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Combined GPR and ERT exploratory geophysical survey of the Medieval Village of Pancorbo Castle (Burgos, Spain)

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ABSTRACT

Ground-penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT) have been fruitfully employed for archaeological purposes. An area at the Pancorbo medieval site in Burgos (Spain) has been jointly explored by GPR and ERT in the search for the buried remains of the Pancorbo medieval village.
After data collection, quality control and merging, a shallow depth of interest was identified and studied in detail. 3D resistivity simulation, considering sensible geometrical structures of the targets helped discover anomalies present in the area. On the other hand, visual GPR inspection was considerably enhanced by trace energy attribute analysis which provided a plan view of the existing anomalies. Two posterior archaeological excavations have a very good correlation between the identified anomalies and the excavated remains. The survey also provides hints for the continuation of the excavation.

1. Introduction

The Pancorbo Castle (Burgos, Spain) has been during the high middle ages a main axis in the Castilla County, south of the Ebro river, which was at the origin of the posterior Castilla Kingdom (Ruiz Gómez, 2002). The castle is documented already since the IX century (Gil Fernández et al., 1986) but many unknowns remain about the particulars of its foundation and the causes of its rise in importance. With very few exceptions like the Tedeja Project (Palomino Lázaro et al., 2012; Quirós Castillo, 2013; Sanz Pascal, 2012) the archaeological knowledge of the numerous castles south of the Ebro river is very limited. A new archaeological project was therefore launched to study both the castle foundation and the suspected (buried) middle age village at its foot. The first phase of the project was to evaluate the archaeological potential of the hypothetical underground remains as a basis for a later intensive and focussed archaeological excavation. Geophysical techniques were employed for this goal.

Ground-penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT), have been selected as adequately and cost effective tools for the preliminary exploration of the site. Both can provide quick on-site approximate results, enabling modifications of the survey planning in almost real time and fast operation in broad, topographically demanding areas as was the selected study site.

Ground-penetrating Radar (GPR) has been widely employed in non-destructive evaluation for many different engineering purposes: concrete reinforcement testing, pipe location, landmine detection, shallow depth geological investigation, hydrogeophysical studies, forensics and criminology, civil engineering and prevention of geological hazards (Barone, 2016; Daniels, 2004; Jol, 2009; Reynolds, 1997; Wai-Lok Lai et al., 2017). GPR together with other geophysical tools is also successfully used in archaeology since the second half of XX century (Campana and Piro, 2009; Conyers, 2016; Gaffney, 2008; Goodman et al., 2009).

Modern GPR antennae work at central frequencies in a wide range from 10 MHz to 2.5 GHz. Lower frequencies reach deeper whereas higher frequencies (near to 1 GHz) are used to locate small shallow objects or structures. Central frequencies around 500 MHz are common in archaeological surveys (Goodman et al., 2009) and a GPR MALÅ™ ProEx System (MALÅ Geoscience AB, 2011) with a shielded 500 MHz antenna has been employed here in the constant offset (fixed emitter receiver offset) configuration. Using "small" antennae (250 MHz or higher, as in this case) the full equipment can be placed in a cart and every measurement is localized using a GPS or an odometer(Annan, 2009). See Fig. 1, left.

Although GPR allows certain features to be identified already in the field, some signal processing is usually needed (Cassidy, 2009). For

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Fig. 1. (Left) MALÅ GPR PRO-Ex with a 500 MHz shielded antenna mounted on a cart at the site. (Right) AGI SuperSting R8 ERT resistivimeter with cables and stainless steel electrodes.

this work, besides standard processing steps (1D and 2D filters and gains), attribute analysis (Zhao et al., 2013) has been performed to establish criteria to identify anomalies. 2D, 2.5D and 3D visualization techniques were also used as an aid for interpretation.

Electrical Resistivity Tomography (ERT) is largely used in subsurface applications, for example in hydrogeology (Revil et al., 2012) or soil sciences (Samouëlian et al., 2005), in archaeology (see for instance (Gaffney, 2008)) to identify man-made structures and in uncovering related geomorphological features (Bermejo et al., 2015; Papadopoulos et al., 2014; Zheng et al., 2013).

ERT profiles have been performed using the multichannel Advanced Geoscience SuperSting R8 (Advanced Geoscience Incorporated, 2005) instrument and stainless steel electrodes (see Fig. 1, right). The dipole-dipole and Wenner-Schlumberger electrode configurations have been employed. The measured apparent resistivity values are transformed into estimates of “true” resistivity values placed in the profile vertical cross section by means of an inversion process. The obtained resistivity distribution reproduces the measured data within an acceptable tolerance level.

2. The site

The Pancorbo Castle lies at the left side of the Oroncillo river, above the modern village of Pancorbo in Burgos (Northern Spain), at the bottom of the Pancorbo gorge, a natural defile of extraordinary historical relevance (see Fig. 2).

The archaeological ensemble contains three units: the castle itself, on top of an almost inaccessible calcareous outcrop (696 m.a.s.l.); a close accessible platform excavated on the rock known as the castle Sala (681 m.a.s.l.) and a fortified area with more than 6000 m^2 called Santa Marta (670 m.a.s.l.). The fact that this area lies between the castle and the modern village at the valley bottom, with its late Middle Ages churches, together with the existing remains of a fortified wall suggested it was an adequate place to explore for deposits with archaeological interest.

3. Geophysical prospection of the site

3.1. Ground-penetrating radar

Twenty six GPR 40 m long (app.) survey lines (labelled P1 to p26 from South) were measured in a West-East direction. The separation between the first ten lines was increased from 1 m, after real time inspection, to 2 m between the remaining lines. Five additional transversal profiles (labelled T1 to T5 from the West), with a length of around 40 m and 10 m spacing were marked and measured along the North-South direction –perpendicular to the 26 initial profiles (see Fig. 3).

Although the use of frequency antennae with less than lower 500 MHz was reported in previous references (Bonomo et al., 2009; Nishimura and Goodman, 2000), in situ trial profiles showed the 500 MHz antenna to provide both better quality data compared to 250 MHz and a sufficient penetration depth. The GPR system was mounted on a cart with an odometer and set up with a trace spacing of 2 cm with automatic stack mode. A time window of 150 ns with a sampling frequency of 5337 MHz was judged adequate. Differential GPS was performed to provide coordinates.

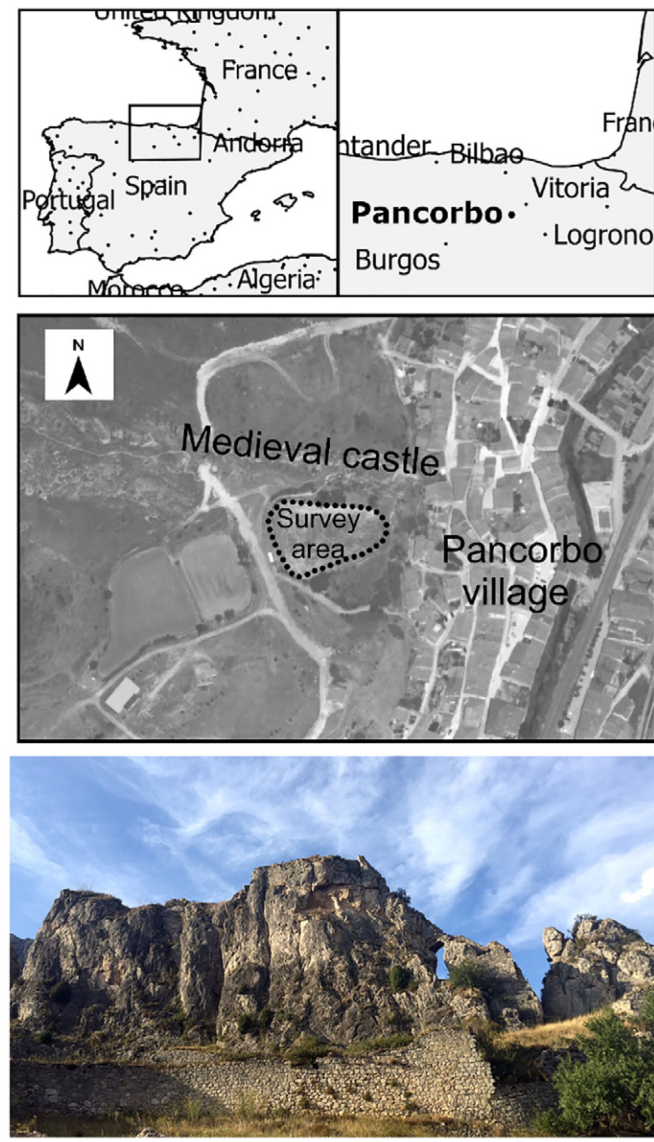

Fig. 2. Geographical location of the Pancorbo site in Burgos, Spain (top). Plan view of the surveyed Santa Marta area between the castle and the modern Pancorbo village (middle) and the ruins of Pancorbo Castle as seen from the surveyed area (bottom).