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Detecting and mapping buried buildings with Ground-Penetrating Radar at an ancient village in northwestern Argentina

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ABSTRACT

We describe an archaeo-geophysical investigation performed near the Palo Blanco archaeological site, Catamarca, Argentina. A large area beyond the northern limit of the site was explored with the Ground-Penetrating Radar (GPR) method in order to detect new buildings. The exploration showed signals of mud-walls in a sector that was located relatively far from the previously known buildings. A detailed survey was performed in this sector, and the results showed that the walls belonged to a large dwelling with several rooms. The discovery of this dwelling has considerably extended the size of the site, showing that the dwellings occupied at least twice the originally assumed area. High-density GPR surveys were acquired at different parts of the discovered building in order to resolve complex structures. Interpreted maps of the building were obtained. Different characteristics of the walls were satisfactory determined, in spite of the low contrast of the dielectric constant at their interfaces and the noticeable spatial fluctuations of the signals due to wall collapses.

Systematic excavations confirmed the GPR maps providing further relevant information about the characteristics of the walls and the occupational floor, as well as material for radiocarbon analyses. These analyses indicated that the discovered building was occupied until about AD 880. This fact extends 180 years the previously known period for the village, and also for the settlements in the region (formerly, AD 200 to AD 700). The performed investigations moreover confirmed different architectural characteristics assumed for Palo Blanco, related to the internal and external layouts. Interconnection between the rooms without intermediary courtyards seems to indicate a better use of the internal spaces and a more integrated spatial conception in Palo Blanco than in other villages of the region.

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1. Introduction

During the last decades, a relevant point in archaeology has been the development and application of methods, techniques and procedures for field reconnaissance. In particular, satellite and geophysical methods have proven to be valuable for detecting and characterizing a variety of archaeological targets (Arciniega-Ceballos et al., 2009; Garrison et al., 2008; Fowler and Fowler, 2005; Leopold and Völkel, 2004; Leucci et al., 2007; Linford, 2006; Orlando and Soldovieri, 2008). The success of these methods has greatly influenced archaeological fieldwork, extending their possibilities and scopes. For example, large areas of the subsoil can be explored avoiding the efforts of excavating them, and very precise and selective excavations can be planed from the results of these methods. One of the most important capabilities of the geophysical methods in relation to Archaeology is that they can detect and map buried structures without disturbing them. In particular, with the Ground-Penetrating Radar (GPR) method it is possible to explore large areas of soil in relatively short times and to obtain precise maps of the buried structures (Bavusi et al., 2009; Francese et al., 2009; Leucci and Negri, 2006; Negri and Leucci, 2006; Pérez-Gracia et al., in press; Piro and Gabrielli, 2009; Shaaban et al., 2009). In particular, in Argentina, the GPR method was initially applied to archaeology in 2000, at the Floridablanca site, a 18th century Spanish Colony located in the Patagonian coastal region (Lascano et al., 2003).

The Palo Blanco archaeological locality is one of the first agricultural-pastoral settlements in the western sector of Catamarca province, in the Andean region of Argentina (Fig. 1a, b). The first archaeological studies in the Palo Blanco village were performed by

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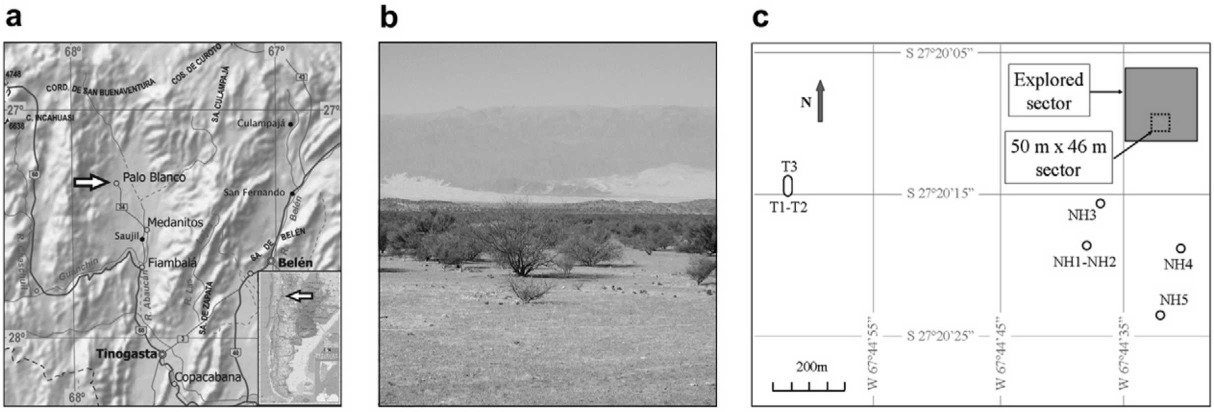

Fig. 1. a) Map of the region. The Palo Blanco archaeological site is located close to the present homonymous village (UTM coordinates: 19J 568654 mE 6872689 mN to 19J 728774 mE 7041403 mN). b) The prospected area. c) Map of the up-to-now known buildings, and the presently explored sector (UTM coordinates: 19J 623538 mE 6977873 mN to 19J 624562 mE 6975861 mN).

C. Sempé in the 1960 decade who reported (1976, 1977) five dwellings, which were termed NH1, NH2, NH3, NH4 and NH5 units. The dwellings occupied an approximately 0.5 km^2 area, with relatively large spaces between them (Fig. 1c). At the time of Sempé's investigations, only parts of the dwellings were visible on surface, with sediment covering most of them. Sempé performed partial or total excavations of some of these dwellings, and different architectural characteristics could be established. For example, all the dwellings consisted of three or four rectangular shaped rooms that were directly connected, or connected through corridors, and one or two courtyards. The walls of the buildings were *tapia*-style, which consists of wetted, compressed and naturally-dried earth. *Tapia* walls are directly builded in-situ, without mud bricks, as in the case of adobe walls. Radiocarbon dating has indicated that the Palo Blanco dwelled sectors originally developed between 200 AD and 700 AD, which correspond to the Formative Period in the Argentinean northwestern region.

The first GPR prospecting at Palo Blanco was carried out in 2004 (Martino et al., 2006) with the objective of obtaining a map of the NH3 unit (Fig. 8 in Martino et al., 2006), since it had become almost completely buried by sediments and there was only incomplete documentation of their structures. The geophysical maps showed a complex wall distribution and a number of unknown enclosures. The excavations confirmed the geophysical interpretations and provided further archaeological information such as complementary dating for the village and evidence on volcanic–clastic flows that had affected NH3 and partially destroyed it. This kind of flow has been considered to be the origin of the abandonment of the NH3 dwelling (Montero López et al., 2009).

In a second stage of the interdisciplinary investigations at Palo Blanco, during 2005, two additional structures (T3 and NH1–NH2 in Fig. 1c) were successfully re-located and mapped with GPR (Bonomo et al., 2009). One of these structures, T3, was a tomb located within a present vineyard, which could be subsequently protected from the farming activities. It was also deduced from the GPR maps that the NH1 and NH2 dwellings constitute a single unit of many rooms (Osella et al., 2009). Prior to this GPR survey the area had been interpreted as separate living units (Sempé, 1976, 1977).

Our previous works in Palo Blanco demonstrated the ability of the GPR method to detect and map *tapia* walls. Since this kind of wall is usually made with the earth around, it presents low relative dielectric permittivity contrasts with the surroundings, often a very difficult characteristic for most of the geophysical imaging methods. Furthermore, natural and cultural agents tend to collapse parts of the walls and mix their materials and the surrounding materials, so uneven and blurred interfaces result. Mixing also occurs at the bases of the walls because of their construction procedure. As a consequence, weak GPR signals result, often with noticeable fluctuations in space that make difficult the identification from constant-time amplitude slices. The processing and interpretation of this kind of data, which made possible to show subtle contrasts between cultural earthen structures and the surrounding matrix has been discussed in our previous works (Martino et al., 2006; Bonomo et al., 2009).

In this article we describe GPR surveys integrated with standard excavations performed in a sector northeast of the dwellings reported by Sempé (Fig. 1c). One of the principal objectives of this exploration was to detect and map unreported buildings,

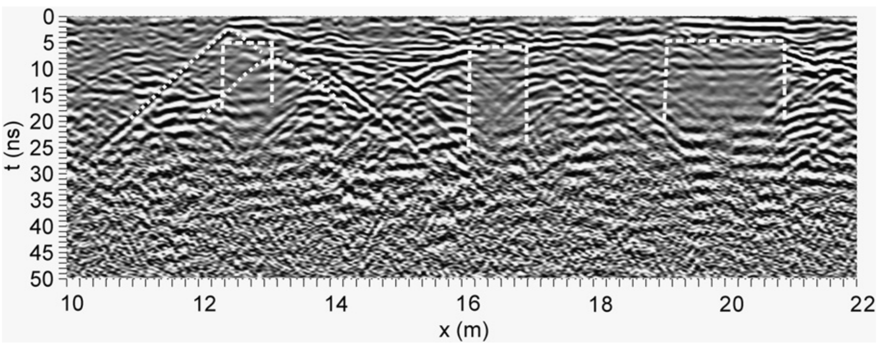

Fig. 2. A typical section of the data presenting signals from *tapia* walls. Dashed lines indicate the approximate contours of the walls. The tiny dotted lines show examples of diffraction hyperbolae. This profile is located at $x = 5$ m, in the 50 m × 46 m sector (Fig. 1c).

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particularly residential units, in order to obtain a complete and detailed map of the village and their constructions. In general, it is well known that the interpretation of a constructed space is important to understand how a society might have been structured in the past. Furthermore, the architectural characteristics can be important to provide new insights about the social dynamics and interpersonal relationships of their inhabitants. Then, this work was conducted not only with the aim of obtaining a detailed map of Palo Blanco, but to investigate the cultural characteristics of its occupational period, as well as the environmental dynamics that appeared to have led to its abandonment.

Within this framework, we first present the geophysical studies that allowed mapping the subsoil of the investigated area, which led to discover a new building, a large dwelling with *tapia* walls. Among the results that are shown in the article, we include 2D and volumetric images of the data and interpreted maps of the building. Next, we describe the main results of the archaeological excavations performed at the building, which have been planed on the basis of these maps. Finally, we integrate the geophysical and archaeological results and analyze their implications for the knowledge of the Palo Blanco and regional societies.

2. Environment at the Palo Blanco site

The Palo Blanco archaeological locality (Fig. 1a, b) is approximately located at 67°44′46″W, 27°20′17″S, in the northwest sector of the Bolsón de Fiambalá area, Catamarca Province, Argentina. The Bolsón de Fiambalá is an arid valley approximately 55 km × 25 km in size with a relatively flat topography gently sloping to the south. The valley is bounded by the San Buenaventura range to the north, the Fiambalá range to the east, and Los Andes foothills to the west and south, with altitude differences about 1000 m between the valley and the peaks. The shallowest strata in the mountains are mainly composed of volcanic materials, such as ash and pumice, although organic sediments are sometimes interleaved between them.

Precipitations are below 300 mm per year in this region, with rains almost exclusively during the summer. Rains are usually scarce in the valley, although they can be considerable at the

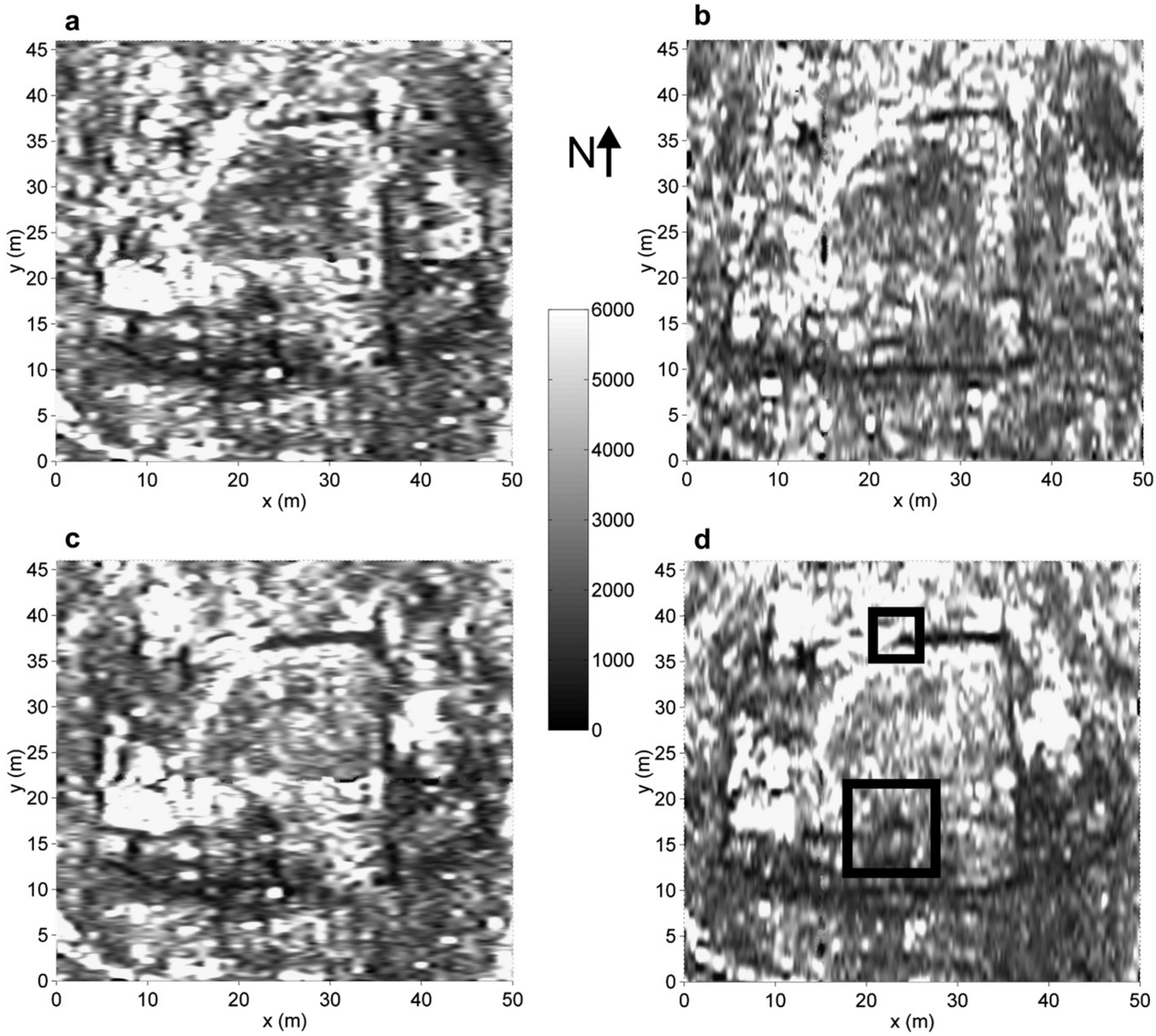

Fig. 3. Constant time slices of the time averaged intensity. For these figures, the modulus of the data has been averaged across one-period time intervals centered at the particular slice times *t*. a) $t = 9$ ns and profiles acquired along the *y*-direction, b) $t = 9$ ns and profiles along the *x*-direction, c) $t = 12$ ns and y-profiles, d) $t = 12$ ns and *x*-profiles. The black squares in Fig. 3d indicate the sectors that were prospected with lower cross-line spacing.

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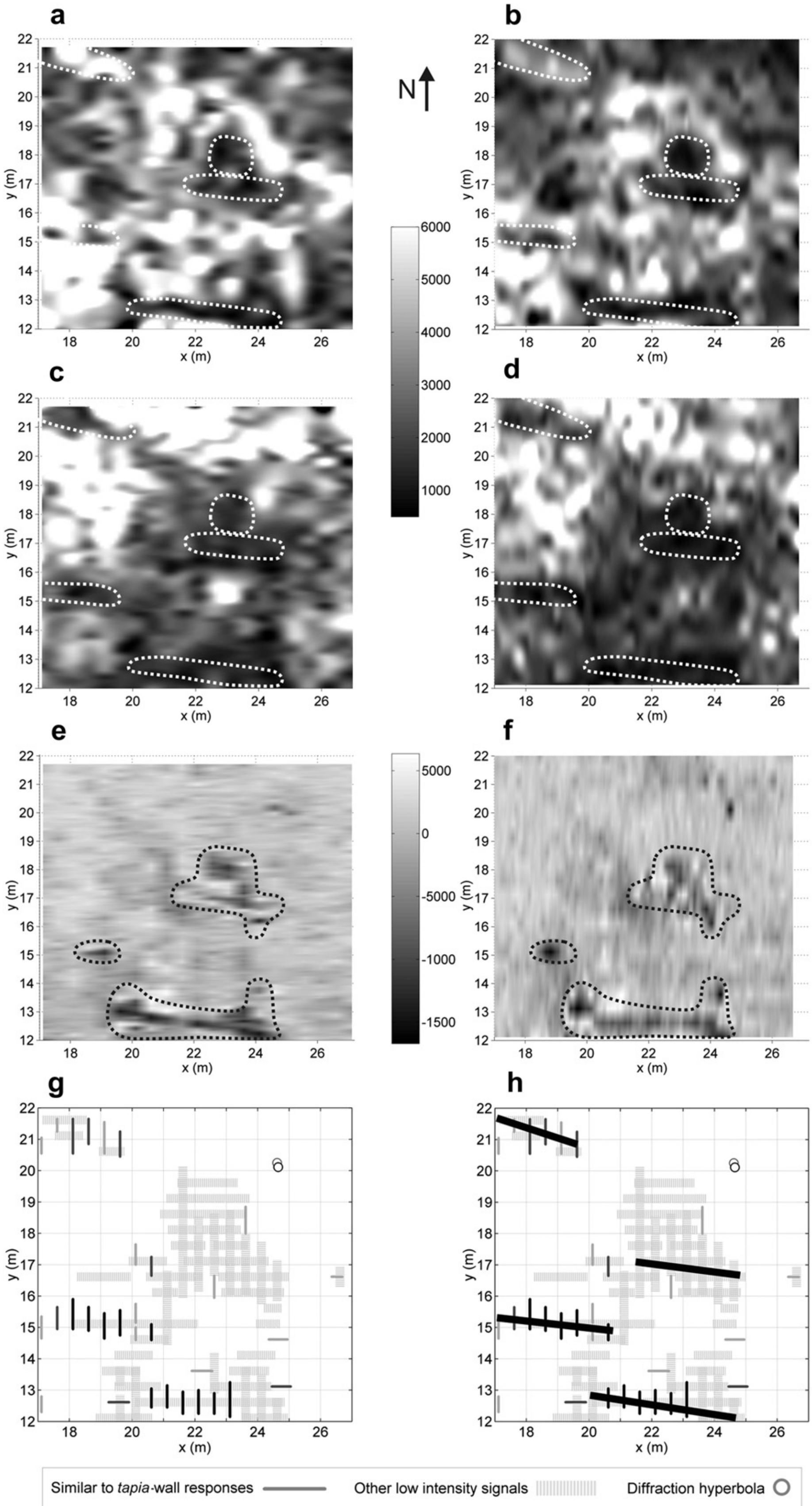

Fig. 4. a) Constant time slice of the time averaged intensity in the central 10 m × 10 m sector. In this figure, $t = 7$ ns and the profiles has been acquired along the *y*-direction, b) Idem, bur for $t = 7$ ns and profiles acquired along the *x*-direction, c) $t = 13$ ns, *y*-profiles, d) $t = 13$ ns, x-profiles. e) Time slice of the data, for $t = 2.5$ ns and *y*-profiles, f) $t = 2.5$ ns and x-profiles, g) map of the characteristic responses obtained from the analysis of the transverse sections, h) final interpretation.

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mountains; then, the descending flows produce channels and accumulate sediments in different sectors of the valley. On the other hand, the surrounding mountain ranges canalize winds in the N–S direction along the valley. In particular, the intense north wind, known as *zonda* in the region, deposits large amounts of sediments from the Argentinean and Bolivian Altiplano in vast sectors of the valley. Mudflows and *zonda* wind are the most important burial agents of the archaeological sites in the area.

3. GPR surveys

The GPR data were collected in July 2007 in an area defined by a concentration of surface shards (Fig. 1b and c). The ground surface was flat, with only a moderate number of shrubs in it. One 200 m × 200 m grid was initially collected with spacing 2 m between profile lines; later a higher resolution grid with line spacing 1 m was collected in a smaller 50 m × 46 m area within the main grid. This smaller grid was defined as a result of a preliminary analysis of the reflection profiles, where we discovered signals of *tapia* walls. Finally, two sub-sectors within the small grid were additionally surveyed with even more density, in order to better resolve the buried structures. In them, we spaced the lines 0.5 m and 0.05 m, respectively. Profiles in both orthogonal directions were acquired in all the cases.

A Sensors & Software Pulse EKKO PRO radar unit with 500 MHz antennas was used. The step size was 0.02 m producing high in-line sampling, with stacking 16. To process and visualize the data as transverse profiles, constant time slices, and volumes, we used software developed by us on Matlab platform. In general, the main processing flow was the following: dewow filtering, background removal, broad band pass filtering both in space and time ([0.1, 15.0] m^{-1} and [0.1, 2.0] GHz, respectively) and fixed-curve gain application.

In Fig. 2 we show a section of the data. Reflections from three *tapia* walls can be observed at the *x*-intervals [2.4, 3.1] m, [6.1, 7.0] m and [9.1, 10.9] m, respectively. V-shape hyperbolas, as those marked with dotted lines, are produced by diffraction at the protuberances of the walls where appreciable contrasts occur. Low intensity areas inside the dashed lines are due to relatively weak or no appreciable reflections inside the walls, because of their rather homogeneous composition. In general, interfaces with simpler geometries and more contrasting transitions between both media produce simpler and more intense reflections, as the diffractions from the top of the left wall, whereas uneven and low contrasting interfaces usually produce more complex and weak reflections, as those from the top of the right wall. Uneven boundaries or smooth transitions could be consequences of partial collapses or mixing of wall and surrounding materials. Mixing normally occurs at the bases of the walls because of wetting and compressing the earth during the construction.

Signals similar to those in Fig. 2 were found in an approximately 50 m × 46 m area (Fig. 1c) during the initial 200 m × 200 m exploration. Then, an orthogonal grid, with line spacing 1 m, was defined in this area in order to detect and map the buried structures. Fig. 3 shows four constant time slices of the time-averaged intensity, for slice times $t = 9$ ns and $t = 12$ ns. For an approximate *x*-depth representation, the time values in the figures can be converted to apparent depths by using half of the average propagation velocity $v = (16.4 \pm 1.1)$ cm/ns as a conversion factor, in this case $d_a = 74$ cm and $d_a = 98$ cm, respectively. This velocity has been obtained by fitting hyperbolae to the diffraction signals in the sector. Through constant time graphs as those in Fig. 3 we analyzed the spatial continuity of the reflections in the sector and their geometrical characteristics. A number of non-natural linear features can be clearly observed in Fig. 3 in dark gray, for example, the features from $(x, y) = (4, 12)$ m to $(x, y) = (37, 11)$ m, from $(x, y) = (37, 11)$ m to $(x, y) = (36, 37)$ m and from $(x, y) = (36, 37)$ m to $(x, y) = (22, 37)$ m. They are visible in both survey directions and for wide ranges of times. The analysis of the transverse sections, as that in Fig. 2, showed that these features corresponded to *tapia* walls: their dark characteristic in Fig. 3 is related to the low intensity response from the interior of the walls, as explained above. Many other dark linear features are visible in the figures, some of them only for small time ranges or in one survey direction. For example, the segment from $(x, y) = (5, 16)$ m to $(x, y) = (10, 15)$ m can be observed only in the profiles acquired along *y* (Fig. 3a and c). These signals could be originated at small size or bad condition walls, but also at natural structures. Later in this section, after presenting the results of the time slices for all the acquired surveys, we will give an overall interpretation of the signals in the sector.

The preliminary analysis of the data performed during the fieldworks also showed us different sub-sectors in which the interpretation of the buried structures was difficult, probably because of complex cultural or natural structures or very low permittivity contrasts. Then, we selected two of them to perform more detailed surveys. These sectors are indicated with black squares in Fig. 3d. In both sectors, signals possibly related to a number of *tapia* walls seemed to appear. In the larger 10 m × 10 m central sector, these signals suggested structures that intersect each other. On the other hand, the 5 m × 5 m north sector appeared as the north end of a building, with two walls and an opening in between them. In both cases we defined small areas of investigation and diminished the cross-line spacing to reduce the longitudinal and transversal errors in positions and to improve the lateral resolution. These errors mainly occurred as consequences of lateral drifts of the tape measure due to the wind, slices of the odometer wheel in loose materials, deviations from the ideal paths when avoiding shrubs and ground irregularities.

In the 10 m × 10 m central sector we defined an orthogonal 0.5 m × 0.5 m-cell grid to acquire the profiles. The main objectives of the survey were to confirm the existence of walls and to determine their relative orientations. Fig. 4a–d are examples of constant time slices of the registered intensity, for $t = 7$ ns and $t = 13$ ns, and for profiles acquired in the *y* and *x* directions. We observe that it is difficult to identify linear features in these figures since the intensity distribution presents important spatial fluctuations and relatively low contrasts. Similar characteristics were observed during the previous fieldworks at Palo Blanco in sub-sectors that included disturbed soils and much deteriorated walls (Bonomo et al., 2009). In spite of the difficulties, we hardly distinguished a number of linear features by analyzing how the different intensity blots continued through consecutive slices. We marked these features with dashed lines in Fig. 4a–d. To complement the interpretation, we analyzed constant time slices of the data (instead of their time averaged intensity, as in the previous slices). Fig. 4e–f is an example of this kind of graph, for $t = 2.5$ ns and profiles acquired along the *y* and *x* directions, respectively. Some of the formerly identified features can also be observed in these figures, but with a better contrast. On the other hand, Fig. 4g is a map of the characteristic signals identified from the analysis of the radargrams of the sector. The narrow solid lines correspond to signals similar to *tapia*-wall responses, the wide lines correspond to low intensity signals that seemed different from this kind of response (for example, signals that could be originated in natural mud blocks, collapsed or deteriorated portions of walls, mixtures of natural and collapsed materials, etc.), whereas circles represent isolated diffraction signals. We use dark colors for better defined *tapia* wall's signals and pale colors for more poorly defined ones. From the joint analysis of Fig. 4a–g we finally obtain an interpretation of the 10 m × 10 m sector,

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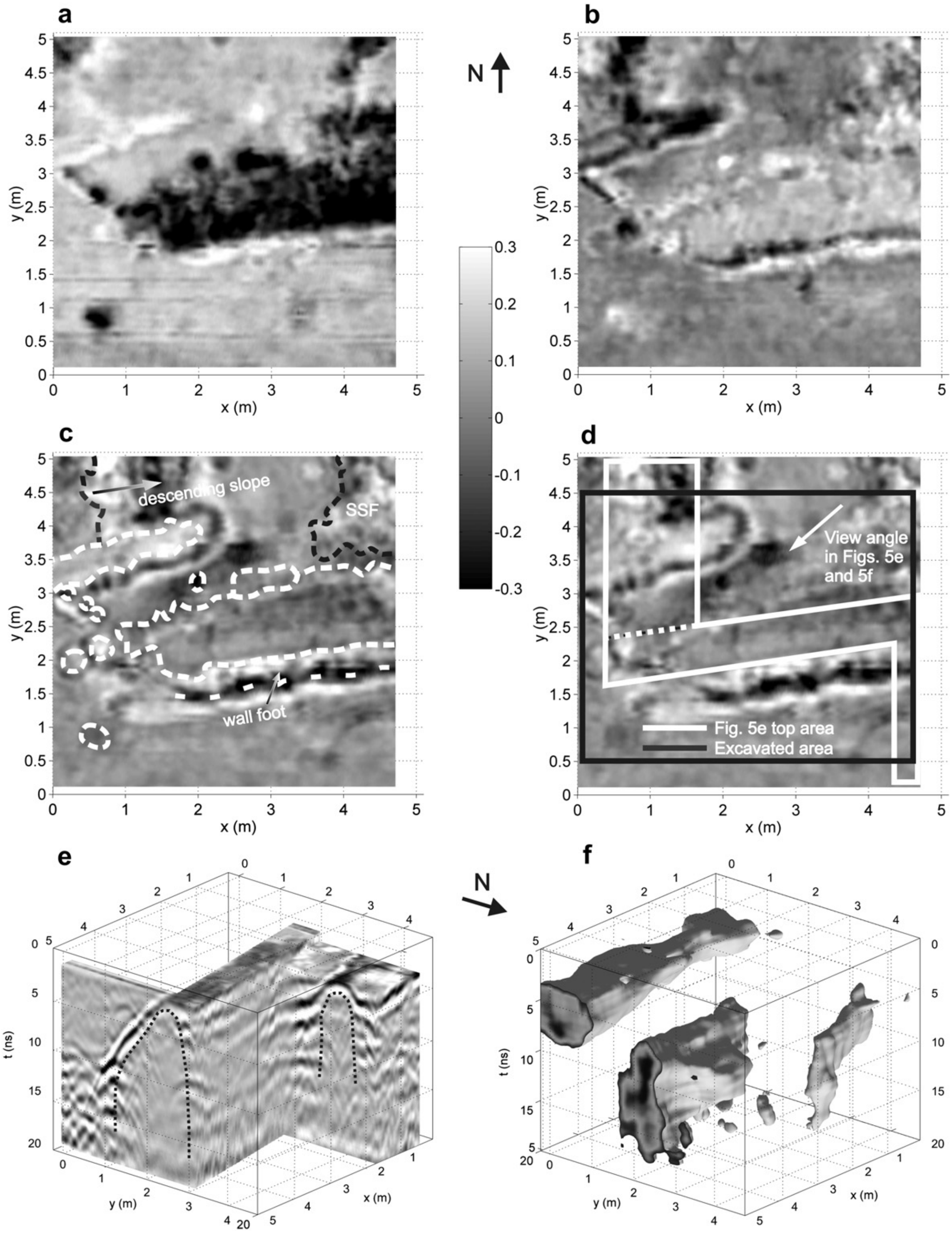

Fig. 5. Some results for the 5 m × 5 m north sector. a) Time slices of the data, for $t = 2$ ns and profiles acquired along the *x*-direction, b) $t = 3$ ns, c) $t = 4$ ns and their interpretation, d) $t = 4$ ns. The clear lines in this figure delineate the top area of the data volume shown in Fig. 5e and the view angle; the black line indicate the subsequently excavated area, e) volume slice of the data, f) constant intensity surfaces of the data.

which is represented in Fig. 4h. Four sections of walls are marked in it. All of them presented similar depths and directions, except for the wall located near the NW extreme, which is deeper than the others and projects in a different angle. This is a rare characteristic in Palo Blanco since all the previous investigations had shown approximately parallel walls. Only collapsed or natural materials seem to spread around the other walls.

To prospect the 5 m × 5 m north sector we employed a 0.05 m × 0.05 m-cell grid. These small values of line spacing were selected in order to evaluate how a very dense array of profiles works with the *tapia* walls (which is the most frequent target in the region), as well as characterizing the two walls inside this area and the apparent opening between them. Fig. 5a–d shows time slices of the data acquired along the *x*-direction, for $t = 2$ ns (a), $t = 3$ ns (b)

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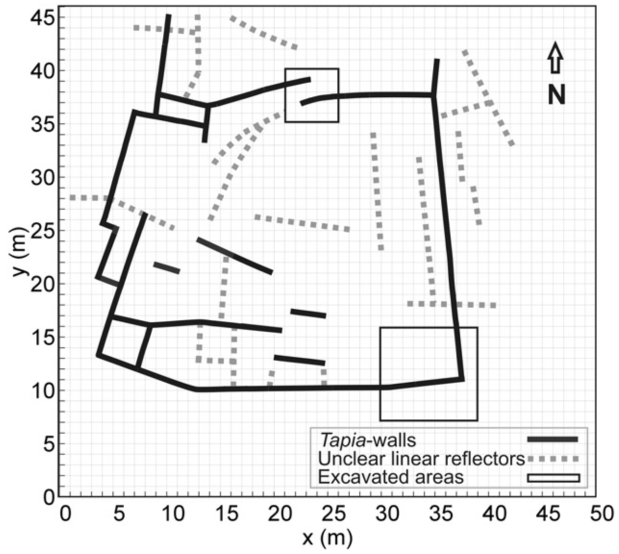

Fig. 6. Map of the predicted *tapia* walls and other unclear linear reflectors. The excavated areas are also indicated in the figure.

and $t = 4$ ns (c and d). A number of reflection events and their temporal evolutions can be observed from Fig. 5a–c. It is clear that many details become visible in the slices as a consequence of the very dense sampling of the sector. In Fig. 5c we show an interpretation of these signals: with clear dashed lines we have indicated the probable contours of the walls and possible fragments of them, whereas with dark dashed lines we marked other kinds of reflectors. It can be observed that the southern wall is wider and shallower than the northern wall and that both structures are approximately 1 m apart, with no evidences of a transversal structure between them. In relation to the isolated clods around the walls, their aspect and spatial distribution seems to indicate that they are collapsed portions of them, rather than part of a transversal structure. The southern wall presents well defined superior edges, with a rather smooth south side that includes a small protuberance as a foot; it has been indicated in the figure with a more spaced dashed line. On the contrary, the north side of this wall is more uneven. With respect to the northern wall, it presents a general uneven aspect, probably due to important deterioration.

High-density data, as those obtained for the 5 m × 5 m area, make possible to construct volume graphs, which often provide more easily interpretable images of the buried structures. Fig. 5e shows a volume graph of the data acquired in this sector. The limits of this volume and the view angle are indicated in Fig. 5d for better clarity. The electromagnetic responses due to both walls are evident in Fig. 5e. The depths and widths of the walls and the enlargement of south-wall base can be clearly observed. On the other hand, Fig. 5f shows constant intensity surfaces of the data for the same view angle than in the previous figure. A relatively low cut off has been used in the figure in order to obtain more defined surfaces, so the obtained structures resulted slightly smaller than the real. Both wall responses can be observed in the figure. Also a shallow block that is approximately centered at $y = 0.5$ m, $t = 5$ ns and crosses the sector from east to west is visible in the figure. This block is related to a natural deposit of clay, as it was verified during the subsequent excavations.

The final interpretation for the whole building is shown in Fig. 6. With solid lines we have indicated the locations predicted for *tapia* walls. These locations have been estimated by identifying the signals that presented characteristics similar to typical *tapia*-wall responses, and by analyzing the signal continuity through consecutive radargrams and constant time slices. Other signals that differed from typical *tapia*-walls responses but that were still linear have been analyzed. In many cases we couldn't confidently identify what kind of reflector produced them; for instance, groups of rocks, very much deteriorated *tapia* walls, banks of natural drainages, etc., could produce these kinds of signals. Then, we have generally related these signals to "unclear linear reflectors" and used this category in Fig. 6 (dashed lines). On the contrary, linear responses that could be clearly identified as different from *tapia* walls signals, such as those related to the descending slope in Fig. 5 (which approximately projected 6 m beyond the 5 m × 5 m sector towards the N), have been excluded from Fig. 6 for simplicity.

Fig. 6 shows that the *tapia* walls occupy a total area of 900 m^2, approximately. Simple straight walls have been predicted as the probable S and E borders of the unit. A more complex distribution of walls seems to constitute the W border. Different sections of walls, with approximate E–W directions are located in the north part of the sector. Although these walls had been originally assumed as the N limit of the unit, Fig. 6 shows that the E and W walls really continue beyond them towards the N. Several sections of walls have been predicted between the aforementioned and also two small enclosures were delimited at the SW and NW vertices of the building.

4. Archaeological excavations

Different areas of the discovered building were excavated in May 2008: the locations of the main two ones are marked in Fig. 6.

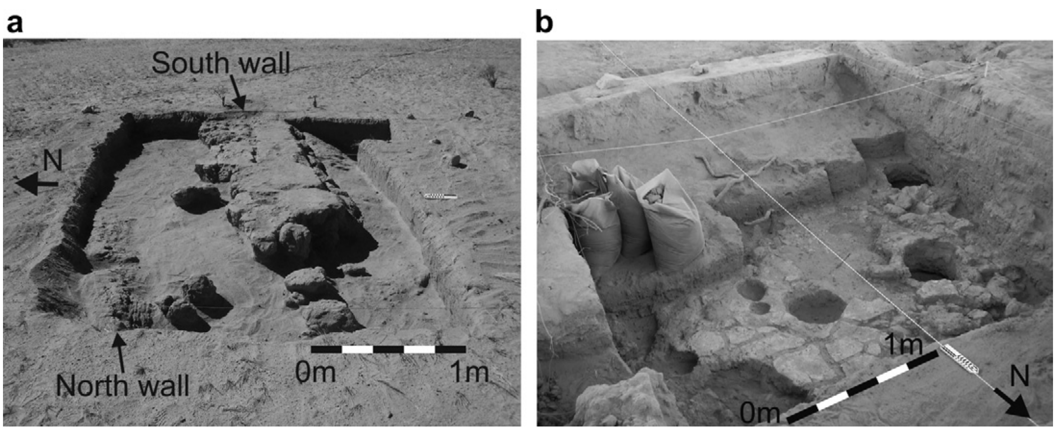

Fig. 7. a) Excavation performed in the 5 m × 5 m north area. b) Southeast area during the excavations.

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Both areas presented at least two buried structures, with a probable higher archaeological integrity in the southeastern one. The small northern area agreed with the 5 m × 5 m area in which high-density GPR profiles had been acquired, and it was mainly chosen in order to corroborate the GPR interpretations. On the other hand, the 10 m × 7 m area was selected to search for additional evidence. This area presented a relatively simple GPR-response distribution, without any relevant anomaly other than those related to the external walls, so a relatively easier access to the occupation floor was expected.

Fig. 7a is a photograph of the excavation performed in the 5 m × 5 m area. This excavation successfully confirmed the predicted wall positions, orientations, widths and depths as well as the details for the wall contours. The enlargement of the south-wall base and the positions and sizes of the dispersed clods were confirmed too. No evidences of N–S orientated walls were obtained from the excavation, so this result also agreed with the GPR interpretation.

Fig. 7b is a pick of the excavations performed in the 10 m × 7 m area. Note that the view angle is opposite to that in the previous GPR slices. The southern external wall can be observed near the top of the figure, whereas the floor of the building is visible in its central and low parts. Approximately 6 m^2 of floor was exposed during the excavations. Collapsed portions of the southern wall were found on the floor mixed with volcanic materials, especially in the west portion of the excavated area. This mixture forms a very compact layer, which was tightly stuck to the floor in most of the excavated area and that unfortunately tends to damage the floor when extracted.

The exposed section of the south wall had an approximate mean width 60 cm, which agreed with the expected values for Palo Blanco. On the other hand, the occupation floor had a depth 1.2 m below the present ground level. Five approximately circular holes were found in it (see Fig. 7). The three larger ones presented diameters between 46 cm and 50 cm. Similar cavities were observed in other archaeological sites in other Andean regions: they have been interpreted as cavities used to introduce vessels with different products (grain, flour, liquids, etc.), in order to storage them (Makowski et al., 2005). Then, it is probable that this sector of the building had been used as a storage place. On the other hand, the two small holes in the floor could be used to fix smaller pottery. Also a relatively large cavity has been found in the NE sector of the exposed floor (see the lowest-central part of Fig. 7) filled with collapsed wall materials. Although its probable purpose is still unclear, it could be similarly used to introduce a vessel in it.

Finally, coal fragments were found in the S wall and on the occupation floor of the building during the excavation. Two radiocarbon analyses were performed and the following dates were obtained: 1236 ± 37 BP (AA-81735) and 1197 ± 37 BP (AA-81736).

5. Conclusions

In this article we have described the main results of a joint archaeo-geophysical investigation performed at the Palo Blanco archaeological locality during 2007 and 2008 fieldworks and their main results. A GPR exploration of a wide sector located to the NE direction from the buildings discovered in the 1960 decade was carried out, looking for new buildings. The area presented a flat ground surface without archaeological signals except for a concentration of shards on surface, which motivated the application of the GPR method and defined the area to be prospected. The initial GPR exploration revealed several *tapia*-wall signals in this area. A detailed GPR prospection of the sub-sector with these signals indicated that they corresponded to a large building, which we called NH6, located at an approximate distance 300 m from the nearest known unit (NH3). Two additional GPR surveys were performed in order to resolve unclear structures. An increment in the density of profiles made possible to clarify the wall distribution in both cases. Furthermore, high-density acquisition and the applied processing provided very detailed images of the subsoil, from which *tapia* walls and other reflectors were resolved and characterized.

From the joint analysis of the transverse sections, time slices and volume slices of the data and their time averaged intensity we have obtained a final map for the new building. Systematic excavations confirmed the GPR predictions at different sub-sectors and provided further archaeological evidence. The following main archaeological results were obtained:

a) The area of the village became almost twice the formerly known. The discovered dwelling warns us about the possible existence of other buried buildings that could further extend the village limits. This suggests us to continue the explorations in Palo Blanco in order to ascertain the actual size and composition of this settlement.
b) The radiocarbon dating significantly extended the previously known period of occupation of Palo Blanco (200 AD to 700 AD), up to approximately 880 AD.
c) The GPR map showed an approximately rectangular shape dwelling with external walls prevailing over the internal walls. This was also observed in the previously surveyed units of Palo Blanco and seems to be a common characteristic. Other architectural characteristics were obtained from the GPR interpretation and the excavation performed in the SE vertex of the unit, such as the composition and sizes of the walls, which agreed with previous measures performed in the village, and the depth of the occupational floor.
d) The excavation of the southeast sector showed a stiff layer that directly lied on the occupation floor. This layer was originated in a volcanic flow and was mainly composed of pumice and collapsed portions of walls. Similar layers were observed in the previously prospected NH3 unit. It is currently investigated if they correspond to the same event or not. Different analyzed hypothesis are that an important volcanic eruption could produce the flows and that they made the original inhabitants to abandon Palo Blanco and, more generally, that an unstable and hostile environment could occur in the region, which finally led the original inhabitants to leave it (Ratto, 2007; Montero López et al., 2009).

Summing up, the applied geophysical and archaeological methods and techniques have successfully contributed to the knowledge of the architectural record of the region, which was possible as a consequence of the multidimensional (material, social and ideological) characteristic of it. As previously stated, architecture is an important aspect in social dynamics and the organization of interpersonal relationships. The architectural boundaries and barriers impose a specific spatial order that sets the scene in which life is organized and takes place, and where social relationships between groups and individuals are structured (for example, Hillier and Hanson, 1984; Kent, 1990; Blanton, 1994; Nielsen, 1995). As a consequence, the investigation and analysis of the architectural record of these sites is very important to deal with archaeological problems related to the social identity and the organization of the people that constructed and inhabited them.

The Palo Blanco archaeological locality is the only up-to-now known settlement in the north sector of the meso-thermal valley (1900 m above sea level) located at the west of Tinogasta, in Catamarca province. This sparse group of buildings (a small village or hamlet) was constructed and inhabited by pre-state egalitarian

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communities that developed in the Fiambalá valley from 200 AD to 880 AD, approximately. An important aspect of Palo Blanco is that its structural layout markedly differs from other villages that developed during the same period in the N–W region of Argentina, as Tafi del Valle and Alamito. Contrarily to these settlements, the organizational criterion in Palo Blanco was more complex and extensive (Sempé, 1977). During the organizational process of Palo Blanco, the central Tafí-type courtyards and the surrounding rooms that individually connected to it were replaced by rectangular-shaped dwellings, with a lateral courtyard and interconnected rooms. Connection between the rooms without an intermediary courtyard indicates a better use of the internal spaces and a more integrated spatial conception.

We can say that a society becomes more complex not necessary as a consequence of emerging hierarchies and inherited (vertical) social differentiation, but due to more complex familiar and work organizations, resource acquisition and distribution, among other social aspects, which are materialized in a specific architectural organization. With respect to this, the archaeo-geophysical discovering and investigation of the new NH6 building have importantly contributed to the NW Argentinean region archaeology. In a first place, these investigations provided new information about the size of this locality, which possibly anticipate other unknown buildings that could be completely buried and without visibility on surface (as occurred with NH6). In a second place, a geophysical map of the whole building was obtained. We expect that future fieldworks further improve the definition of the internal segmentation in order to deepen our knowledge of the socio-spatial organization of the group and the regulation of their public and private spaces (Hillier and Hanson, 1984; Blanton, 1994). These analyses and the subsequent comparison to other pre-state buildings in the region will help us to interpret the continuities and changes in the social organization of the so-called egalitarian societies.

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