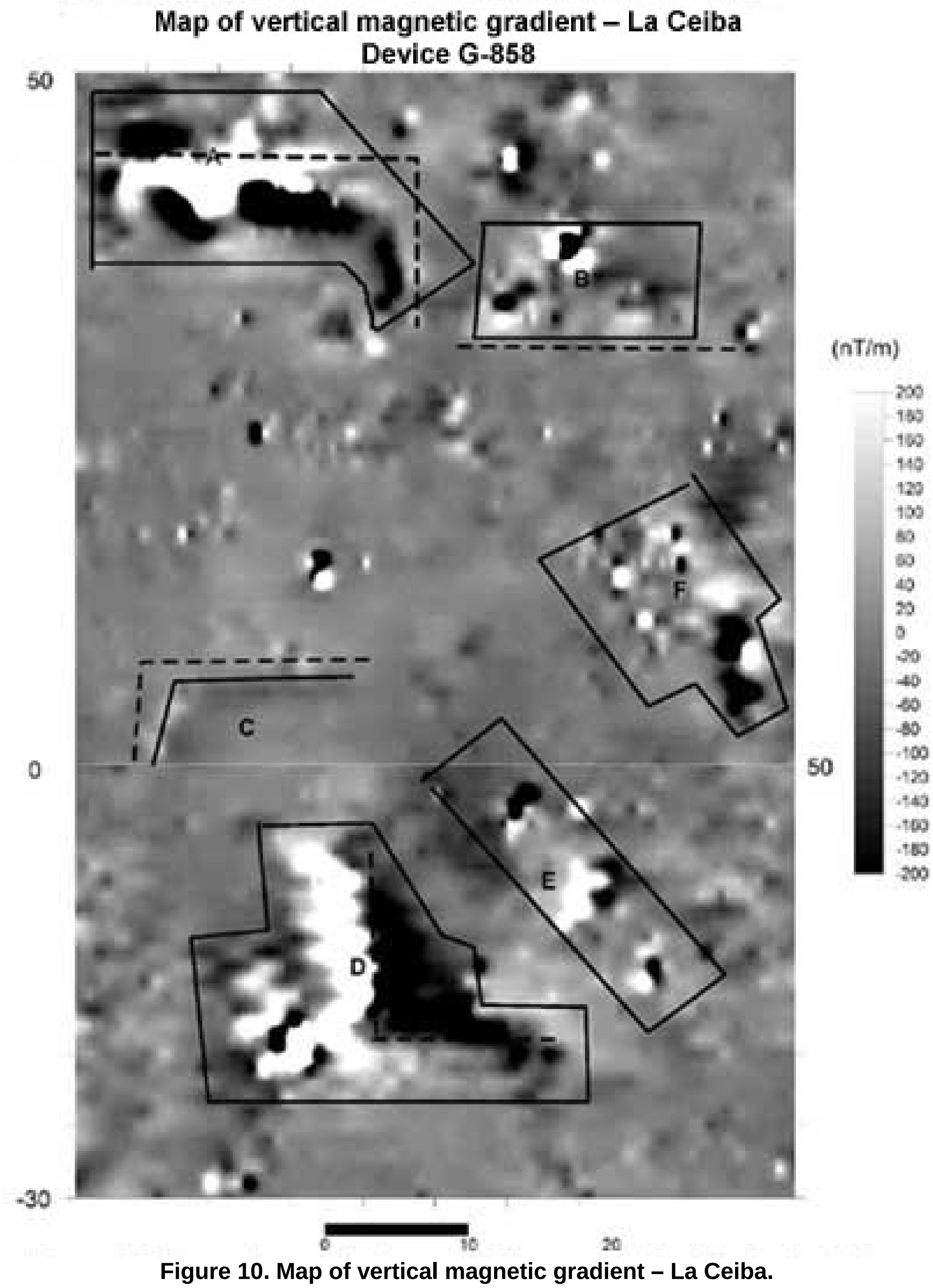

Figure 10. Map of vertical magnetic gradient – La Ceiba.

CONCLUSION

Survey Geophysics constitute a powerful “non-destructive” tool that may be used by archaeologist in the search and parameterization of the possible archaeological structures buried in the subsoil. The main objective of the VI School of Applied Geophysics was that the participants from the Central American countries could share the experiences in the field and the knowledge, for a better performance in their future scientific activities. This objective was fully achieved, and it is our hope that it succeeded in generating an interest and a basic training for the application of geophysical methods to the archaeological investigation in the region.

In the work of geophysical survey conducted, the geomagnetic method showed a finer resolution and demonstrated to be the technique that yielded the most results as far as identification of cultural traits in all sites surveyed is concerned. The methods of electromagnetic and electric survey proved more susceptible to the irregularities of the ground, caused by constant plowing activities.

The Cotzumalguapa area offers a field of application for the geophysical methods, whose results would be of great value to guide archaeological investigation. The importance of the site in the context of Mesoamerican archaeology is just beginning to be known, and the geophysical methods could turn into an important tool in this region, as well as in others.

In the course of this school we proved the applicability of the magnetic method using a protonic precession magnetometer available in Guatemala for some years now, property of the National Institute of Electrification. The rent of this equipment includes the time of a labourer with a sound operational knowledge. Also, in the country it is now being used the EM-38 equipment of electromagnetic survey owned by the Forensic Anthropological Foundation. The staff of the foundation has responded in a positive way to the possibility of using that equipment in other works of archaeological investigation. Hopefully, these resources will be more and more used by Guatemalan archaeologists.

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Figure 1 Some results.

Figure 2 Some results.

Figure 3 Some results.

Figure 4 Some results.

Figure 5 Geomagnetic map on the site of Las Vacas.

Figure 6 Map of vertical magnetic gradient – Las Vacas.

Figure 7 Map of apparent resistivity – Las Vacas.

Figure 8 Map of vertical magnetic gradient – Ballgame.

Figure 9 Map of apparent resistivity – Ballgame.

Figure 10 Map of vertical magnetic gradient – La Ceiba.