Retrieving 3D Subsurface Structures with Geoelectric for Archaeological Decision Support in Nemi, Italy

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Abstract. Visualizing antique structures is essential in archaeological research. Most visual reconstructions are based on measured, modeled and displayed excavated building structures. However, in various excavations subsurface structures are not accessible. One suitable method which allows investigation of those structures is geoelectric. Subsurface materials show different resistivity values. Thus, the type of underground material can be derived from geoelectrical measurements. In this paper we describe an implemented workflow about identifying, capturing, analyzing and visualizing belowground ancient structures. Application case is an excavation of the sanctuary of Diana in Nemi, Italy.

Keywords: geoelectrics, archaeology, 3D visualization

1. Introduction - Geoelectrics in Archaeology

Since the 1980s applied geophysical techniques of non-destructive subsurface investigations have been practiced, applied and further developed in archaeology in order to identify belowground antique structures. Beside geomagnetic, electromagnetic and georadar-techniques, geoelectric is a long- established and well-documented application of near-surface geophysics (Mauriello et al. 1998). Early approaches had been published in (Noel & Xu 1991; Patella 1978; Wynn 1986). Hence, it is possible - under optimal conditions - to reconstruct an entire antique settlement without excavation. Using non-invasive geophysical exploration techniques, the different local physical properties of rocks and soil play a crucial role for choosing an appropriate technique. It is assumed that undiscovered belowground ancient structures have significant different properties in comparison with the surrounded and superficial layers of the soil and rocks.

The main objective of this work is to identify, capture, analyze and visualize belowground ancient structures (e.g., buildings, roads) of an archaeological site with the use of Geoelectrical measurements.

2. Study Area and Previous on-site Works

The sanctuary of Diana is located inside an extinct volcano in the territory of Nemi, just at the south of Rome. The sanctuary covers an area of about two hectares and is known for at least two centuries. Archaeological researches in accordance with modern scientific methods have started in 1989 by the provincial archaeological authority “Soprintendenza per i Beni Archeologici del Lazio”. In 2003 the University of Perugia and in 2012 the Technical University of Munich joined this excavation and archaeological documentation campaign (Filser et al. 2013). Human settlement in the area of Nemi started from the Neolithic period and is well attested in the Bronze Age. The main building of the shrine is the temple, which includes several building periods. Furthermore, the sanctuary is rich in structures; many of them are still undiscovered and only assumed to be located belowground at the archaeological stock. Geoelectric survey is one suitable method which allows us to investigate areas of the sanctuary in which it is impossible to carry out excavations, due to the vegetation, cultivation, lawful conditions or logistical difficulties.

During the last ten years the Sanctuary, including temple, terrace walls, roman streets and other antique structures had been excavated and investigated. Furthermore, an Archeological Geographic Information System (A-GIS) had been created. The concept and implementation of the A-GIS applied to the Sanctuary of Diana (Nemi) was published by Peters et al. (2013).

Figure 1 illustrates in red colour all above ground captured antique structures, such as the temple (centre), a part of the terrace wall (right) and 2 parts of the roman road “Via Apia” (left). The blue circle marks an area, wherein archeologists expect further antique structures, based on the previously accumulated knowledge of the sanctuary.

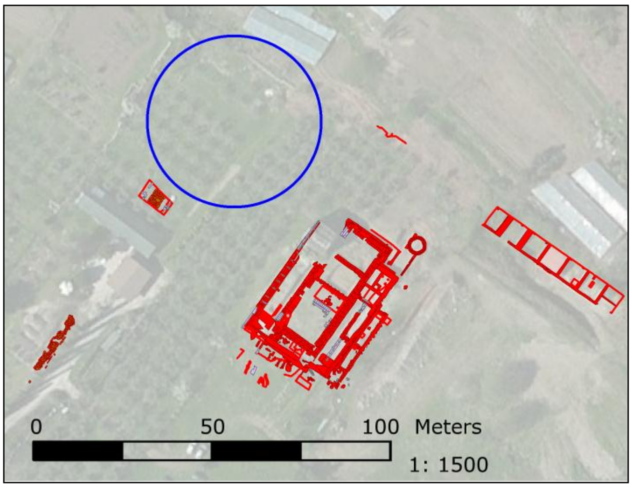

Figure 1. Excavated antique structures (red) and assumed area for belowground findings (blue circle).

The sanctuary is located in a volcanic territory and thus antique structures were made out of basaltic rocks. Due to this geological subsurface composition Geoelectric is one of the most appropriate geophysics methods for our purpose.

3. Geoelectrical Measurement

Geoelectric is a geophysical method in order to explore and extract subsurface objects. It is based on resistivity contrasts of subsurface materials. Resistivity of different materials in nature (Ward 1990). A straight geoelectric measurement line, as unfolded between point 'A' and 'B' in *Figure 2* forms an electric field. Along that line, electrodes are placed in equidistant spatial intervals. Furthermore, *Figure 2* demonstrates current flow lines (solid) and equipotential lines (dashed) for a two-layer case with larger resistivity in the first layer.

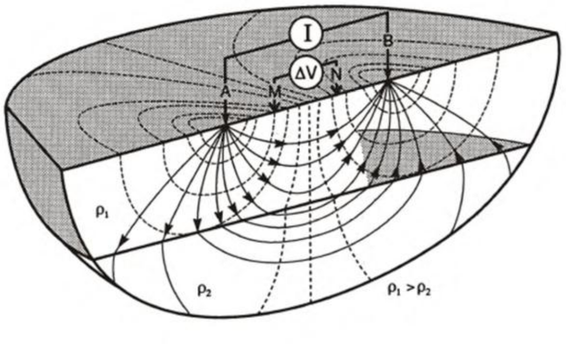

Figure 2. Schematic illustration of a four-electrode arrangement after (Knödel et al. 2006)

Subsurface materials show different resistivity values. Thus, the type of underground material can be derived from geoelectrical measurements.

4. Resistivity Analysis and Visualization in 2D and 3D

Figure 3 illustrates the composition of geoelectric measurement lines in our area of interest. The map is oriented to the north. Altogether 8 lines (Nemi03 – Nemi10) were aligned in parallel (with a distance of about 5m between each line). To dense the underground resistivity measurements in the area of interest, three further vertical placed lines (Nemi11-Nemi13) were installed. Each line consists of altogether 41 diodes with a distance of 1,30m between them. Thus, every line reaches 52m. All lines were geodetically surveyed, using total station, transformed into the reference system (WGS84), and imported into the A-GIS.

Geoelectrical measurement leads to electrical resistivity values for each grid point on the 2D transverse section below each geoelectrical measurement line.

Figure 3. Geoelectric measurement lines (red).

Interpolation and subsequent classification of captured underground material resistivity values produces a contour map as illustrated in *Figure 4*. Within the classification we focused on resistivity values representative for basalt rock formations: Values range from 250 (blue) until 700 (red) ohm-m. Previous studies about correlations between materials and resistivities had proven that the resistivity of basalt range from 250 ohm-m and higher and hence differ from other materials such as topsoil, clay and sand which also occur in Nemi (Drury & Hyndman 1979).

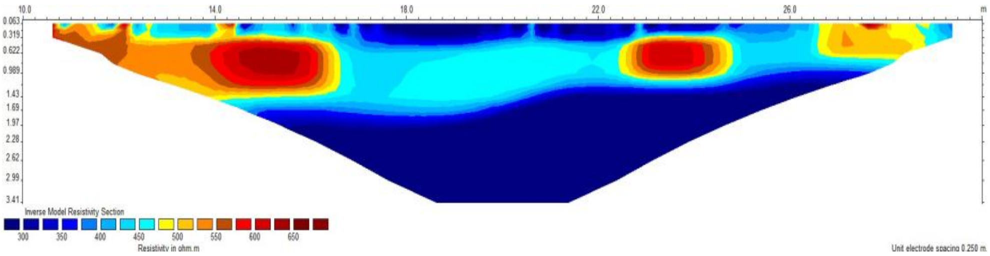

Figure 4. Contour map of resistvity measurements.

Figure 4 is already a useful result. In order to derive information about basaltic rock deposits between the geoelectric lines further interpolations are necessary. *Figure 5* shows the distribution of all measured resistivity values (sample points) using different colours depending on the z-value. One goal was to create a 2D map illustrating assumed basalt subsurface deposits.

Therefore we can only assume one resistivity value for each location (x,y). In a first step for each above ground sample point, a representative resistivity value has to be determined. This can be done by calculating either the mean or maximum of all vertical values. We decided to perform the subsequent interpolation with all mean values.

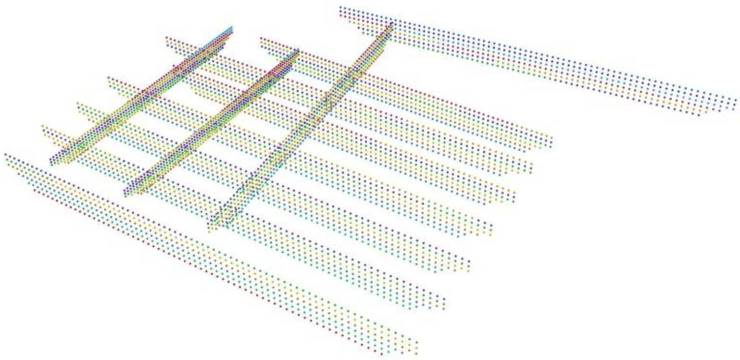

Figure 5. 3D plot (side-perspective) of resistivity sample points.

Common 2D interpolation of sample points are Inverse-distance-weighted interpolation (IDW), Spline-Interpolation or Kriging (Peters 2009). We decided to apply IDW-interpolation. Interpolated values were classified and a contour map was produced. Classification and color scheme are crucial for appropriate map reading.

3D interpolation will result much more information about belowground basaltic assumptions. Methods can be divided in linear, nearest neighbour, cubic and spline interpolations. Applying these methods to our sample data, results differ not significantly.

Figure *6* illustrates interpolated resistivity values in 3D and *Figure 7* in 2D (using Matlab software). For better illustration of the important resistivities, values below 500 ohm-m were not displayed. An adequate choice of graphic variables, such as colour and transparency is important. Furthermore, an interactive use of the graphic will help archaeologists to gain information about assumed belowground basaltic locations.

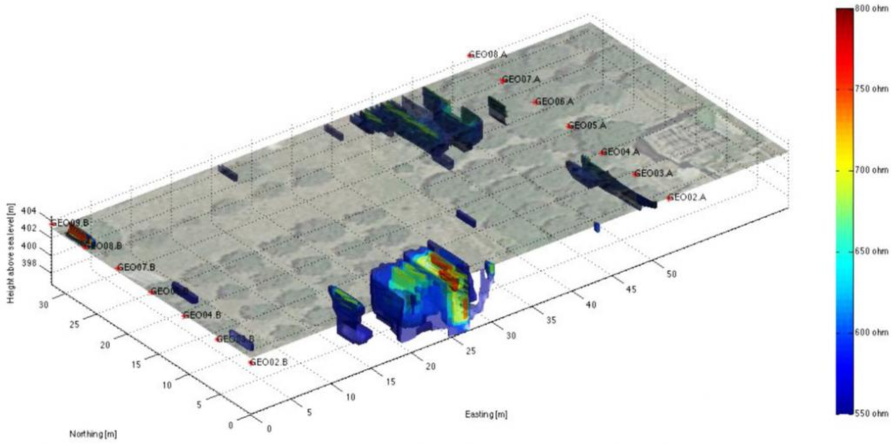

Figure 6. 3D visualization of resistivity of interest and aerial photo overlay.

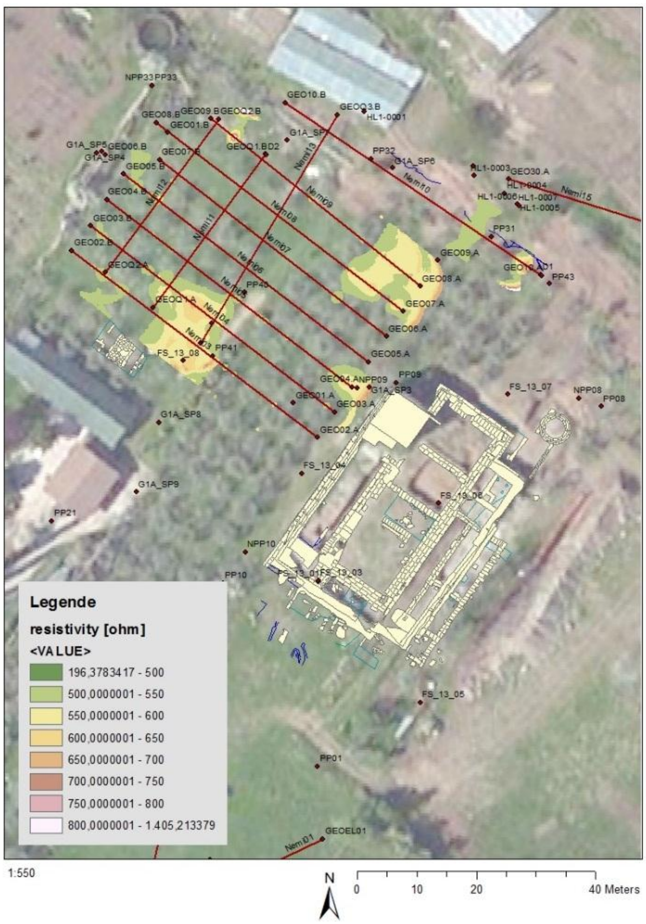

Figure 7. 2D visualization of resistivity of interest and aerial photo overlay.

5. Conclusion and Outlook

Geodata acquisition, data management as well as visual presentation and analysis are crucial for archaeologists in order to investigate antique structures.

In order to derive useful belowground material information in an area of interest while using geoelectric, we can conclude that the following points are very important: the composition of geoelectric lines, the choice of an appropriate interpolation method, and an adequate visualization of interpolated results (interactive, 3D, etc.). Further investigations are considered involving a denser geoelectric surveying to refine results and to prove results through test-excavations.

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