PERDIKA 1

Archaeological Background

Magoula "Perdika 1" or "Dautza" is located at the western part of the Almyros plain. It is a low tell beside a river. Although the site is known to be a Neolithic settlement since the very beginning of the 20th century, no archaeological excavations have been carried out. However, archaeological surveys have been made by the IG' EPKA (2007-2008).

Archaeological material collected on the surface of the site indicates that the settlement was active during Early Neolithic, Middle Neolithic and Middle Bronze Age. It is noteworthy that archaeological material can be also found outside of the main area of the magoula towards the southeast.

Satellite Remote Sensing and Historical Aerial Photography Survey

A GeoEye-1 image from 3 June 2010 was used for satellite remote sensing at Perdika 1 (Figure 1). The satellite image has an off-nadir angle of 9.8° and a ground sampling distance (GSD) of 0.50 m (panchromatic) and 1.92 m (multispectral). In addition to the satellite imagery, two historical aerial photographs were used for remote sensing. One was taken in 1971 (date unknown) with a scale of 1:10,000, and another on 22 August 2003 with a scale of 1:30,000 (Figure 2).

The broader landscape around the prehistoric tell is diverse and characterized by flat agricultural floodplains, large river and stream beds producing deep gorges, and mountains on the western and northern peripheries. A few modern villages and roads pocket the terrain, but for the most part the region is devoid of modern constructions and farming facilities. The courses of two modern rivers impact the immediate vicinity of Perdika 1 today: one lies alongside the northern periphery of the settlement and another runs 500 m further to the south. During the extraction date of the 3 June 2010 GeoEye-1 imagery, most of the agricultural fields were recently harvested, apparently for wheat. As a result, there is limited green vegetation in the satellite imagery within and around the site. Elevations around the site range from 240-260 masl.

A comparison of the aerial photo from 1971 with the 3 June 2010 GeoEye-1 shows that the landscape around Perdika 1, including the courses of rivers and streams and the organization of agricultural fields, is little changed in the 40 year period between the two images. Palaeochannels appear to be more abundant in the 1971 photograph around the prehistoric settlement, but the difference is not significant. The quality of the 22 August 2003 aerial photograph is too grainy to evaluate in the same context.

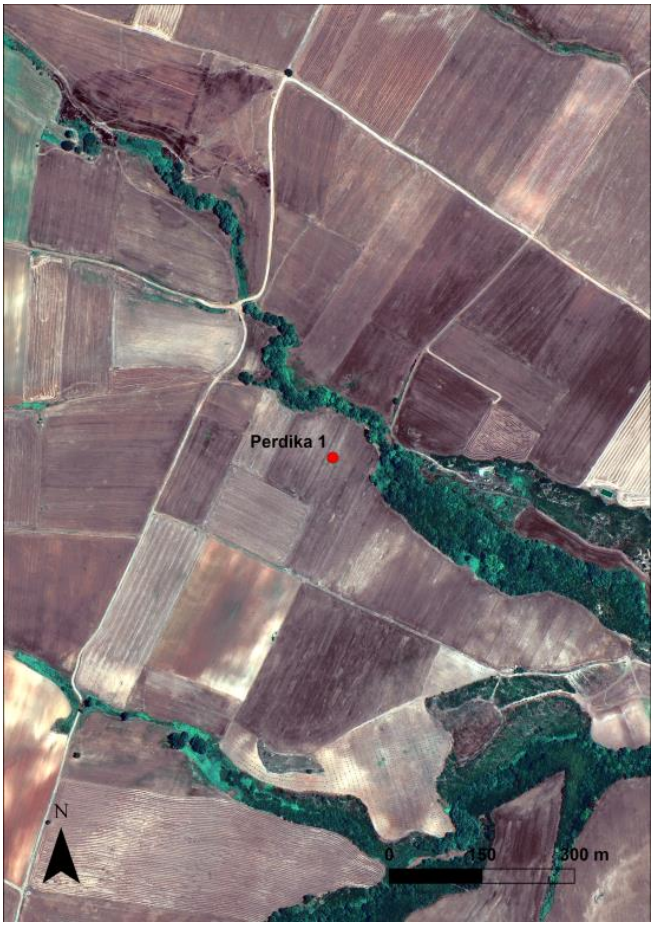


Figure 1: GeoEye-1 image of the settlement

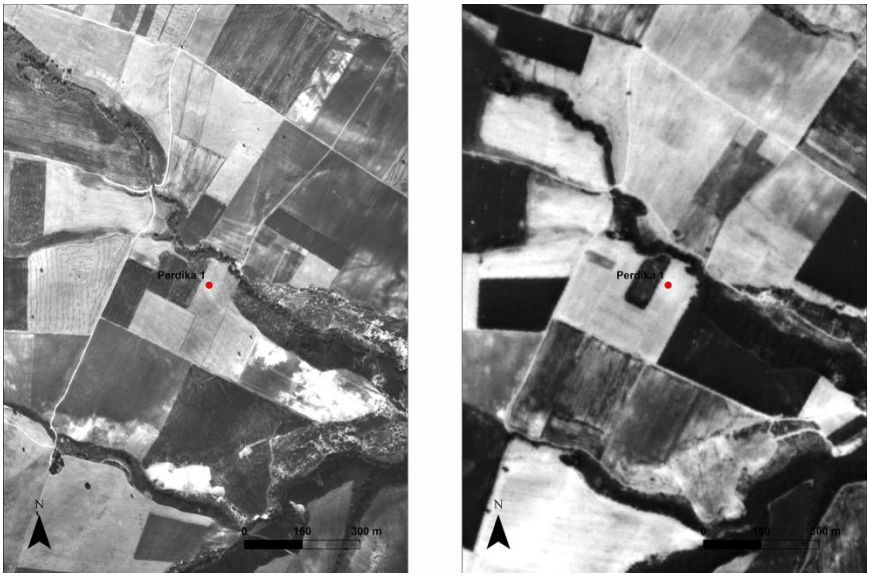


Figure 2: Historic aerial photography from the area

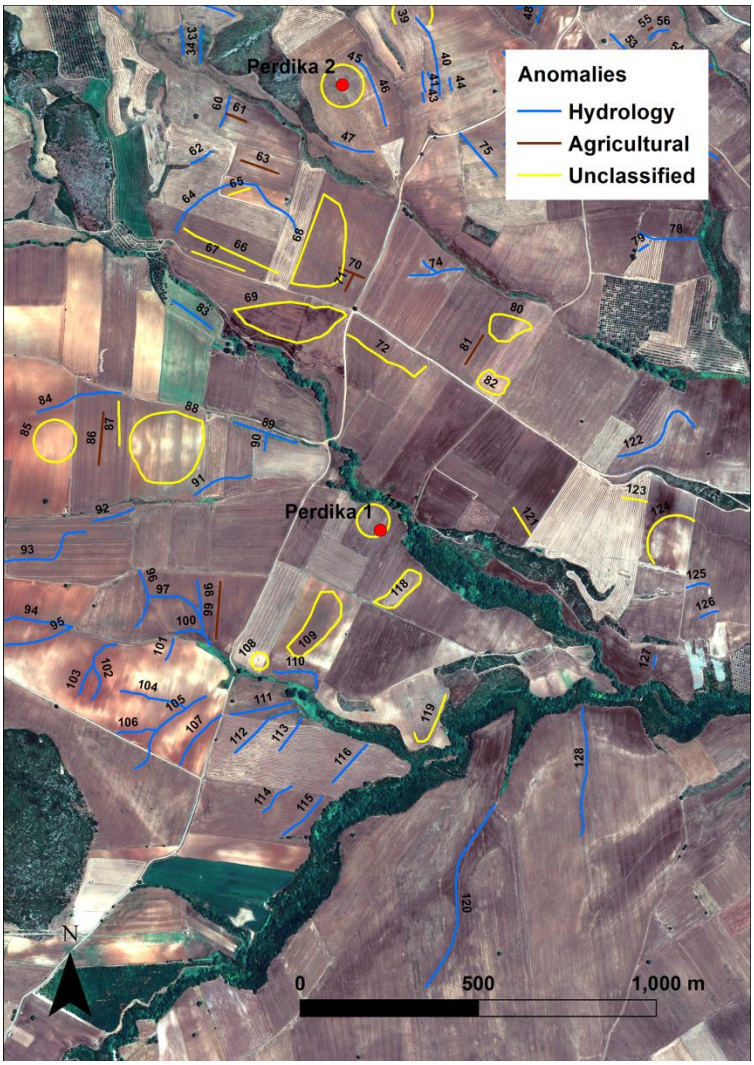


Figure 3: Detected anomalies on GeoEye-1 imagery.

Satellite remote sensing within a 1 km radius around Perdika 1 produced modest results (Figures 3-4). The majority of features correspond to palaeochannels (blue) associated with the rivers and streams that pocket the terrain. The two rivers that pass immediately north of the prehistoric tell and 500 m to the south were apparently supplied by a greater number of feeder streams that are now covered by agricultural fields. Therefore, at some time in the past, and before 1971, the area around Perdika 1 was more hydrologically active than it is today. Other anomalies seem to relate to agricultural activity (brown), such as former field divisions and plow lines. A third category of anomalies is unclassified (yellow). The majority of these has globular and roughly circular formations and likely relates to small lakes from seasonal flooding or designates the courses of former river beds. However, the circular anomaly on the prehistoric tell should be associated with the settlement and not a hydrological feature. Soil marks in RGB images and spectral filters indicate the presence of a near circular feature about 90 m in diameter (Figure 5). It is unlikely other surface anomalies within a 1 km radius around Perdika 1 are potential archaeological features.

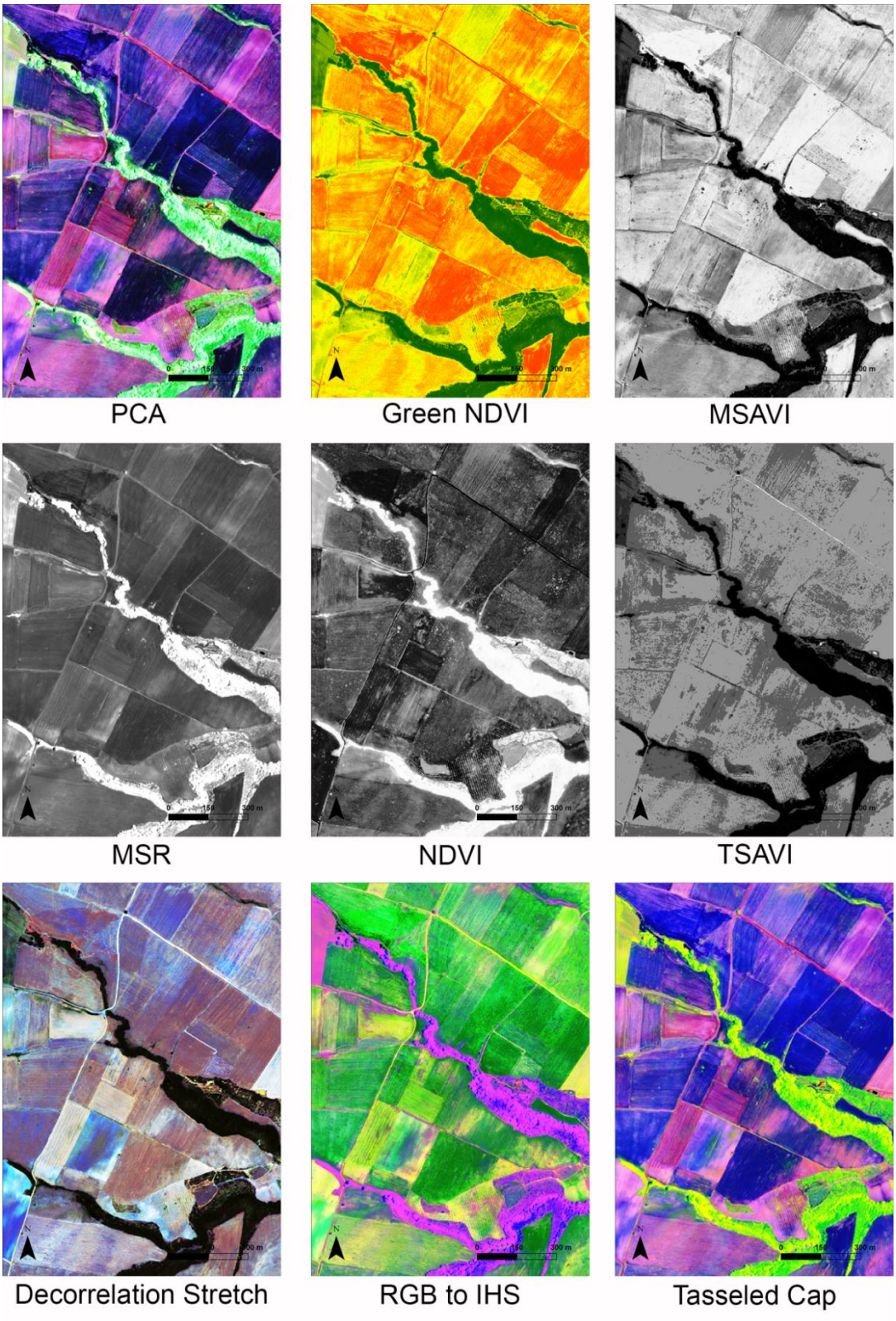


Figure 4: Satellite data products

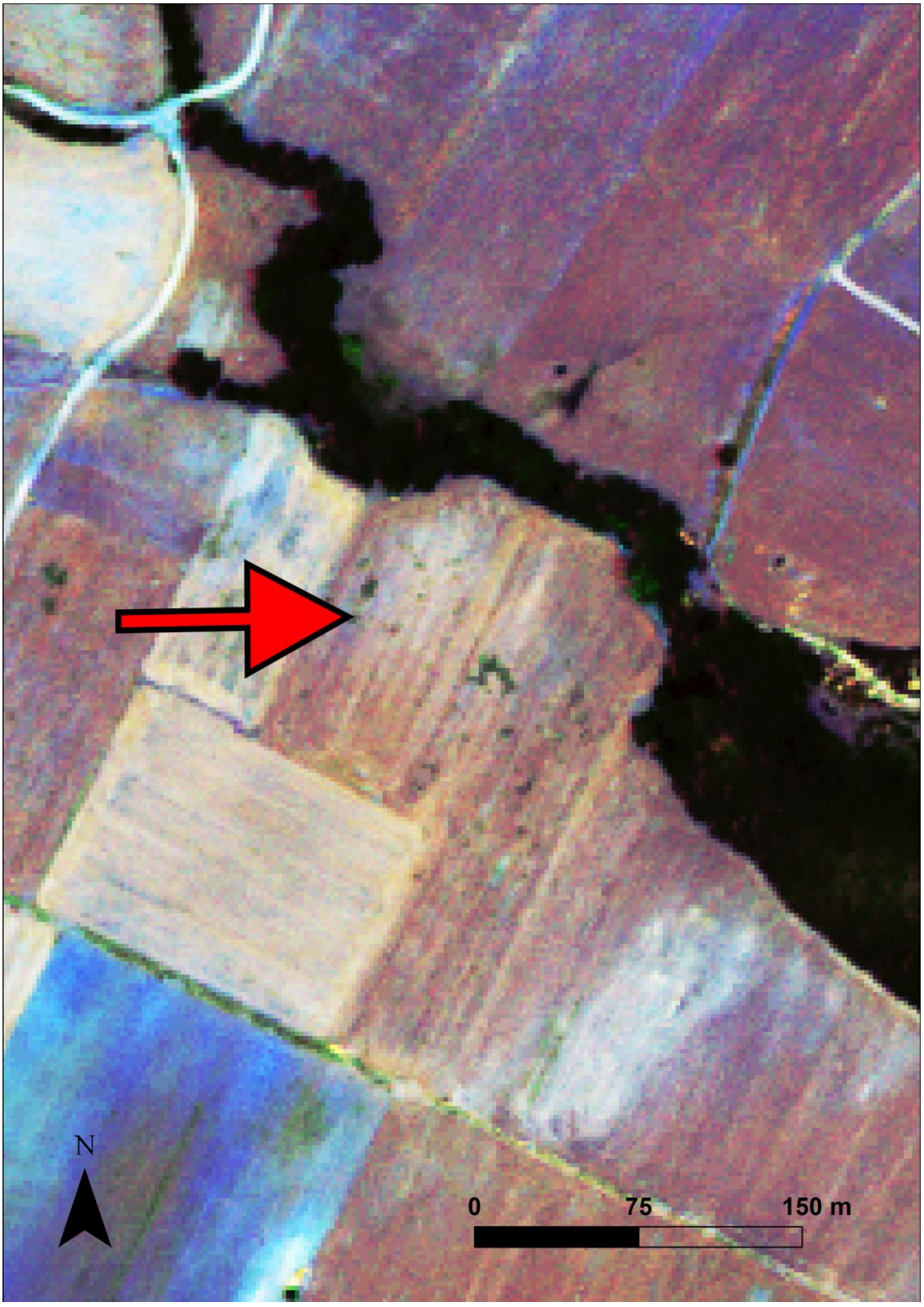


Figure 5: Soil marks are visible in the RGB image

Remotely Piloted Aircraft Systems (RPAS) Survey

The final product from photogrammetry processing for Perdika 1 does not have uniform coverage, but it is very accurate. The Southern part of the orthophoto and digital model is incomplete, due to insufficient overlapping for the photographs collected in that area.

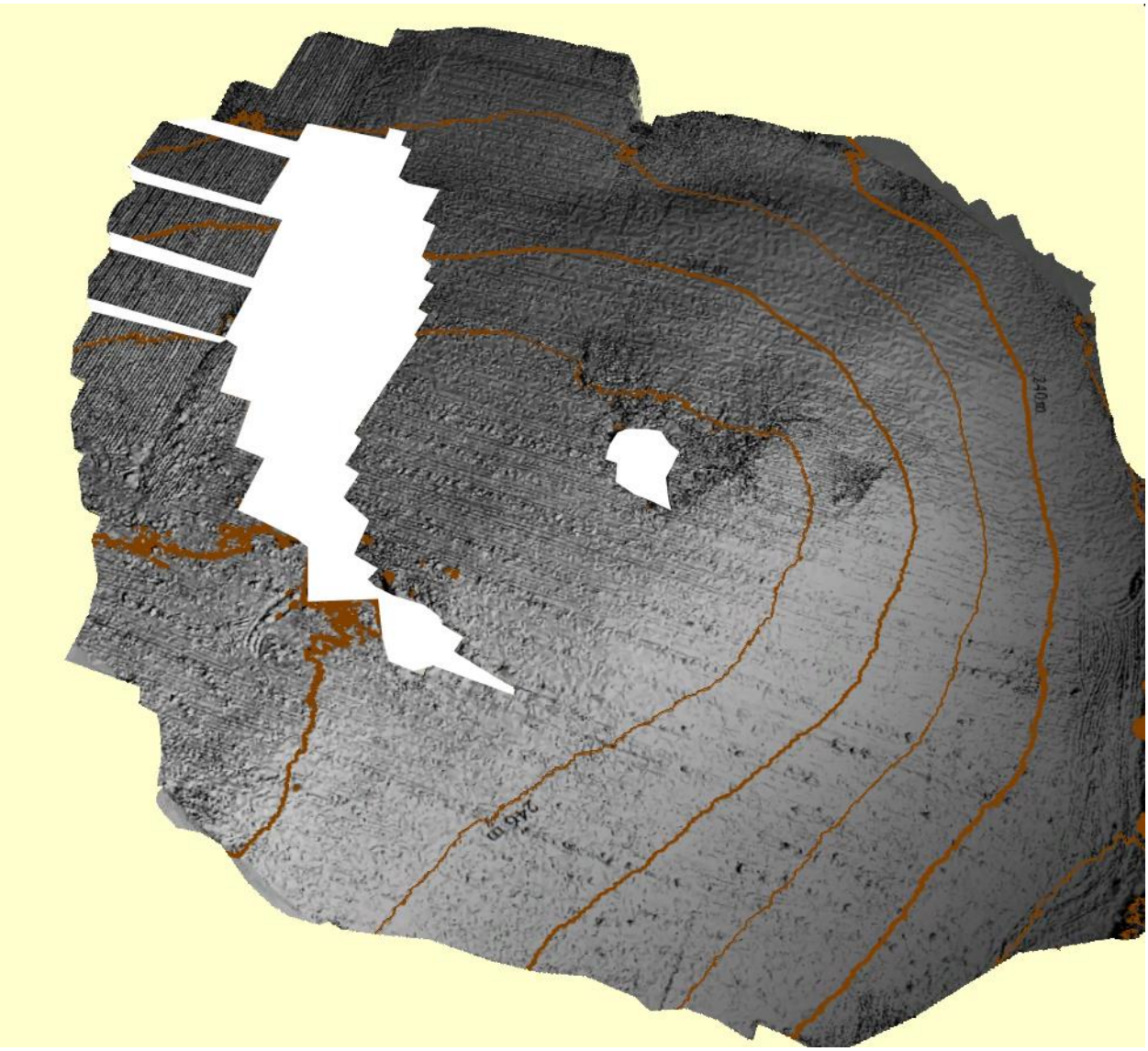


Figure 6: Perspective view of the DEM in hill-shade mode with isolines every 2 meters. Gaps in the model are due to insufficient overlapping of the captured photographs.

Nevertheless, very little photo interpretation could be extrapolated from the photogrammetric processing, since the field had recently been ploughed when the UAV survey took place. Ridges and furrows are clearly visible in the digital model, in addition to the details of the output image. However, these ridges and furrows impede visualizing potential soil-marks.

The most useful output of the UAV survey regards the overall shape of the terrain. Indeed, the elevation seems to correspond with the main structures identified with geophysical prospection,

with the features restricted in a defined area. As for the linear anomalies located with the SENSYS magnetic survey and defining an oblong shape going NW-SE, the digital terrain model seems to highlight an oval shape that bends in proximity with the westernmost linear feature (note also the isolines behavior in the same area).

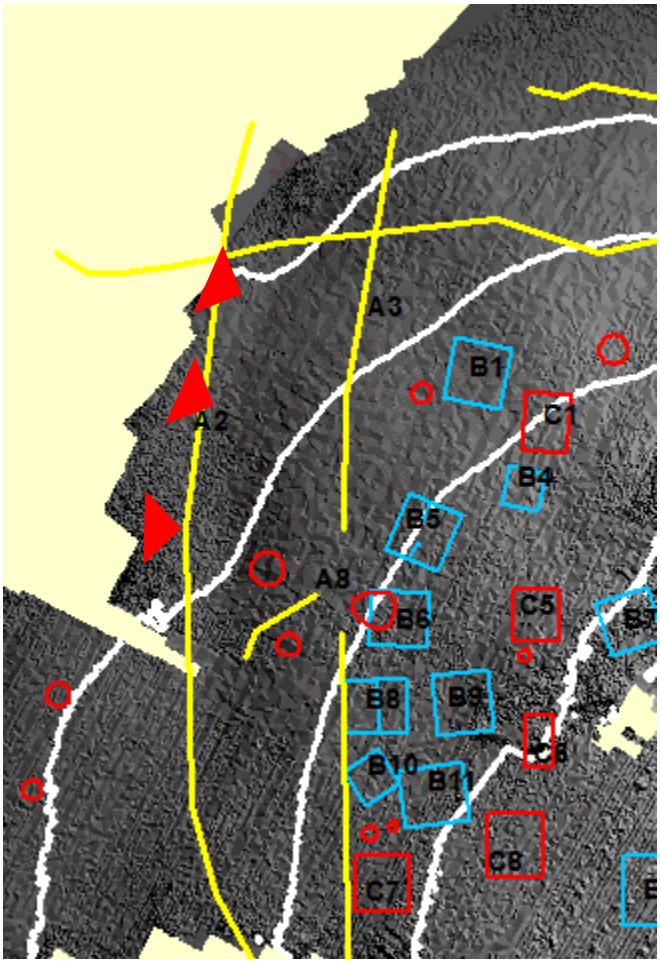


Figure 7: Westernmost side of the magoula with the digital model curvature (highlighted with red arrows) matching the SENSYS linear anomalies. Note also the isolines (white lines) in the same spot.

Geophysical Prospection

Geomagnetic Survey

Magnetic data from Perdika 1 reveal astonishing results with respect to architectural elements at the site. The orientation of the buildings and even some rooms are visible via magnetic prospection. Though not as clear as the settlement's architecture, there is evidence for a series of enclosures around the site. Nevertheless, the immediate separation between site and non-site provide information on the extent of the settlement.

The first area of concern in the geomagnetic data is a cluster of buildings (C52) with high magnetic properties, indicating a firing event. These buildings are tightly packed in a small space

and differ from the rest of the settlement in terms of their organizational layout. A11 is another anomaly located immediately east of C52. The area is homogenous in terms of magnetic readings, suggesting an avoidance of use or frequent cleaning throughout occupation. The function and meaning behind this space remains to be explained and any further comment would be speculative at this stage of analysis.

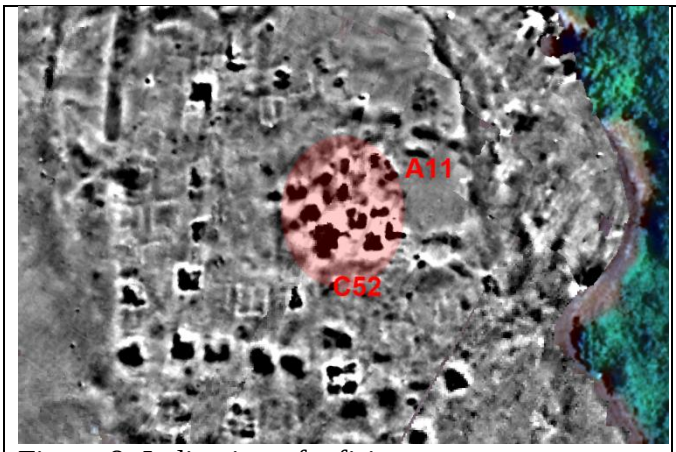


Figure 8: Indication of a firing event

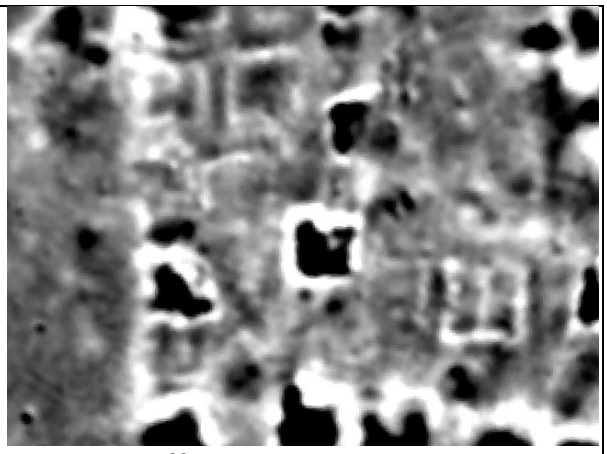


Figure 9: Different architectural styles

Magnetic prospection from Perdika 1 provides a clear difference of architectural practices at the site. We clearly observe two main types of anomalies. The first type (depicted in white color) indicates the use of non-magnetic material as foundation material. Considering how the angles of rectangular buildings are preserved all over the site it is likely that the foundations were built out of large stone slabs rather than smaller pieces. However, it is also possible that conglomerated sediments might also have been in use. This might be indeed the case as the settlement stands in close proximity to a creek as a potential source for non-magnetic building material. In this group of anomalies, architectural partitions are also visible in some cases. The second group is composed of buildings with high magnetic readings. It is possible that these buildings were made of mud-brick and burning resulted in distinct signals at a later period. Intentional burning of structures is well attested in Neolithic Europe and elsewhere.

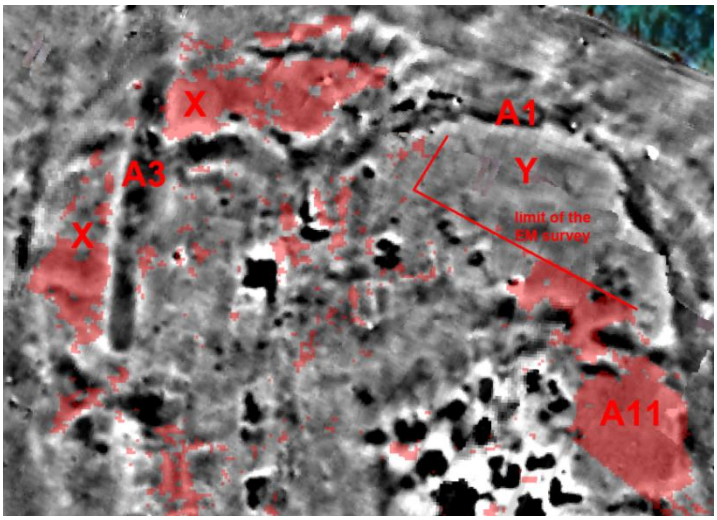


Figure 10: The distribution of geomagnetic anomalies with evidence of low magnetic susceptibly

The third point of interest relates to the site enclosures. Even though the layout of these enclosures is not complete, the existing evidence, especially to the north, is clear in terms of the morphology of the enclosure. A set of anomalies similar to A11 also exists to the north of the site. Areas void of magnetic clusters are either located between architectural features and enclosures or between the elements of enclosures. These areas are also well marked with low susceptibility readings (Areas X and A11 are shown in red). The EM survey does not extend as much as the enclosure, but existing data already suggests low susceptibility readings for the un-surveyed area Y. A3 is another interesting feature that requires some discussion. At first glance, it appears to be part of the enclosure system of the site. However, considering how it cuts the east-west running anomaly A1, it is also possible to suggest A3 was a later addition to the system, and in fact did not serve the purpose of an enclosure.

Electromagnetic Induction Survey

EM measurements were done on the site of Perdika 1 with the GEM-2 from Geophex. It was used with a GPS unit, acquiring simultaneously the location of the point and the value of the EM field for five different frequencies (from 5 kHz up to 90 kHz). Only the first two frequencies were used to extract from the raw signal the value of the complex magnetic susceptibility and the electrical conductivity. As the coil spacing is 1.6 m and the coil geometries used is HCP we have 2.5 m depth of investigation for the electrical conductivity and 1.6 m for the complex magnetic susceptibility. The instrument was carried at an elevation of 0.3 m. We covered an area of 2.21 ha, completed in one and a half days by two surveyors.

The complex magnetic susceptibility is presented through the map of the magnetic susceptibility (or the real part of the complex magnetic susceptibility) and the magnetic viscosity (or the imaginary part of the complex magnetic susceptibility). Depths of investigation are the same for both magnetic properties.

We also used the CMD Mini-Explorer from GF Instrument. Data acquisition was based on several grids to localize the points. Measurements were carried out along transects 1m apart and 6 maps were obtained corresponding to three depths of electrical conductivity and three depths of magnetic susceptibility. The CMD was used in a VCP configuration. The instrument was carried at an elevation of 0.3 meter. This data acquisition was done as a test to assess the benefit of a multi-depth characterization. The grid covers an area of 0.36 ha.

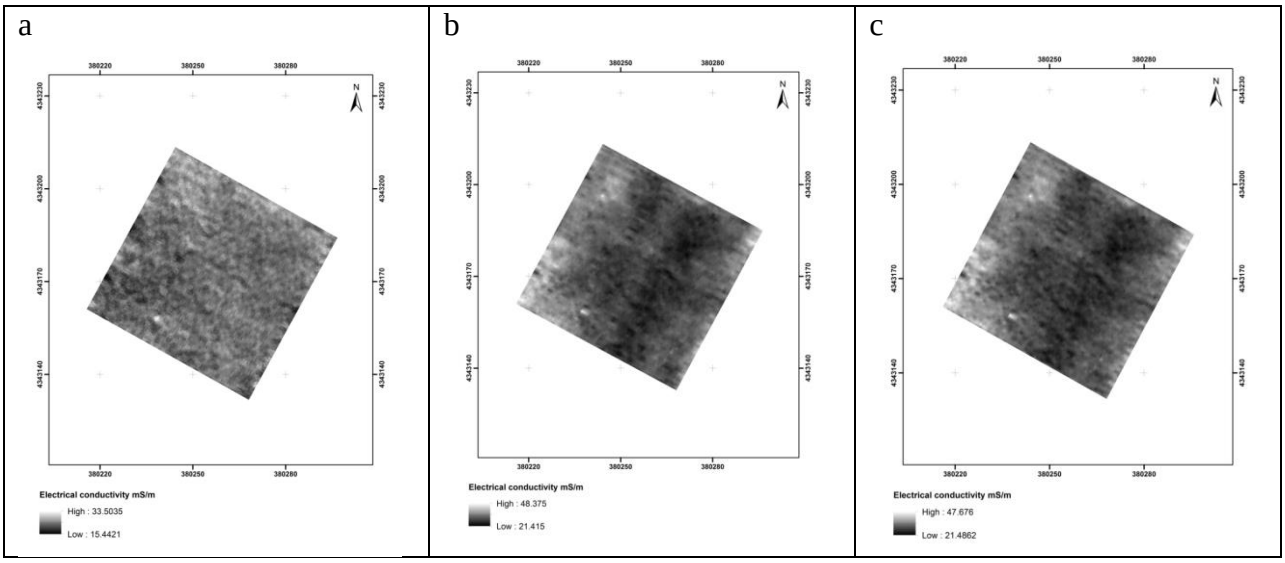


Figure 11: Apparent electrical conductivity (CMD MiniExplorer – VCP): Coil spacing a-0.32 m, b-0.71, c-1.3m

The electrical conductivity does not reveal any clear information. Only the two deeper depths show some linear anomalies, but these could correspond to an instrumental effect. Nevertheless, we can see on the west side a higher conductivity corresponding to the limit of the settlement.

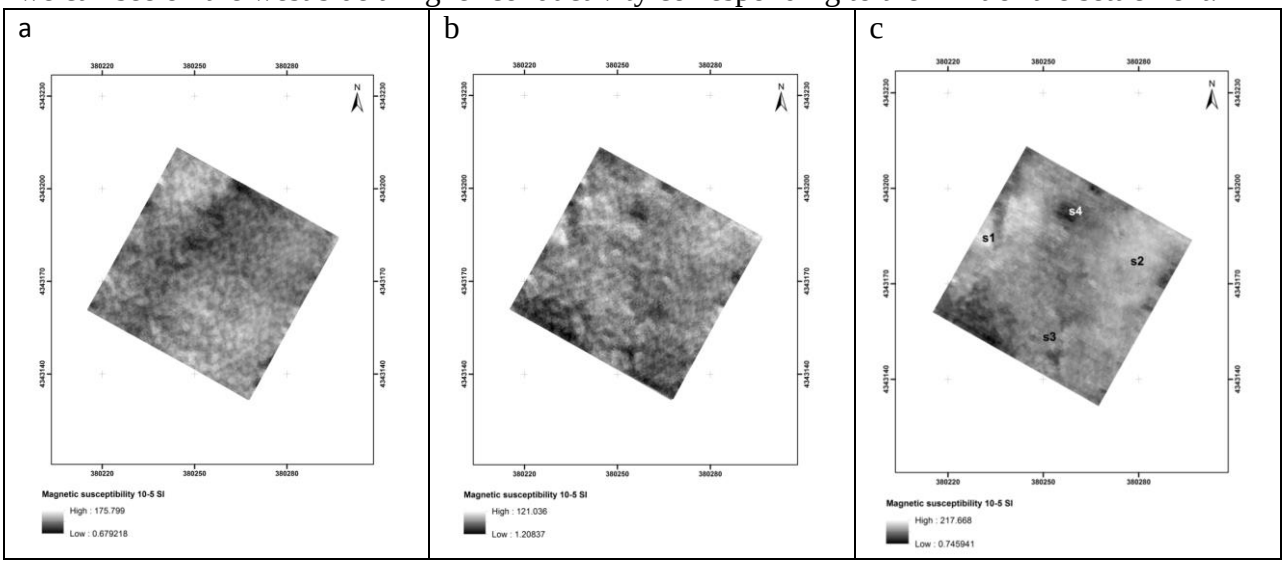


Figure 12: Apparent magnetic susceptibility (CMD MiniExplorer –VCP): Coil spacing a-0.32 m, b-0.71, c-1.3m.

The magnetic susceptibility for the first depth of investigation is very noisy and does not show any valuable archaeological information. Archaeological features start to be visible on the second depth corresponding to 0.8 m. For the last depth of investigation the anomalies are clearest, probably because they are left affected by the heterogeneous topsoil. This map reveals a linear magnetic anomaly (s1) (also visible on the magnetic data) and localized anomalies (s3, s4). The area corresponding to the top part of the magoula does not reveal any anomalies, but only a low susceptibility area (s2). This observation could be explained by the depth of the archaeological and magnetic target maybe deeper in this area than the other part of the site.

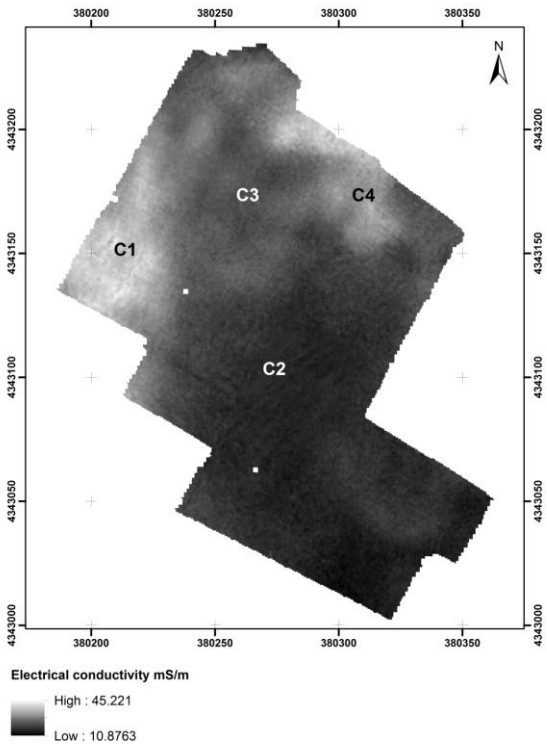


Figure 13: Apparent electrical conductivity (GEM2 – HCP)

The electrical conductivity recorded with the GEM2 does not show an accurate distribution of the archaeological artefacts on this site, but only a global view of the nature of the soil. The high value of conductivity (C1) defines the western boundaries of the site. Although the low conductivity values show the anthropogenic soils (C2-C3). In the north (C3) of this area, the value of conductivity is not entirely homogeneous, but was probably affected by several buildings. In the north (C4) the conductivity shows a low value that probably corresponds to the crew deposit (clay and silk deposit). As the magnetic data does not show a disturbing area here but more in the north direction, we could expect an area with some specific activities free of buildings, perhaps used as a place for animal husbandry, a garden, or simply a free place.

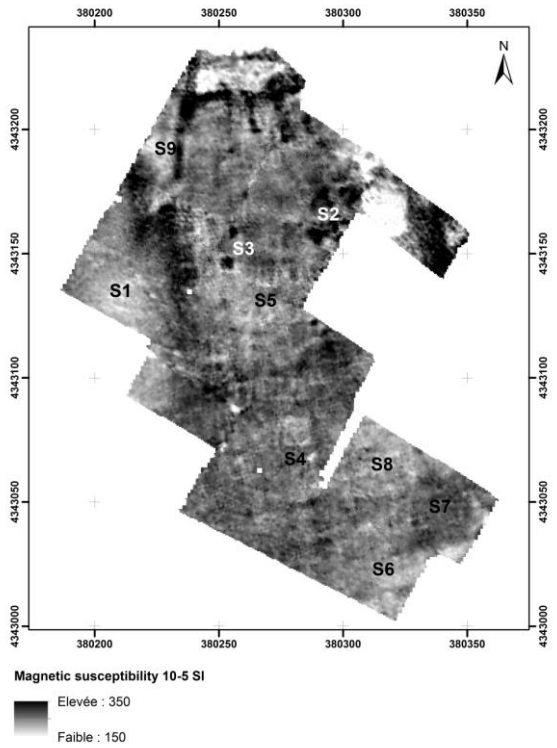


Figure 14: Apparent magnetic susceptibility (GEM2 – HCP)

In contrast to the electrical conductivity, the magnetic susceptibility shows a lot of valuable information and seems to complement the magnetic data. As for the conductivity, we can see on the western part a free area (S1) corresponding to the limit of the settlement. It seems separated by walls (S9) interrupted in the south, marking probably an entrance. On the core of the magoula several strong anomalies (S2) refer to areas of burnt clay or magnetic material (probably associated with a thermos remnant magnetization). Around this core only a few anomalies present a very high value of susceptibility (S3) where the magnetic prospection reveals dozen of very high magnetic anomalies. At the same time, the magnetic susceptibility shows many buildings (S5). The data are accurate enough to show walls of this building. Difference between the magnetic data and the magnetic susceptibility could come from different depth of investigation. The magnetic local anomalies (show by the magnetic survey) are maybe too deep to be observable by the magnetic susceptibility. On the magnetic map these high magnetic anomalies could also mask the weak anomalies corresponding to the walls. Taking into account this observation we can suggest that the burnt clay is deeper than the walls.

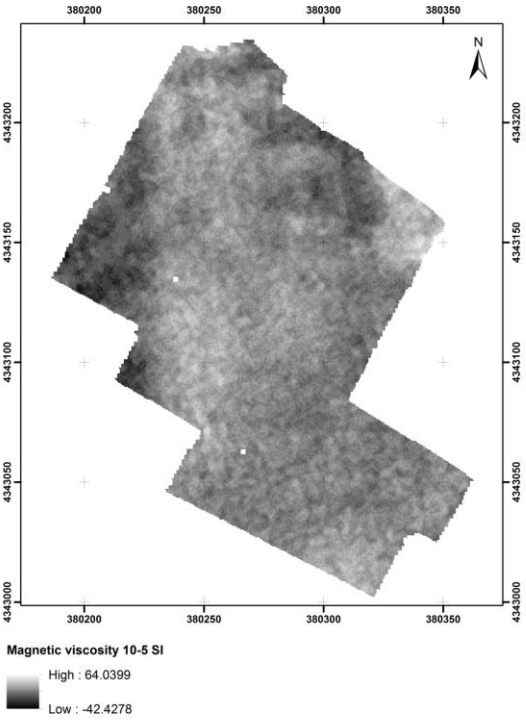


Figure 15: Apparent magnetic viscosity (GEM2-HCP)

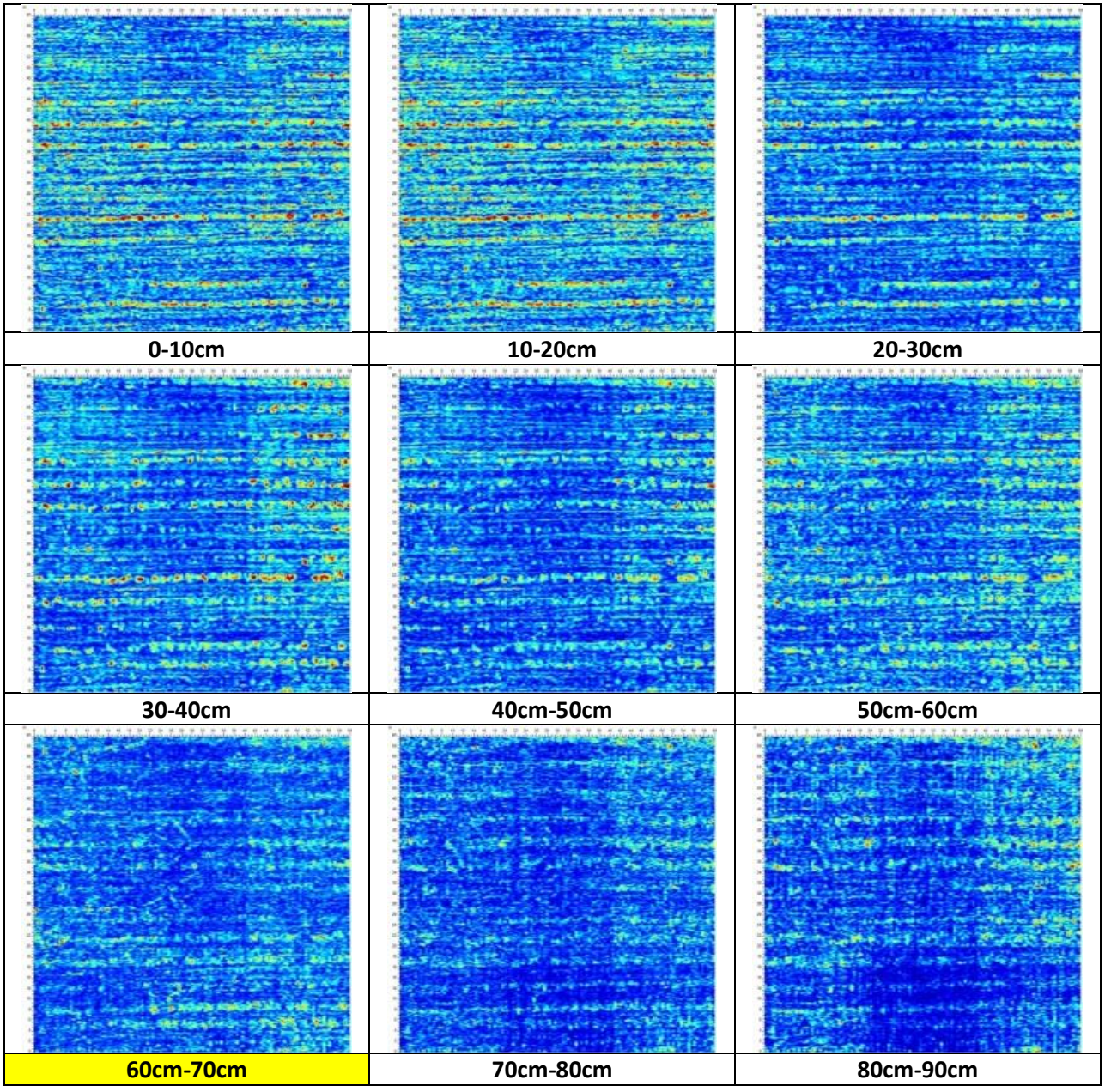
The magnetic viscosity does not show any clear information about the archeological target. Moreover, it seems strongly affected by the electrical conductivity. Nevertheless there are also some differences. For example, the western side shows q as an area of very low magnetic viscosity, while in the central part of the site the magnetic viscosity is higher. This observation could be done also in the northeastern part of the site where the magnetic viscosity is very high while the electrical conductivity does not show a so strong contrast.

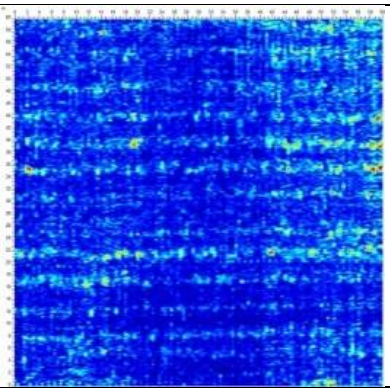
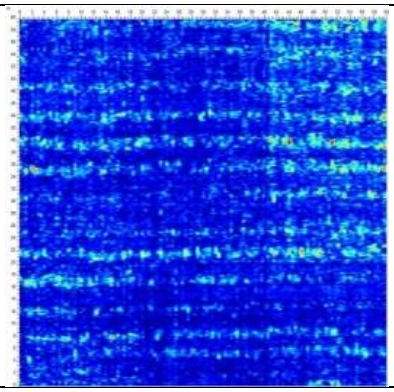
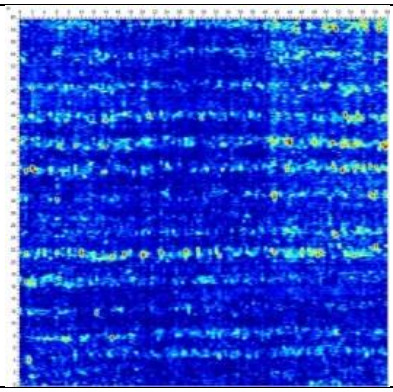
Ground Penetrating Radar Survey

The results obtained from Perdika 1 are presented in Tables 1 and 2. The total area covered was 4400 m^2 and consisted of six survey grids. The filters and corrections applied for the data collected within the grids P1 to P5 (Table 1) is Trace reposition, Repick first break (10%), Dewow, Background average subtraction, Lowpass filter (f=50% Nyquist), Highpass filter (30% Nyquist), while in case of P10 (Table 2) are: Trace reposition, Repick first break (10%), Dewow, SEC2(Atn=25 dB_m,StrtG=5,MaxG=800), Background average subtraction, Lowpass filter (f=50% Nyquist), Highpass filter (30% Nyquist).

In contrast to the results of magnetics and EM, the data from the GPR did not produce information related to the Neolithic features identified with the other methods. The signal's attenuation was very high, especially in the grids P1 to P5, where only noise is visible. The noise has stipes that correspond to plow lines. A few anomalies are visible in grid P10, but since they are isolated features that do not appear in the results of the other methods applied, we consider them to be related with geological features, since the grid was set close to the stream.

Figure 16 presents two representative GPR slices along with the features identified from the other methods (magnetic, EM, electrical resistivity). The GPR results do not present reflections related with the identified features.

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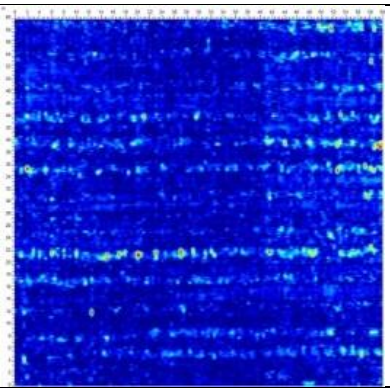	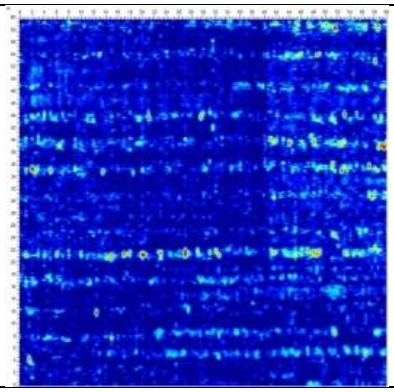	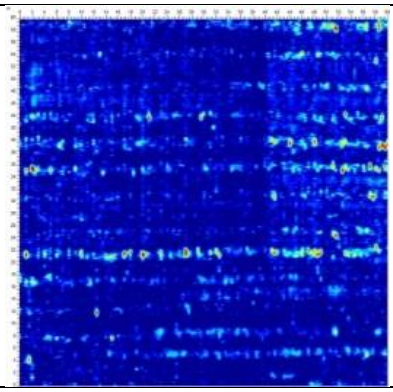
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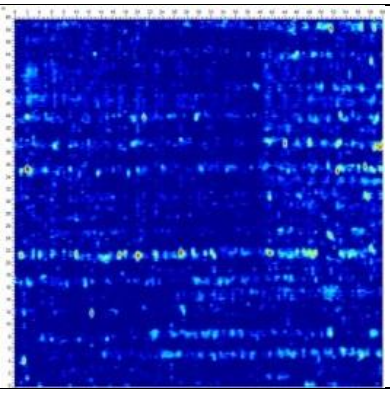	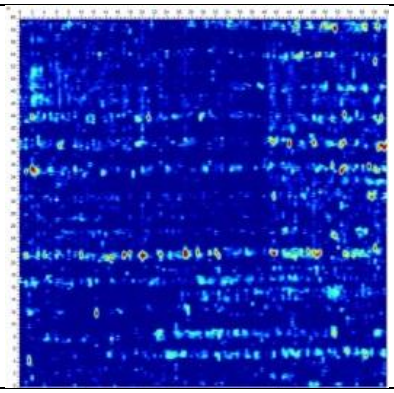	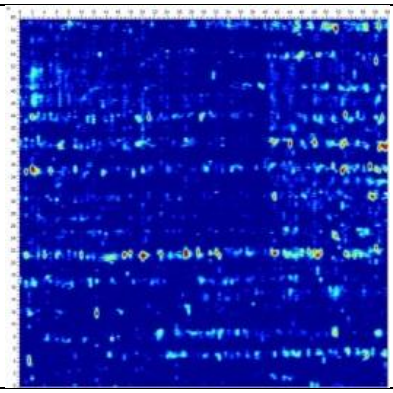
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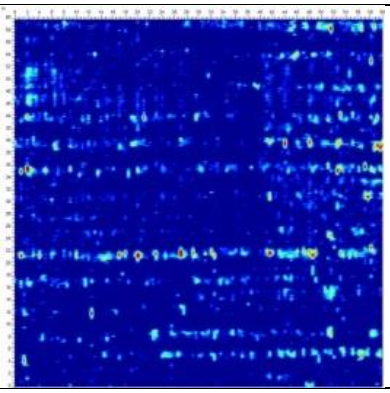
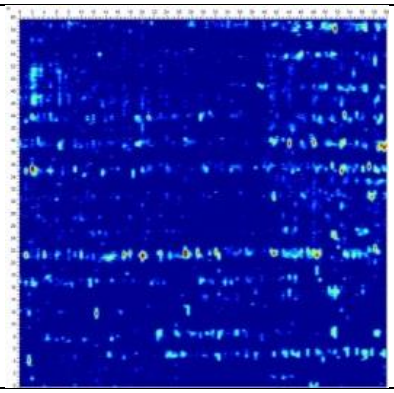
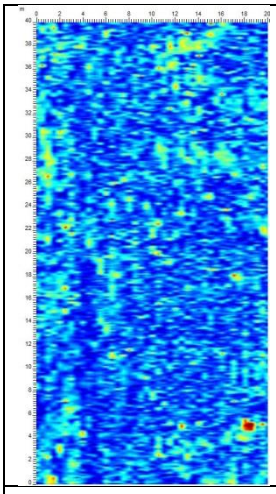
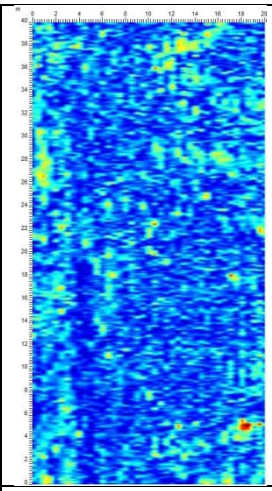
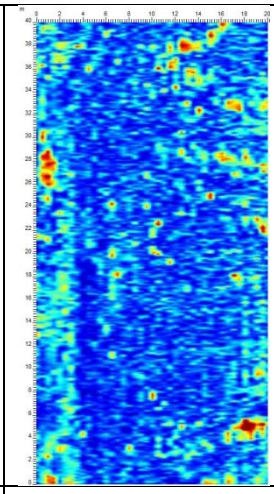
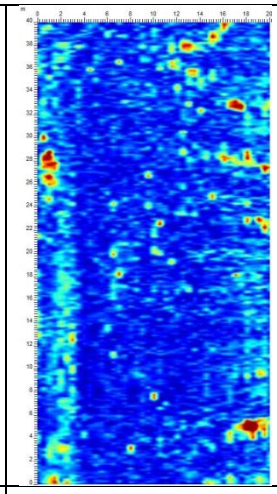
		Table 1 GPR depth slices for the grids with codes name P1 to P5, at Perdika 1 with 10 cm thickness.
180cm-190cm	**190cm-200cm**	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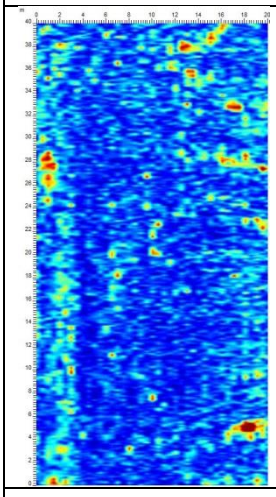
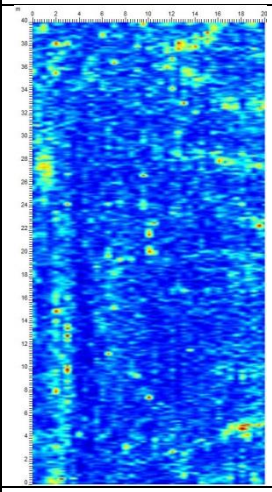
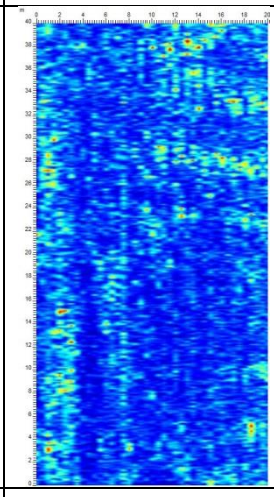
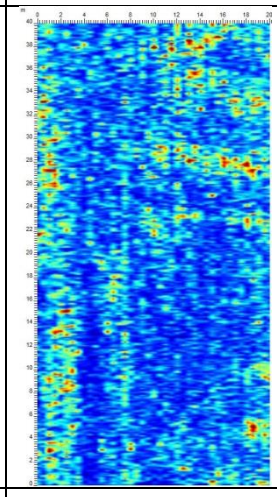
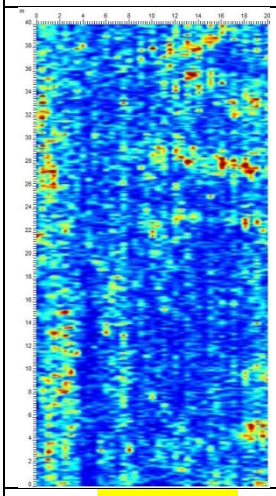
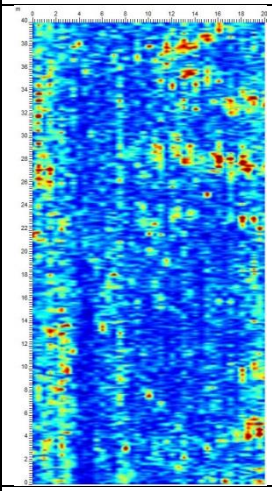
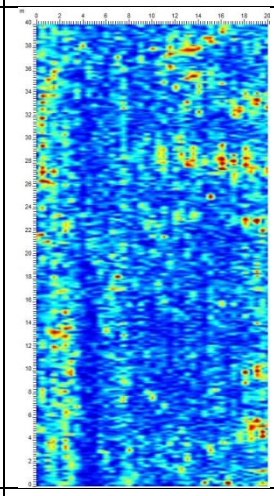
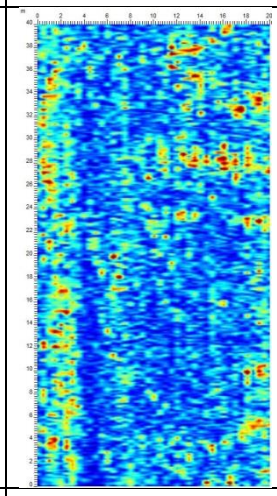
			
40cm-50cm	50cm-60cm	60cm-70cm	70cm-80cm
			
80cm-90cm	90cm-100cm	100cm-110cm	110cm-120cm

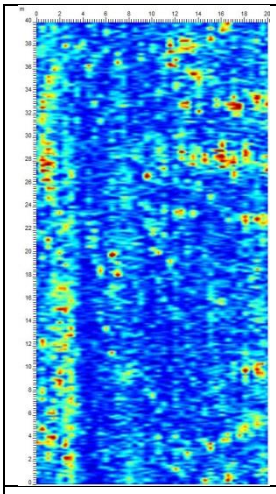
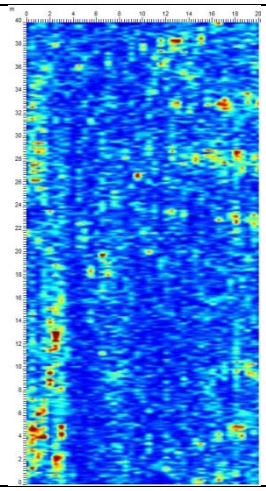
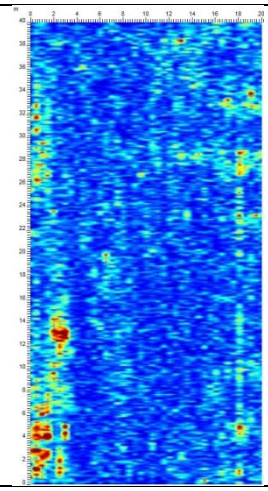
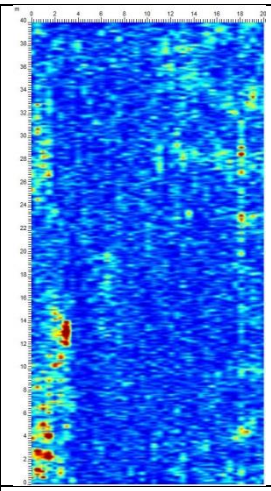
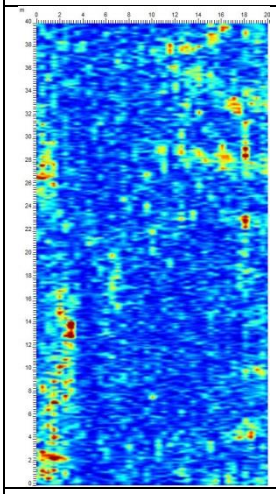
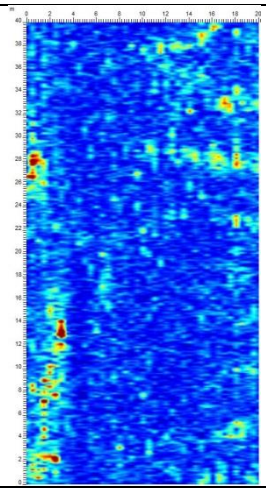
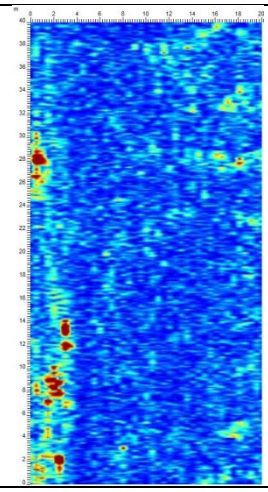
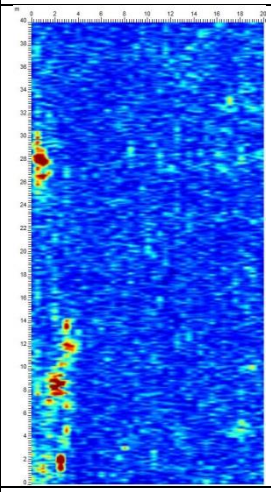
			
120cm-130cm	**130cm-140cm**	**140cm-150cm**	**150cm-160cm**
			
160cm-170cm	**170cm-180cm**	**180cm-190cm**	**190cm-200cm**

Table 2: GPR depth slices for the grid with code name P10, at Perdika 1 with 10 cm thickness.

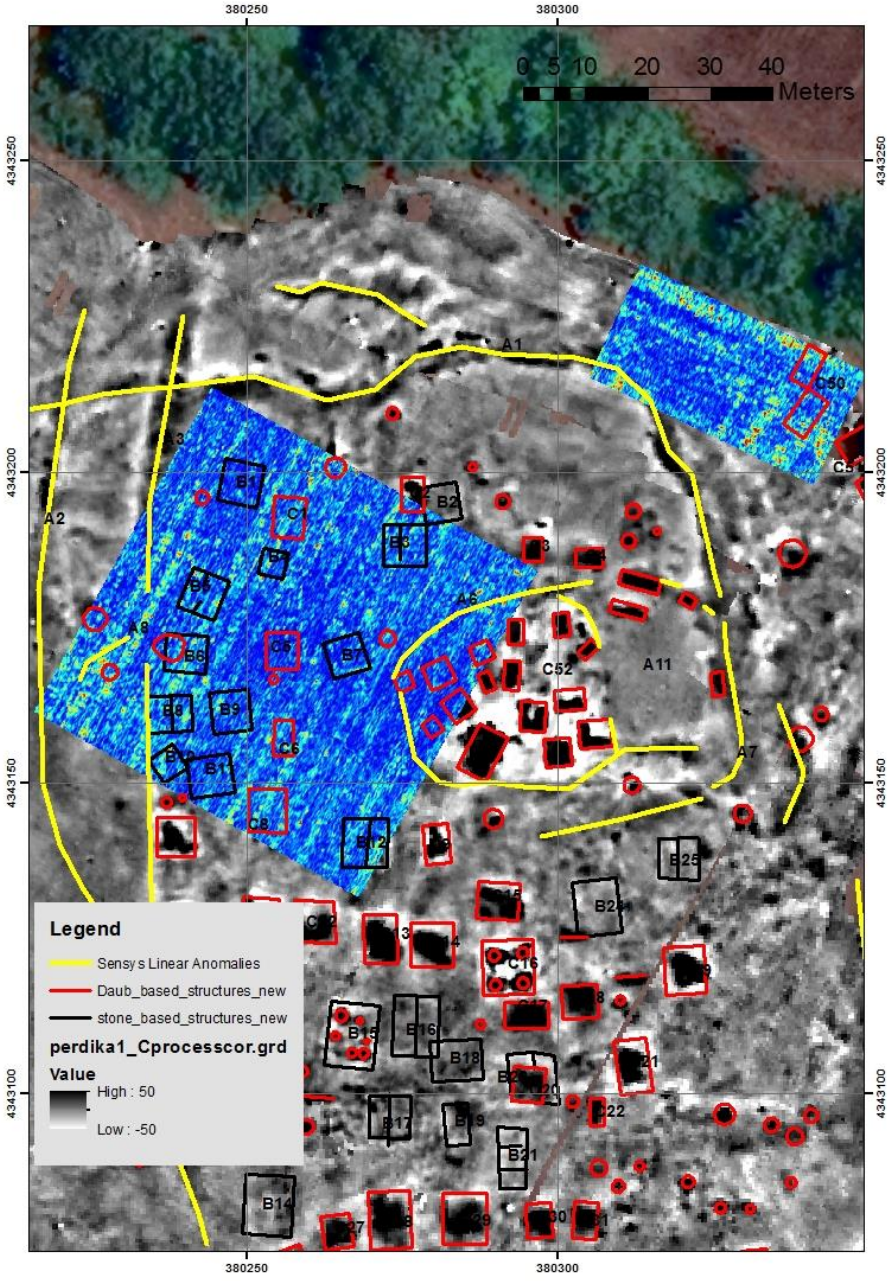


Figure 16: Georeferenced GPR slices along with the magnetic results and the features identified by other methods in Perdika 1.

Resistance Survey

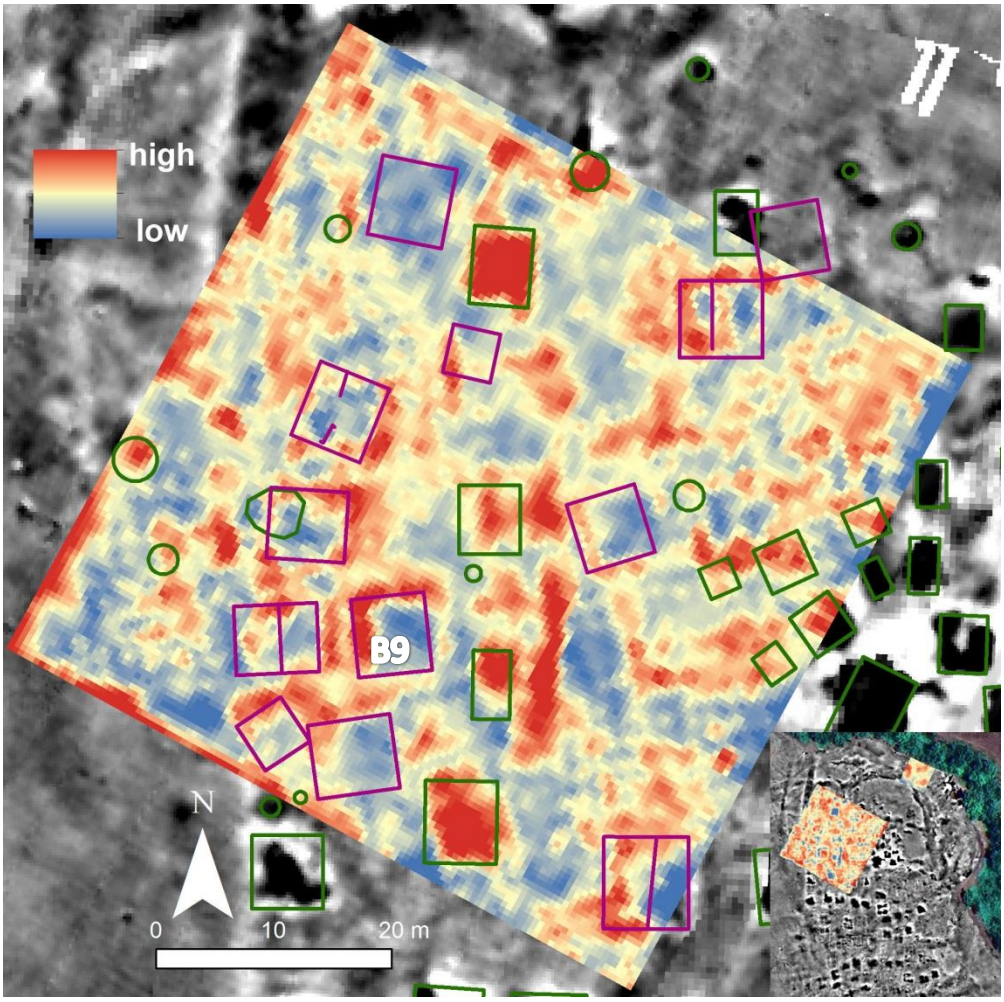


Figure 17: Results of the main resistance survey in Perdika 1

The resistance survey at Perdika 1 provided complementary information to other geophysical techniques. It also adds to the existing features-inventory list of this phenomenal site. Based on magnetic prospection, some stone architecture (purple polygons) and daub architecture (green polygons) are also visible in the resistivity data. B9 is especially informative in terms of its building material and preservation conditions. High resistance values are further indications of stone-based architecture for the western and northern walls which appear better preserved than the southern and eastern walls. However, if this interpretation is true, it becomes a curious case where C1 and C8 (daub architecture) also exhibit high resistivity values alongside high magnetic values. This combination of data makes it likely that a paved floor with magnetically rich stones/pebbles is present, rather than a sign of collapsed daub architecture.

Curiously, the large anomaly A3, detected in magnetics, is somewhat invisible in the resistivity data. Its presence is only detected via low-resistivity values surrounded by high-resistance areas with crooked boundaries.

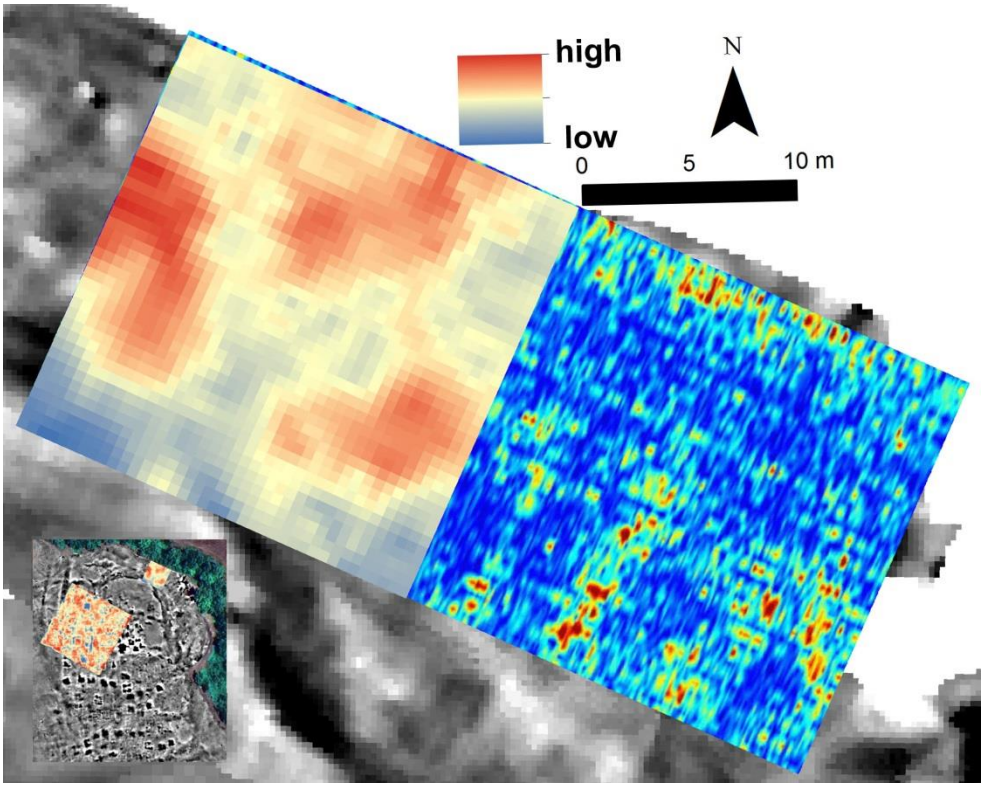


Figure 18: The secondary resistance survey overlaid with the GPR results

A smaller resistance survey was conducted to the north of the settlement where GPR was also employed. Here, we observe three distinct areas with high resistivity. These clusters do not provide clear forms, but they do attest to potential anthropogenic activity outside of the main habitation mound, as the geomagnetic data did with anomalies C50 and C51.

Integration of Geophysical Results

Magoula Perdika 1 was covered by various methodologies with the most extensive coverage coming from the magnetic gradiometer SENSYS and the EMI GEM-2 instrumentation. An area of 60 x 60 sq m was measured with the soil resistance resistivity Geoscan RM15 and EM CMD Mini-explorer, while a much smaller section of 40 x 20 sq m close to the banks of the nearby stream to the north and a section of the top of the magoula were measured with the GPR Noggin Plus. All methods combined to reveal the details of an organized settlement with at least two likely occupational phases, as shown from the different geophysical signatures of the discovered structures.

The area of habitation covers an area of about 230 x 140 sq m and consists of a densely organized settlement which develops mainly to the south, west, and northwest of the core magoula. The settlement is encircled by at least one to two enclosures. The enclosures are more evident to the north and northeast (A1) and northwest (A2 and A3) and even with a faint signal and a lot of breaks towards the south (A4 and A5) as well. The enclosures which are about 2-3 m wide are mostly evident from the SENSYS magnetic data, but appear as faint features in other datasets. The system of double enclosures is mostly evident towards the northwest. At least two entrances are also obvious at A8 and A9 to the west, and one more (A7) to the east. Some

segments that possibly designate other enclosures are suggested at the south of the settlement. It is possible that soil erosion activity due to intense rainfall has damaged the remaining traces of these enclosures.

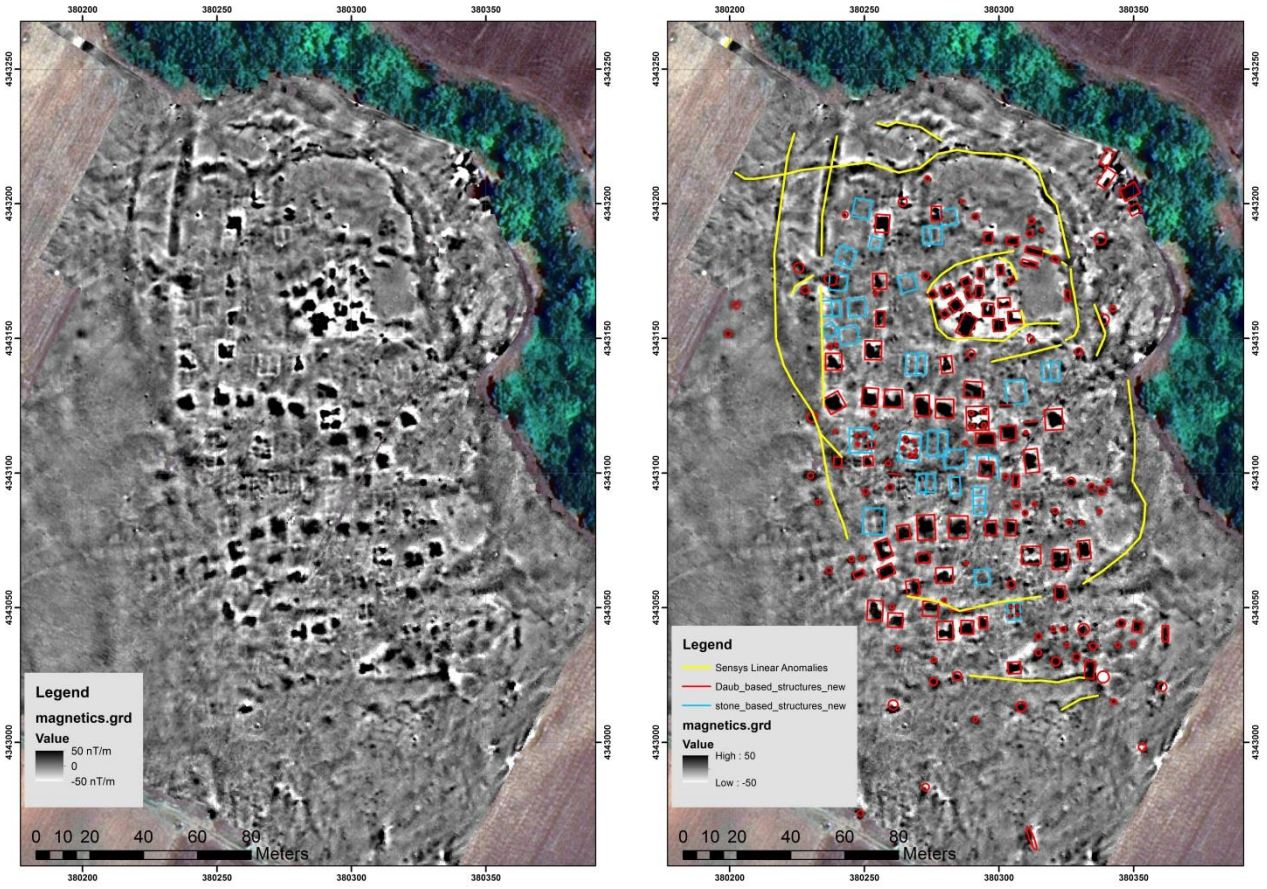


Figure 19: A detailed analysis of the geomagnetic anomalies

The core habitation zone on the tell's summit is confined by a small enclosure, inside which there are at least 13 structures (the cluster of houses annotated with C52 with residues of burning. This almost circular enclosure (anomaly A6 of diameter of about 31-34 m) is clearly separated from an almost empty area at A11 to the east. The low values of the vertical magnetic gradient in region A11 match completely the very low magnetic susceptibility contrast that is exhibited from the same area through the measurements of the EMI GEM2. The clustering of the dwellings within the core habitation zone is clearly defined.

The manifestation of the structural remains as thermal targets (C#s) suggests they are of burnt clay and mudbrick. About 52 additional structures have been found spread out all over the settlement, most of which are within the enclosures. Four such structures (C50 and C51) are located close to the stream to the southeast. It is worth noting that the structures on the plateau and within the enclosure are not aligned in a circular formation, but instead they are organized in a rectilinear fashion (ca. 2.2 degrees relative to the true north). In general, the size of the structures is larger than those within the core zone of the magoula itself, spanning from about 8-64 sq m, with an average size of 31 sq m (taking into account 46 structures).

From a statistical point of view (Hot Spot Analysis using the Getis-Ord Gi* test), the small size daub structures within the core habitation zone are indicated as a cold spot reflecting a statistical significance with a 99% confidence level, whereas the corresponding larger daub structures immediately to the south of the core habitation zone constitute a hot spot with the same confidence limit.

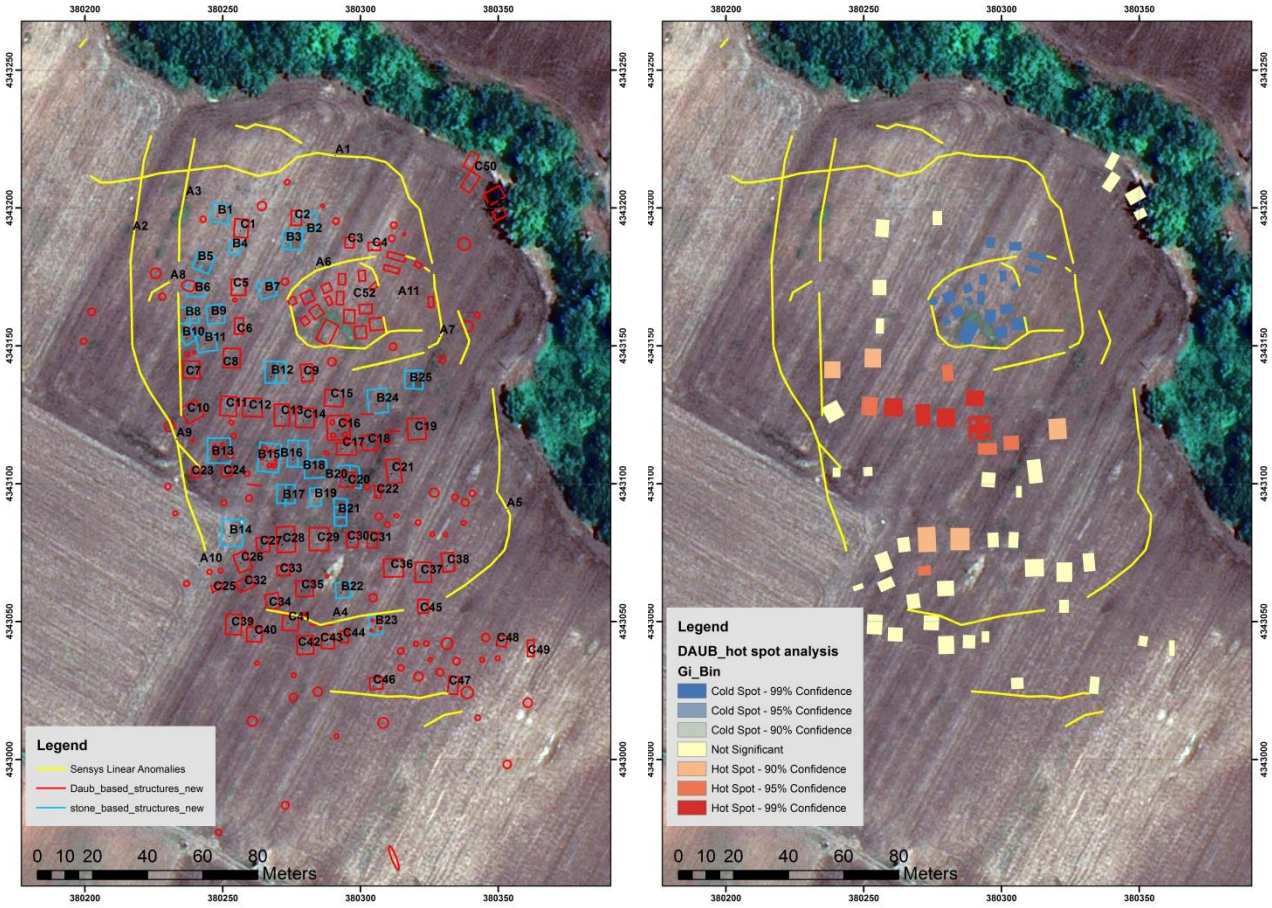


Figure 20: Statistical analysis of possible domestic structures within the boundaries of the settlement

Apart for the above structures, it is obvious that the rectangular buildings (B#s) with low magnetic values are indicative of another occupational phase of the settlement. The particular type of architecture spatially blends with the high magnetic mud-brick structures. As the resistivity values suggest (B1, B3, B4, B5, B6, B7, B8, B9, B10 and B11), the specific buildings are probably built from stone and consist of two rooms. The fact that there is a lack of overlap between the two different types of architecture suggests that the stone based buildings were either constructed in between the empty space of the previous occupation phase, or there was some kind of clearance and removal of the residues of the older structural remains. It is also important to note that this phase of construction avoided any large scale modifications to the core habitation zone of the magoula.

About 25 (B#s) such stone based structures have been identified mainly from the magnetic survey. The structures are again confined within the enclosures of the settlement and seem to

avoid the eastern part which has a steeper slope than the western side of the settlement. Their orientation is very similar to the previous occupational phase (oriented towards the north) and their sizes are relatively larger than the daub architecture, ranging from 14-80 sq m (average of 40 sq m).

Perdika 1 appears to consist of a magoula and a flat settlement having at least two phases of occupation. It is possible that the original habitation zone on the summit of the magoula expanded outside the limits of it, followed by a second phase of occupation. The large population of the settlement could be sustained by the fresh water springs that exist even today close to the stream and by the cultivation of the surrounding fields.

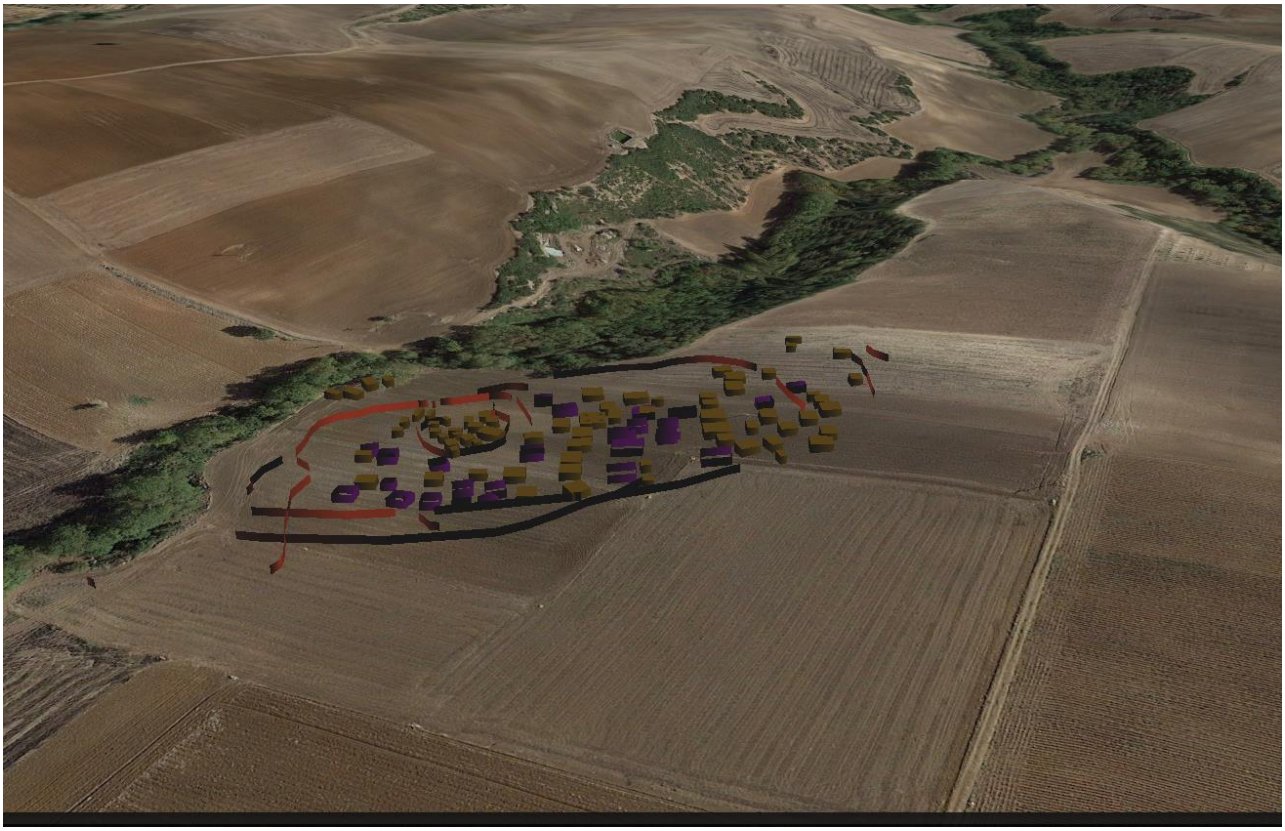


Figure 21: A reconstruction of ancient settlement with respect to its modern landscape

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