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Palaeotopography
The Use of GIS Software with Data Derived from Resistivity Surveys and Stratigraphic Profiles to Reconstruct Sites and Past Terrains

Abstract: The aim of this study was to recreate the past terrain and major features of a site using data from stratigraphic profiles and data from earth resistivity surveys. Stratigraphic information throughout the site was gathered through traditional excavations over the last four years. Resistivity surveys were conducted over larger areas to produce 2D multi-depth inversion profiles and single depth plans. Resistivity analyses were calibrated with known depths from excavation stratigraphic profiles. The information from both sources was plotted three-dimensionally in ArcGIS 9, where data layers were created for different pedological and archaeological strata and features. Points that would have been on the surfaces of the ground or features at different points during the past were determined. These points were then used to recreate the past topographies and produce 3D and 2D map reconstructions of the site.

Introduction

The objectives of this study were relatively simple. Its goals were to use existing data from the research at a site to recreate the ancient topography and make reconstructions of the archaeological features. In this case, the data was derived from resistivity surveys (inversion profiles and traditional single depth grid plans) and traditional excavation profiles and plans.

Background Information

This study was conducted on the river facing terraces at Mă gura Uroiului ("The Uroi Hill") in Romania. More precisely, this site is located in south-western Transylvania in the county of Hunedoara. Although studies were done throughout Terrace 1, the most intensive research was conducted in the SW part of Terrace 1 (near Terrace 3) and on Terrace 3. Both terraces can be seen here in *Fig.* 1 (a topographic and relief overview map of the two terraces). In *Fig.* 1 the terraces are outlined (by orange lines) to show their boundaries. Several of the excavation trenches are indicated on this map by light blue rectangles. The lines, where resistivity profiles were made are indicated by short straight red lines. The modern roads are shown in grey. These are significant, as can be noticed when studying the location of the ancient roads which appear to be in the same location for part of the terrace. The area separating the two terraces is a relatively steep slope about 3 m high and has a man-made ditch and a rock/earth fortification at the top (post holes and traces of additional wooden fortifications have also been identified). The area at the edges of the terraces where pieces of rock and relief evidence of the earth wall is visible at the surface is indicated on the map with sets of yellow lines running relatively parallel.

Data Collection

Traditional Excavations and Stratigraphic Profiles

On Terrace 3, situated at the base of a short slope connecting it to Terrace 1, a stone platform was found 1.14 m below the surface. It appears to have a constant width of almost 2 m, a thickness of about 0.8 m and a length of at least 15.5 m (the full length is unknown). Beneath the stone structure are burials and pottery from the First Iron Age. Artefacts and adobe huts discovered above or directly on top of the platform were from the Second Iron Age (Ardeu / Bălos 2002). Archaeological investigations at the periphery of Terrace 1 showed the existence of a low earth wall covered by stones (likely for reinforcement) running its length. Many of the stones from the upper part of the wall have fallen down to the lower part of the outside slope and over the features from Terrace 3. These features and strati-

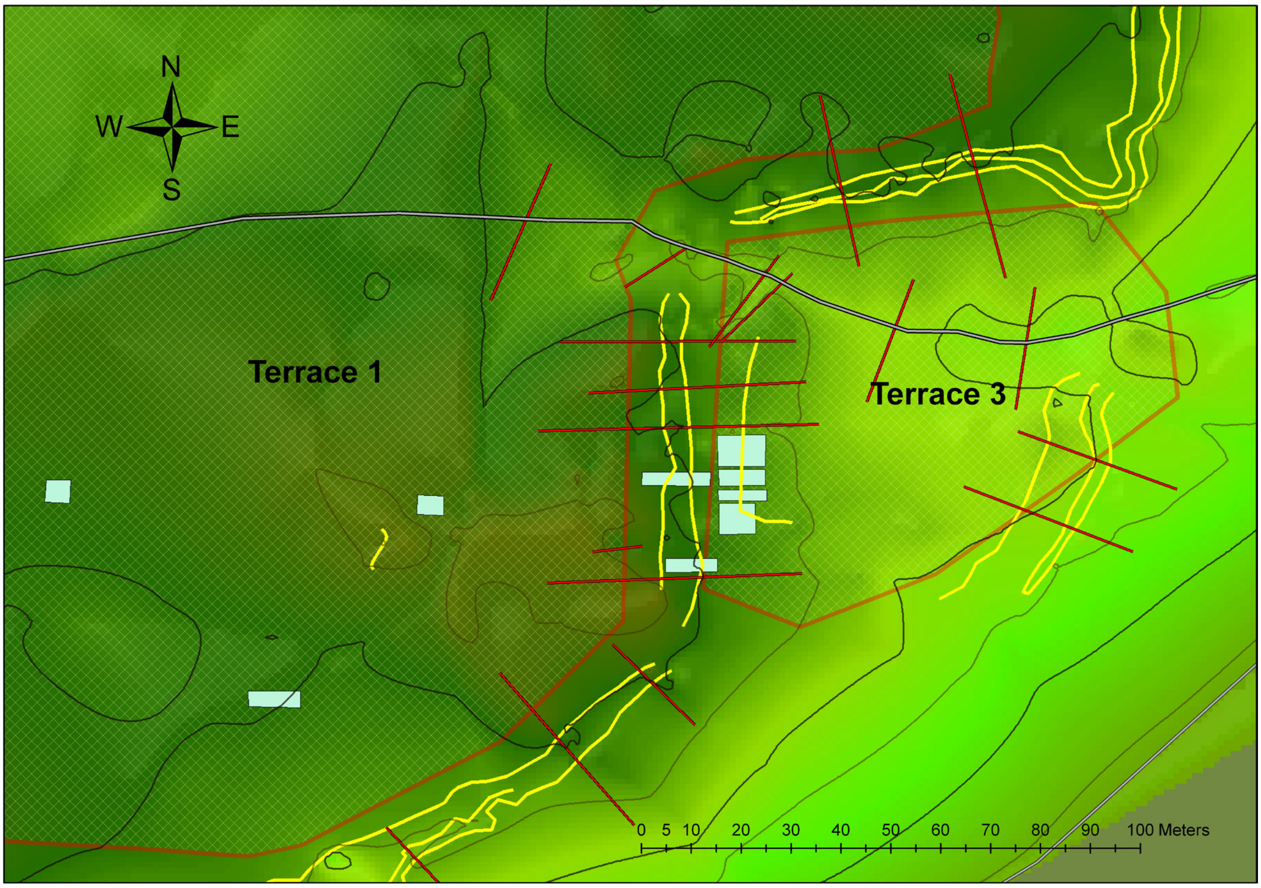

Fig. 1. Map of Terraces 1 and 3.

graphies can be seen relatively clearly in the 2D resistivity inversion profiles. Preliminary field walks and geophysics surveys suggest that Terrace 3 may also have been fortified at its outer periphery. The stratigraphy suggests that at their time of final abandonment the stone platform of Terrace 3 was contemporary with the stone cover of the Terrace 1 earth wall (i.e. both were at the surface). Since it is thought that the platform was placed over the burials, the platform is likely older than the earth wall but was still in use when the wall was constructed. This chronology was noted when reconstructions were made. In all of the excavation trench profiles, the stone platform, the earth wall (and its stone cover) as well as rocks fallen down the slope are all clearly visible. Examples are shown in *Fig.* 2.

Of final note, there is a modern dirt road that passes through Terrace 3, an opening in the earth wall fortifications and through Terrace 1. It is possible that this road was in use in ancient times as well because the fortifications do not exist in this part and it is one of only two ways of entering Terrace 1 without crossing the fortifications (natural or man-made), the other entrance being on the opposite side of the terrace. At the opening to the left of the road, resistivity surveys revealed a large stone object (likely over a metre long and half a metre wide) buried near the surface. Resistivity surveys done on Terrace 3 near and through the opening in the fortification suggest that to the left of the stone object there was a second lane running parallel to the lane in modern usage and that there may also have been slight ditches on each side of both lanes.

Resistivity Surveys

Resistivity profiles were created by surveying lines of probes and measuring multiple depths. The profile lines ran perpendicular to the edge of Terrace 1, down the slope and into Terrace 3, several crossing the stone platform. Probe spacings were from 1 m to 6 m separation. The Res2DInv software package was used to process the resisitivity datasets to produce predictions of the depth of features along the profile lines. The first results show a very good reconstruction of the actual profile but the more processed

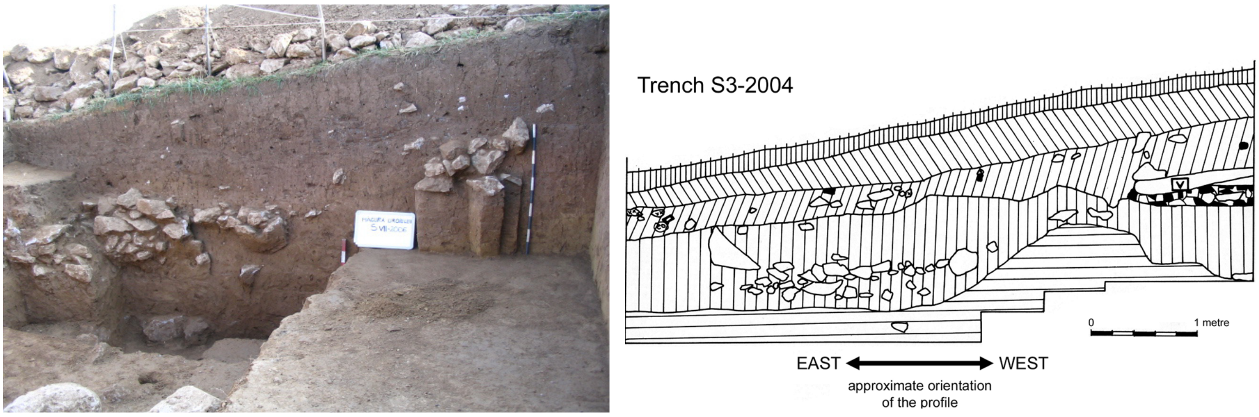

Fig. 2a. Photo of Terrace 3. b. Diagram of Terrace 3.

results (those with more iterations) show the depth more accurately. At the left, the mortuary platform shows up. To the right, one can see evidence of the rocks which have rolled down from the top of the slope. Note that the stone platform appears much thicker in the resistivity profiles than in the excavation profiles. This illustrated the great value of being able to calibrate the resistivity results with information gathered from several excavations.

It should be noted that although the data presented in this image is flat, the software used can also plot it with topographic data to give the true contour of the profile, however this requires the user to have a registered version of the software. Res2DInv is capable of outputting data either as a graphic file or as simple data. The data used for the latter reconstructions was from simple Cartesian coordinates (length and depth from the beginning of the survey line) of the different resistance bands determined by the software. Dates for lines indicating the top and bottom of features were particularly noted for use later in reconstructions.

A few survey lines were conducted over the suspected road to confirm its profile. Since the road is relatively close to the surface, 1 m grid surveys were conducted as well. These measured the resistivity to approximately 0.5 m depth. Surveys were conducted in the area of the suspected gate and along a regular section of the road. The roads appear to have been curved, rather than flat, surfaces with drainage gutters at the sides. In the centre of the opening in the fortifications is a large object. Surface inspections indicate that it is either one large rock or several medium sized rocks grouped together, with a few edges extending to the surface. Although the modern road is only a single lane, the ancient road appears to have been two lanes wide as it leads up to the gate/entrance to the terrace. The right lane is located beneath the modern road. This probably accounts for the difference in resistivity of the two lanes, since continual use would have packed the earth down more. The location of the road was plotted geographically for later use.

Modern Topographic Surveying and Georeferencing of Studied Areas

Topographic surveys recorded the relief of the terraces as well as the outlines of the excavation trenches, the resistivity surveys and interesting features that have been found during field walks. ArcGIS 9 software suite was used to create a digital elevation model (DEM) from the raw data. In particular, a raster image was interpolated using the "Natural Neighbours" function of the 3D Analyst tools. The location of the features shown in the excavation and resistivity profiles were plotted out on the surface of the DEM and the modern surface above these features was recorded.

Results – Reconstructions of Ancient Topography and Features

Once the data from the excavation and resistivity profiles was georeferenced, it was possible to begin creating the reconstructions. To make the reconstructions, each feature and the ancient ground surface were created separately in ArcGIS and then assembled together at the end. For the excavation profiles, the depths of the stratigraphic layers and the features were subtracted from the altitude of their corresponding modern surface points. This was based on the data from the DEM file and the edges of the excavation trenches (which had previously been georeferenced and plotted in ArcGIS). Various points were chosen at even intervals or at points where the edge of the feature or ground surface altered significantly. This data was stored in a table. For each point the latitude, longitude and altitude (above sea level) were noted. With the resistivity data a similar process was carried out. The depths of features were already recorded in the inversion profiles. These depths were again subtracted from the modern surface altitudes at the corresponding locations along the georeferenced resistivity survey lines. The depths of the features in the resistivity profiles were checked against the excavation profiles and calibrated if necessary. This was often necessary for the underside of features (from which some of the ancient ground surface was derived) because the resistivity profiles often made the features look thicker than they actually were. Once the depths were established, it was possible to subtract those depths from the modern surface depths. For the upper surfaces of features, this was generally not a problem but for the bottom surfaces, comparison to known feature depths and ultimately corrections were needed. As well as appearing thicker in the resistivity inversion profiles, the shapes of the features are also less detailed, and needed to be slightly modified to conform to the general forms found in the excavation profiles. This data could then be used to recreate the ancient ground surface and the features.

To recreate the ancient ground surface, it was necessary to observe the detailed stratigraphy in the excavation profiles. These clearly showed where the surface layer was during both the First and Second Iron Ages. The relationship of the ancient ground surface to the features was noted, with special attention paid to which features lay above and below the surface. The slope between the terraces seems to have been relatively direct and went under the rock cover at the top and arrived at the rock platform at the bottom, with a few rocks above ground level at the bottom of the slope. The depth of the ground level on the terraces seems to be relatively even in areas away from the slope as well. Therefore, the elevation of the ancient ground was assumed to be uniform across Terrace 1 and evenly distributed on Terrace 3 from the stone platform to the depths recorded at the opposite side of the terrace. The ancient ground surface was reconstructed using the values for the underside of the rock cover and the top of the rock platform, combined with the even depths in Terrace 1 and Terrace 3.

Using the same topographic modelling functions from ArcGIS that were used to create the modern topographic relief model (the DEM file), the upper and lower surfaces (separately) of features were recreated. Unfortunately this was not as successful as hoped. The "natural neighbours" function often smoothed the points that stuck up a lot. The results were not very good and the reconstructed features sat too close to the surface that represented the ancient ground, sometimes sitting right on it, or even below. A decision was made to recreate the upper surfaces of the features using the TIN function of the 3D Analyst tools. The results were more angular and looked less realistic, but they retained their form better, which made them more visible. A downside to using either of these methods is that they are best suited for simple polygon-type shapes (e.g. rectangles, circles, etc.), not the long and bended form of the fortifications. For this reason, it was necessary to reconstruct the fortifications in segments. Otherwise, the software attempts to represent the detail on the inner side of all the bends, which distinctly distorts the appearance of the fortifications.

The road was more difficult to reconstruct in detail as only a few sections of it were researched by resistivity. For the road, it was assumed that the sections identified in the resistivity survey were connected uniformly and that they continued to follow the modern road (as that is the only easy way to get to and from Terrace 3). In the reconstructions, the road simply appeared as a slightly raised surface over the ancient ground surface layer. It is suspected that the road is not very deep below the modern surface.

All of these objects (features, ancient road and ancient ground surface) were viewed together in ArcMap to produce a possible map of how the area would have been during the Second Iron Age. The set of files was also viewed using ArcScene to produce 3D views of the area.

Fig. 3 shows a predictive reconstruction of the topography and relief at the time of the fortifications (the Second Iron Age). It is almost the same as the modern topography except for a more steep slope between the two terraces. The black and white objects are the fortifications that showed up in the excavations and resistivity profiles. Note that there are not only fortifications along the edge of Terrace 1, but also along the lower edge of Terrace 3. During

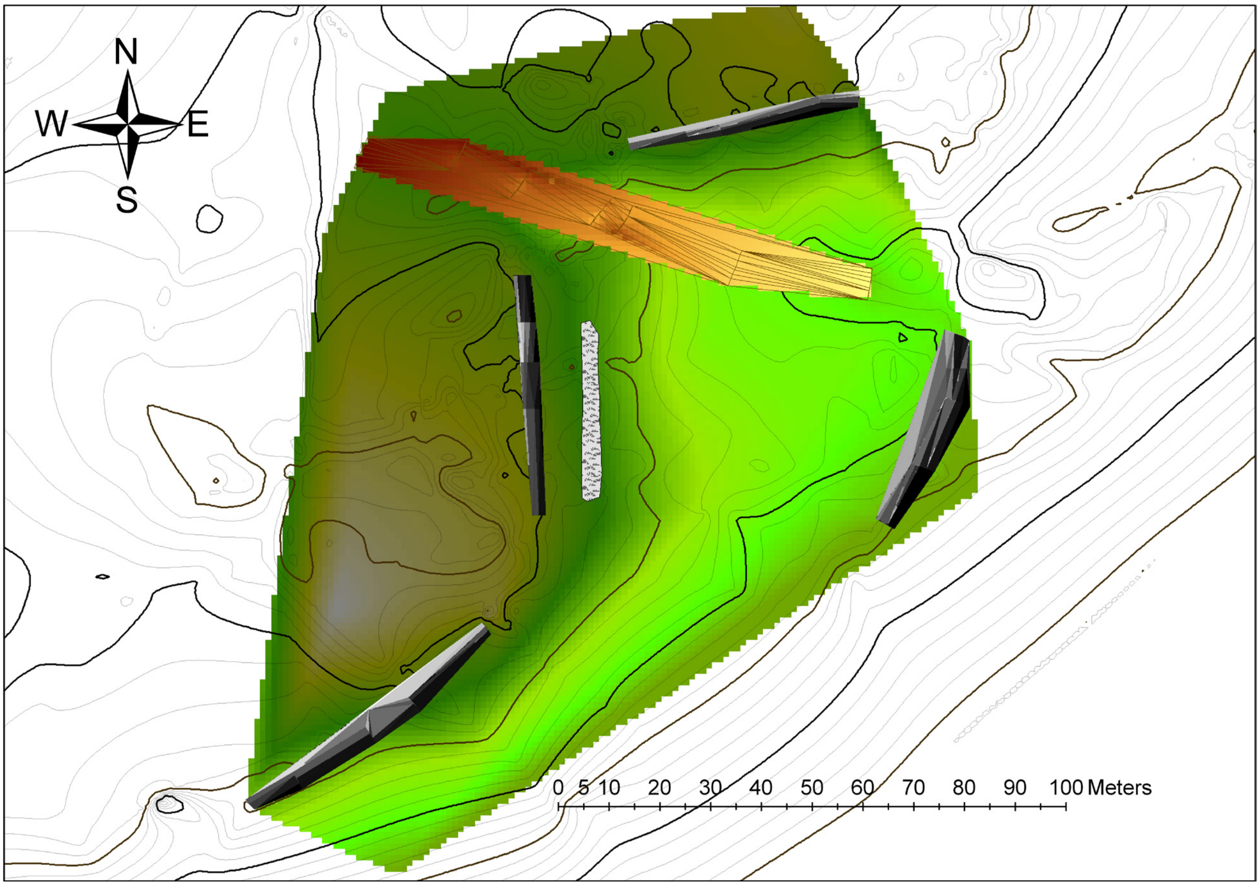

Fig. 3. Map showing the relief and features.

a previous excavation in this region, military equipment was also found and it is suspected that near this fortification there was some sort of fortified building such as a tower. The light grey object at the base of the slope in the western part of Terrace 3 is the stone platform that was above the graves. The orange coloured object is the road that was revealed by resistivity surveys (it is believed to extend down the slope more but only this part of it was analysed by resistivity surveys). This road will be further investigated by test pits in future excavations. *Fig.* 4 shows a 3D view of the same area. In this 3D image, one of the fortifications segments has been left as a DEM type object to illustrate the difference between DEM and TIN type objects.

Conclusions

Uses for this Type of Reconstruction

There are various uses for this type of project. Traditionally, resistivity surveys and the predicted extent of features placed on a map have been used to help a researcher to predict the best places to dig to find desired features. Predicted reconstructions also make it easier to visualise how a site appeared, thus giving researchers a better impression of the site in past times. By creating the reconstructions from data files that already exist or require only slight modifications, one can produce visual results in a shorter time. This is particularly valuable when funding for the next season depends on showing interesting results from the previous season. Similarly, reconstructions in general make site reports more appealing to non-archaeologists, which may include possible sponsors for future excavations.

The main outcome of this study of the Măgura Uroiului Project was that it was possible to quickly adapt data that was already available, in a format that was already in use, to produce visual representations of the ancient site, including both the topography-relief and the major features. This is important in Romanian research because funding for each year depends largely on how spectacular the discoveries of the previous year were. The audi-

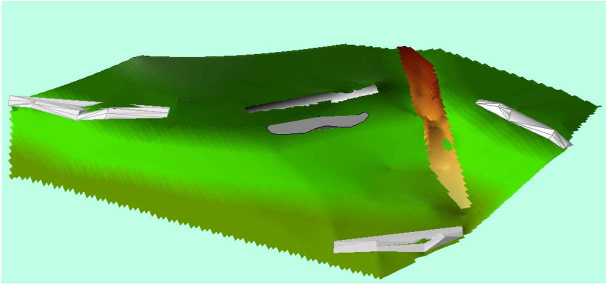

Fig. 4. 3D view of the ancient site during the Second Iron Age.

ence, however, often consists of non-archaeologists, who may not judge the discoveries according the the same criteria that an archaeologist would.

Future Developments of this Type of Project

The value of this type of study could be further enhanced by anyone of a number of different future developments. The data used in this study (and in some cases produced as a result of the study) could be imported into more visually appealing software such as 3D Studio Max or AutoCAD. This would give a more realistic appearance to the reconstructions by giving them more details as well as the ability to paste realistic textures over the features instead of the highly vectorised, single monochrome coloured features created by ArcGIS. In addition, other data types (such as ground penetrating radar and aerial photography) could be incorporated into the data set. If time and resources permit, it would be advantageous to do parallel resistivity profiles in order to do 3D inversion reconstructions, which would improve the quality of the reconstructions significantly (particularly the reconstructions of the features).

References

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