Integral geophysical study to characterise archaeological structures in Los Teteles De Ocotitla, Mexico

Pedro López-García,[1]
Denisse L. Argote-Espino,[1]
Andres Tejero-Andrade,[2]
Rene E. Chávez Segura[2]
[1]Instituto Nacional de Antropología e Historia, Mexico City; [2]Facultad de Ingenieria and Instituto de Geofísica, Universidad Nacional de Antropología e Historia, Mexico City, Mexico

Abstract

In archaeology, geophysical methods had been applied usually in a qualitative form, limited only to the use of filters that enhance the data display. The main objective in this work is the implementation of an integral geophysical study complemented by 3D modelling techniques that allowed us to reconstruct the geometry and depth of buried bodies in the archaeological site of Los Teteles de Ocotitla, in the state of Tlaxcala, Mexico. The distribution and shape of underlying archaeological remains were inferred by geophysical methods and corroborated by archaeological excavations. High-resolution magnetic, ground penetrating radar and electric prospection were carried out in selected terraces. This investigation demonstrates the potential of quantitative geophysical methods for the characterisation of archaeological structures, in extension and depth.

Introduction

Los Teteles de Ocotitla (Teteles means in Nahuatl *bunch of rocks*) is an archaeological site located towards the northeast portion of the volcano La Malinche, in the municipality of Altzayanca, State of Tlaxcala, in the northern hillside of the gully called La Caldera. Rocks of volcanic and lacustrine origin of tertiary age are found within the region of study. The volcanic rocks are mainly effusive tuffs of andesitic composition, widely distributed within the axis of the Transmexican Volcanic Belt, which were used as construction material by the ancient dwellers. Reduced extensions of the sedimentary rocks are found within the lower parts of the slopes ranges. These are constituted by conglomerates and alluvium. The horizon of Quaternary age is conformed by basaltic deposits distributed as lava flows and volcanic cones. The Malintzin volcano located to the South of the city of Huamantla is an example.

This site is conformed of several terraces with evidence of human occupation, probably from Tenanyecac phase contemporary to Teotihuacan I and II phases. The presence of several mounds, as well as some exposed walls and floors, can be observed. Archaeological materials (ceramics and lithics) are also found in great amounts on the ground. This site possesses a great importance, since it might have been an obligated path during pre-Hispanic times between the Valley of Mexico and the sea to the east (Gulf of Mexico). One of the upper terraces was excavated by the archaeologist García-Cook *et al*. (1997) in the decade of 1970, finding a tomb with nearly 300 offerings. The chronology assigned to the objects associated with the tomb was between the years 50 and 200 B.C. (Peña Gómez, 1997). He reported that this tomb had the form of a rectangular room, whose floor, ceiling and walls were constructed with slices of tuff, a characteristic rock of this region.

Today, the terraces are relatively flat and are used for agriculture, presenting small furrows done by the plow. The physical characteristics of the ground of the archaeological site of Los Teteles (basaltic-andesitic rocks employed as construction materials buried within sedimentary soils and relatively flat terraces with small-scale surface roughness due to plow furrows) allowed us to design an investigation using magnetic method (total field and magnetic gradient), ground penetrating radar (GPR) and electric tomography. Therefore, geophysical methods were applied to recognise more archaeological structures, like tombs house-rooms, and other features buried beneath the terraces. Other important goals were: to map the spatial distribution of main archaeological features, asses the importance of the archaeological site and define excavation targets.

Materials and Methods

The geophysical methods more suitable for the conditions at this site, where the total magnetic field, the GPR and the electric tomography with 3D display of data. The geophysical study covered several portions (terraces) of the archaeological site (Figure 1). The studied area depicts several human-made terraces, nowadays devoted to agricultural labour. Terrace M5 is particular interesting since García-Cook (1997) excavated here a pre-Hispanic tomb in 1975.

A Geophysical Survey Systems Inc. (GSSI) SIR 2000 GPR with a 270 MHz mono-static antenna was employed in the present study in terraces M1, M3 and M5. Transects were made with a separation of 1 m between adjacent lines. A finite impulse response (FIR) filter was applied to attenuate frequencies between 70 to 300 MHz. This range was selected by means of an analysis of the power spectrum for each GPR profile. In this form, noisy artifacts were adequately eliminated. In addition stacking was made (average) each 29 traces to smooth the information, and attenuate jump in the radagrams caused by the discontinuities of the terrain, when the antenna was slided. Finally, a background removal filter was applied to eliminate a series of horizontal bands present in the radargrams. 3D display of radargrams is presented as isosurfaces with the programme SLICER.

A high-resolution magnetic field survey was carried out in terraces M1, M2, M3 M4 and M5. The equipment employed was a GEM-GSM19W magnetometer with a resolution of 0.0015 nT. Continuous observations were made along transects N-S oriented. Positioning of each station was obtained with a GPS system integrated to the magnetometer console. Later, 3D modelling was applied to isolated magnetic anomalies to characterise geometry and depth of structures by determining the physical response of the underground structures or bodies. This is done by means of the estimation of the magnetic moments of archaeological objects using a three-dimensional mesh of

Correspondence: Denisse Argote-Espino, Instituto Nacional de Antropología e Historia, Moneda 45, 06060 Cuauhtemoc, Mexico City, Mexico. Tel./Fax: +52.5.5522.4162.
E-mail: efenfi@gmail.com

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individual magnetic dipoles using the least squares method and the singular value decomposition of a weighted matrix to solve the linear problem (Argote *et al*., 2009).

Finally, IRIS equipment was employed to obtain an electric tomography of terraces M6 and M7. Distance between electrodes and lines were of 2.5 m, covering an area of 55x10 m^2 in both terraces. 3D maps are presented. In terraces M1 and M3 archaeological excavations were made in selected points where important magnetic and GPR anomalies were found, corroborating the results of the geophysical prospection.

Results and Discussion

In terrace M1, total magnetic observations were acquired along a series of GPR profiles to the NW portion of the terrace. The GPR section (Figure 2, upper right) depicts different structures related with the location of possible floors and fallen walls with a depth to the top less than 1m. The magnetic field observed (Figure 2, lower left) depicts a series of interesting anomalies, giving a good correlation between the GPR anomalies with the magnetic features. The total magnetic field map displays also a series of anomalies along a corridor of about 30 m long and 10 m width, approximately. This could be due to the presence of a pre-Hispanic floor or the remains of a more complex structure, as the GPR section shows. An area of 15x16 m around the most important magnetic anomaly located to the NE portion of the magnetic map was isolated and introduced to the 3D modelling software created by our team in order to characterise the geometry and possible depth of the magnetic source.

As can be seen in Figure 2, the anomaly calculated (upper left) from the inverted magnetic moments and the excavated archaeological body (lower right) are practically equivalent. The first three slices (Z=30 cm until Z=1.30 m) show the presence of several diagonal bodies (possible walls) placed side by side with a NW-SE orientation. These walls tend to fade away with depth, estimating the base of the body approximately at a 2.30 m depth. In the archaeological excavation of this small area, we found part of the body of a pre-Hispanic pyramid with at least four construction phases oriented in a NW-SE direction, which explains side by side diagonal bodies defined by the inverse model. This also explains the GPR anomaly associated to this archaeological feature, similar to fallen walls or several walls placed side to side. Due to limited time and funding, the excavation unit covered only a small portion of the pyramidal structure, and did not reach its base. Thus, the depth to the base determined by the inversion could not be veri-

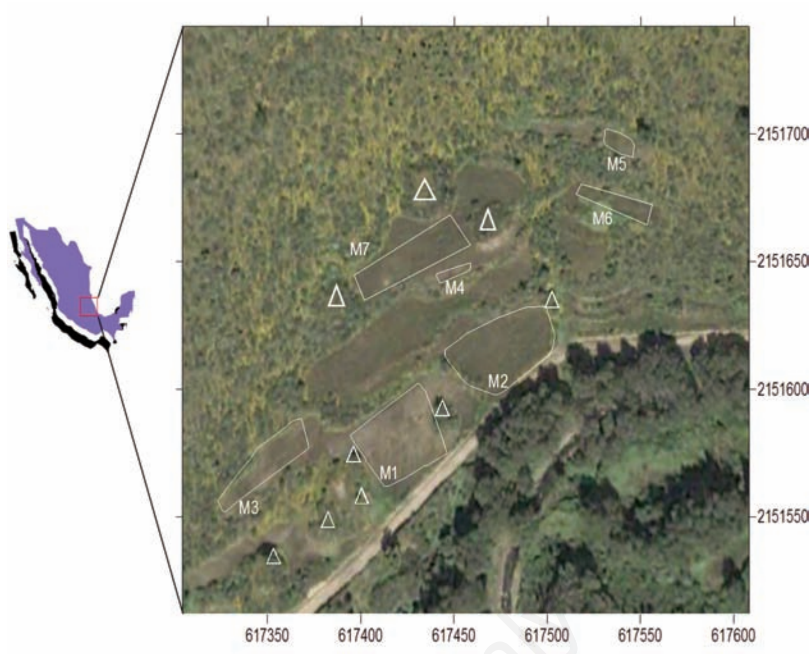

Figure 1. The area of study is found within a series of man-made terraces. The selected terraces are marked with polygons (M1 to M7). Triangles depict the location of pyramid remains. Terrace M5 is particularly important since Garcia-Cook (1997) carried out here the first archaeological investigation in this site, discovering an ancient tomb.

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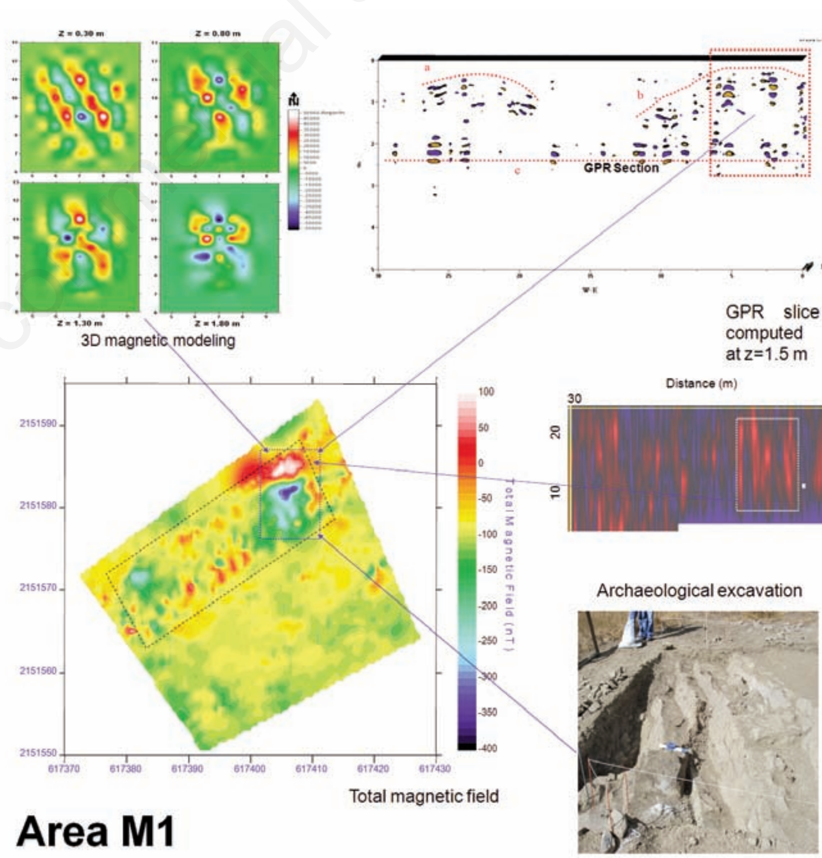

Figure 2. Geophysical results obtained on terrace M1. The GPR section (right top) and slice (right center) and the total magnetic field map (left bottom) show the position of the principal archaeological structure (marked with a dashed line rectangle). The geometry of the structure (diagonal superposed bodies) was depicted by the 3D modelling (left top) and corroborated in the archaeological excavation (right bottom).

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fied.

In terrace M3, around its most relevant anomaly at the middle of the magnetic map (Figure 3, lower right), we delineated a study area of about 5x9.5 m. This is an inverted anomaly (positive pole above and negative pole below), which can be explained in general terms by the presence of a body with high contents of remnant magnetisation or by a void within a highly magnetised body (Arzate *et al.*, 1990). The inverted model for this anomaly (lower left) depicts a body with a rectangular form and rounded corners, and a less magnetic center. The zone of influence of the body covers an estimated area of 1.2x1 m, and was located at an approximate depth of 70 cm. This model and the estimated spatial coordinates of the observed anomaly were used to locate a 4x4 m excavation unit during the archaeological work season. Around a depth of 73 cm, the rectangular base of a 110 by 80 cm kiln was found (upper left). The kiln had rounded corners and was made of burned clay and its surface covered with lime, which explains the inverted anomaly. The GPR section depicts the presence of a floor around 2 m deep and over it is an important feature in the same spatial location of the kiln and with a similar geometry. In terrace M5, there is a magnetic and EM anomaly that corresponds to the position of tomb discovered by Garcia-Cook and his team in 1974. Garcia-Cook (1997) and Garcia-Cook *et al*. (1997) describe the discovery of 2.10x1.45 m rectangular based tomb built with worked volcanic rocks, located at a mean depth of 2 m. Around the tomb were traces of clay floors and several secondary human burials. After all the archaeological artifacts and bones were recovered, they proceed to cover up the tomb again with the rocks and the soil took from it, leaving the architectonic remains unmodified except for the tomb's roof. The vertical magnetic gradient depicts several anomalies; in particular, a dipolar anomaly can be seen to the right hand side of map (Figure 4, bottom, red square). Such an anomaly can be correlated with the GPR feature shown in that diagram (Figure 4, middle, black square). This structure is 3x3 m^2 and is found to a depth of 1 m, approximately. The structure resembles a small room, similar to the tomb reported by Cook. For the 3D modelling, an area of 7.5x6 m was selected from the magnetic anomaly map (Figure 4, bottom). Upon examination of the graphic of the spatial distribution for the magnetisations obtained from the inverted dipoles (Figure 4, top) and the GPR profile (Figure 4, middle), the shape of a rectangular room can be clearly seen, similar to the tomb. The dimensions of the magnetic modelled room are larger than those described by Garcia-Cook. This can be explained by the fact that Garcia-Cook, when he excavated the tomb, placed a lot of the same basaltic rocks around

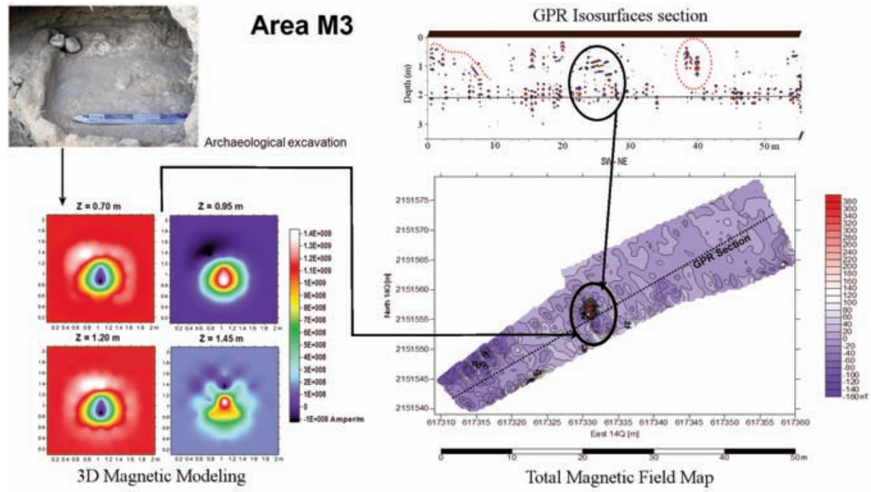

Figure 3. Geophysical results obtained on terrace M3. The GPR section (right top) and the Total magnetic field map (right bottom) showed the presence of an important anomaly (marked with a dashed lined circle). The 3D modelling (left bottom) depicted a highly magnetic structure with a quadrangular geometry proceeding from a pre-Hispanic kiln, as discovered during the excavation (right top).

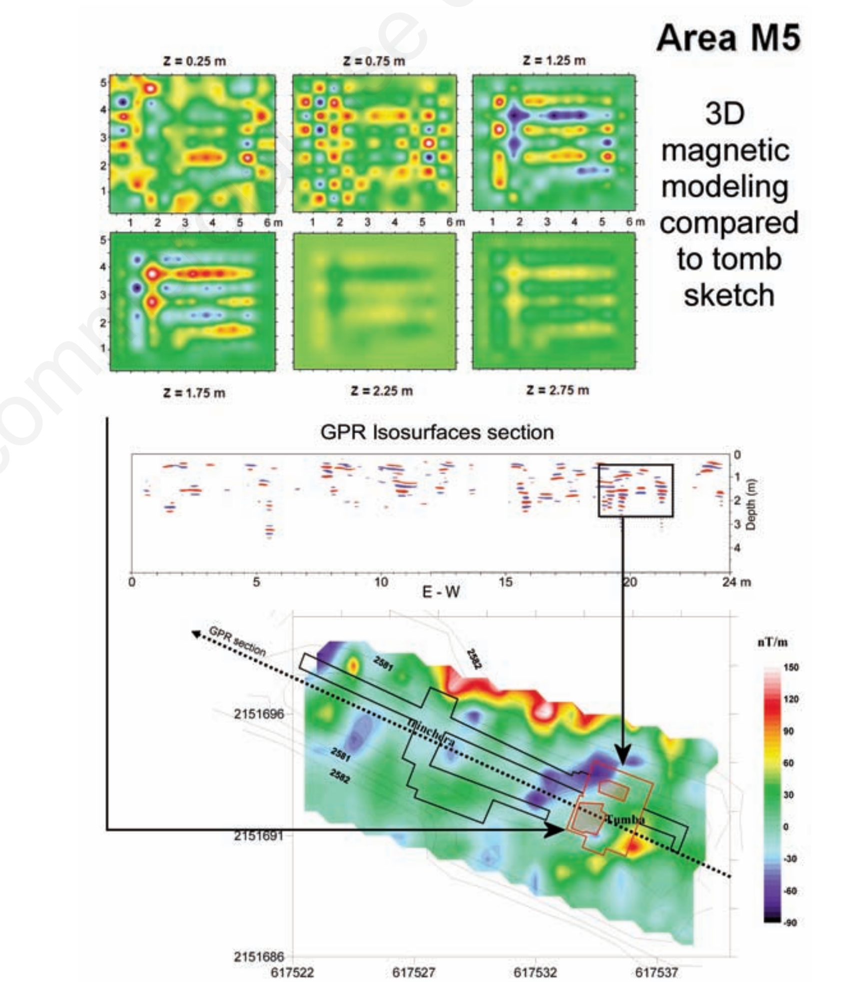

Figure 4. Geophysical results obtained on terrace M5. The GPR section (middle) and the total magnetic field map (bottom) show the position of the tomb excavated by Garcia Cook in 1974 associated with an important anomaly. The results of the 3D modelling of the magnetic anomaly asociated with the tomb (top) correspond to the dimensions and geometry described by Garcia-Cook (1997) and Garcia-Cook *et al.* (1997).

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and inside the tomb. Finally, he covered all, including the walls, with soil. This can produce the effect of false walls in the magnetic investigation, since they are also highly magnetic bodies with an orientation similar to the archaeological walls.

In terraces M6 and M7, only the electric tomography method was applied. In both terraces, interesting near surface high resistivities can be related to archaeological remains. In terrace M7, there is a low resistivity anomaly that starts near the surface and ends around 10-12 m deep. This feature could represent a major void partially filled with loose but moister material, although its origin (natural or archaeological) cannot be determined yet. The electric anomalies observed in these 3D displays are been analysed as potential targets of future archaeological excavations.

Conclusions

The different buried pre-Hispanic features obtained through the geophysical investigation allowed defining the size and depths of possible structures of archaeological interest. These data are important for the interpretation of the site according to the space distribution of their elements, and was useful as a base for the archaeological excavations done in the site. The magnetic prospection of the pre-Hispanic site combined with the application of an innovative 3D inversion modelling allowed us to define the size and depth of architectonical structures of archaeological interest. The magnetic data depicted a series of dipolar anomalies related to important archaeological remains, such as kilns, walls and a pyramid base. The investigation developed demonstrates that, with a suitable strategy of investigation and previous knowledge of the zone, the geophysical methods are effective and valuable tools in the archaeological investigation, furthermore than simple graphical displays.

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