

Using the micro – resistivity method to detect hispanic ancient floors at Nombre de Dios, Panamá

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ABSTRACT

This article describes the application of the method of electric prospection to the detection of floors of hispanic type associated with the site of Nombre de Dios. This site represents an important and ancient Spanish settlement founded during the time of the European conquest in the American continent around the year 1510. The electric prospection developed in the site was conformed by a mapping of apparent resistivity of a small area (10 x 10) m obtained through an electrode arrangement pole - pole type and developed during the dry time. The results obtained in the interpolation process for the obtaining of the apparent resistivity map of the subsoil showed a group of electric anomalies with high values, which went associated to a ground system of pebbles built during the period. The areas with low values of apparent resistivity were associated to the sedimentary material that characterizes the region. Later on, the excavation works carried out on one of the electric strong anomalies agreed with the results of this geophysical prospection; a probe of 0.5 x 0.5 x 0.2 m revealed the superior part of a floor of pebbles; and this colonial structure rests under a *wet layer* of superficial sedimentary material. Below the hispanic floors, the moisture turned out to be bigger. Later to the excavations, and with the objective of generating a synthetic map of electrical resistivity with the same characteristics observed in the map of values of measured resistivity, it was intended a 3D geoelectric model incorporating the main characteristics of the floor of pebbles detected during the excavation, as well as the surrounding materials.

Keywords: Electric Prospection, apparent resistivity, apparent resistivity mapping, floor of pebbles, Nombre de Dios, 3D modeling.

RESUMEN

Este artículo describe la aplicación del método de prospección eléctrica para la detección de un piso de tipo hispánico asociado con el lugar denominado "Nombre de Dios". Este sitio representa una importante y antigua colonia española fundada en la época de la conquista europea en el continente americano alrededor del año 1510. La prospección eléctrica desplegada en el sitio estuvo conformada por un mapeo de resistividad aparente en un área pequeña (10 x 10) m obtenida a través de un arreglo de electrodos polo - polo y se desarrolló durante la época de verano. Los resultados obtenidos en el proceso de interpolación para la obtención del mapa de resistividad del subsuelo mostraron un grupo de anomalías geoelectricas con valores altos, las cuales fueron asociadas con pisos de guijarros construidos durante este período. Las áreas con bajos valores de resistividad aparente se asociaron a los materiales sedimentarios que caracterizan la región. Más tarde, los trabajos de excavación llevados a cabo en una de las zonas con anomalías eléctricas fuertes concordaron con los resultados de esta prospección geofísica, un sondeo de 0,5 x 0,5 x 0,2 m reveló la parte superior de un nivel de guijarros, y esta estructura colonial descasaba sobre una capa húmeda de material sedimentario superficial.

Palabras clave: Prospección Eléctrica, resistividad aparente, mapeo aparente resistividad, guijarros, Nombre de Dios, modelo 3D.

Por debajo de los pisos hispánicos, la humedad resultó ser más elevada. Posterior a las excavaciones, y con el objetivo de generar un mapa sintético de resistividad eléctrica con las mismas características observadas en el mapa de valores de resistividad medida, se desarrolló un modelo geoelectrico 3D incorporando las principales características de piso de piedra y de los materiales del entorno detectados durante el excavación.

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Introduction

The city of Nombre de Dios was one of the first European settlements founded in the Atlantic coast of the Isthmus of Panama and in American mainland and for this reason, it is considered as one of the oldest Hispanic sites. This city was founded in the year of 1510 by Diego de Nicuesa and its importance resided on its belonging to the port of the Atlantic that connected Spain with many colonies of South America. After this port was abandoned in 1597 because of the attack of the English pirates, Nombre de Dios was forgotten for four centuries, fact that helped it to preserve part of its archaeological remains (Salamanca, 2007). After these events, the city is occupied and nowadays it is consolidated as one of the main section called Santa Isabel's district, province of Colón (North of Panama).

With the passing of time the population went growing and some places lie below certain structures for what it was necessary to carry out an archeological evaluation of the place; and based on this, a multi-disciplinary team accomplished certain scientific activities that represent the electric prospection. This arises from the fact that the study of the physical properties of the subsoil, through measurements realized in the surface of it can give referent lights to the presence and or absence of archeological buried features. These archeological elements are characterized for presenting physical properties (electric, magnetic, thermic or electromagnetic) different to the way that surrounds them, which make them potentially detectable. These techniques of exploration of the subsoil have been successfully applied in some archeological sites of colonial type in the American continent. (Pastor *et al.*, 2001; Lascano *et al.*, 2003; Mojica *et al.*, 2004; Caballero *et al.*, 2004; Chávez *et al.*, 2005; Mojica, 2007a, 2007b; Mojica and Garcés, 2008; Mojica *et al.*, 2009). These techniques, which are categorized as non-destructive, play a very important role in the process of the extended description of an archeological site.

A geophysical prospection based in the electric method was developed in the southwest part of the actual settlement of Nombre de Dios, with the principal objective to detect pavements or floors characteristic of the period of the Spanish conquest.

Site description and historical setting

Nombre de Dios is located to 23 km east of Portobelo, at the Atlantic coast of the Isthmus of Panama (Figure 1). The place, repose on a sedimentary formation of the Secondary Period in which limestones and tuffs become present from the Ocu Formation. Few kilometers from the site, it is encountered the Río Hato Formation of the Quaternary, which is characterized by the existence of conglomerates, sandstones, lutites, tuffs and non-consolidated sandstones.

Related to the historical context, mentioning that Christopher Columbus in his fourth voyage was searching a new route toward the Asiatic continent, and he went over the Caribbean coast of the Isthmus of Panama and found (in 1503) in its central zone, the first Spanish village on the continent called Santa María de Belén, which time later was going to be destroyed by the natives of the region. After that, numerous expeditions were carried out in the all region with the objective to find deposits of precious metals. At a later time The Spain in the desire to colonize mainland decides to divide the explored zone into two governments: Nueva Andalucía and Castilla de Oro. The government of Castilla de Oro was ranged from Cabo Gracias a Dios (located in the actual Nicaragua) to the boundary with the government of Nueva Andalucía which is located in the middle of Uraba's gulf (actual Colombia). In the year of 1510, it was founded in Castilla de Oro's government, a port in the Caribbean coast of Panama which was named Nombre de Dios; later on this port played a very important role in the commerce between Spain and the originating wealth of Panama City, as a result of the conquest process of South America.

Geophysical test principles and field procedures

The use of the techniques of geophysical prospection in archaeological explorations is a topic that has been strongly compiled in a utter literature and as example of it we can find the works of Scollar *et al.* (1990), Dabas *et al.* (1998), Milsom (2003), Campana and Piro (2009) among others. One of the most important geophysical techniques used in archaeology is the electric

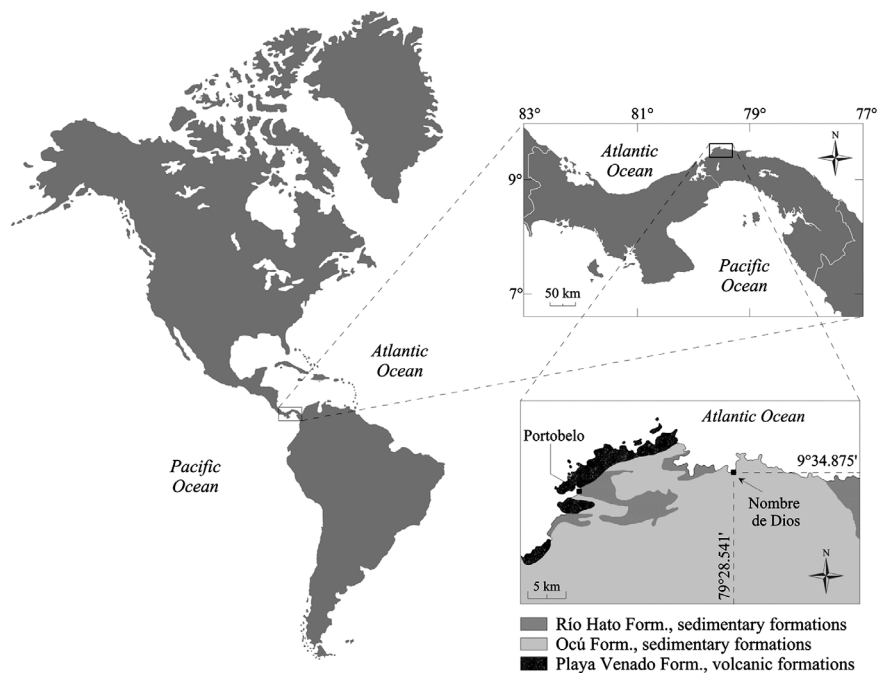


Figure 1. Geographical location of Nombre de Dios and simplified geologic map of its surroundings.

prospection (Tabbagh, 1992; Dabas et al. 1998); which is used to measure differences in the electric resistivity of the subsoil. This physical parameter of the subsoil constitutes the base of this type of explorations, and the same one is affected by the differences in the porosity of the grounds, its content of water, its chemical nature and its thermodynamic properties (Nover, 2005). The device of electric prospection used in this study is composed of a source of AC power, which is connected to two metallic electrodes (A and B) inserted in the ground. When a certain current intensity i (in mA) flows through the subsoil another couple of electrodes (M and N) register the difference of electric potential V (in mV) generated in the subsoil. Thanks to the data of V , i and a parameter k (in meter) that depends of the geometry of the four electrodes aligned in the surface it is possible to determine the distribution of the electric apparent resistivity (ρ_{ap}) in the subsoil through the following equation:

$$\rho_{ap} = 2\pi k \frac{V}{i} \quad (1)$$

For effects of mapping this physical parameter, it is necessary to maintain fixed the distance among these electrodes, displacing them all equally through the separate profiles. The exploration depth doesn't vary and it is determined through the separation among the electrodes.

With the idea of obtaining an image at level of pixels on the variations of the electric resistivity of the ground for a constant depth, it was used a pole-pole electrode configuration, which is composed by a movil part that carries wooden electrodes with the couple of A and M electrodes separated in a distance of 0.50 m; the other couple of electrodes (B and N) is located far from the prospecting area (see Figure 2).

The operation of measuring values of the difference of electric potential throughout a profile is repeated in other parallel profiles and separated to each other in a fixed distance covering in this way, the surface of interest and keeping constant the electrical current i (5 mA in this case). This methodology has been used for different authors (Hesse, 1994; Dabas et al. 2000; Caballero et al. 2004; Matias et al. 2006; Mojica 2007a; Tonkov, 2008).

The nature of the superficial ground (in this case sedimentary) the low level of contamination and the superficial archaeological evidence (ceramic remains and metallic materials characteristic of the period) constituted the necessary conditions for the development of an electrical prospection. However, elements like the density of the flora and some topographical aspects were the factors that influenced in the election of the area whose dimension of its surface was of (10 x 10) m (see Figure 3). The measurements of the difference of electric potential were carried out throughout profiles of 10 m of longitude separated to a distance of 0.50 m among them, being obtained a total of 441 registrations. There were used in this study, electrodes of stainless steel of 30 cm of longitude by 5 cm diameter. The used resistivimeter consisted of a source of AC power of 50 V of output and a maximum current electricity of 5 mA.

Geophysical results, interpretation and archaeological excavation

The result of the interpolation on a 0.25 m regular grid obtained in this study is shown in Figure 4(a). The apparent electrical resistivity values range is extended between 90 and 360 ohm.m. This result shows two strong anomalies (A and B) in dark tonality with values of apparent resistivity greater than 180 ohm.m, which can be associated to cultural material. It also shows up a conducting area with anomalies in light gray tonality, with values of apparent electrical resistivity below 180 ohm.m which can be associated to the sedimentary material characteristic of the place. The dotted lines in the map correspond to the possible limits of these strong anomalies.

Based on this result, an archaeological excavation of (0.5 x 0.5 x 0.2) m of dimension that was developed in the central coordinates $x = 9$ m and $y = 4$ m (Figure 4 (b)). The result obtained in the excavation revealed the existence of a superficial *wet layer* of 0.20 m of thickness constituted by sedimentary material (organic material) characteristic of the dry station. Then it was detected a floor of pebbles very similar to the ones found in the hispanic site of Old Panama, located in the pacific coast of the isthmus of Panama. The thickness average of this layer oscillates among the 0.10 m. The two layers lie on the same sedimentary material, but with a strong moisture level.

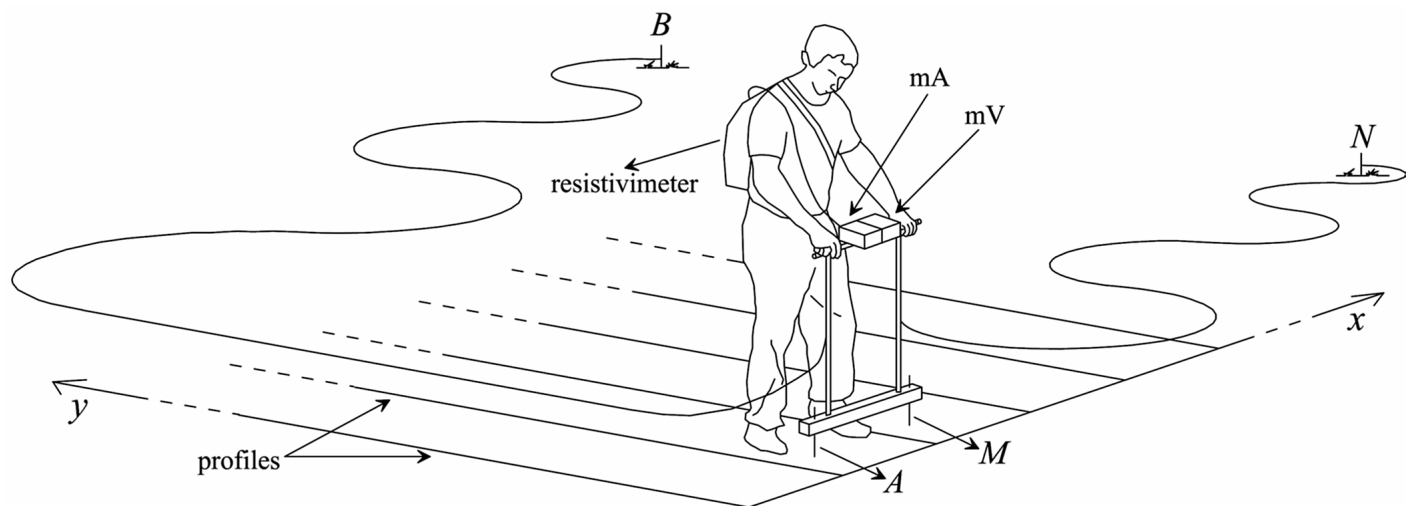


Figure 2. General scheme of measurement processes and acquisition of data in field through a pole - pole electrode configuration.

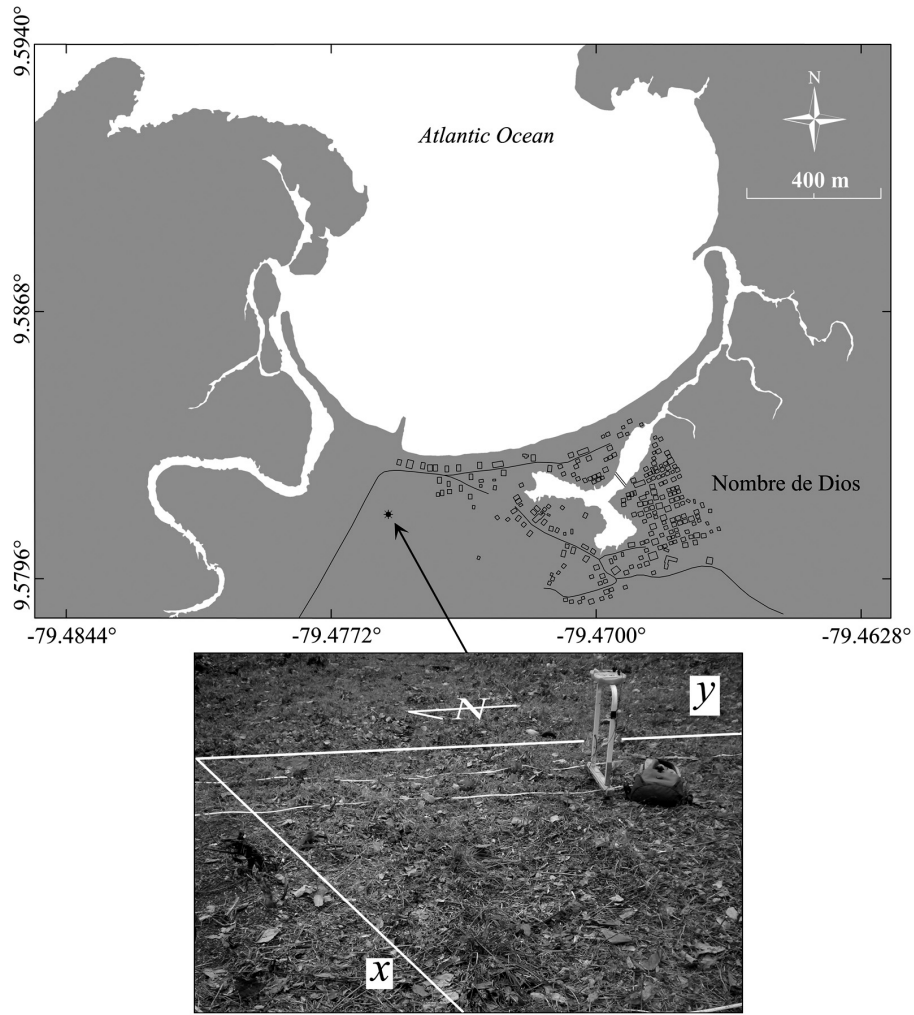


Figure 3. Map of the Nombre de Dios community and interest area.

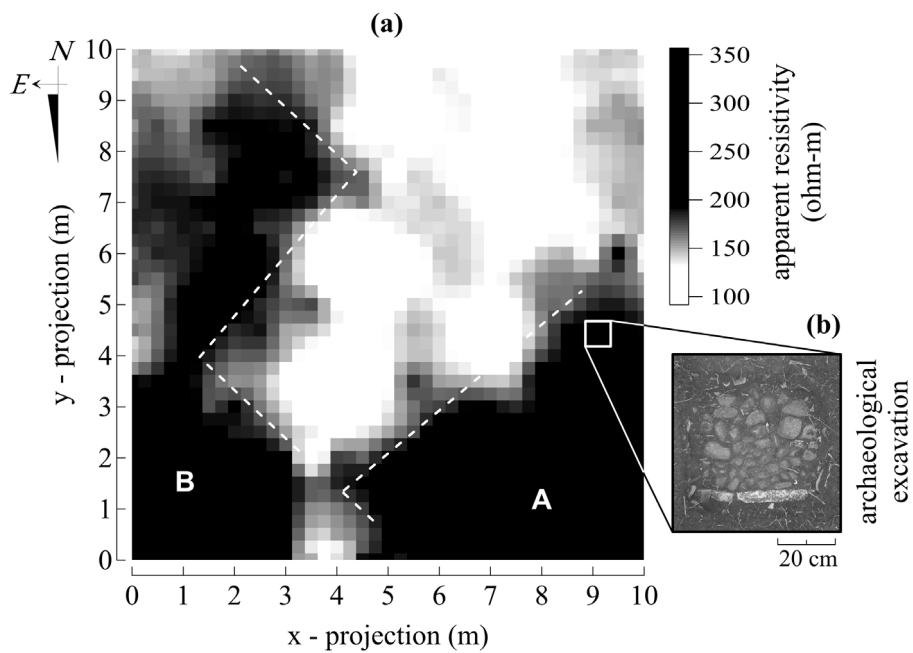


Figure 4. (a) Map of apparent electrical resistivity of the prospected zone and final interpretation, and (b) result of the archaeological excavation with dimensions (0.5 x 0.5 x 0.2) m in the place of Nombre de Dios.

A Posteriori 3D forward modelling

With the objective of deepening in the results obtained in the electric and archaeological prospectations, it was intended the reconstruction of a synthetic map of apparent resistivity based on the dimensions of the prospected area, the electrode configuration used (pole-pole in this case,) the dimensions and geoelectric characteristics of the structures contained in the subsoil (superficial layer with organic material, floor of pebbles and sedimentary ground, characteristic of the site). The response to the 3D model of electrical resistivity applied in this work was calculated through a numerical approximation of finite difference. This method is used to solve the distribution of the electric potential V due to a punctual source of electric flow in the surface of a half-space that possesses a three-dimensional arbitrary distribution of electrical resistivity (Dey and Morrison, 1979). These potential and electric current are related to the electrical resistivity of the structures by the equation:

$$-\nabla \cdot \left\{ \frac{1}{\rho(x, y, z)} \nabla V(x, y, z) \right\} = \left\{ \frac{\partial \gamma}{\partial t} \right\} \cdot \delta(x-x_s) \delta(y-y_s) \delta(z-z_s) \quad (2)$$

In this equation (x_s, y_s, z_s) correspond to the reference of the punctual source of electric flow, γ is the load density in a point of the Cartesian space (x, y, z) , ρ is the electric resistivity and δ represents the Dirac delta function. The solution of $V(x, y, z)$ is obtained by deriving the difference equations of (2) through a discretization of the (x, y, z) space over which the problem is to be solved (Dey and Morrison, 1979). The space (that represents the subsoil) is discretized through a mesh of rectangular prisms whose nodes are separated from irregular forms in the directions x, y and z , and indexed for (j, k, l) for each direction. In each one of these nodes (where the electric potential V is unknown) the equation (2) is integrated under a corresponding elementary volume (v) and it is obtained:

$$-\iiint_{v(j,k,l)} \nabla \cdot \left\{ \frac{1}{\rho(x, y, z)} \nabla V(x, y, z) \right\} dx_j dy_k dz_l = i(x_s, y_s, z_s) \quad (3)$$

Thanks to the transformation of the integral volume of the left member of the equation (3) to an integral surface through Green's theorem; a separated equation is obtained for a single node inside the mesh. This equation possesses bound functions to: (i) the geometry of the mesh and the value of the electrical resistivity (by default) of each rectangular prism, and (ii) the unknown value of the electric potential (V). If they take into account the differential equations of all the nodes of the analyzed mesh, it is obtained a matrix representation in the way:

$$[C][V] = [I] \quad (4)$$

In this equation C represents a matrix related to the geometry and the distribution of the electrical resistivity in the mesh, which corresponds to well-known terms, V is another matrix that contains the unknown values of the electric potential in all the nodes, and I represents a matrix related with the well-known terms of intensity of electric current. The program used in this study was Res3Dmod (version 2.0, developed by M.H. Loke) and it is based on the works of Dey and Morrison (1979). In the 3D electrical resistivity model proposed in this study, there were established 4 levels composed by rectangular prisms whose characteristic are shown in Table 1. The values of electrical resistivity assigned to the rectangular prisms of the proposed model were chosen according to the Standard Guide of Using the Direct Current Resistivity Method for Subsurface Investigation (Designation D 6431 – 99).

Figure 5(a) shows the three-dimensional representation of the group of structures and Figure 5 (b) a plan view of the same structures extended among 0.20 and 0.30 m of depth. The application of the program generated a synthetic dataset of apparent resistivity to different depths with 5% of noise (given in terms of the separation of the voltage of electrodes and electricity in the pole-pole setting); from the generated data, there were extracted those corresponding to the first level of depth for all the profiles, that is to say for the distance AM = 0.5 m and after that, the next was to map this information using the same procedure than the one carried out with the data of apparent electrical resistivity measure. The result of this process is shown in Figure 6 which is very similar to the one obtained in Figure 4 (a), which means that the distribution of

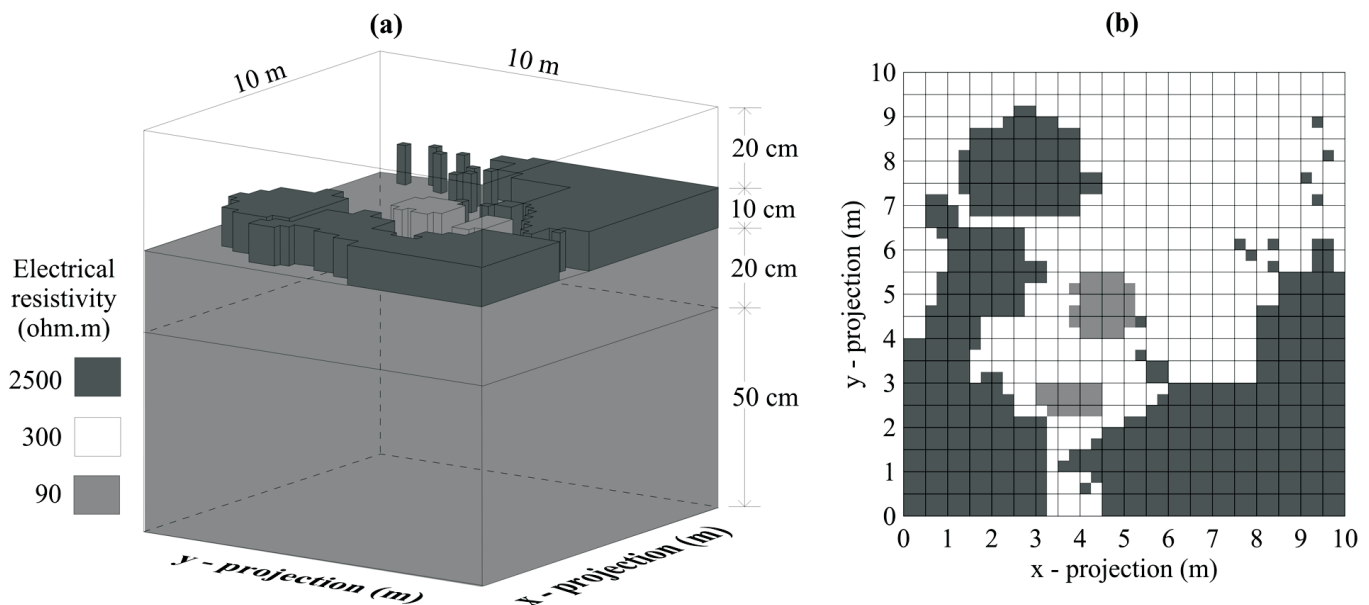


Figure 5. (a) Three-dimensional model of prisms that represent the grounds of pebbles (2500 ohm.m) and the other elements (sedimentary materials of 300 ohm.m between 0 and 0.20 m, and 90 ohm.m to deeper), and (b) plan view of the prisms model used in this study for a range of depth extended between 0.20 and 0.30 m.

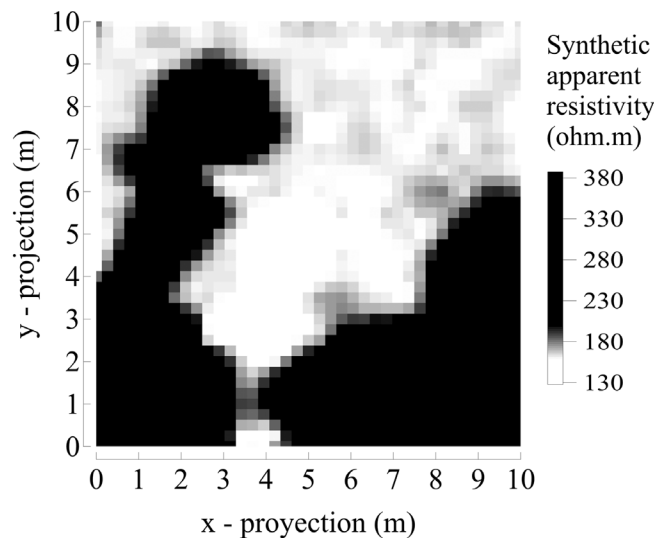


Figure 6. Synthetic horizontal map of apparent resistivity obtained from the prisms model presented in Figure 5.

the rectangular prisms of Figure 5, constitutes a good model for the representation and study of the electric anomalies associated to colonial floors.

Discussion

The results of the electric prospecting developed in the site of Nombre de Dios, have revealed the existence of strong electric anomalies of the subsoil with values above 180 ohm.m and that they are associated to a floors of pebbles system, which were very common in the colonial period. The range of apparent resistivity values obtained for the superficial layer is associated to the sedimentary material of the Secondary Period that is also composed of organic material. In this same aspect, the synthetic map generated by the three-dimensional modeling through the discretization of the subsoil for finite difference, possesses similar characteristic to the map of apparent electrical resistivity measured of Figure 4 (a), with a first layer of rectangular homogeneous prisms of 0.20 m of thickness and 300 ohm.m of resistivity; representing to the superficial sedimentary layer. The second layer (located between 0.20 and 0.30 m of depth) is more complex and it reveals a group of prisms with 3 different values of electrical resistivity: the rectangular prisms of 2500 ohm.m that represent the system of floors of boulders, the prisms of 300 ohm.m associated to sedimentary floor with organic components, and those of 90 ohm.m with the same characteristics that the floor type described previously, but with certain level of moisture. Below these two levels, it shows up a group of homogeneous prisms that are extended until 1 m of depth and of 90 ohm.m of electrical resistivity.

Conclusions

Even the prospected area doesn't possess a significant extension, the results obtained in it demonstrates in first place, a good lateral resolution referring to electric mapping with electric anomalies that define the limits of floors of pebbles characteristic of the foundation period of the old city. Thanks to this geophysical intervention it became evident the existence of archaeological features of Hispanic type, being demonstrated in this way, the historical importance of the site. In this same aspect the three-dimensional model of rectangular prisms proposed in this work, constitutes a good model for the representation of old floors and the surrounding subsoil. Based on the

previously exposed thing, it becomes necessary a more extensive exploration to detect other archaeological features of this site, so that the life forms of the first European in the Isthmus of Panama can be understood.

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