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GPR PROSPECTING AT THE CASTLE OF ALCESTE IN SAN VITO DEI NORMANNI (BRINDISI, ITALY)

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Abstract

In this contribution we will show the results of a non-invasive GPR prospecting performed in the archaeological site of San Vito dei Normanni, in the outskirts of Brindisi, Apulia region, southern Italy, where the ancient population of the Messapians had an important settlement. The present work was performed in the framework of a school in the field financed by the Basilicata Region. The interpretation of the data has been based on the depth slices, on the processed Bscans and on the a-priori available information is provided. Future excavations will be driven also by the results achieved from this GPR prospecting.

Keywords

Ground Penetrating Radar, Archaeology, Messapic Settlement, Castello di Alceste.

1. *Introduction*

Non-invasive prospecting of archaeological sites and monuments is a topic of interest for modern archaeology, where the demand of knowledge about the buried scenario is often combined (and traded-off) with the practical impossibility of extensive and/or invasive excavations (Cardarelli et al., 2008; Linford et al., 2010; Shahruk et al., 2021; Piro et al., 2009; Piro et al., 2014; Persico et al., 2014; Persico et al., 2019), with the exigency of identifying, understanding and possibly preserving at least the most important remains against modern urban expansions (Barone et al., 2010; McCann, 1995), with the proper addressing of possible restoration works or post-intervention monitoring (Leucci et al., 2011; Masini et al., 2010) and/or just with the acquisition of a larger and deeper knowledge of the monuments, that might reveal part of their history through their invisible parts (Pieraccini et al., 2006; Utsi, 2009).

In this paper, we present a non-destructive Ground Penetrating Radar (GPR) measurement campaign conducted in the archaeological park of San Vito dei Normanni (Apulia region, southern Italy), where an important Messapic site is present. The geographic location of the site is specified in Fig. 1, upper and lower panel.

In particular, a few hundred metres South of the town of San Vito dei Normanni stands the hill of the *Castle of Alceste*, one of the most southerly heights of the Murge hills. From the summit, 108 m above sea level, you can survey the territory for miles around. The excavation campaigns conducted by the University of Salento led to the identification of an Archaic settlement built in the 6th century B.C. over a village of the Iron age (8th century B.C.) (Semeraro, 2009). During the first phase the village was constituted of oval-shaped huts roofed with perishable material, organised into clusters separated by open spaces, following a pattern of settlement recognised in other contemporary sites in Iron Age Messapia. A defensive wall encloses an area of 3 hectares on the top of the hill. On the basis of data acquired during the field survey, the Iron Age settlement seems to have been concentrated on the upper part of the hill, occupying an area of just over 10 hectares (Semeraro, 2015). During the Archaic period the village underwent a very important transformation. The layout of the Archaic site on the hill suggests a well-organised settlement, which reflects the adoption of "urban"-type settlement patterns and the presence of a society organised along different lines with respect to those of the preceding Iron Age. The settlement is surrounded now by a large defensive wall, clearly visible in aerial photographs, which encloses an area of about 25 hectares and contains the whole settlement. The houses were built with dry-stone walls and roofs of flat and curved tiles and were divided into separate rooms. The dwellings faced on roads paved with pebbles and small shards of earthenware that led to a large open space on the highest part of the hill.

The eastern side of the open space is characterised by a much larger structure covering an area of about 600 m2 referred to as the "Large Building", that had a sturdy outer wall.

In recent years, the archaeological research has focused on the systematic exploration of this complex, because it represents an absolute first case in the archaeology of Archaic Messapia. In particular, this was a "palace"-type structure combining the most important functions for ancient societies, not just residential, but also political, ceremonial and religious (Semeraro 2019).

In the area of the Large Building, numerous ceramics imported from Greece or the Greek cities of southern Italy such as Taras and Metapontion were discovered (Semeraro et. al., 2017; Notarstefano et al., 2018), indicating close relations with other civilisations, which also developed via the nearby natural harbours of Brindisi and Torre S. Sabina.

With respect to the performed prospecting presented here, one of the problems of interest in this survey was to investigate the possible presence of cisterns in the investigated areas. The presence of cisterns somewhere in the site (not necessarily in the prospected areas) is postulated because it was a habit of the Messapians to gather the rain water for domestic and/or agricultural use, as witnessed in other archaeological sites within east-southern Italy (the area is a part of the Apulia Region called Salento), as e.g. Cavallino (Morel, 1979; D'Andria, 2005).

2. *The GPR Technique*

The technique of the ground penetrating radar (GPR) is the geophysical technique that allows the best resolution. It is based on a radar system that radiates electromagnetic pusles and receives the electromagnetic echoes reflected and scattered from the buried targets (Daniels, 2004; Jol, 2009). The echoes are received at several positions along straight lines with a fixed spatial step, and then along parallel lines with a fixed interline space, also called transet (Utsi, 2017). When possible, the same measurement procedure is repeated along the orthogonal direction, so that in the end a regular grid of measurement lines is gone trough by the instrument. The in-line spatial step of the data is ruled by means of an odometer, divided into separate rooms. The dwellings faced on roads paved with pebbles and small shards of earthenware that led to a large open space on the highest part of the hill whereas the transet is just set and measured by tapes.

The data needs to be processed, and the quality of the final results depends both on the choice of the antennas and on the execution of the measurements (Persico et al., 2005; Soldovieri et al., 2005; Persico et al., 2006; Gennarelli et al., 2015). In particular, the transect is the most delicate aspect in this sense, because the in-line step is set by the odometer automatically smaller than the spatial Nyquist rate in most cases. In other words, it is quite easy to have a narrow in-line spatial step (e.g. of the order of 1 cm), but it is unpractical to guarantee a transet of such an order of size. After gathering the data some processing is needed. There is a large literature on the GPR data processing, but the basic processing step can be resumed in many cases in a few points, and in particular we also will follow the following more or less standard steps:

a. Zero Timing
b. Background removal
c. Gain variable vs. time
d. 1D filtering
e. Evaluation of the propagation velocity
f. Migration
g. Construction of time slices

The zero timing is the procedure that allows to start the evaluation of the return time of the signal at the instant where the propagation of the wave in the soil starts. This time instant is not the same as the starting point of the pulse in the generator, because the signal has to propagate into the system itself (which modifies it also due to the finite band of all the electromagnetic components of the GPR, and in particular of the antennas). It is not a theoretical easy task to establish the exact zero time of a GPR signal (Yelf, 2004), but a good and common choice is to assume the zero time at the maximum modulus of the echo caused by the air-soil interface. The background removal is aimed to remove constant or quasi-constant horizontal echoes, due first of all to the air soil interface, but also possibly to the interface between two buried layers or to some machine that moves together with the instrument, or even to some ill-functioning of the antennas that provide a strong ringing of the signal (Daniels, 2004). There are different kinds and "degrees" of background removal, with their own pros and cons. The experience of the operator should evaluate the most suitable in the case at hand. There are even cases when a simple muting of the interface might replace the background removal, but these cases are in practice quite rare. A theoretical study of the the properties of the background removal can be found in (Persico and Soldovieri, 2008).

The gain variable vs the time is a processing step aimed to counteract the attenuation suffered by the signal during its propagation in the soil (from the transmitting antenna to the target and then back to the receiving antenna). The attenuation is due to the geometrical spreading of the radiated energy along shperes with a progressively larger radius, but above all it is due to the losses in the probed medium, that transform into heat a meaningful share of the radiated and scattered energy. The measure of the exact amount of these losses is not an easy task in the field, and in general it is also variale from point to point.

Therefore, it is customarily applied a gain that increases vs. time, trying to equalize the attenuation that the signal has suffered. It it statistically virtually impossible that the counteraction of the attenuation that we achieve is exact, but the experience of the human operator can allow to apply a reasonable gain. In particular, if we see that the deeper buried targets systematically give back stronger and stronger echoes echoes with respect to the shallower ones, then probably we have exaggerated the applied gain.

The gain produces an enargement of the spectrum of the signal, especially on the low frequency side, which produces well recognizable disturbing effects in the signal. This is technically due to the fact that the spectrum of the amplified signal is given by the convolution of the original signal and of the spectrum of the amplifying function. A 1D filter, i.e. a filter separately applied to each GPR signal gathered in each measurement point, can approximately restore the original band wideness of the signal, so mitigating the spurious and unwanted effects of the variable gain. The evaluation of the propagation velocity of the waves in the soil can be performed on the basis of the gathered data, and has a twofold valence. In fact, on one side it allows to evaluate the real depth of the met targets (the GPR signal in itself gives back essentially the return time of the echoes from buried targets, which does not represent in itself the depth).

Moreover, it is propedeutical to the migration of the signal, that needs the propagation velocity as an input parameter. The migration of the signal is in a sense the most mathematical one among the described processing steps. It has been historically imported from the seismics (Stolt, 1978; Schneider, 1978), but can be also derived directly from the Maxwell's equations (Persico, 2010). The Migration is funded on several assumption and approximations, and in some applications it is not even applied because it might have a limited or questionable usefulness.

However, in many cases the migrated images are clearer than the nonmigrated ones. The migration allows to condensate the image of the buried targets into their physical volume, erasing the spurious "tails" that they show in the nonmigrated data. These tails are caused by the movement of the antennas, that "see" the targets when approaching their position, while passing on them, and then still for one or more meters while getting far from them.

The time slices (Conyers and Goodman, 1997; Conyers, 2004) are achieved joining all the echoes arrived at the same time on different spatial measurement points along all the measurement lines. They represent approximately horizontal sections of the underground scenario, which is particularly important in archaeological prospecting, because it can provide maps of ancient structures that cannot be visualized by any single measurement line. It is recommended to construct depth slices only with migrated data, otherwise the "tails" of the targets can produce artifacts.

In general, also perspective visualization can be achieved. These are more or less useful depending on the case. In the case at hand, we will not propose them. So, the processing applied on the data will be based on the described passages.

3. *GPR Survey*

We have prospected two fenced areas close the so called "Castle of Alceste", within the archaeological park, as shown in Fig. 1 (lower panel). The prospecting was performed with a Ris Hi-Mod GPR system, manufactured by the IDS corporation and equipped with two couples of antennas with nominal central frequencies at 200 and 600 MHz, respectively. In this paper results achieved from the antennas at 600 MHz will be shown.

Crossed and orthogonal radar Bscans with a transect of 40 cm were collected in both the studied areas. The bottom time scale was 80 ns, sampled with 512 time samples. The in-line spatial sampling was 1.54 cm.

The first studied area (Area 1) is located on the right side of the Castle of Alceste in Fig. 1 and it is delimited by a dry-stone wall (i.e. a wall constructed superposing the stones without mortar, according to the ancient local tradition). In particular, we have investigated a rectangle sized about 108 square meters (9 x 12 m). Twentythree Bscans have been collected parallel to the "long" direction (named L_1-L_{23}) and thirtyone Bscans have been collected along the cross direction (named C_1-C_{31}).

The second area (Area 2), situated on the left side of the castle (Fig. 1, lower panel, right hand site), is instead a rectangle about sized 105 square meters (7 x 15 m). Here, seventeen Bscans have been collected parallel to the "long" direction (named L_1-L_{17}) and thirtyseven Bscans have been collected along the cross direction (named C_1-C_{37}).

The two datasets have been processed according to the standard steps described in the previous section, namely zero timing, background removal on all tracks (Persico and Soldovieri, 2008), variable gain in depth, 1D bandpass filter and two dimensional Kirchoff migration (Schneider, 1978; Pierri et al., 2001).

In particular, on the basis of the shape of the diffraction hyperbolas (Mertens et al., 2016; Persico et al., 2015), the estimated average propagation speed of the electromagnetic waves in the ground was about 0.08 m/ns in Area 1 and 0.10 m/ns in Area 2. Depth-time slices at several depths were also obtained starting from processed radar sections.

The main results of the two GPR surveys are shown in the following section.

4. Results

In Fig. 2 some depth slices achieved in Area 1 are provided. Looking at the slides, we see clearly (indicated with an arrow) at the estimated depth of 36 cm, on the left hand side of the image, an area with intense reflections due to the presence of a (modern) paved floor close to the wall, also visible in Fig. 1 (right hand panel). Apart from this, both at 36 cm and 60 cm, a corridor where the reflections are markedly lower is evident. In particular, the right hand edge of this scarcely reflecting area is marked in the depth slice at 60 cm.

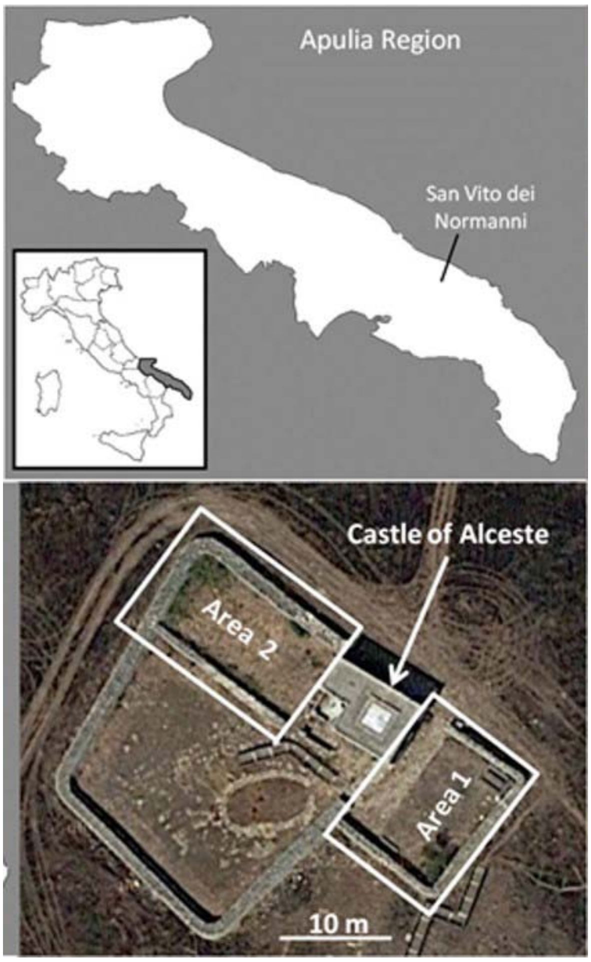

Fig. 1: Upper panel: The location of the site.Lower panel: The two studied areas in the archaeological park of San Vito dei Normanni nearby the castle of Alceste.

This might delineate the edge of some masonry structure, which is made likely also by the Bscans, that show quite well defined anomalies, in some cases showing quite precisely a top and a bottom. This makes us think of wall structures. However, at least part of these reflections might be due to cisterns. In fact, messapic cisterns possibly present here are not expected to be particularly large, a mouth of the order of one meter is enough, neither are they expected to show a particular demijohn-like enlargement under the mouth, which is instead typical of posterior cisterns.

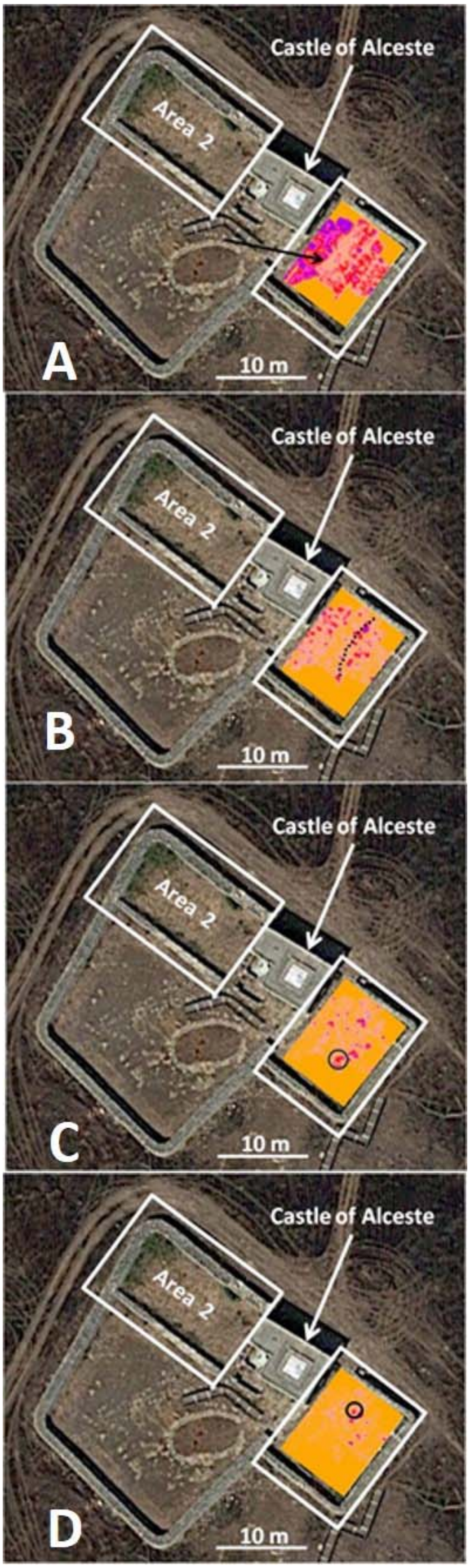

Fig. 2: Depth slice at different levels in Area 1. Panel A: 9 ns (about 36 cm); Panel B: 15 ns (about 60 cm); Panel C: 27 ns (about 108 cm); Panel D: 42 ns (about 168 cm).

Finally, it is not necessarily expected a void associated to the cistern, because its ancient ceiling is likely to be collapsed. So, in the end the remains of a cistern can be just wall structures.

At the levels of 108 and 168 cm, these features are still visible but are weaker than some other stronger isolated anomalies, whose interpretation is quite tricky. Maybe, the bottom of the masonries is deeper in some point respect to some other.

Some Bscans are shown in Fig. 3, from which we appreciate the fact that well defined anomalies appears along the "long" side of the area, compatible with wall structures crossed by the GPR, and many among them appear also quite flat. Converting the time in depth according to the estimated propagation velocity of 0.08 m/ns, the depth of these structures ranges from 40 to 200 cm.

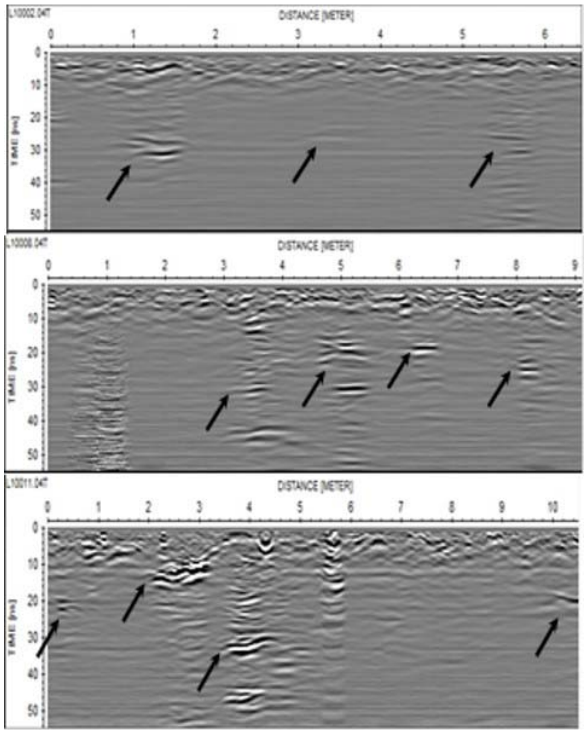

Fig. 3: Some of the gathered Bscans in Area 1. Upper panel: Profile L_2; Medium Panel: Profile L_8; Lower Panel L_{11}. As can be seen, some anomalies appears quite clear.

In Fig. 4, some depth slices achieved in Area 2 are shown.

In this case, the slices apparently reveal features roughly mainly parallel to the short side of the investigated area. With some points where the reflection is stronger. At least part of them, and especially in the most shallower layers (up to about 50 cm), seems to be ascribable to ancient walls.

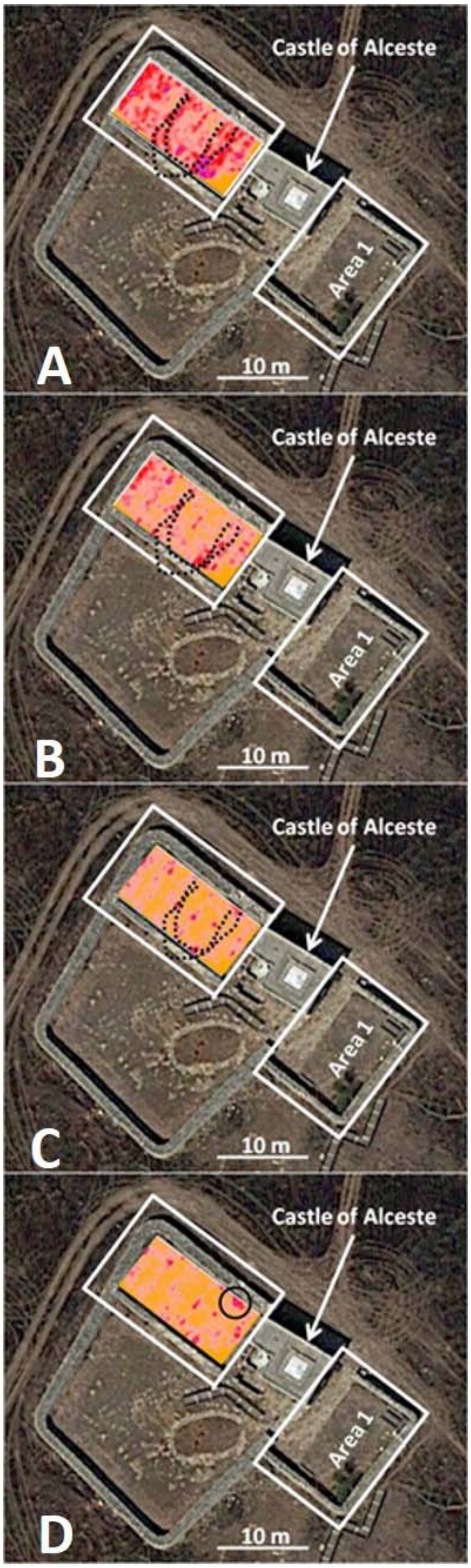

Fig. 4: Depth slice at different levels in Area 2. Panel A: 7 ns (about 36 cm); Panel B: 9.5 ns (about 48 cm); Panel C: 14.5 ns (about 72 cm); Panel D: 17 ns (about 84 cm).

Some effect might have been accentuated by the background removal procedure, but let us remind that the profiles have been taken along an orthogonal grid.

Therefore, if the only cause of these anomalies were the background removal, this effect should appear along both the long and short side of Area 2.

The interpretation is also in this case the presence of some walls. A possible track of part of them is put into evidence in the first three images of Fig. 4. Finally, Fig. 5 shows some of the Bscans where some isolated, flat and quite marked anomalies, similar to those visible in Area 1, are visible. According to the propagation velocity estimated to be about equal to 10 cm/ns, their depth ranges between 75 and 150 cm. In both areas, these features are likely to be ascribable to the top of squared off stones, likely to be man-made structures of Messapic age.

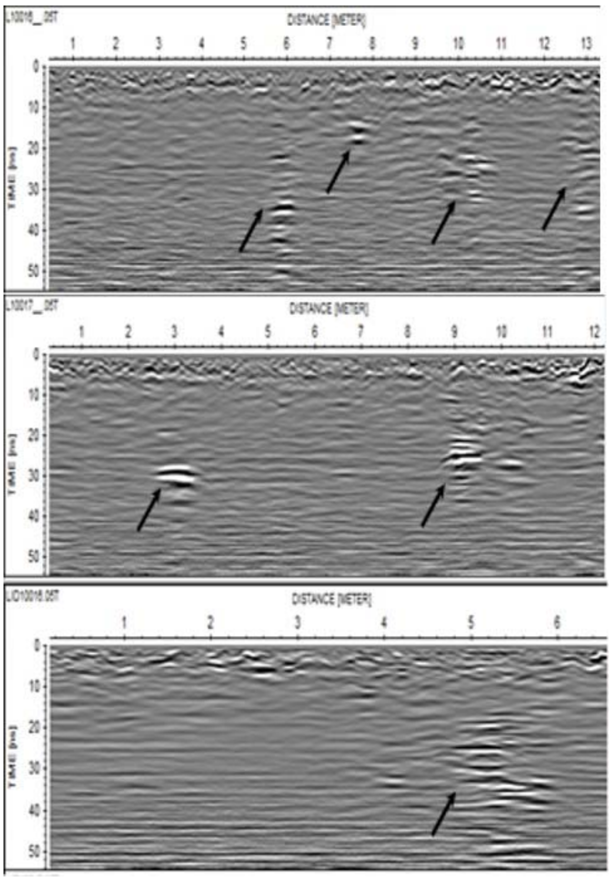

Fig. 5: Some of the gathered Bscans in Area 2. Upper panel: Profile L_{16}; Medium Panel: Profile L_{17}; Lower Panel C_{17}. Some anomalies are similar to those in Area 1.

5. Conclusions

In this paper the results of a GPR measurement campaign in the Messapic archaeological site of San Vito dei Normanni (Brindisi, Italy) have been shown. The interpretation of the data relies on the result of the processing and on the a-priori information available for the case at hand (we expect that possible Messapic remains are at relatively shallow depth levels). The buried scenario appear confused, but the use of referenced depth slices together with the Bscans allows to identify relatively short and flat anomalies, likely to be ascribable to wall structures. Due to the a-priori information related to the archaeological similarities known in other Messapic sites, part of these anomalies might be ascribed to walls and part to cisterns (maybe the deeper ones). It is not easy to distinguish "what is what", because the track expected by a Messapic cistern in the Bscan is essentially the same expected from a wall. Some more meaningful difference of course would be expected within the slices, where the cisterns should appear as more localized targets with respect to the ancient walls, and in this sense the dotted lines and the circles in Figs. 2 and 4 can be indicative. In particular, the range of depths of the "flat and short" anomalies in Area 2 is reduced with respect to Area 1, which could indicate the presence of a better preserved wall structure. However, in general the remains of the walls could be in their turn not complete and the buried remains of ancient walls might be shallower in some points (where the wall is better preserved) and deeper, and so in the case at hand we are not able to provide a detailed interpretation on the nature of the reflections. Only an excavation can provide the full ground truth, but the present results show that both investigated areas appear promising in this sense.

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