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Geoelectric and magnetic surveys at La Libertad archaeological site (San Cayetano County, Buenos Aires Province, Argentina): A transdisciplinary approach

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A B S T R A C T

Archaeological investigations have been taking place since 2006 regarding 19th century Creole rural settlements in the southeastern portion of Buenos Aires Province. The results of applying two geophysical prospection methods at La Libertad archaeological site, a large livestock ranch in San Cayetano County, are presented. The main objectives were to delimitate possible structures, including moats and tunnel; to detect and explore the most relevant geophysical anomalies; to evaluate the use of two geophysical methods at a reduced scale of analysis (m); and to analyze and discuss the archaeological materials.

Using an electrical imaging technique, the electrical resistivity of the subsoil was studied over an area covering most of the site. The resistance anomalies observed may indicate the presence of distinct features such as burrows, roots, brick structures, and archaeological material. Magnetic susceptibility data was registered in some of the electrical profiles. The archaeological materials recovered were bone, glass, ceramic, metal, bricks and one fallen wall, among others, all corresponding to the last quarter of the 19th century and coinciding with the different written sources concerning the La Libertad of Gomila ranch (photographs, letters, memoirs, etc.).

1. Introduction

Since the colonial period, the Hispanic-Creole conquest and settlement in the Argentinean Pampean region unfolded slowly but continuously. It had its major influence at the beginning of the second half of the 19th century. This process concluded with the expulsion and extermination by 1880 of different Pampean and Patagonian aboriginal groups that inhabited these regions (Walter, 1970; Comando General del Ejército, 1974). This type of coercive and violent domination, not only in the Pampean region but also in other American states, involved the formation and settlement of successive borderline areas (the mission, the militia and the villages) where various ethnic and social groups came together, such as indigenous peoples, missionaries, military personnel, tradesmen, landowners, and farmers. Thus, the border was a heterogeneous and dynamic space where multiple inter-social relations were developed that harbored diverse types of settlements including *puestos* (establishments), ranches, *pulperías* (general stores), *tolderías* (indigenous settlements), forts and military posts (Mandrini, 1992; Cusick, 1998; Mayo, 2000; Palermo, 2000; Ratto, 2003; Pedrotta, 2005). These are all samples that could be studied from a geophysical as well as an archaeological point of view.

Since 2006 systematic studies have been being developed regarding the Creole rural settlements established in southern Buenos Aires Province from 1840, when the first lands were yielded by Emphyteusis Law in this area (Fig. 1). This decree of November 26, 1826 allowed the rent of public land in Buenos Aires Province for very long periods of time with the objectives of settling vast territories, providing resources to the government, and reducing the public debt. This system was intermediate between leasing and ownership, because the occupied land could be used freely, but it could not be sold. The plots between Cristiano Muerto and Claromecó creek were measured in 1835 (Eiras and Vassolo, 1981; Bagaloni, 2009).

In this paper, the ways at which territorial expansion occurred and its relations with agricultural and livestock activities inside and outside the government-established borders are discussed. The commercial interaction networks within local, regional and extra-

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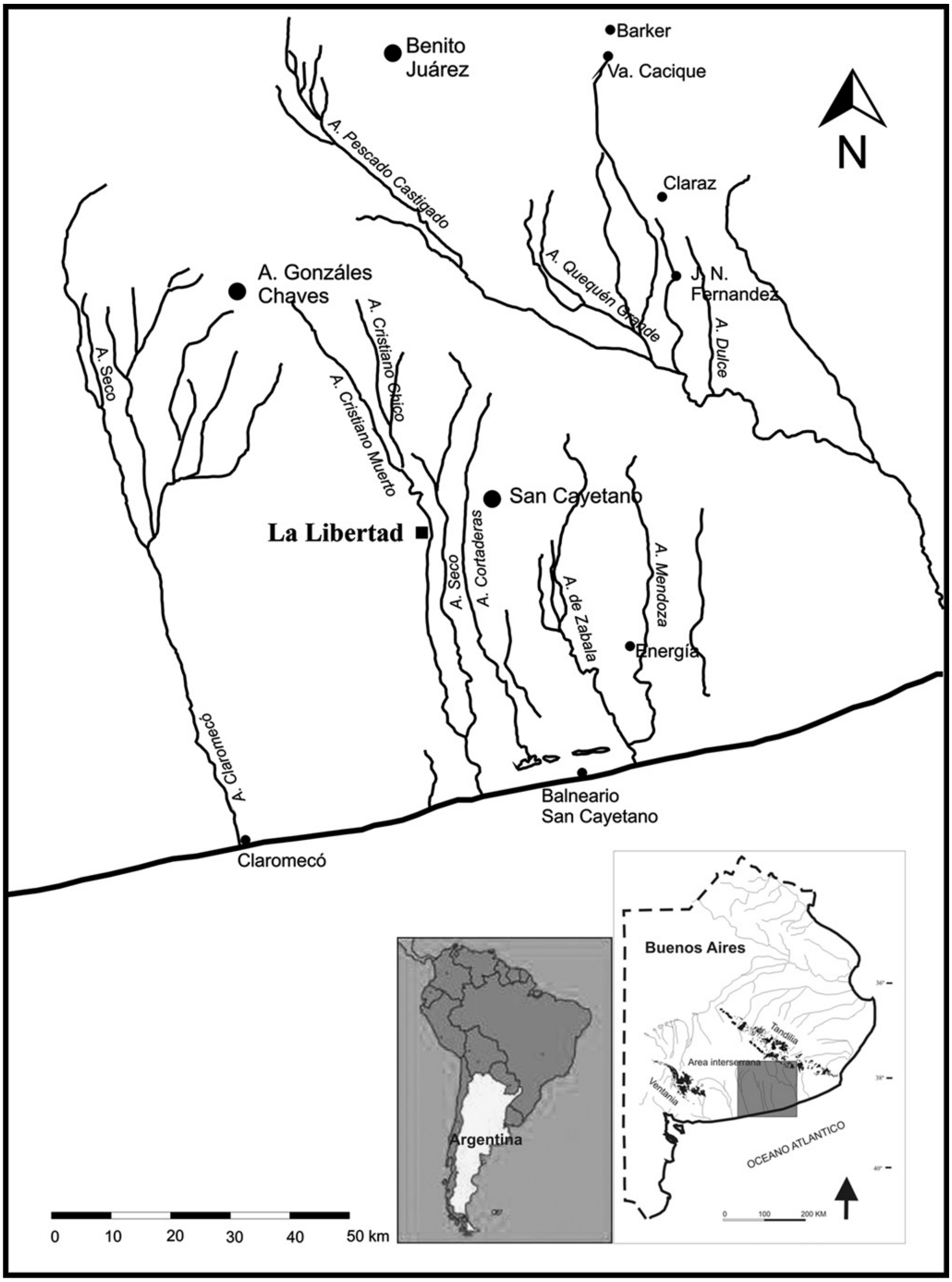

Fig. 1. Location of the archaeological site La Libertad (Buenos Aires Province, Argentina).

regional centers, Creole sectors and aboriginal groups are also analyzed. The local, regional and global influences of modernization and industrial capitalism in the rural societies from the middle of the 19th century are also assessed (Wolf, 1993; Hobsbawn, 1998). The ranches of Pampean region were characterized during the second half of the 19th century by: 1) the land was subdivided with *puestos*, strategically located, where control and monitoring could be exerted; 2) the breeding, exploitation and consumption of domestic animals intensively "in barnyard", especially sheep; 3) the emergence of different spaces with specific functions (house of the landlord, house of the farm workers, sheds, barnyard, etc.) increasing individual use of spaces and materials, and generating a greater social distance; and 4) the preference for the consumption of certain goods and imported products that marked new behaviors in daily life, due to the expansion of pre-existing commercial circuits that modified the supply and distribution of goods, and that were facilitated by changes in the transport routes (Mayo, 2000; Brittez, 2007).

Two parallel lines of investigation were applied in a combined manner: geophysics and archaeology. On the one hand, the efficiency and applicability of geoelectric and magnetic methods for the reconnaissance of possible places for excavation with features of rural Creole settlements was considered. This geophysics approach attempted to deal with the difficulties in studying sites of considerable size, by minimizing the number of intensive and systematic archaeological excavations, preserving the materials and reducing time and costs. On the other hand, the archaeological approach, the ways of living, the consumption patterns and the daily behavior in the different rural settlements of the studied region during the 19th century were discussed through the recovered archaeological materials.

Electric and magnetic survey methods in archaeological investigations have been applied throughout Latin America in order to obtain a fast reconnaissance of the sub-surface remains (Alves, 1979; Hesse et al., 1997; Panissod et al., 1998; Pastor et al., 2001; Scholkmann et al., 2006; Patzelt et al., 2007; among others), and more recently in Argentina (Ponti et al., 1996; Buscaglia et al., 2005; Aguilera et al., 2006; Bongiovanni et al., 2006; Osella and Lanata, 2006; Castellano and Togo, 2007; Leoni et al., 2007). In the Pampean region, a geophysical survey of the subsoil was performed at the Fuerte General Paz site, an old military base located in Carlos Casares county, Buenos Aries Province (Leoni et al., 2007), where two similar methods were applied: electrical imaging and profiling. At this site, different anomalies were detected indicating the presence of brick floors, structures and/or sub-surface contexts, consistent with those expected for a military settlement of that scale. Díaz Vázquez (1993) explained diverse causes for changes in magnetic susceptibility in archaeological sites, but there are only a few examples of application (Schmidt, 2009). An important precedent is the research made by Mamaní et al. (2006), who used magnetic susceptibility to detect the presence of small ancient bakeries or fire pits in archaeological sites from Santa Rita de Catuna (La Rioja Province, Argentina).

This paper is focused on the study of the archaeological site of La Libertad. The great extent of the site of 19,000 m^2, in comparison with other sites of the Pampean region, constituted a methodological challenge for applying geophysical methods and techniques at a reduced scale (m) and in this type of rural settlement. Until now they were used for delimitate possible excavation areas in fort and blockhouse contexts. The archaeological question was to determine if a square building structure was place in that area, based on the documents and photographs of the ranch "La Libertad de Gomila", and oral testimonies. There is no observable evidence on the surface, or exposed foundations. It is possible that a tunnel began in the main house and was surrounded by a moat. Thus, the first aim was to detect and delimit the presence of these possible structures, moats, and tunnels as described in written sources and photographs using geophysical prospecting methods in a sector of the site where archaeological evidence was previously recovered on the surface and in stratigraphic position. A second objective was to detect and archaeologically investigate the most relevant geophysical anomalies. The third goal was to analyze and discuss the archaeological collection. The final goal was to assess possible areas for future excavation planning and to evaluate the utilization of electric and magnetic geophysical survey methods at a meter scale, differing from that habitually employed in geophysical research and its applications in Argentina.

Firstly, La Libertad archaeological site will be characterized and the archaeological materials recovered before the geophysical survey will be presented. The analysis of the historical documents, cartography, and photographs that relate to various particularities of the farming settlement that was established at the site will also be discussed. Secondly, the methodology applied in the geoelectric survey and the use of a magnetic susceptibility meter in the field will be developed, including the criterion used for data processing and analysis. Results obtained from both geophysical surveys and the proposed hypothesis from the previous archaeological excavations will be presented, as well as detailed description and analysis of the recovered archaeological collections. Finally, the contribution of these two geophysical methods to archaeological research in the region will be evaluated, and the composition, function and chronology of the archaeological materials will be discussed.

2. Materials and methods

2.1. Written sources

The archaeological site is located on a ranch named "La Libertad de Gomila", mentioned in the Tres Arroyos county measurements N° 64 (1875) and 136 (1892) (Fig. 2a). According to these measurements and some works of local and regional history (Romeo, 1935, 1949; Girado, 1977; Eiras and Vassolo, 1981), in 1865 the ranch belonged to Mr. Justo de la Lastra. It was later occupied, until the end of the 19th century, by one of Mr. Justo's daughters and her husband, Teófilo C. Gomila, who established a large commercial farm (Bagaloni, 2009).

In addition, written reports describe the existence of a fortified house with a watchtower and cannon, surrounded by a moat from which a tunnel extended from the Cristiano Muerto stream as an eventual escape route from approaching *malones* (indigenous raids) (Romeo, 1935, 1949; Eiras and Vassolo, 1981). Girado (1977) also emphasizes that in addition to the central residence, there existed a general store with a large living area for laborers and other dependents. The main building was of solid construction, built over a surface of approximately 50 × 50 m. All four walls of the building were complete, including a second floor room that functioned as a lookout oriented to the west (Fig. 2b). According to data from former employers of the ranch, during 1920 and 1930 almost all of the structures were dismantled for the fabrication of a new building located 2 km away. By the 1950s, what had remained standing finally collapsed, including the main entrance with the watchtower, two rooms located on the east side, and the kitchen floor located to the west (Ms. Rosa and María Cayuela, and Mr. Guillermo Vassolo personal communication). At present, there is no evidence of any type of architectural feature in the surface.

2.2. Archaeological site La Libertad

The site of La Libertad is located on the right margin of the Cristiano Muerto stream at 38°29′27.1″S; 59°44′16.9″W (Fig. 1). The site is situated along the interhill plains area, characterized by rolling landscapes and fluvial valleys. The inter-fluvial areas form extensive surfaces covered of caliche layers developed on a substrate of silt-sandy sediments. Locally, caliche levels are buried by a 1–2 m thick aeolian deposit, which corresponds to the geologic formation of La Postrera (Fidalgo et al., 1975), the parent geologic material on which modern soils develop. By the end of the 19th century in southeast Buenos Aires Province, agriculture, stockbreeding, and modern hydraulic constructions changed the geomorphologic systems and substantially transformed the natural drainage, producing accelerated erosion and sediment accumulation (Zárate and Rabassa, 2005).

The site comprises diverse low humps, less than 1 m in height, and a large quantity of surface material dispersed over 19,000 m^2, surrounded by *Eucalyptus camaldulensis* and *Tamarix gallica* trees, and bordered by two rural roads (Fig. 3). The land where the site is located is presently used for bovine grazing. Three important perturbation episodes had occurred associated with flooding events, when soil deposits were extracted to refill adjoining roads.

In 2007, the first archaeological fieldwork was undertaken through five superficial transects 30 m long (each separated by a width of 2 m), and one shovel test of 20 × 20 cm, covering an area of 240 m^2 (Fig. 3). A total of 1903 objects were recovered on the surface ($n = 1153$) and buried ($n = 750$). Allochthonous domestic species and wild fauna represent more than 61% of the findings (Fig. 2c), whereas construction material, mainly brick, comprises 15%. Recovered materials in lesser percentages include: metals (9%), charcoal (7%), glass (7%) such as window glass, flasks, jars,

Fig. 2. a. Measurement of Tres Arroyos County N° 136 (1892). b. Photograph of '*Estancia La Libertad de Gomila*' taken in 1879. c. Archaeological materials of the survey carried out in 2007. Bone remains. d. Tubes of kaolin pipes. e. Fragments of glass buttons. f. Whiteware earthenware dish edge.

bottles and buttons (Fig. 2e), and ceramic material (1%) such as fragments of English crockery (Fig. 2f) and kaolin pipes (Fig. 2d). Additionally, a brick floor of less than 1 m^2 was identified, situated approximately 30 m from the sector where the previous materials were encountered (Bagaloni, 2009).

2.3. Geoelectrical survey

The aim of this survey was to characterize the ground's resistivity variations. During the 2009 fieldwork, five electrical images of 90 m length were obtained over 8100 m^2, each one represented as a line in Fig. 3. Parallel lines L1, L2, and L3 were separated by 45 m from each other. Line L4 was set up between L2 and L3 in order to increase information in that zone. Line L5 was at 90° to the four previous lines and placed northward.

The electrical resistivity method measures the property of materials for conducting an electrical current (Sharma, 1997). The difficulty in establishing a current flow through any material is called electric resistance. In a homogeneous body of length L and cross section S, the resistance R is expressed as:

Fig. 3. Geophysical and archaeological surveys.

$$R = \rho \frac{L}{S} \quad (1)$$

The quantity ρ, in Equation (1), is electrical resistivity and is expressed in ohm meter (Ωm) in SI. In contrast, the electric conductivity is defined as the reciprocal of resistivity and expressed in Siemens per meter (S/m).

$$\sigma = \frac{1}{\rho} \quad (2)$$

Through the following expression, it is possible to estimate the resistivity of a homogeneous medium, by injecting a continuous current I on its surface and measuring the voltage difference produced:

$$\rho = K \frac{\Delta V}{I} \quad (3)$$

In Equation (3), K is a geometrical constant that depends on the relative position of the electrodes in the field, in other words, the array type. For inhomogeneous media, the magnitude calculated with the previous expression results in an "apparent" resistivity.

The electrical imaging technique analyses the lateral and vertical variation of apparent resistivity, resulting in a 2D representation of this property. For practical purpose the collected data is ordered in a regular grid, called a pseudosection (Orellana, 1982). Through numerical and computational procedures (Dey and Morrison, 1979; Hohmann, 1982), it is possible to obtain a calculated pseudosection for a "true" resistivity distribution model. The difference between the calculated and observed pseudosections is measured through a root mean square estimation (RMS) expressed as a percentage, and the model is modified interactively until this coefficient is sufficiently small (5%). Thereby, the inverse problem is solved. In summary, the objective of the electrical imaging technique is to reach a "true" 2D resistivity distribution model of the subsoil that must be in agreement with previous physical and geological information.

During the electrical imaging survey of La Libertad, a resistivity meter system developed at Facultad de Ciencias Astronómicas y Geofísicas de la Universidad de La Plata (Pinciroli, 2000) and ten stainless steel electrodes were used to inject current into the ground as well as to measure voltage differences (Fig. 4c and d). Because of the assumed presence of vertical structures, lateral changes in resistivity were of greater interest rather than in the vertical direction. It is for this reason that a dipole–dipole array was employed, since it is very sensitive to changes in the horizontal direction (Loke, 2004). Furthermore, this array provides good

Fig. 4. Geophysical survey: equipment and devices. a. Magnetic Susceptibility meter b. Dipole device installation. c. Measure resistivity. d. Resistivity Meter System manufactured at Facultad de Ciencias Astronómicas y Geofísicas. Universidad Nacional de La Plata.

vertical penetration, and the field procedure is very simple. Concerning the probable size of the walls and foundations, a 1 m distance between dipoles was chosen, which provides a good resolution and resolves anomalies with the required detail in this evaluative stage of the project (Fig. 4b and c). Inversion of the data was performed using Res2dInv developed by Geotomo. This software modifies interactively a 2D model block cells of “true” resistivity and compares it to the observed data. The iteration process stops when a previously defined RMS is reached (Loke, 2004). Due to the importance of resistivity changes in the horizontal direction, the parameters that control the inversion process were chosen with the assumption that they constitute an abrupt transition in the natural environment. For a more detail description of the inversion process and the parameters used, refer to Perdomo (2009).

2.4. Magnetic prospection

Magnetic susceptibility is an intrinsic property that reflects the response of a material in the presence of an external magnetic field. A body of volume V subject to a magnetizing field H acquires a magnetic moment (Telford et al., 1996). The magnetization M is the magnetic moment per volume unit, as shown in Equation (4):

$$M = \frac{m}{V} \tag{4}$$

This magnitude is proportional to the magnetizing field H.

$$M = \chi H \tag{5}$$

The magnetic susceptibility χ is a dimensionless number in the SI units, since M and H are measured in the same units (A/m). According to their magnetic behavior, materials can be classified as:

- Diamagnetic, with negative and low magnetic susceptibility
- Paramagnetic, susceptibility is positive and low
- Ferromagnetic, susceptibility is positive and high

Minerals with high magnetic susceptibility are mainly iron oxides, especially magnetite and hematite. When a rock or material presents large values of magnetic susceptibility, it is due to the presence of this kind of mineral. There is a process in which iron oxides are enhanced through heating. Therefore, by measuring this property it is possible to determine areas influenced by human activities (i.e. the presence of burnt construction elements or burnt zones), as well as metal objects (Piro, 2009).

During the 2009 fieldwork, as a complementary method, magnetic susceptibility data was also registered on the electric profiles L1, L2, and L3. Data collected every 1 m with the MS2D system (Bartington Instruments Ltd.) permitted differentiation of the characteristics of the topsoil, because it detects ferromagnetic materials at 0.1 m depth (Fig. 4a).

The characterization of the electric resistivity and magnetic susceptibility allowed the planning of archaeological excavations. Given the large number of armadillo burrows, geoelectric transects were not set up in the sector explored during the 2007 fieldwork. Notwithstanding, in this sector, magnetic susceptibility was measured in order to obtain a comparative response with respect to nearby archaeologically sterile land.

3. Results

3.1. Electrical imaging

The aeolian mantle was commonly encountered during the archaeological and geophysical surveys to depths of up to 1.20 m. Based on the inverted model and fieldwork observations, different contour values were chosen to recognize the expected anomalies. Natural terrain was assigned a resistivity smaller than 40 Ωm, and anomalous values were ranked from 100 to 200 Ωm. Fig. 5 shows the five inverted models for each line as well as the superficial observations made during the survey. All the anomalies were more resistive than the natural environment. Some possible causes for resistivity anomalies were verified in situ at the moment of measurement: the presence of armadillo burrows, tree roots (eucalyptus), changes in the terrain morphology, and bricks.

In Line 1, a small hump of material was observed on the surface between 42 and 45 m and 52–54 m. It constitutes a linear feature that may represent the foundations of an old wall. In this same area, electrical imaging shows anomalous resistivity zones at an approximate depth of 0.5 m. In the first 7 m of this line, a resistive zone is clearly defined. At 4 m, an armadillo burrow was recorded that could have been the cause of this anomaly, although the anomaly size may indicate other causes. Similarly, at 16 m a resistive anomaly appeared with large horizontal and vertical development, in spite of a lack of surficial evidence. At 34 m, a small anomalous sector was observed in the top layer. Toward the end of Line 1, at 73 m and 82 m, lower values than the last ones were found, but nevertheless they constitute a possible area to explore. At 88 m, the anomalous values may be artifacts of bordering effects produced during inversion. There were no surficial features or structures evident in any of the cases (Fig. 5, Line 1).

In Line 2, the small humps of material referenced at 17 m, 30 m, 38 m and 42 m are show in the inverted model as zones within the anomaly resistivity range (100–200 Ωm.). A vertical development is also clear, so they might not be only surficial features. Furthermore, isolated anomalies are observed at 20 m, 78 m, and 88 m. Between 46 and 63 m, a zone of anomalous values in the uppermost surficial layer may indicate some type of a long structure, for example, a floor (Fig. 5, Line 2).

Along the entire third profile, neither structural features nor the presence of scattered material were found. Nevertheless, in some sectors, such as between 40 and 60 m, the characteristics of the soil were significantly softer than in the previous lines (Fig. 5, Line 3). Toward the end of the profile, the presence of eucalyptus roots might be evident in resistive anomalies. Anomalous values were observed between 5 and 10 m, and between 16 and 20 m. Superficial resistive values are seen at 36 m and 40 m. Two more resistive zones are clearly emphasized between 50 and 60 m, and between 64 and 80 m. Within these zones, higher anomaly values (300 and 500 Ωm.) were found at 49, 59, 72, and 83 m.

Due to the large variations of the resistivity in the surficial layer, a greater number of iterations were required to reach an acceptable model for Line 4, evidently complicating the process of inversion. Nevertheless, the resistive anomalies concur with the observed characteristics of the other lines. At the beginning of Line 4, more resistive sectors are present at 8 m, 15 m, and between 25 and 31 m (Fig. 5, Line 4). Some smaller anomalies were evident in the most surficial layer toward the end of the line.

Electrical image 5 was set up transverse with respect to the previous four lines and toward the north border of the area. The inverted model shows that this sector is almost unperturbed. Isolated anomalies are observed, but because of their low values, this line is not considered as a zone of prospective interest.

3.2. Magnetic susceptibility

In an archaeologically sterile area adjacent to the site, data was taken from an area of 2000 m^2, with a mean value of 239 SI (x10^{-3}), and a standard deviation of 46 SI (x10^{-3}). In order to analyze and compare the occurrence of anomalous values, mean value was

Fig. 5. Inverted resistivity sections processed with Res2DInv. Resistive anomalies are highlighted in the five lines with the field observations.

subtracted from measured data. Areas showing values above the standard deviation might indicate the presence of ferromagnetic material or sectors with chemical alteration because of fire or high temperatures exposure (Gaffney et al., 2002).

In addition, a 16 m^2 grid was built with a 1 m data spacing surrounding an archaeological shovel test performed in 2007, to explore a sector with known archaeological material. It is in this sector that the highest magnetic susceptibility values were observed. Similar values did not appear in a continuous form in none of the profiles, but isolated values were obtained at 9 m and 20 m of Line 1.

As seen in Fig. 6, in Line 1, zones with magnetic susceptibility greater than the standard deviation between 40 and 43 m and 45–50 m were measured. The same occurred in Line 2 between 10 and 18 m and at 32 m. In Line 3, lower values than standard deviation were observed in a large zone between 50 and 80 m, which probably are the result of changes in the superficial characteristics of the soil (greater amount of organic material).

3.3. Archaeological excavations

Results obtained from electrical imaging survey indicate diverse anomalies. According to field observations and archaeological and historical information, some of these anomalies might be related to foundation structures and accumulation of different kinds of archaeological material. These are indicated principally in Line 1 at 16 m, 42–45 m, and 52–54 m; in Line 2 at 16, 27, 30, 36, 46, 54, 60, 63 m; in Line 3 at 25, 44, 52 m; and in Line 4 between 8–9, 15–16, and 29–31 m.

Furthermore, according to magnetic susceptibility, measurements analyzed in lines 1, 2, 3, and in the grid reveal that an increment in values might be indicative of possible places for archaeological excavations. The study of magnetic susceptibility would allow identification of altered zones or those with conditions different to the natural soil that could not be evident, for example, if the site is covered by vegetation.

The information generated from the geoelectric and magnetic surveys were combined with excavations and superficial observations to complement the interpretation of anomalies. In 2010, 1 × 1 m archaeological grids and 0.40 × 0.40 m shovel tests were placed at the base of the Lines 1, 2, and 3 (Fig. 3). The archaeological materials recovered during this fieldwork are still being processed. In the following discussion, the type of material and the place where it was recovered is mentioned. Three-dimensional data were registered only for archaeological remains bigger than 2 cm and those with diagnostic characteristics. Only one sample of building materials (bricks, fragments of floor, plaster, etc.) was collected per level excavated. Only the small materials with three-dimensional data are considered in detail.

In Line 1, four grids were excavated in relation to locations 16, 42, and 43 m. In the grid L1C1, which corresponds to 16 m, a dense deposit of materials was found in the first 25 cm of excavation (Fig. 7a). Identified remains include bone, glass, ceramics (crockery, stoneware and kaolin), bricks, metals, and tiles, among other things

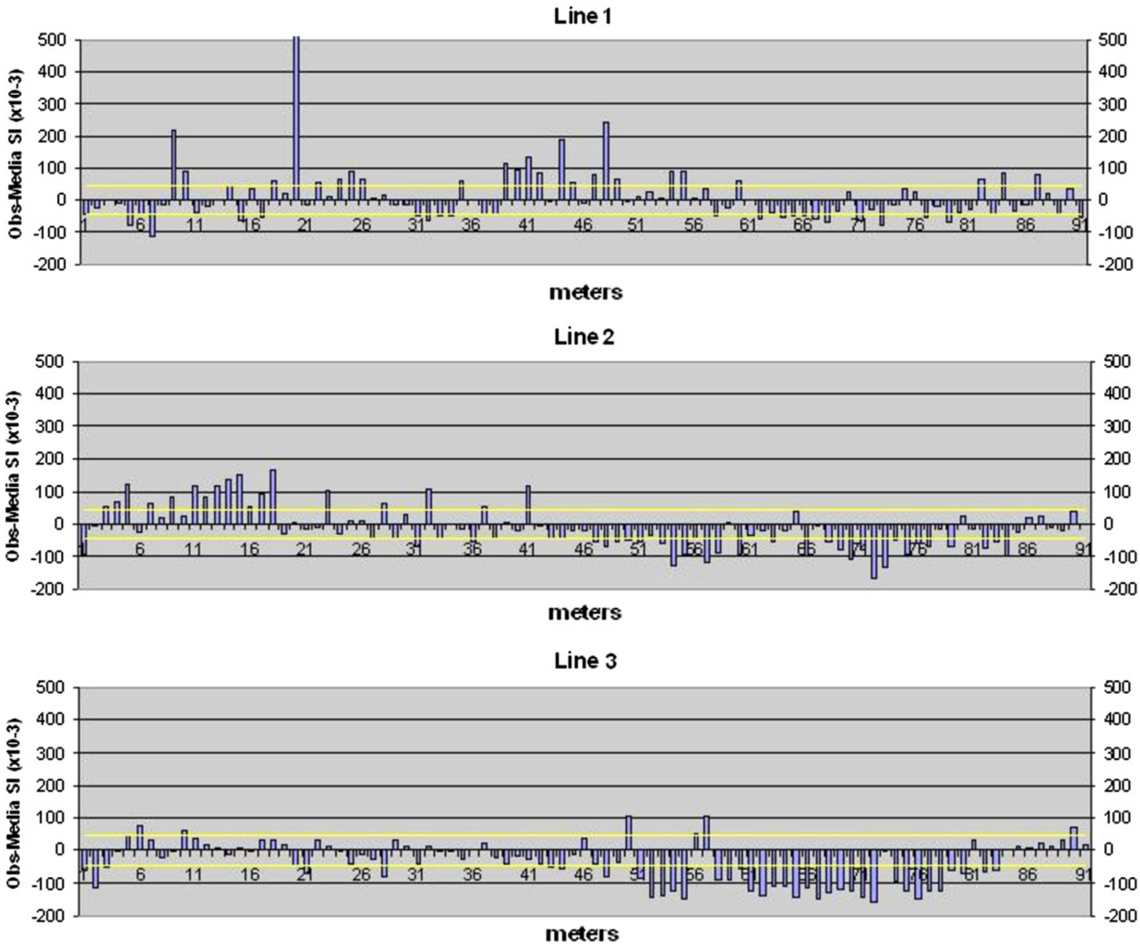

Fig. 6. Magnetic susceptibility in Lines 1, 2 and 3. The bars show the difference between the observed value and the mean value. The values that exceed the specified standard deviation are of interest.

(Fig. 7b), constituting a total of 558 three-dimensional objects as indicated in Table 1. It is important to emphasize the presence of large size metals (two of which are larger than 1 m), as well as the presence of bricks and complete bone elements.

In the grids L1C2, L1C3 and L1C4, related to location 42–43 m, 237 three-dimensional materials similar to those mentioned above were recovered at a depth of 0.6 m (Fig. 7e). These grids are related to one of the humps visible from the terrain. Although grid L1C2 presented a large quantity of debris and iron columns (Fig. 7c and d), continuity was not evident in the other units explored for the possible presence of foundations. Therefore, the regularity of the hump is the result of at least three interventions of road construction machinery, as previously mentioned.

Two grids were excavated in Line 2, between 16 and 17 m (L2C1) and 35–36 m (L2C2). The first grid revealed scarce glass and construction materials ($n = 8$), but the second grid presented a greater diversity of materials ($n = 50$) such as bone, glass, ceramics (crockery and stoneware), metals, and construction debris (mostly plaster and bricks). The construction materials showed some kind of regularity, possibly indicating a fallen wall (Fig. 7f). Bricks $31 \times 16 \times 0.5$ cm have been in use since the 1880s (Moreno, 1995).

In Table 2, a synthesis of the shovel tests is presented along with their material remains. Only four of the eleven shovel tests performed in the three lines showed archaeological remains. In Line 1 (73 m), Line 2 (64 m), and Line 3 (5 m and 46 m), bone, glass, and construction materials were found. The rest of the shovel tests were archaeologically sterile. The presence of armadillo burrows was detected in Line 2 between 31 and 32 m, 50–51 m, and 60–61 m, and therefore no shovel tests were performed in this area.

Combining geophysical methods and archaeological excavations refined the relation between archaeological record and geophysical anomalies at La Libertad. Most of the zones explored in Lines 1 and 2 show a coincidence between the resistive anomalies (100–250 Ωm.) and the presence of archaeological material. Although the resistive values of Line 3 reached 300 Ωm at 48–82 m, archaeological material was not found; neither were caves, roots or other types of elements that could have produced a resistive anomaly. This distortion may be caused by variations in the sub-surface resistivity in a direction perpendicular to the profile, as a 2D model does not account for this effect.

The archaeological collection comprises 53% bone fragments. Most are *Ovis aires* and *Bos taurus* taxon, showing cutmarks made with some kind of metallic object. Metallic pieces represent 30% of the sample, including nails, wire, iron of several thicknesses, and objects for personal use. Glass material (7.8%) mostly includes plain glass such as “window glass”, cylindrical bottles of French wine and *Hesperidina*, squared bottles or *limetas*, and perfume and/or pharmacy flasks. The analyzed ceramic remains (1.8%) are English refined earthenware (whiteware plates and cups), kaolin pipes, and stoneware gin bottles. Building materials represent 6.5% of the collection. Great amounts of bricks, plaster, renders and tiles were

Fig. 7. Photos of 2010 excavations with various archaeological materials buried in Line 1 (a. and b. level 4 and 5 of grid 1; c. and d level 2 and 4 of grid 2; e. grids 2, 3 and 4) and Line 2 (f. level 10, grid 2).

registered but not collected. In L2C2 grid square, a piece of fallen wall made of bricks dated at least from 1880 was also found.

To sum up, 92% of the six grids and six shovel tests were successful, as archaeological material was registered. All were based and planned on the results of the geophysical survey. In this percentage analysis, the shovel tests (see Table 2) in lines L2 (82 m and 88 m) and L3 (59 m, 60 m and 72 m) were not taken into account, because they were made with the purpose of generating

Table 1
Archaeological materials found in the grids dug in Lines 1 and 2 (2010 fieldwork). G = grid, P = location (progressive). D/cm = depth in cm. Others = wood, charcoal and plastic.

	G	P	D/cm	Archaeological materials						
				Bone	Glass	Ceramic	Metal	Construction materials	Others	Total
L 1	1	16	25	371	29	5	131	19	3	558
	2	42–43	30	3	1	–	42	16	2	64
	3	42–43	60	24	13	1	38	11	1	88
	4	42–43	60	32	15	4	32	2	–	85
L 2	1	16–17	40	–	4	–	–	4	–	8
	2	35–36	55	23	5	5	11	5	1	50
Total										853

Table 2
Shovel tests carried out during the year 2010 indicating presence/absence of archaeological materials. P = location (progressive). D/cm = depth in cm. X = Presence.

	P	D/cm	Archaeological materials					
			Bone	Glass	Ceramic	Metal	Construction materials	Others
L 1	73	65	X	X	–	X	X	–
L 2	64	40	X	X	–	–	X	–
	82	45	–	–	–	–	–	–
	88	20	–	–	–	–	–	–
L 3	5	40	–	–	–	–	X	–
	16	65	–	–	–	–	–	–
	27	20	–	–	–	–	–	–
	46	50	X	X	–	–	X	–
	59	80	–	–	–	–	–	–
	60	80	–	–	–	–	–	–
	72	100	–	–	–	–	–	–

an interpretative data base for a clear understanding of the studied area, as this is the first precedent in the application of geophysical researches in rural sites of the southeast Pampean region.

4. Discussion

The electric method is commonly applied to hydrogeology, mining, and petroleum exploration. As the depth increases, the resolution is reduced, and the working scale usually is not less than 10s of meters. However, this paper verified the validity and versatility of this method in a reduced working scale, investigating anomalies of 0.5 m depth. In this case, by using the electric and magnetic prospecting methods over an area of more than 8000 m^2, rapid knowledge of the archaeological record was obtained without damaging the integrity of the material evidence.

Comparing the archaeological 2007 fieldwork in which surface materials were collected over a 300 m^2 area with the 2010 studies, the use of geoelectric and magnetic methods provide a major surface coverage, with a minor archaeological disturbance, obtaining a wider perspective in the vertical as well as horizontal directions. If the site would have been surveyed only with archaeological techniques, the perturbation might have been greater. Regular shovel tests, each 5 or 10 m apart, would have been set up in the whole area, because there was no surficial evidence. It would have also taken a greater amount of time, people, and money. Geophysical methods allow planning and performing archaeological excavations. When the electric method is applied at a meter scale, it is very useful to detect architectural structures, archaeological materials, and sub-surface alterations. Furthermore, the exploration performed with a magnetic susceptibility meter, a method that was not used previously in the Pampean region, was satisfactory to provide simple interpretative data and additional information for surficial archaeological research.

It was extremely important to make observations at the surficial level at the same time as the geophysical data is being collected, because they are very useful during the interpretation stage. In addition, the large quantity of site contextual data (written records, cartography, plans, measurements, photographs, etc.) was useful for planning and delimitating the geophysical exploration area and to interpret the electrical imaging results.

According to the resistivity and magnetic susceptibility anomalies and the presence of archaeological materials in the grids and shovel tests (bone, glass, ceramics and mainly buildings materials, as well as the segment of fallen wall), the house was built between lines L1 and L2 (between 15 m and 60 m). The geophysical data would not clearly indicate the presence of a tunnel of a considerable size where two persons were able to walk upright, as was described by local historians and oral testimonies. If such a tunnel exists today, it was not inferred by a resistivity anomaly that indicated the expected size or depth. Furthermore, if it is filled with sediments, it should appear an anomaly that takes account of the borders, roof or floor, especially at the beginning of line L3, where two old women remembered some remains of the house during the 1920 decade (see references to their interview above).

The alleged presence of a depression in the perimeter of the house was not corroborated either by geophysical or archaeological surveys. There were no detected changes in the sedimentation or accumulation of material that would indicate the filling of a moat. Future surveys will be developed at a greater depth, despite decreasing resolution, in order to dismiss the possibility that the tunnel or the moat would have been covered by more than 1.5 m of sediments.

On the other hand, the archaeological collection recovered at La Libertad site is diverse in composition, origin, and function. The glass remains (Dutch gin *limetas*, French wine bottles), ceramics (whiteware and kaolin pipes) and construction was not taken into account (e.g. bricks) are all similar to the archaeological context already registered in 2007 that indicated a chronology of the last quarter of the 19^{th} century. In the same way, the presence of the domestic animal species *Ovis aries* coincides with the “wool fever”: the explosive sheep production in the Pampean region ca. 1840–1880 (Sábato, 1989; Reguera, 2006). This chronology coincides with the importation of products and goods from Europe (mainly Holland, England and France) during the middle of 19^{th} century that arrived in the borderline areas through a wide net of rural commercial circuits.

Finally, thanks to Teófilo Gomila’s passion for photography and for the registration of every step in his life, there are numerous written papers available that supported the presence of an important settlement near the Cristiano Muerto stream. These include the newspaper “Los Libres del Sur” (1887–1894) edited by Teófilo Gomila, his memoirs, will, pictures of the ranch, employees and domestic animals, letters to neighboring farmers, as well as documents from the Buenos Aires Province Historic Archive and the Mulazzi Museum in Tres Arroyos county, that are still being studied, all referring to the ranch “La Libertad” (Bagaloni, 2009; Bagaloni and Carrascosa Estenoz, 2010). For example, in 1887, a property of 4838 ha was registered in Mr. Gomila’s will, with eight buildings, a main house and seven mud shelters, 10,000 sheep, 605 cows and 300 horses, among others (Teófilo Carlos Gomila’s testament registered in front of public notary Ángel Insúa, January 3 1887, in Tres Arroyos County, Buenos Aires Province Notary School, Bahía Blanca Delegation). Besides, these sources also indicate the presence of a butler in “La Libertad”, domestic personnel, farm workers, the use of English dishes, the consumption of alcoholic drinks at the rural table, and other personal elements such as perfume, medicinal products, and tobacco. They also mention the installation of a cattle-breeding ranch called “Cabaña La Libertad” for mainly Hampshire Down and Lincoln’s Santorens sheep imported from England (Bagaloni and Carrascosa Estenoz, 2010).

The archaeological and written records indicate that a large rural settlement was established during the last quarter of the 19^{th} century to the beginning of the 20^{th} century. It had a distinctive organization and use of space compared to other middle 19^{th} century rural settlements from the southern Pampean frontier that were associated with an increasing industrial capitalism and the modernization of the rural world.

5. Final considerations

In summary, the combined use of geoelectric, magnetic, archaeological and historic methods allowed:

- study of the resistivity and magnetic characteristics of the subsurface in an 8000 m^2 area, detecting significant resistive and magnetic anomalies in the archaeological site La Libertad.
- testing of the instrument capacity and geoelectric and magnetic methodology on a meter scale, producing successful results from the first geophysical intervention in a historical rural settlement in southeast Buenos Aires Province.
- excavation at 12 locations using only the interpretation of resistivity and magnetic anomalies, with 92% success, recovering several types of archaeological materials (bone, glass, ceramic, metal and construction) determined by their composition, function, origin and chronology.
- discovery of a portion of fallen wall in L2C2, but not the certain presence of a tunnel or of a surrounding moat, as described in the written sources and oral testimonies.
- integration of the archaeological information with that obtained from historical records to preliminarily consider La Libertad as a ranch type settlement from the late 19th century. This is based on the archaeological material (glass, ceramics and bricks), measurements, local and regional historiography, the photographic records, the analyzed expedients and documents, as well as the oral records.

Finally, the interaction of historical archaeology and applied geophysics in La Libertad site constitutes an important contribution to the progress of archaeological investigations.

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