NON-DESTRUCTIVE TECHNIQUES IN ARCHAEOLOGY: RECENT GPR INVESTIGATIONS IN *CRUSTUMERIUM*

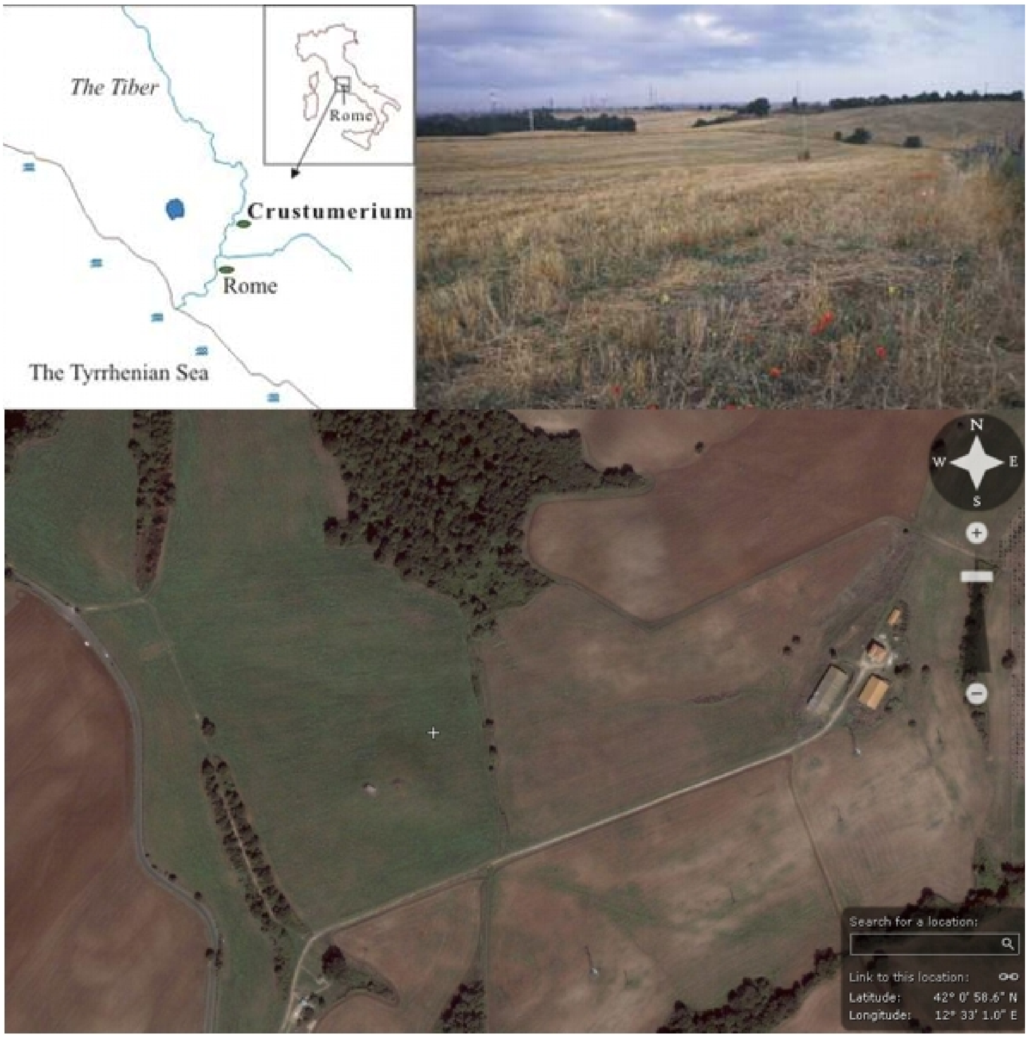

Fig. 1: The archaeological site of *Crustumerium*.

INTRODUCTION

At the end of July 2007, GPR data have been collected in the archaeological site of *Crustumerium*, 15 km north of Rome, beside the Salaria road (Fig. 1). The site has been a continuous settlement from the Latin period until the Roman, and it represents an ideal area to perform a geophysical survey because the modern urbanisation did not compromise its historical preservation and its natural landscape.

1. THE GPR TECHNIQUE

Ground Penetrating Radar (or GPR) technique is a geophysical method which uses radio waves, typically in the frequency range 10-3000 MHz, to map structure and features buried in the ground. Radar transmitting antenna emits an electromagnetic impulse which can be reflected or scattered by a dielectric discontinuity in the ground, and gathered by receiving antenna.

The equipment used in all GPR systems consists of four main elements: a transmitting unit; a receiving unit; a control unit; and a display unit. The transmitter produces a short duration, high voltage pulse. This pulse is applied to the transmitting antenna, which radiates the pulse into the ground. This transmitted signal travels in the ground with the reflected or scattered signals travelling back to the receiving antenna and then to the receiver. The latter amplifies the signals and formats them for display by the control unit. Many GPR can operate at different frequencies. The antennas are the bandwidth limiting devices, so the same transmitter and receiver can be used with a number of different antennas (Fig. 2).

The electrical properties of geological materials are primarily controlled by the water content. Variations in the electrical properties of soils are in fact usually associated with changes in volumetric water content, which, in turns, give rise to radar reflections.

The velocity and the attenuation are the factors that describe the propagation of high frequency radio waves in the ground. These factors depend on the dielectric and conductivity properties of the materials.

The factors that affect radar signal range in the ground are: radar system performance, attenuation in the ground and the reflection properties at boundary where the electrical properties vary. From the attenuation values in geological materials and the nature of the frequency dependence, it follows that for a given signal detection threshold the maximum depth of investigation decreases rapidly with increasing frequency, and almost all subsurface radar systems operate at frequencies less than 3 GHz. The GPR system measures the signal travel time, and crates a 2D image of the subsurface, with the antennas position on the X axis and the tow-way travel time on the Y axis. Because different antennas frequencies can be used, different vertical and horizontal resolution can be also achieved. Resolution is the ability of the system to distinguish two signals that are close to each other in time, therefore, the shorter is the time pulse width the higher is the resolution, i.e. the closest is the distance between two reflectors in the subsurface.

GPR has the advantage of being a non-passive technique with controllable input, non-destructive, rapid with the creation of large quantities of data and capable of being used in both step (i.e. point) and continuous monitoring modes.

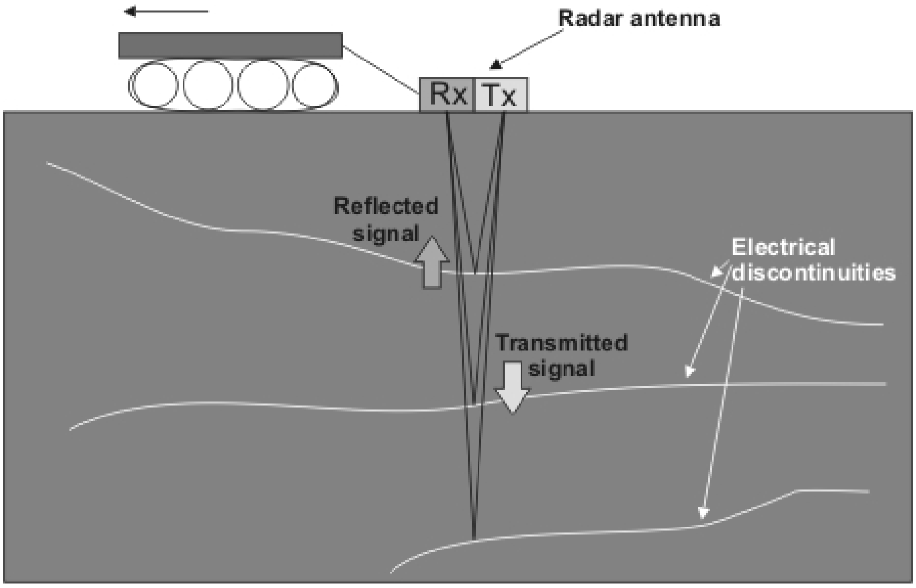

Fig. 2: Schematic of the GPR technique.

2. THE GPR ACQUISITION

The GPR data have been acquired in two different areas, on two different archaeological targets, for a total of about 700 linear meters. In both areas, a PulsEkko PRO system, equipped with 500 MHz shielded transducers (or antennas) was used., and in all sections a time window of 60 ns and a stacking of 4 (Fig. 3) were selected. During the survey the GPR was deployed in the reflection mode (Fig. 4), in which antennas are kept in a fix configuration and move over the ground so that a section showing time to the radar reflectors on the vertical axis is displayed with antenna position along the horizontal axis.

Fig. 3: The GPR system used in these archaeological investigations.

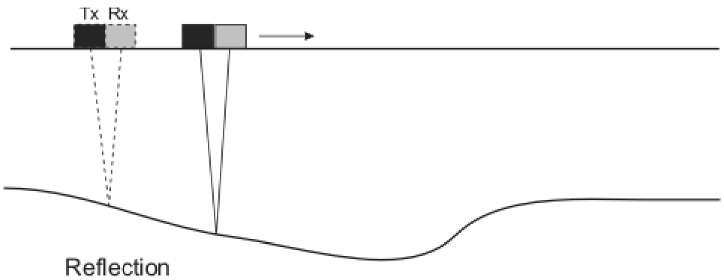

Fig. 4: Schematic of the reflection mode technique (Tx is the transmitter antenna and Rx is the receiver antenna).

In the Area 1, two grids have been collected with the same dimension (12 x 12 m) and the same numbers of parallel profiles (25 with a distance between each line of 0.50 m): the first grid was acquired with the survey lines oriented in the W-E direction whereas the second one with the lines oriented in the S-N direction. An average velocity of about 0.11 m/ns was calculated for all sections on the basis of hyperbola calibration technique.. The S-N grid in this area had a slight slope and it was necessary to perform a topographical correction using six quoted points along this slope (Fig. 3).

Fig. 3: The Area 1 and the grids' directions.

In the Area 2, a single 10 x 38 m grid has been collected, with the 21 parallel profiles oriented in the W-E direction (and a distance between each profile of 0.50 m). Again, the average velocity estimated using the hyperbola calibration technique was 0.11 m/ns (Fig 4).

Fig. 4: The Area 2 and the grid orientation.

3. THE GPR RESULTS

The investigated areas had two different archaeological targets: in the Area 1 the aim was to detect a Latin tomb with the classical typology *dromos* + rectangular death chamber; in the Area 2 the aim was to identify a Roman road and some archaeological remains of a *domus* correlated to some evidences found during a recent excavations.

In both areas the signal penetration was reduced due to attenuation caused by the presence of tufa soil, which is generally quite conductive; however, the attenuation was lower in Area 2 than in Area 1, where the conductive soil has sometime strongly limited the subsurface signal penetration, causing a lack of GPR data and affecting the correct data interpretation.

3.1 Area 1

The GPR data were used to create several penetration maps of Area 1, on which the geometry and orientation of the radar anomalies could be easily recognized. The maps were generated using Ekko Mapper software, and the average amplitude algorithm. Although the results are not very clear, it is still possible to delimit an area with stronger geophysical anomalies, which could indicate the presence of archaeological remains possibly due to the tomb. In fact, on both grids (W-E and S-N) which investigate the same area, but "illuminate" the subsurface structures with a different direction of the electric filed, there is an area, shown in Figure 5, were the anomalies are located in the same position and at the same depth (0.40 m ca.).

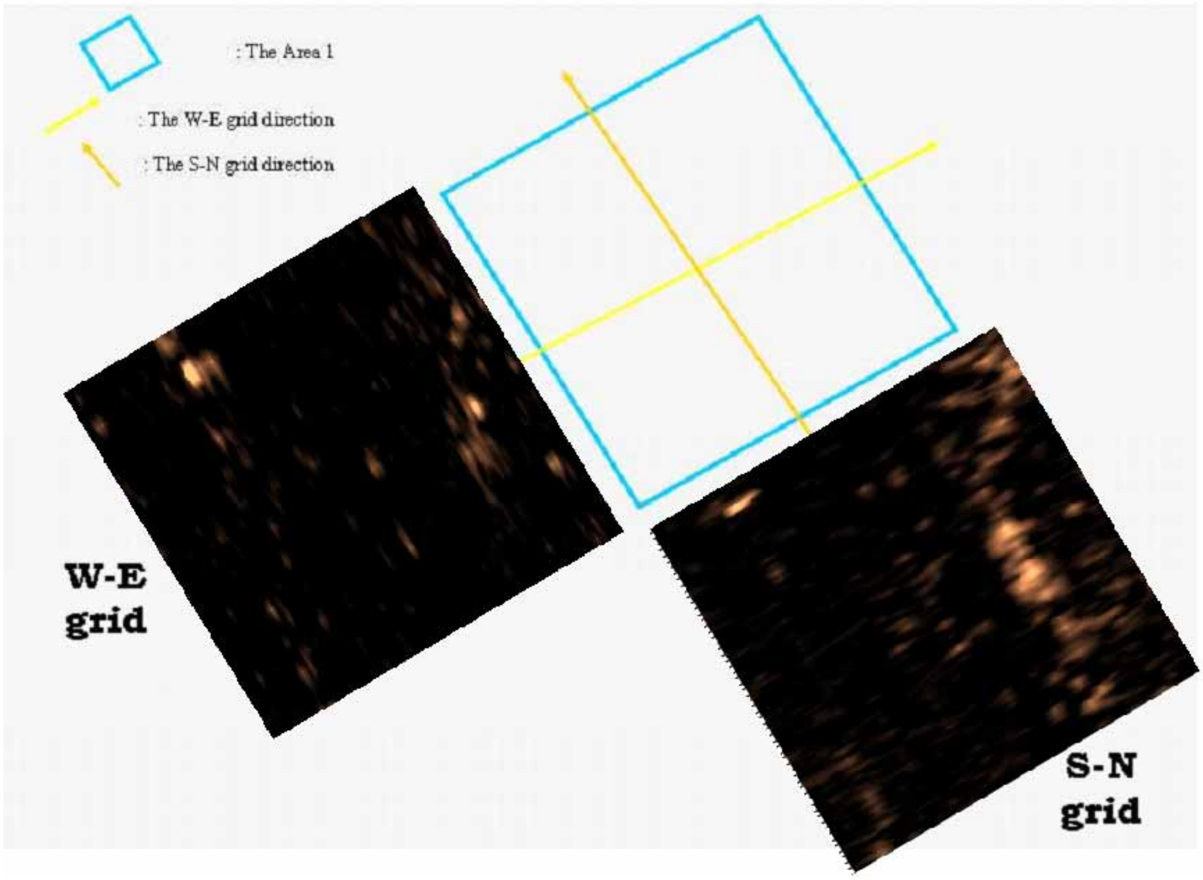

Fig. 5: In Fig. 6 are presented the sketch and the penetration maps of Area 1 (in the right part of each maps it is possible to note a zone of particular interest).

3.2 Area 2

The GPR data were used to create several penetration maps of Area 2, on which the geometry and orientation of the radar anomalies could be easily recognized. The maps were generated using Ekko Mapper software, and the average amplitude algorithm. Respect to the Area 1, the GPR data collected in the Area 2 have given better result both in terms of vertical resolution and signal penetration, despite the surface sediments were of the same type.. In fact, the maps show some clear evidences of the presence of a Roman road at a depth ranging from 0.30 m to 0.60 m. Moreover, some small anomalies due to the Roman *domus* are visible at 0.30 m depth; it was also possible to detect a modern road, partially located above the Roman road, at 0.20 m depth, as shown in Fig. 6. The difference in thickness of the anomalies are quite interesting: the Roman road is visible in several penetration maps (from 0.30 m to 0.60 m depth), because the structure of a Roman road is, usually, very thick; on the contrary, the anomalies due to the Roman *domus*, are just visible at a depth of 0.30 m, because correspond to the top of the building walls.

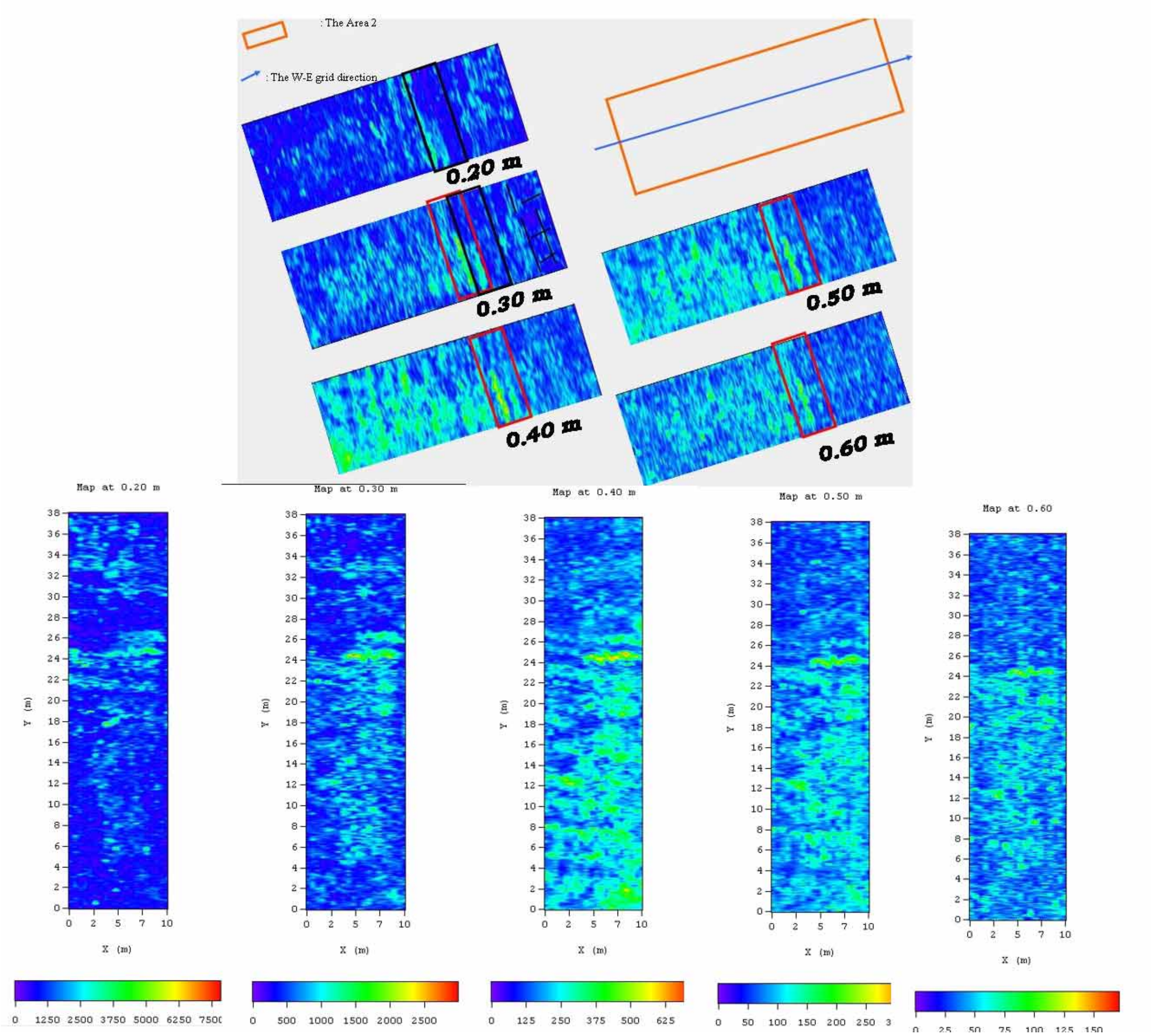

Fig. 6: The top part of this figure shows the sketch and the penetration maps, at different depths, of the Area 2; it is possible to note the modern road at 0.20 m, the overlap of the modern and the Roman road and the remains of the Roman *domus* at 0.30 m; after this depth, it is possible to follow the Roman road up to e depth of about l 0.60 m. The bottom part of the figure shows the five penetration maps from 0.20 m to 0.60 m depth of the W-E grid.

CONCLUSION

The GPR survey conducted on the two different areas have shown a remarkable different in signal penetration, despite the apparent consistency of the surface sediments. Although this fact have limited the interpretations of the results obtained in Area 1, the data collected on Area 2, have provide precise indications about the location of the Roman road. It is possible to conclude that the further use of such a geophysical technique in this area could have some potential.

The application of non-invasive geophysical techniques, such as GPR, has the potential to give important archaeological and historical information precisely, without compromising the physical integrity of the cultural heritage.

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