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GPR imaging and characterization of ancient Roman ruins in the Aquileia Archaeological Park, NE Italy

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ABSTRACT

Ground-Penetrating Radar (GPR) can successfully image buried archaeological structures based on changes in the electro-magnetic properties of the investigated materials. Particularly, GPR data interpretation is facilitated by the development of modern 3-D analysis techniques. Attribute analysis, originally developed to improve the quality and efficiency of data interpretation for hydrocarbon exploitation, was applied to our GPR study to image and characterize an archaeological site along the Roman fluvial harbor in the Aquileia Archaeological Park, NE Italy, namely one of the most important Roman archaeological areas in Europe. We calculated GPR attributes on GPR datasets. In detail, the *energy* was calculated towards comprehensive pseudo 3-D GPR interpretation, while *similarity* was analyzed to emphasize the continuity of the archaeological structures in a highly inhomogeneous background. The GPR results can correlate and calibrate previous limited archaeological pit tests, and provide detailed information about buried remains to plan further excavations. The subsequent localized excavations also validated the results obtained from the GPR survey. The research demonstrates that it is useful, and sometimes essential, applying GPR attribute analysis especially when GPR records with low signal-to-noise ratio are available and when the subsurface stratigraphy is complex due to several superimposed archaeological levels.

1. Introduction

Ground-Penetrating Radar (GPR) is a non-invasive geophysical method for high-resolution imaging and characterization of shallow buried objects, based on electromagnetic (EM) waves propagating through materials where the contrasts of electromagnetic impedance are large enough to produce detectable reflections, diffractions and refractions from subsurface targets [2]. The method uses high frequency (0.01–6 GHz) EM waves to probe "*the ground*", i.e. any low-loss dielectric material [37]. Since the first attempts to measure subsurface features with radio wave signals were reported (e.g. [18]), and numerous commercial instruments were developed during 1970s and 1980s [35,15], GPR has come into a well-accepted technique in a variety of domains (e.g. [41,42,8,9,24,44,49,51,32]).

In particular, as far as archaeological applications are concerned, GPR can accurately detect, image and map the spatial extension of near-surface archaeological features or changes in the matrix of a site in an absolutely non-destructive and cost-effective way [13,21]. It is further recommended as a valid method to extend archaeological results or to optimize location and design of new excavations. At present, such technique is extensively applied to pre-excavation studies, with the primary goals of identifying possible buried remains in large areas (e.g. [20,46,48]), mapping the basement of existing buildings (e.g. [36,6,17]), identifying structures or infrastructures like ditches, walls, roads and so on (e.g. [4,38,47,50]), locating and imaging graves and funeral monuments (e.g. [40,25,14]), and characterizing ancient urban sites (e.g. [33,43]).

In recent years, progressively more sophisticated GPR data acquisition and processing techniques have been applied to archaeological studies, all of them aiming at increasing the overall resolution, the achievable penetration depth, and at improving the imaging and characterization of the buried structures. GPR data may be acquired and processed using multi-fold techniques [39,42,4,7,26]. To improve focusing and accuracy in target positioning and shape reconstruction, the radargrams can be corrected for the topography and antenna tilting [31,30], while to improve spatial resolution, GPR data can be acquired according to full-resolution criteria, made easier by true 3-D multichannel GPR surveys [46,34].

However, nowadays common offset data (i.e. single fold) is still the most frequent GPR acquisition technique, as it is relatively fast and

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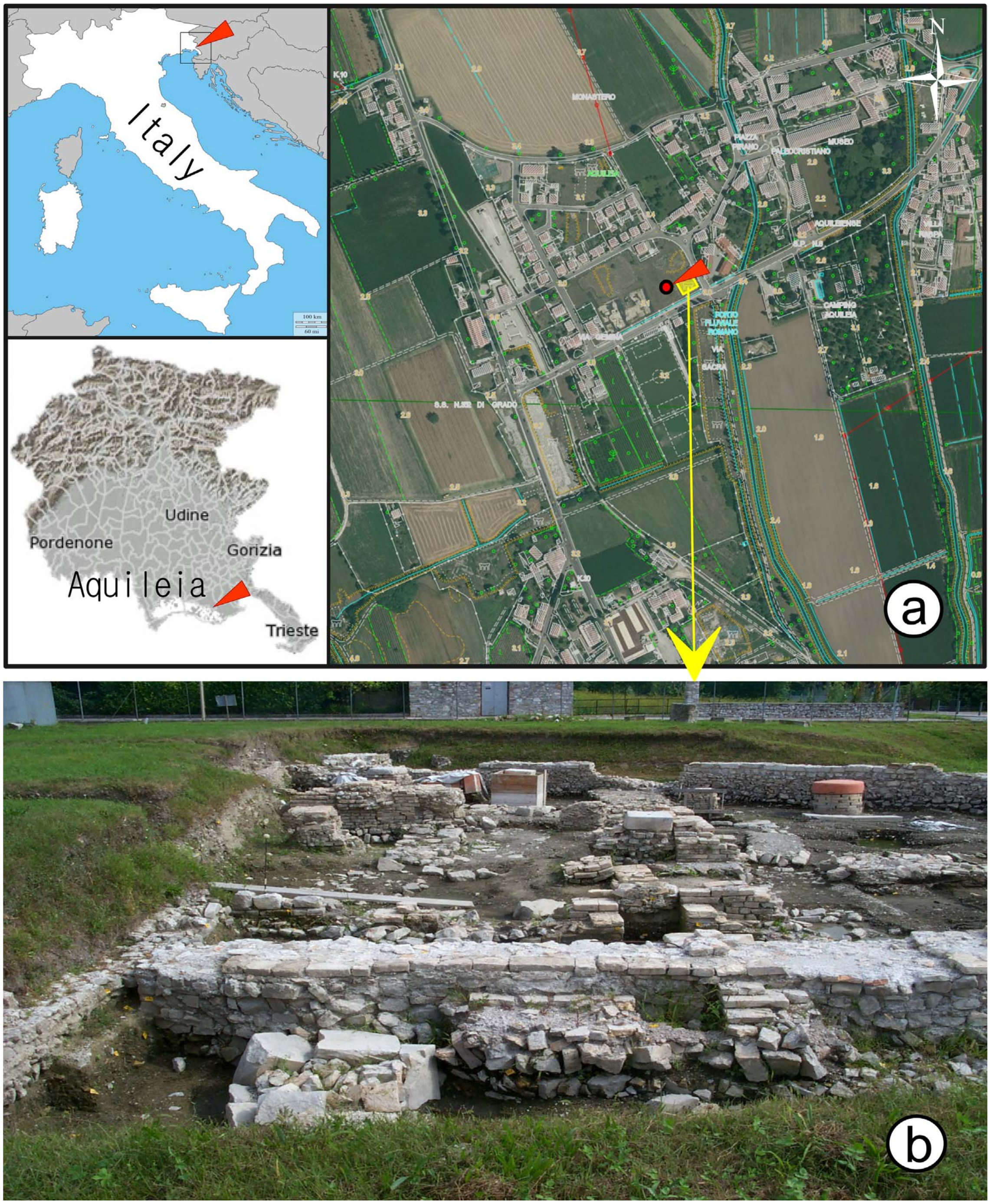

Fig. 1. Location map of the study area (a), adjacent to a previously excavated area (b), in the Aquileia Archaeological Park, NE Italy.

requires in many cases a quite simple processing. In such applications, 2-D reflections can be correlated from profile to profile throughout a grid, from which a better understanding of the spatial extent of targets is obtained. This "pseudo 3-D" volume (maybe "2.5-D" expression could be more appropriate) obtained combining series of in-lines and/or cross-lines has become increasingly common for archaeological surveys throughout the world (e.g. [36,5,13,3]). Such large GPR datasets can be nowadays managed by improved and more intuitive software, extending the GPR applicability and affordability.

Attribute analysis technology, which was originally developed in hydrocarbon seismic exploration (e.g. [28,12]), has been proposed and successfully applied into the GPR field [27,19,49,51]. GPR attribute analysis can maximize radar performances, as GPR attributes are potential indicators of meaningful subsurface changes in lithology or other physical properties of archaeological interests (e.g. [52,50]). Moreover, GPR attributes can often reveal or emphasize features or patterns not clearly visible on the usual amplitude data.

In this study, we calculated different attributes on common offset 2.5-D GPR grids to provide new information about the buried cultural heritage and the subsurface conditions in a sector of the Aquileia Archaeological Park, NE Italy. The analysis of GPR attribute helps correlating previous limited archaeological pit tests and integrating previous standard GPR analysis and interpretation.