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Geophysical investigations of tumuli: a continuously challenging problem

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INTRODUCTION

A tumulus is a superficial hill constructed once upon a time as a burial monument and it comprises a landmark (Fig. 1). Usually, it conceals one or more tombs which may be monumental and if not looted, they may contain important finds. The bad practice of the past was to destroy the embankment in search of concealed tombs. After the destruction, despite the fact that the tumuli by themselves are monuments, the embankment was seldom restored.

By definition, geophysics is the main scientific discipline which may help in locating the concealed tombs and thus lead to excavation of a small portion of the whole structure, preventing its complete destruction. However, the geophysical investigation of a tumulus involves a difficult and occasionally challenging approach. The survey must be performed on uneven ground and the target might be small compared to the distance from the surface. Moreover, the tumulus embankment is usually inhomogeneous and it may consist of several layers. Also, in some kinds of tumuli, in particular the so-called "Macedonian" type that is very common in northern Greece, a pit was opened and a "dromos" was constructed leading to the tomb (or tombs). Then, all these structures were buried under the embankment. In these cases, the edges of the pit form an extra anomaly in the geophysical fields, tentatively confusing the interpretation of the geophysical data. Confusion may also be created by the presence of an enclosing or supporting wall.

The aforementioned reasons render the whole operation very difficult and challenging. If the operation is successful, it is rather rewarding, since it largely contributes to saving the integrity of the monument.

NON-TOMOGRAPHIC APPROACHES

Electrical mapping methods were employed to investigate Thracian tumuli in Bulgaria (Petkov and Georgiev 1988: 1095; Tonkov and Katevski 1996: 122). They conducted radial and circular profiles and then constructed apparent resistivity contour maps. Several successes were claimed, but the detected tombs were rather large compared to the size of the tumuli they were buried in and the material was rather homogeneous.

Vertical electrical soundings (VES) were used by Tsokas and Rocca (1987: 100–101) in northern Greece and Pinar and Akcig (1997) on the coast of the Marmara sea.

Several other methods have also been used with varying success and for particular types of tumuli. Indicatively, the electromagnetic method was applied in Switzerland (Frohlich Gugler, Gex 1996), mag-

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Fig. 1. Tumuli are artificial funerary hills comprising landmarks, meaning they can be seen from far distances. The tumulus shown here is in the Region of Macedonia (North Greece) and it is one of the larger ones, having a diameter of about 100 m and a height of about 19 m

netic and GPR prospecting was applied by Sarris *et al.* (2000), and Smekalova *et al.* (2005) successfully employed the magnetic method on tumuli in Denmark and Crimea (Ukraine).

The technique of seismic refraction fan shooting was employed in Greece by Tsokas *et al.* (1995: 1736–1737) and Vafidis *et al.* (1995: 120–121) to investigate the so-called "Macedonian" tumuli. In fact, seismic waves were created by a sledge hammer on the top of the tumuli and their arrivals were recorded on geophones arranged along the periphery. In this way, delayed arrivals were detected because of the presence of a "dromos" and therefore the concealed tomb was located indirectly. The technique seems to produce good results for that particular type of tumulus.

TOMOGRAPHIC METHODS

Polymenakos *et al.* (2004: 147–149) employed seismic tomography in Greece while Forte and Pipan (2008: 2615–2616) used the same method plus GPR surveying in northern Italy.

The use of electrical resistivity tomography (ERT) proved to be advantageous in investigating the interior of tumuli. Several successful examples can be found in literature including the implementations of Tonkov and Loke (2006: 133–134) and Astin *et al.* (2007: 29), which show the potential of the method.

The potential of the 3D ERT survey was shown by Papadopoulos *et al.* (2010). Further, Tsourlos *et al.* (2014) compared the relative merits and drawbacks of the regular rectangular grid against the grid of 2D radial tomographies. In both cases the data were inverted using a 3D algorithm.

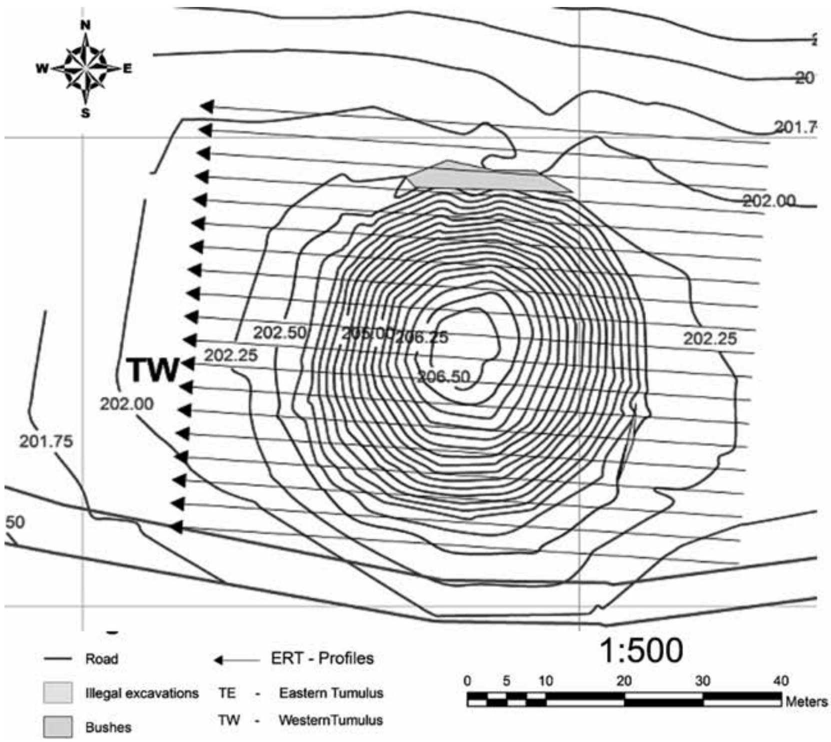

Fig. 2. The transects, along which ERTs were carried out, have been superimposed on a topographic sketch map. The tumulus shown in this example is near the village of Spilaion in Thrace (North Greece)

The example that is next demonstrated has been taken from the survey of tumuli near the village of Spilaion in the prefecture of Evros in Thrace (Northern Greece). Parallel ERTs were carried out covering the given tumulus and the surrounding ground (Fig. 2).

The data were inverted employing the 3D algorithm described by Tsourlos and Ogilvy (1999) and they were further processed using the algorithm of Yi and Kim (2003), which is of similar type. The 3D distribution of resistivities was then used to produce vertical and horizontal slices. Shown here is the horizontal resistivity distribution for the elevation 202.5 m above the mean sea level (Fig. 3). Clearly there is a high-resistivity anomaly at the center and other northwards at the periphery of the tumulus. They both comprise targets for future excavation.

CONCLUSIONS

Geophysical prospecting methods comprise the only technology to investigate the interior of tumuli without destroying them by excavation designed to search for potential concealed monuments. In this respect, geophysics act toward preserving most of the initial shape of the tumulus, which is a monument in itself.

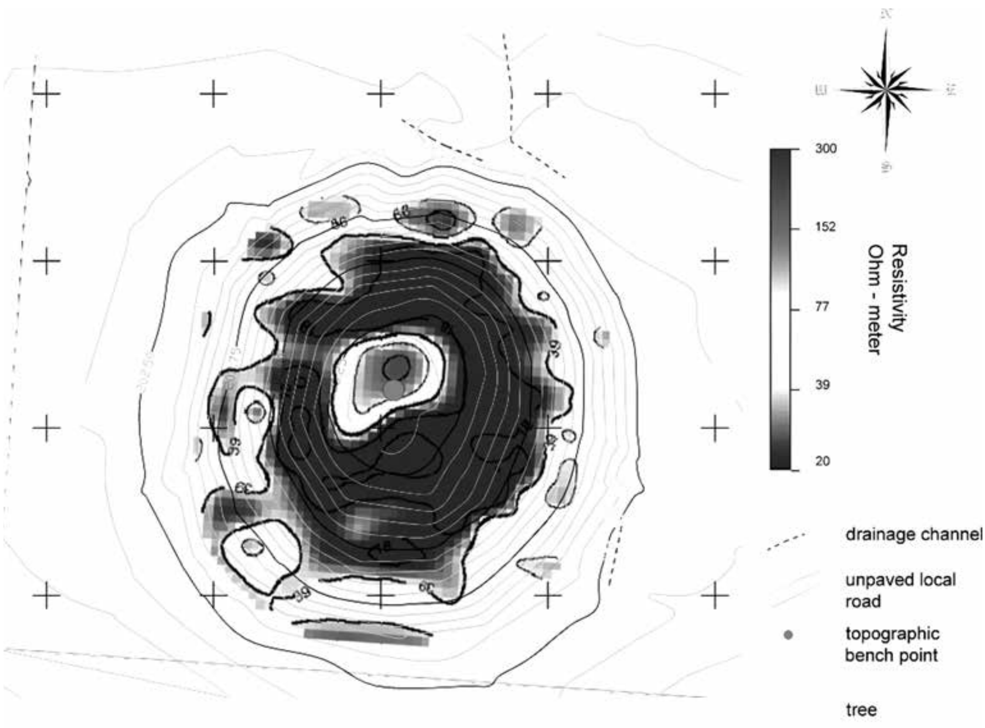

Fig. 3. Distribution of resistivity at a depth slice at 202.5 m above the mean sea level

Resistivity tomography is one of the most reliable tools for such a purpose. Moreover, it works in all environments, whereas the other methods tried so far seem to be applicable under special conditions.

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