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The contribution of geophysical prospecting to the multidisciplinary study of the Sarno Baths, Pompeii

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ABSTRACT

This paper focuses on the contribution of geophysical measurements to the study of the Sarno Baths in Pompeii in the context of the MACH project funded by the University of Padua. Between 2016 and 2017, a series of geophysical measurements were carried out inside and outside the Sarno Baths in order to support the multidisciplinary study of this archaeological site. High-frequency ground penetrating radar (GPR) antennas have been applied to the characterization of horizontal and vertical structural elements (vaults and walls) of the building, where GPR acquisitions and electrical resistivity tomography (ERT) were used in the open field to identifying possible archaeological features. In general, the results made by these geophysical measurements provide new information supporting both structural analysis and preliminary archaeological excavation conducted in this area.

1. Introduction

The use of geophysical measurements, and in particular the application of ground penetrating radar (GPR) and electrical resistivity tomography (ERT) is well documented in the literature, also concerning the archaeological research at Pompeii [1–5]. These methods, in fact, exploiting different physical properties of the investigated materials, allow the effective identification of most common and interesting archaeological features, such as buried walls, tombs, palaeo-channels, etc., resulting in great interest also in the investigation of this large and complex archaeological site.

Ground penetrating radar (GPR) is a useful non-invasive method, based on the propagation of high frequency (MHz to GHz) electromagnetic (EM) waves. The emission and the registration of a GPR signal are guaranteed by two different antennas (transmitter and receiver), both generally hosted in a common partly shielded box. The result of the GPR acquisition along a transect is a section primarily containing information about the reflections produced by the buried materials having different dielectric properties [6]. Being completely non-invasive, this geophysical method is widely used for archaeological investigations before the excavation, in urban or rural areas and in the diagnostic for non-destructive testing [7–9], both inside and outside the buildings, on floors and walls.

Electrical resistivity tomography (ERT) is another popular geophysical method based on electrode galvanic contact and Ohm's law. The electrical resistivity ρ is an intrinsic property of the materials indicating the attitude to contrast the flow of the electric current. In general, the electrical methods measure the resistivity of the subsoil through the use of a quadrupole consisting of two current electrodes (current dipole, e.g. A and B) and two (potential dipole, e.g. C and D) potential electrodes, fixed in the ground according to different geometrical arrays (e.g. Wenner, Schlumberger, Dipole-Dipole, etc.). An injected current flow in the media by the current dipole producing a voltage distribution directly related to the electrical properties (electrical conductivity or resistivity) of the media and measured by the specific potential dipole. In general, the electrical properties depend on the saturation of the media and their porosity, according to Archie's law [10].

In archaeology, the use of electrical resistivity tomography (ERT) has gained popularity than most of the other geophysical methods, thanks to its applicability in rural areas and considering the very good results obtained, also in the complex environment [11–13]. On the other hand, the applicability of the ERT in urban areas or in the analysis of structural elements in built structures is still limited by the constraints posed to current injection in paved or plastered surfaces [14,15].

In the case of the Sarno Baths in Pompeii, in particular, three different aspects were addressed using geophysical measurements:

- the research of buried archaeological remains outside the building with GPR and ERT acquisitions;
- the study of the geological context using ERT measurements;
- the analysis of horizontal and vertical elements (vaults and walls) in some specific parts of the building using the GPR method.

These geophysical measurements undoubtedly well integrate the archaeological, geological, structural and topographical studies carried out in the frame the multidisciplinary study of the bath complex,

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providing new elements and supporting the evidence highlighted by other direct or non-direct investigation realized in this preliminary phase.

2. Acquisition procedures and techniques

In May 2016, the first series of geophysical acquisitions were carried out inside and outside of Sarno Bath building. In particular, the southern part at the foot of the complex was investigated by six coincident ERT and GPR transects and an extensive GPR mapping close to the building (Fig. 1a) in order to collect some archaeological information about this not well-documented area. The GPR acquisitions were performed using an IDS Ris Hi-Mod dual frequency system with 400–900 MHz antennas, hosted in the same shield box, mounted on a cart equipped with a magnetic encoder. To map this area with GPR measurements, we carried out parallel transects spaced 0.5 m apart and S-N oriented. For GPR data processing ReflexW software was used, applying the dewow filtering, the time-zero correction, the gain recovering, the background-removal filtering and the hyperbola analysis, assuming a propagation speed equal to 0.1 m/ns to the depth calculation. The ERT lines, overlapping in the same area the GPR transects (Fig. 1a), were collected using an IRIS Syscal Pro 72 resistivity meter. For each ERT line, we used 48 electrodes, spaced 0.5 m for the lines L1-2, L3, L4 and spaced 1 m for the lines L5 and L6. For the ERT measurements a skip 4 dipole-dipole array, with the full reciprocal acquisition for error estimation, was applied [16]. In particular, the L1-2 ERT line is a result of a roll-along acquisition (24 channels overlap), obtaining 72 channels and 35.5 m length, in total (Fig. 2). All the ERT data inversion were performed by using ProfileR freeware code, based on the Occam approach [17].

Still, in May 2016 some GPR acquisitions were carried out inside the building (consisting in total of four levels) for the analysis of the thickness of vaults in some rooms at level -3 and more in general for the analysis of specific structural parts (Fig. 3). Finally, a number of tests were conducted on the southern façade of the building using a high-frequency GPR antenna (IDS system with 2 GHz full polar antenna), to help localize the metallic reinforcements in the walls (Fig. 4).

This first geophysical fieldwork, carried out in May 2016 was followed by two more different acquisition campaigns in February and May 2017. In particular, in February 2017, one ERT line was collected in the south-eastern part (Fig. 5), NW-SE oriented, to investigate the geological context close to the building in this area, using 48 electrodes spaced 2 m and a skip 4 dipole-dipole acquisition scheme, full reciprocal check and the same acquisition parameters and the inversion procedure used in 2016 for this kind of measurements.

In May 2017 a new GPR field acquisition using the IDS Ris Hi-Mod Dual frequency system with 200–600 MHz antennas was carried out in the level 0 of the building, corresponding to the ground floor accessible from Via delle Scuole (Fig. 6), to check for the presence of archaeological remains below the actual ground level. The GPR data processing was performed, as for the previous acquisitions carried out in 2016, using ReflexW software, applying the dewow filtering, the time-zero correction, the gain recovering and the background removal filtering and using the hyperbola analysis to convert the two-way travel time of the GPR signal in the depth of investigation.

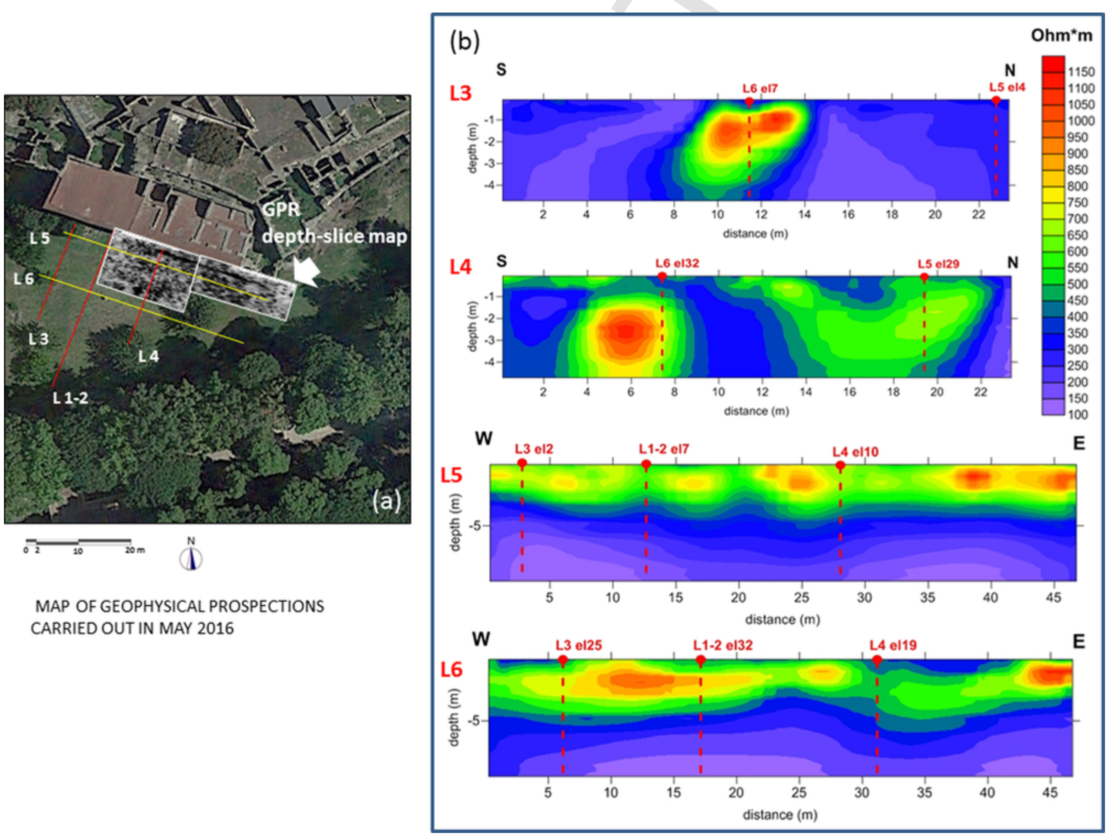

Fig. 1. a: ap of geophysical prospecting with the position of ERT lines and a GPR depth-slice map; b: results of L3, L4, L5 and L6 ERT acquisitions carried out in May 2016 at the foot of the southern façade of the Sarno Bath complex.

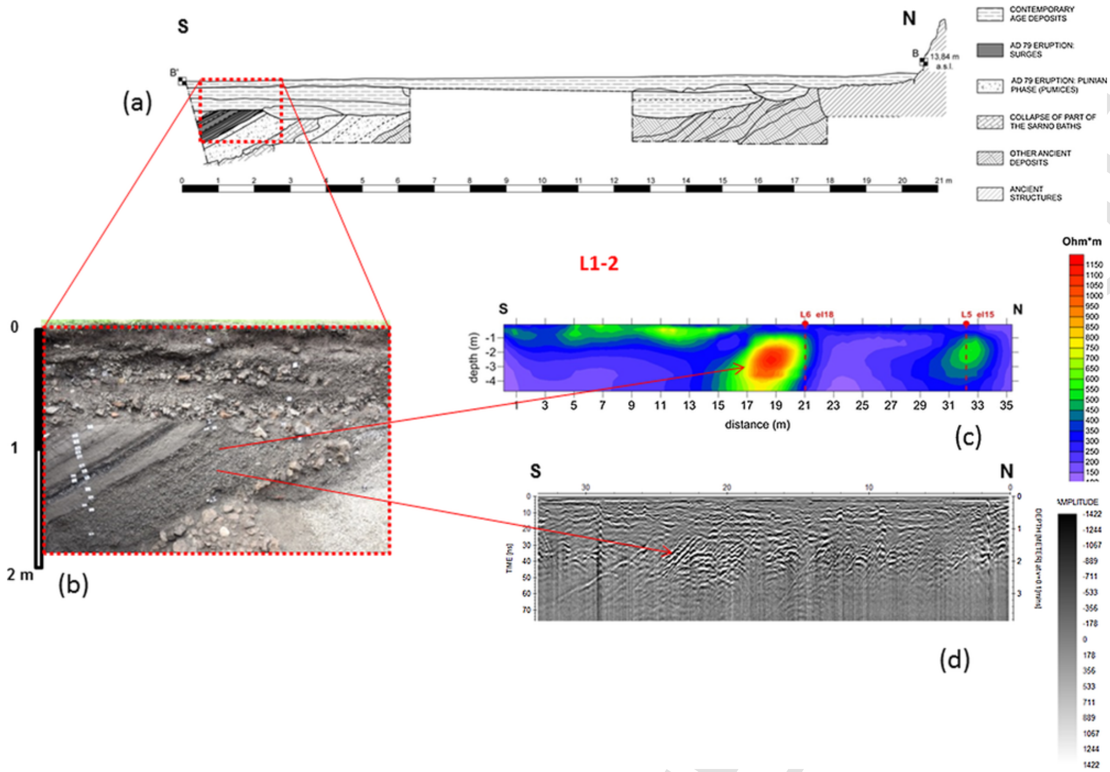

Fig. 2. a-b: Comparison between the result of the archaeological trench excavated along the L1-2 transect [18]; c-d: ERT and GPR lines previously carried out in 2016 in the same position (see Fig. 1) at the foot of the southern façade of the Sarno Bath complex.

3. Results and discussion

3.1. Geophysical measurements for the archaeological research

As evident from the plan and the internal distribution of the Sarno Bath building, the today's structure is the result of a number of transformations occurred over the centuries that can be traced back only by jointly reading the present building with the archaeological remains hidden in the subsoil. In this sense, the geophysical measurements, carried out in 2016 outside the Sarno Bath complex in the southern part at the foot of the building, provide new elements to support the archaeological interpretation. In Fig. 2 the result of the L1-2 ERT section is compared with that of the GPR transect collected in the same position and with the archaeological trench here excavated after the geophysical highlights. In particular, the ERT section clearly shows the presence of two main resistive anomalies. The main anomaly is located, along the section, between 15 m and 21 m, whereas the second one, less resistive and smaller than the first one, is located between 31 m and 33 m along the same transect, in north direction. The GPR section, overlapping the ERT line, does not show the two anomalies in the same way but highlights effectively the oblique pattern visible in the main, central resistive anomaly, in the ERT section.

On the basis of these geophysical indications, in particular considering the high value of the main ERT anomaly, apparently also crossed, in different positions, by the ERT lines L3 and L4 (Fig. 1b), a first archaeological trench was excavated over the L1-2 line (Fig. 1a). The results of this archaeological excavation (Fig. 2a, b) confirm the oblique pattern of the buried layers, detected by geophysical measurements, probably generated by the lava deposition over a slope, whereas the main high resistive body, identified by the ERT L1-2 section, corresponds to a pumice layer. For more details about the stratigraphy and the archaeological layers here found, see Bonetto et al. [18]. Some interesting resistivity anomalies, apparently related to buried structures perpendicular to the façade (probably walls), are visible in the ERT line L5. Other structures parallel to the façade of the building are visible in the same figure, in the GPR depth-slice map corresponding to a (pseudo) depth of investigation of 1 m below the ground (assuming, with the hyperbola analysis, a GPR velocity v = 0.1 m/ns).

Some examples of the results of the GPR acquisitions carried out in May 2017 in the upper part of the Sarno Bath complex are shown, instead, in Fig. 6. These results, despite the bad signal to noise ratio, also document the presence of some interesting anomalies in the subsoil of this specific area, probably related to the most ancient phases of the building. However, this hypothesis can only be confirmed by future archaeological excavations.

3.2. Geophysical measurements for structural analysis

The result of the 900 MHz GPR acquisition over the floor/vault in room 9 at level -3, inside the building, is shown in Fig. 3c. In the same Figure is also shown the result of the GPR section collected in corridor 2 (Fig. 3d) at the same level (Fig. 3b). Both GPR sections clearly show the shape of the vaults below these floors and their thickness, obtained by the velocity estimation of the GPR signal with the hyperbola analysis. A posteriori, the GPR result has been confirmed by the 3D relief here realized with the use of integrated geomatic methodologies [19]. A different example of a GPR section, collected along the external wall of the southern façade, is shown in Fig.4. This high-resolution GPR section has been collected in correspondence of a metallic reinforcement inserted in the masonry from within the building, and not visible outside. As highlighted by the cir-

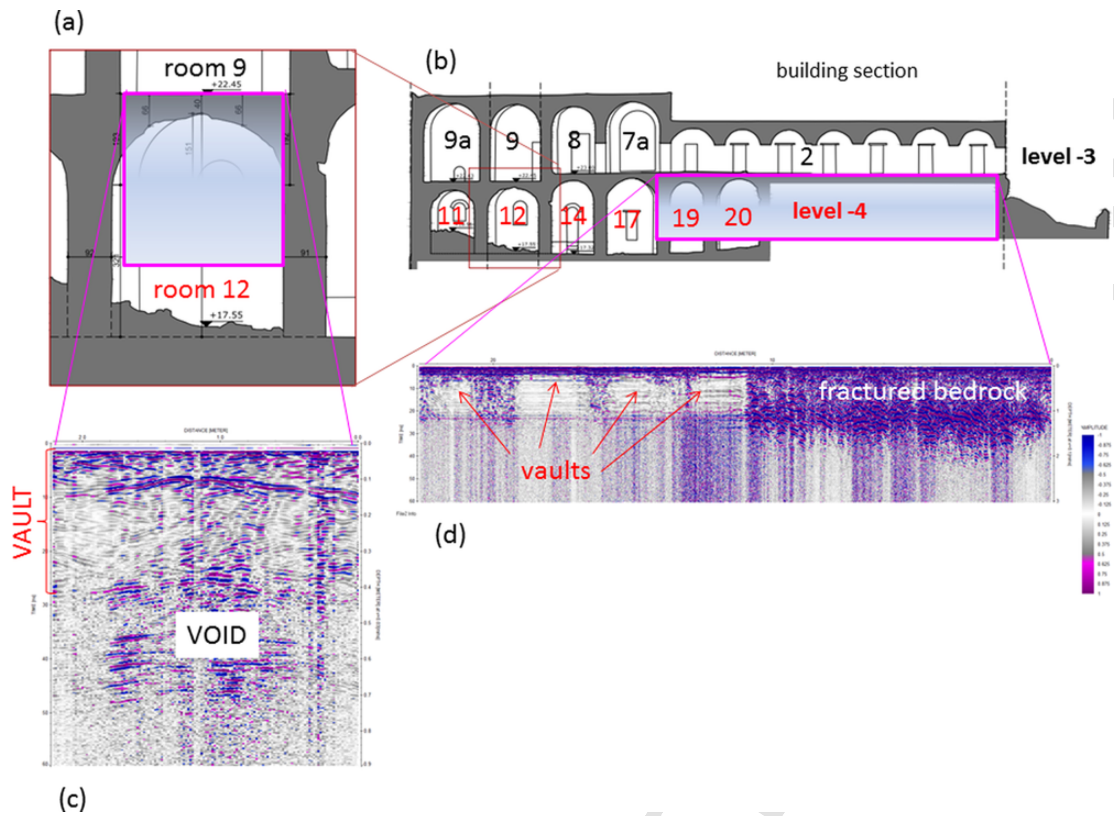

Fig. 3. GPR sections (900 MHz antenna) collected on the floor at level -3 inside of the Sarno Bath building: a: detail of the GPR acquisition over the vault of the room 12, b: Sarno Bath building section (levels -3 and -4), c: GPR section of the vault of the room 12, d: GPR section over the floor in the corridor 2 at level -3.

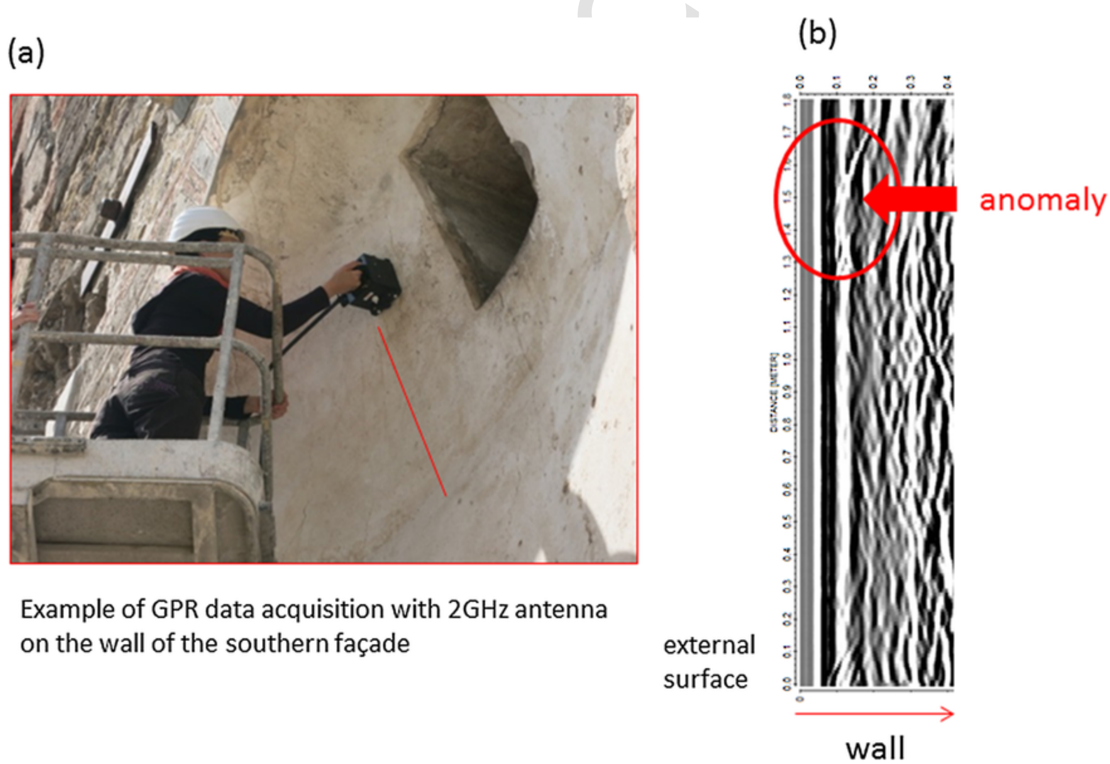

Fig. 4. Example of high-resolution GPR measurements on the southern façade of the Sarno Bath building.

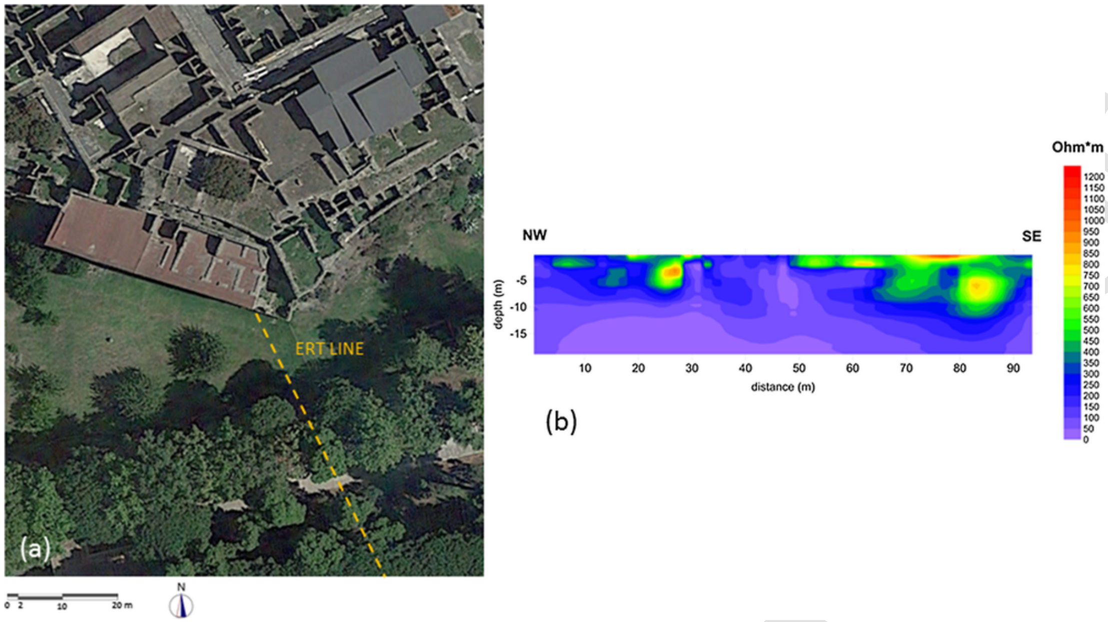

Fig. 5. ERT line collected in the south-eastern part of the Sarno Bath complex to investigate the geological setting in this area: a: localization of the ERT line; b: ERT result.

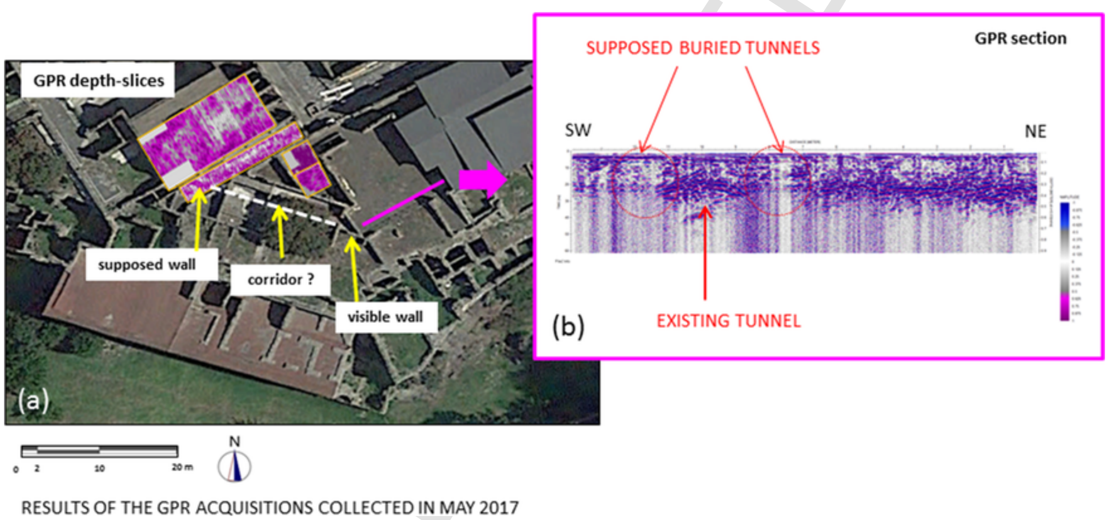

Fig. 6. Results of the GPR acquisitions carried out in May 2017 at the ground level (Via delle Scuole) of the Sarno Bath building.

cle and the arrow in the GPR section in Fig. 4, a shallow anomaly is visible under the external homogeneous surface, supporting other NDT measurements carried out in the building to the structural analysis [20].

3.3. Geophysical measurements for geological settings

The result of the ERT line collected in the south-eastern part, outside of the Sarno Bath complex, at the foot of the building, is shown in Fig. 5. The aim of this geophysical acquisition was to investigate the geological setting in the southern part closest to the building. Up to now, in fact, no reliable confirmation has been found on the exact position of the ancient riverbed of the Sarno river, which certainly flowed to the South of the thermal building. From the analysis of the ERT section, however, no conclusive details appear that allow the identification of a riverbed along the investigated transect.

4. Conclusions

The geophysical measurements carried out in 2016-2017 at the Sarno Baths in Pompeii provide new information about the building's structure, the archaeological features and geological setting in the external surrounding area, helpful for structural, archaeological and geological studies of this complex. In particular, the ERT measurements collected in the southern external part, at the foot of the building, highlight the presence of some anomalies probably related to the volcanic activity, rather than to the existence of archaeological buried remains. The direct validation of these geophysical evidence and hypotheses have been provided by a specific archaeological trench excavated a-posteriori, overlapping one of ERT and GPR transects collected in this area. The excavation, in fact, confirms the pattern of the geophysical anomalies, due to the presence of lava deposits, in particular, a pumice layer, identified by the ERT measurements with a high resistive anomaly. Other smaller anomalies have been identified by the GPR measurements, closer to the building in this area and at level 0, in the upper part of the complex. These anomalies are probably related to the presence of some residual archaeological remains, linked to the transformation of the Sarno Bath complex during centuries, but these need to be verified by future targeted archaeological excavations. Thanks to the ERT measurements, we also can collect some information about the ancient riverbed of the Sarno river, excluding its presence closer to the south-eastern part at the foot of the building. Finally, a series of high-resolution GPR measurements have been collected inside the building for the analysis of the horizontal and vertical structural elements. These geophysical measurements, contribute, in non-destructive manner, to identify the right size and the shape of the detected elements, as after confirmed by the 3D relief made by geomatic measurements, and provided new data about the inner structure of these elements of the building, supporting the structural analysis, thus confirming the high value of these non-invasive measurements also in this specific context.

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