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Integrated Archaeological and Geophysical Surveys in the Historical Center of Augusta (Eastern Sicily, Italy).

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Abstract. Augusta was founded by Emperor Frederick II between 1233/34 and 1238/39 on a peninsula. Despite its short history, over the centuries the town has undergone profound transformations due to demolitions (1680-1682) and earthquakes (1542, 1693) that have changed its architectural and urban features. Integrated archaeological and geophysical investigations were undertaken to solve specific archaeological problems which are part of a wider debate regarding the phenomena connected to the medieval and urban layout and archaeological potential analysis. Particularly the geophysical surveys undertaken in the historical center of Augusta, by means Ground-penetrating Radar (GPR), allowed a 3D reconstruction of archaeological structures in the subsoil until the depth of about 4m.

1. Introduction

Augusta is a town on the east coast of Sicily, located between Syracuse and Catania. It was originally located on a peninsula, but in the mid-17th century the isthmus that joined it to Sicily was cut off and the town became an island connected to the mainland by two bridges. Between 1233/34 and 1238/39, the Emperor Frederick II founded Augusta, populating it with citizens coming from Catania and probably other cities of eastern Sicily that had rebelled against imperial power. On the northern part of the peninsula Frederick II ordered the construction of the Swabian Castle to control access to the town from the isthmus and the port. The urban area, on the other hand, was built south of the Castle with a regular and orthogonal layout. After its foundation, the town had a very troubled life. It suffered many destructions (1269, 1360, 1551) and pillages (1287, 1327, 1352, 1364, 1379, 1527, 1552-53, 1560, 1588, 1675) that had an impact on the urban development.
The most important events that have profoundly influenced the urban layout and image of the town in the past are the extension of the fortifications and earthquakes. Between 1680 and 1683, the military engineer Carlos De Grunembergh was commissioned to build a new line of fortifications around the medieval castle to defend it on the basis of new warfare techniques. He therefore decided to extend the fortifications towards the town, which was a weak side for the defence of the castle. This extension therefore led to the destruction of the three northernmost blocks of Augusta. This effectively obliterated the oldest part of the urban layout and left in its place a large empty square to allow cannon fire from the new fortifications. At the same time, the earthquakes of 1542 and 1693 had a strong impact on the town. In particular, the second earthquake totally destroyed the town, which was completely rebuilt but respecting the old urban layout. The reconstruction caused the definitive demolition and burial of some buildings and entire parts of the town.
Although Augusta underwent these transformations in a relatively recent period, it is not always possible to identify and reconstruct the areas that were demolished or eliminated from the urban layout. The presence of numerous maps made between the end of the 16th and the first half of the 18th century allow us to acquire some important information, but they have not been conclusive for the knowledge of the medieval and modern town. The complex urban history and the profound transformations that occurred between the medieval and modern ages therefore constitute a unique context for developing integrated

research strategies in which historical, archaeological and geophysical methods can yield important results for identifying and reconstructing urban portions that have never been investigated through archaeological surveys and excavations. The research activities, therefore, were aimed at investigating the area of the Public Urban Park of Augusta, which corresponds to the portion of the city demolished by De Grunembergh between 1680 and 1682, in the northern part of the island. In particular, the research was aimed at the identification of archaeological structures pertaining to buildings and the identification of portions of the urban layout.

Figure 1. The surveyed area

2. GPR data acquisition and analysis

The GPR survey was performed, with IDS Hi Mod georadar system, along parallel profiles at 0.25 m spacing using a dual band 200–600 MHz centre frequency antennae. The following acquisition parameters were selected: samples per scan, 512; recording time window, 80 ns for 600 MHz antenna and 160 ns for 200 MHz antenna; gain function, manual. The arrangement of the profiles in a grid has allowed us to correlate, spatially, the important electromagnetic wave reflections (due to the presence of electromagnetic discontinuities) within two-dimensional reflection profiles (standard radar sections). A way to obtain visually useful maps for understanding the plan distribution of reflection amplitudes within specific time intervals is the creation of horizontal time slices. Time slices examine only reflection amplitude changes (or energy changes if the square value is used instead of the absolute value) within specific time intervals, and thus within consecutive soil layers of nearly constant thickness. Each time slice is, therefore, roughly comparable to a standard archaeological excavation level [1,2]. Areas of low reflection amplitude (or energy) indicate uniform matrix materials or quite homogeneous soils, whereas those of high amplitude denote zones of high die-electrical subsurface properties contrast, such as buried archaeological features, voids or important stratigraphical changes. In the present work the time slice technique has been used to display the energy variations within the 5 ns time window.
The most crucial step in GPR data interpretation is studying and understanding in a general way the components of 2D reflection profiles and then the reflection profiles themselves ([3]Conyers, 2012). Only when these components are understood can other displays such as amplitude maps and isosurfaces be interpreted [3]. Take into account that the GPR profiles were normalised for amplitude, had

background removed and were migrated using a Kirchoff 2D method. In order to perform a 2D Kirchoff migration the electromagnetic (EM) wave velocity was determined from the reflection profiles acquired in continuous mode, using the characteristic hyperbolic shape of reflection from a point source [2]. This is a very common method of velocity estimation and it is based on the phenomenon that a small object reflects EM-waves in almost every direction. The general stratigraphy in all profiles shows an unconsolidated surface soil with many stones that produced point-source reflections, as well as a few metal objects and pebbles (Figure 2) that enable the EM wave velocity analysis to be performed.
The processing and imaging software (GPRSlice) allows the interactive velocity adaptation of a diffraction or reflection hyperbola by calculating a hyperbola of defined velocity and width. The velocities are combined into a 2D model using a special interpolation method. The interpolation is performed as follows: all actual velocities are summed for every point in the x–t range, proportional to the square of their distance from the (x, t) point. This method provides only the average EM-wave velocity to the depth of the source-point reflector. This type of 2D velocity distribution may be used in the 2D migration processing step. Application of this method gives an average velocity of 0.11 m/ns. Figure 2 show the processed R1 profile related to 600 MHz antenna.
Many reflection features are related to underground utilities and they are visible in the first metre of depth (Figure 2).

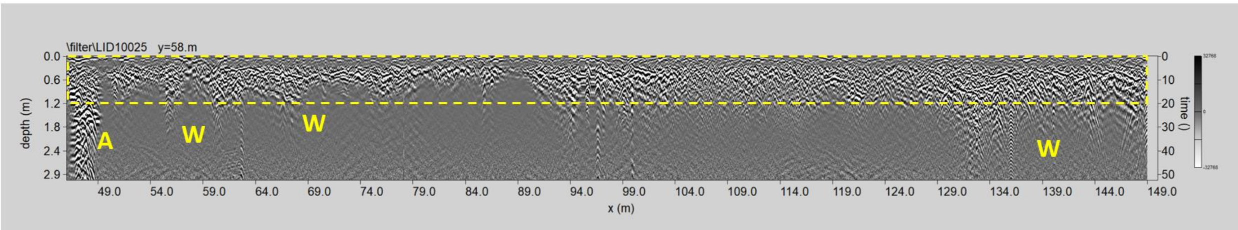

Figure 2. The processed radar section

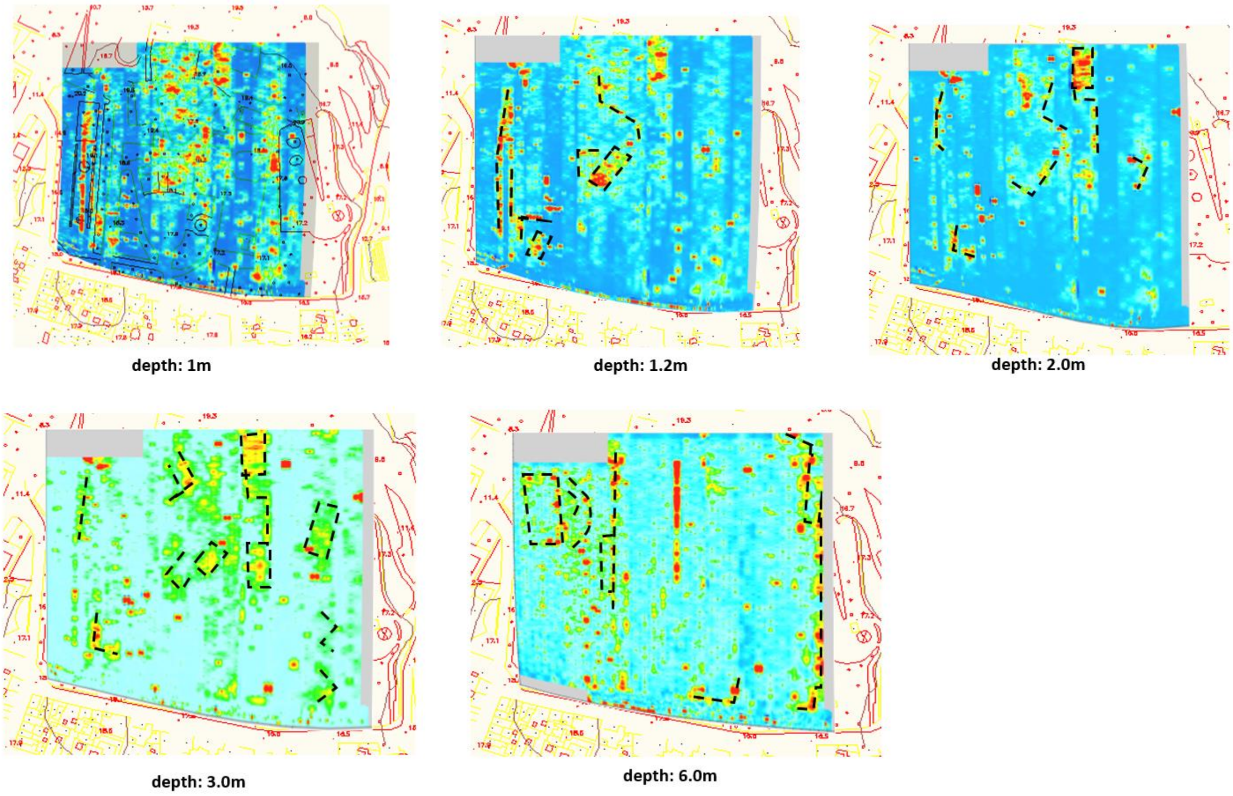

Figure 3. The time slices

In the depth ranging between 0.2 and 1.0 m, it is possible to identify the presence of the anthropic subsoil where several piping are present (dashed yellow rectangular). At greater depths it is possible to identify some electromagnetic wave reflections (labelled A and W). These complex reflections generated at depth ranging between 1.2 m and 2.4 m were produced by the archaeological structures related to walls (W) and other structure (A). Using the GPR-Slice software (www.gpr-survey.com/), including the overlay analysis [4,5] the time slices were built. As affirmed by [5], the key elements in the overlay analysis are: (1) generating time slices of amplitude energy (not pulse amplitude); (2) choosing a range of individual time slices where pertinent information is contained; (3) weighting each individual time slice with a unique colour transform; and (4) overlaying the relative – strongest – reflector normalised from each time slice level. This analysis allows evidencing also the deeper low amplitude reflections. Several reflection features (Figure 3) visible until 1 m of depth can be related to the buildings that occupied the surveyed area.

3. Conclusions

This case study highlights the difficulties and the problems encountered in undertaking GPR measurements in urban areas, characterised by a continuity of life and the presence of several piping. In particular, the main difficulties derive from: (1) the circumstance that the investigations were limited at a few modern roads and square; and (2) the concentrations of many modern underground pipelines and ducts in the investigated areas, which produce many reflection features that complicate the data interpretation. Despite these difficulties, some interesting data were acquired. Time-slices georeferenced in the archaeological map and used mainly to enhance the horizontal relationships between amplitude reflection features found in the standard two dimensional radar sections, point to several reflection features that can be interpreted as buried structures of probable anthropogenic origin. For the interpretation of GPR it was very important to georeference the time slices in the archaeological map, aimed at understanding the relationship with already known data, and the systematic study of historical cartography. Therefore, this study allowed us to interpret correctly such reflection features and to avoid attributing them to the medieval and modern period. So, the results show us the correct position of some medieval and modern buildings and portion of urban layout otherwise known only from old map and photographs. The methodological approach proposed in this paper allows a complete and integrated way to analyse the archaeological evidence in the ground before starting the excavations.

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