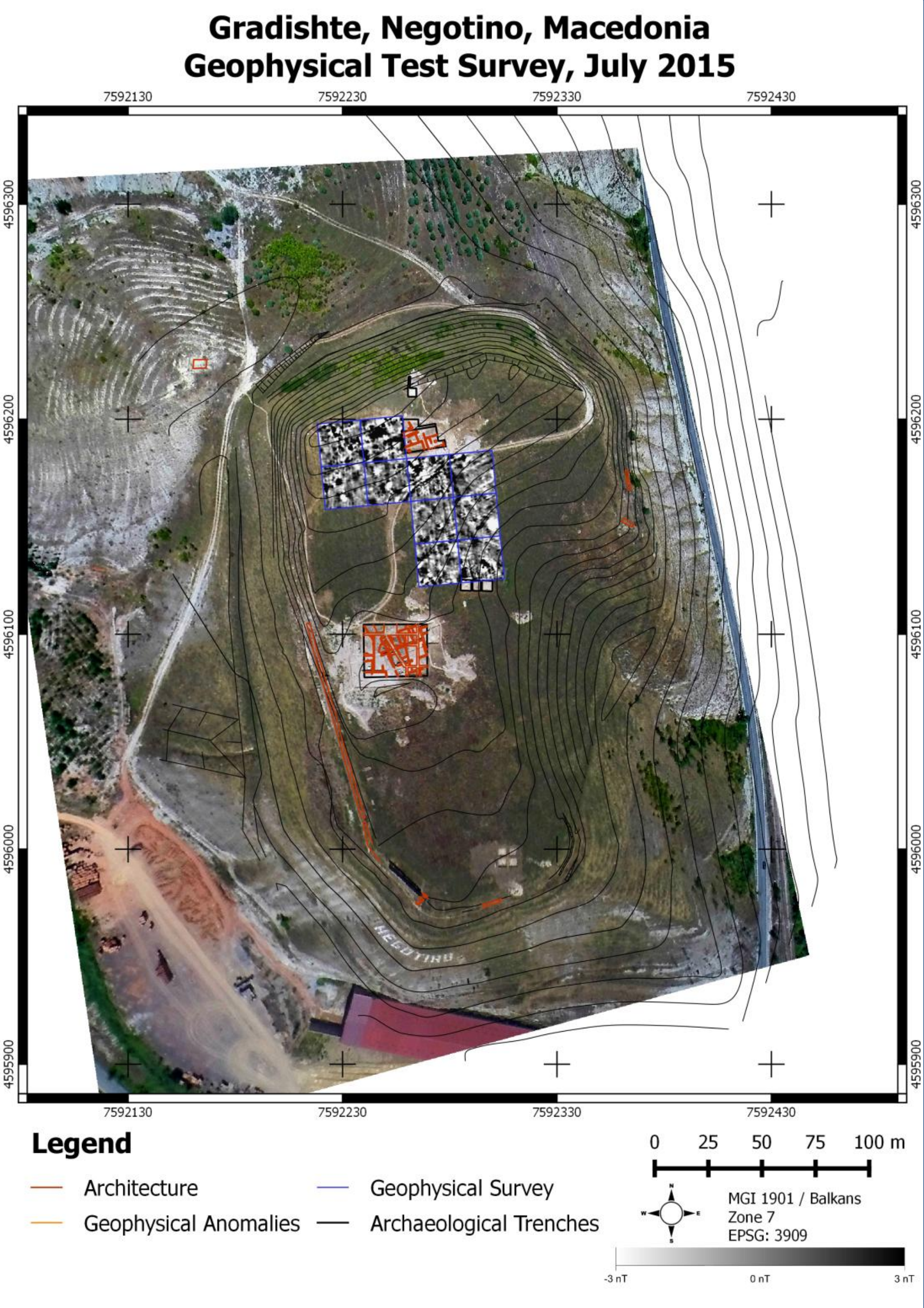
Geophysical Test Survey at Negotino in 2015



Results of the geophysical test survey at the Gradishte site (Negotino) in July 2015

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Warszawa 2015

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INTRODUCTION

In July 2015 a geophysical test survey was conducted on two sites in the town of Negotino in Macedonia (Municipality Negotino). It consisted of magnetic measurements and earth resistance measurements applied in order to examine the potential of geophysical non-invasive techniques in the recognition of archaeological resources. These measurements were conducted on the site of Gradishte – a hill located north-east of the present city, and a second site on the northern outskirts of the city, adherent to a local football field. The Gradishte site contains architectural remains of an ancient city dated to Hellenistic and Roman periods, that are being excavated by Macedonian and Polish archaeological missions. The second site, located south of the hill in the northern region of the city may supposedly contain remains of an ancient cemetery. The non-invasive survey on both sites was conducted to establish the capabilities of the applied techniques and instruments in the existing natural conditions and sought targets.

Magnetic measurements were carried with a Bartington Grad601-2 fluxgate gradiometer with two sensors and earth resistance measurements with the use of a Geoscan Research RM15-D Advanced instrument in *Wenner* electrode configuration. Grids were set up in field with the use of a Leica TS02 7" Total Station. The location of vertex points of the grid were measured with a Trimble 5800 GPS RTK and its positions were related to the fixed geodetic measurement points present at the site.

Non-invasive prospection procedure was based on the guidelines and methodology recommended by English Heritage (*Geophysical Survey In Archaeological Field Evaluation*) and Archaeological Data Service (*Archaeological Data Service/Digital Antiquity, Guide to Good Practice*) with regard to the local natural conditions and Employer's remarks. The outcome of the procedures was aimed at producing a complementary and integrated data resource as a base of further analysis leading to recognition of unknown archaeological resources and future fieldwork planning.

SCOPE OF WORKS

The non-invasive research in Negotino consisted of the following components, being part of both field and analytic stages of the process:

- Geodetic measurements;
- Geophysical measurements: magnetic, geoelectric;
- Geophysical and archaeological interpretation of acquired data;
- Integration of digital and visual data in a geographical information system database with use of open source software QGIS;
- Post-processing of data, completed with a research report that includes the criteria of conducted analysis, technical parameters and interpretation of results.

The end product of the geophysical research comes in the form of digital and text documentation, containing the results as digital files (visualisations of measurements, interpretation of results) and their print-outs together with a written report. These elements, handed on in printed and digital form include:

- Visualisations of magnetic measurements as maps and georeferenced rasters;
- Written report containing elaboration of received results;
- Print-outs of thematic maps with geophys layers and interpretation of results;
- Dataset of geodetic coordinates in *.txt format.

ENCOUNTERED NATURAL CONDITIONS

The Gradishte hill is located north-east of the present city of Negotino. The base of the hill is surrounded by various infrastructure elements of the 8^{th} November Brick Factory. The top, where the archaeological site is located has a form of a plateau elevated at the northern side and slightly sloping towards south. Geophysical measurements were conducted in the northern part, in the direct vicinity of archaeological trenches. Wild, high and dense vegetation, including thick thistle bushes covered most of the plateau's surface and necessitated preparation of the survey area . Vegetation in the northern and western part of survey area was mowed , allowing uninterrupted measurements. Remaining obstacles that might had influence on the results of the survey were located in the central part where stone slabs from the architectural remains have been piled and also in the east and south part, where wild vegetation was still present. It must be noticed, that the results obtained beyond the cleared area should be considered as less reliable due to surface obstacles. The survey area on the Gradishte site was adjacent to north-east and south to recent archaeological digs that uncovered remains of ancient structures. The survey team was informed that the area of the plateau was plowed in the past as a part of abandoned forestation effort. Rough plough marks were visible to this day in the areas cleared of vegetation.

The survey area on the supposed cemetery site was located on the northern culmination of a small plateau, east of the road leading north out of Negotino, and just south of its crossroads with the A1 "Alexander the Great" Highway. The survey area was directly adjacent to the northern side of a football field belonging to a sport complex. The surface of the plateau was partially covered with vegetation, including high thistle bushes. The grid layout covered most of the available and open terrain. The survey area was limited to the east by a modern road, to the south by the football field's metal fence, to the west by thistle bushes and to north by the sharply descending slopes of the plateau. This whole area bore evidence of artificial levelling and clearing with use of heavy machinery. It is unknown whether the plateau has been formed as an artificial extension of the elevated terrain or is a natural land feature.

Due to high temperatures and lack of moisture in the topsoil geoelectric measurements were limited to a basic testing stage, performed at the Gradishte site. Hot summer weather had also the effect of hardening the surface of the ground making it most impenetrable by the probes, thus further earth resistance measurements were postponed for a more suitable occasion.

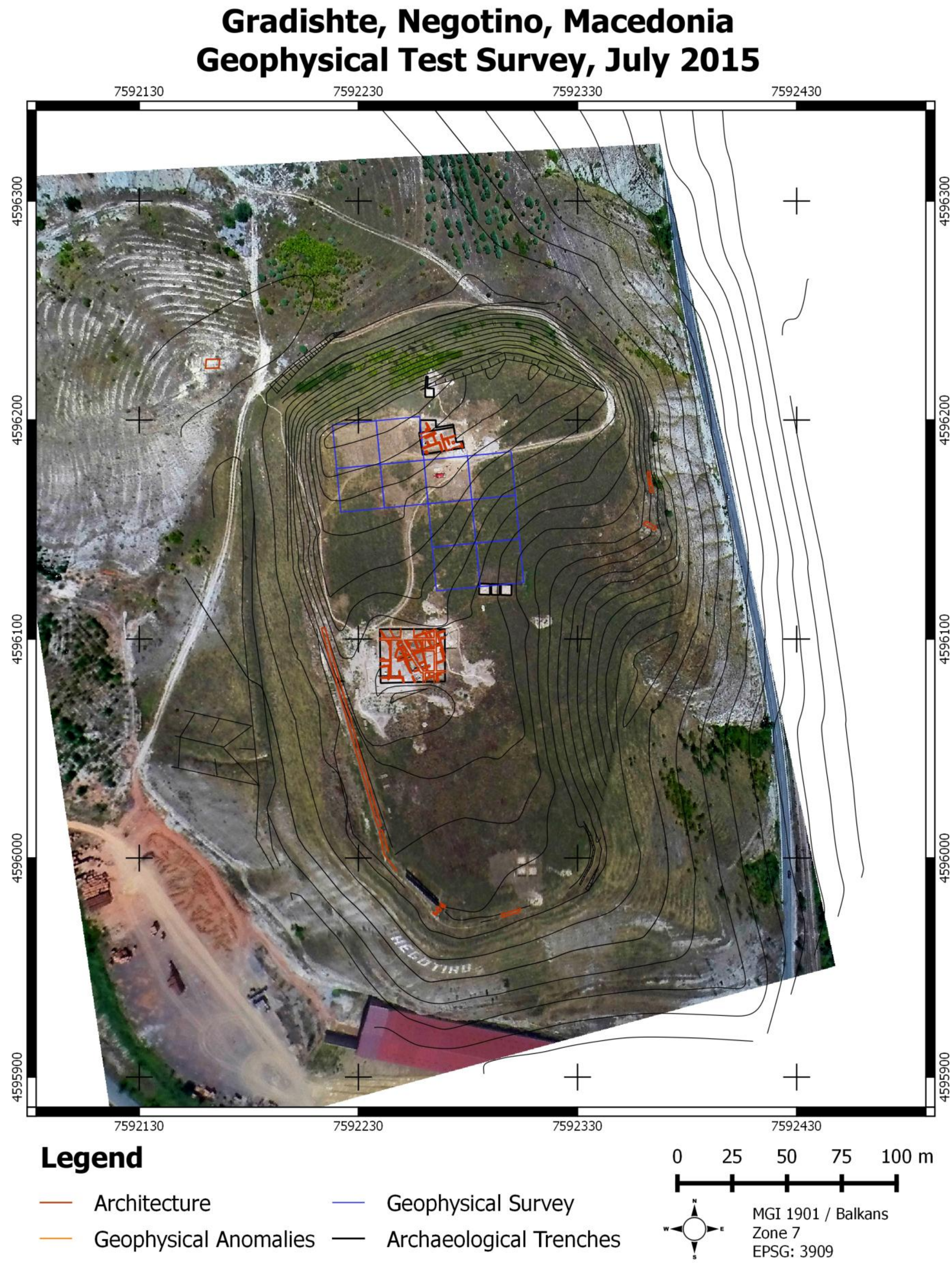

Fig. 1 – Location of the test survey grids at the Gradishte site in 2015

METHODS

Geophysical survey as a one of non-invasive approaches in archaeological prospection allow for the recognition of natural and archaeological subsurface features without any interference in the structure of the soil. The choice of methods and their specification, including the precision and density of geophysical and geodetic measurements was done so, that a complex dataset of anomalies registered underground could be obtained. Its interpretation is based on the analysis of the contrast between registered natural geological background response and visible anomalies. A clearer image of the anomalies and therefore a more reliable interpretation can be obtained by registering not only the outline of geophysical features but also the area surrounding them. This leads to preference of wide area surveys in archaeological prospection, that allow a more in-depth analysis and interpretation of results of complex sites.

Magnetic measurements are the basic geophysical technique applied in non-invasive archaeology for general site evaluation. Magnetic gradiometry allows the fastest surface coverage among all available techniques and are able to register a wide range of anomalies caused by past human activities. That is why they usually are the first geophysical method applied for a detailed site evaluation. Magnetic gradiometry allows to register the location and extent of anomalies and also to estimate the range and character of supposed archaeological resources present at a site.

Magnetic anomalies identified with classic archaeological objects (as filled pits) are usually registered as places of increased value of the vertical component of the magnetic field (so called "positive anomalies"). Other features, like architectural constructions especially ones built with use of thermally processed material (bricks) or destroyed through fire (burned wood) manifest themselves usually in form of dipolar anomalies, and the destructs or debris fields from them as zones of dipolar anomalies. Anomalies of negative vertical component of the magnetic field value (so called "negative anomalies") occur either when a part of a magnetic top-soil has been locally removed, either when there is material present in the subsoil with lower magnetic properties then the surrounding soil.

The limitation of this method is that modern detritus or modern surface infrastructure are the source of strong magnetic anomalies. Archaeological features are usually registered as anomalies with low dynamic value range, that can be easily overlapped by any modern interference.

Due to this earth resistance surveys are usually used as a secondary, auxilliary method. Creating an artificial electrical field and allowing the current to flow between electrodes in various probe configurations allows controlling the depth of penetration of the current in order to register different values of earth resistance. This technique allows to identify archaeological features (like ditches and pits) because they retain a different amount of moisture level than the surrounding soil. Earth resistance measurements produce information about the location and value of high- and low-resistance zones, that can be identified either with compact infrastructural remains, filled-in pits, either any buried remains of earthworks. Decrease of resistance is most often connected with features retaining more water, whereas increase is generated by non-conductive features like compact structures (bricks, stones) or drier subsoil.

Geodesy

The Gradishte site allowed to design a series of research grids 20x20m in size. They were located in a way to utilise to maximum the amount of available open space and extend the grids further without other serious obstacles. A total of 10 grids were staked out, with their vertex points measured with a Leica TS02 7” Total Station and a Trimble 5800 GPS RTK. The grid plot was fixed to the local geodetic reference points, moreover the vertex points of the nearest archaeological digs were measured as well.

On the supposed cemetery site in the outskirts of Negotino the Leica TS02 7” Total Station was used to stake out a grid consisting of 40x40m polygons. Only one such polygon was possible to be fixed on the site, yet the measurements were extended to all adjoining sides where the area allowed, resulting in taking measurements within a total of 5 polygons. The vertex points were measured with a Trimble 5800 GPS RTK, which allowed to locate the survey area with reference to WGS 84 coordinates.

Magnetic measurements

The measurements were taken with application of a Bartington Grad601-2 fluxgate gradiometer with 2 attached sensors. The data has been collected in parallel lines with measurement density of 0.5x0.25m within each of the 20x20m and 40x40 polygons on both sites. The area covered by this method sums up to 0.4 ha on the Gradishte site and around 0.36 ha on the supposed cemetery site – 0.76 ha in total overview.

Area covered	0.76 ha
Polygon size	20 x 20 m, 40 x 40 m
Instrument	Bartington Grad601-Dual gradiometer
Number of polygons	10 (20x20m), 5 (40x40m)
Number of sensors	2
Type of instrument	Fluxgate gradiometer
Resolution	0.03 nT on ±100nT range
Traverse start axis	N → S
Traverse direction	W → E, W → E
Traverse pattern	Zigzag
Lines per meter	2
Measurements per meter	4
Measurement density	0.5 x 0.25 m
Range	-100/100 nT
Date of survey	July 2015

Tab. 1 – Specification of magnetic prospection in Negotino (2015).

Geoelectric measurements (earth resistance)

Earth resistance measurements were taken within the north-western grid of the Gradishte plot. The area was surveyed using Geoscan Research RM15-D instrument. The probes were set up using the Wenner configuration, allowing the current to penetrate up to 0,5m depth into the ground. The data was collected in lines, spaced 1 m away of each other with a measurement density of 1 x 1 m.

Area covered	1.2 ares
Polygon size	20 x 20 m
Number of polygons	1
Instrument	Geoscan RM15-D Advanced
Probe configuration	*Wenner* (0,5 m)
Resolution	1 x 1 m
Traverse pattern	Zigzag
Traverse start axis	N → S
Traverse direction	W → E, E → W
Date of survey	July 2015

Tab. 2 – Specification of earth resistance prospection in Negotino (2015).

Data post-processing

Magnetic and geoelectric measurement data was post-processed with use of geophysical software TerraSurveyor and Geoplot 3. Data was filtered to enhance the registered anomalies. Geodetic, geophysical and visual data together with archaeological documentation was assembled in QGIS software to create a spatial module allowing further data interpretation. The results were organised in the form of visualisations and graphics depicting the data as various colour maps with different dynamic ranges. Moreover, simple animations in *.gif format were created to enhance the differences between particular colour maps and dynamic ranges.

The differentiated values of registered magnetic anomalies require application of various dynamic ranges, to enhance changes in the magnetic field. It is conducted also to clearly point out the places of extreme high and low values. Magnetic anomalies generated by archaeological features usually are visible in broader ranges, due to their low dynamic. Other objects, on the other hand, like f. ex. kilns, elements of modern infrastructure or metal objects can generate anomalies covering a significant area. To minimise their impact on the visibility of other anomalies broader dynamic ranges are applied to the visualisations. The applied approach was aimed at creating visualisations that gradually widen, from very broad ones (-1/1nT) to relatively wide ones (-10/10 nT or -20/20nT). In perspective, this allows further interpretations regarding location and character of archaeological resources at the site.

The visualisations of geophysical data were created with application of grayscale colour maps as a basic way of depicting the results, but simple coloured palettes (RedBlue) were also created to depict the dynamics distribution of registered anomalies. Each way of applied data visualisation helps to point out the geophysical features that might be generated by archaeological objects and artefacts.

Fig. 2 – Geodetic measurements on the Gradishte hill (author: M. Jaworski).

Fig. 3 – Magnetic measurements on the supposed cemetery site with the Gradishte hill in the background (author: P. Wroniecki).

Results and Interpretation

The magnetic survey at both Negotino sites produced results that allowed a basic interpretative model of the anomalies. The Gradishte site was free of obstacles and modern infrastructure, yet the results from the east and south part of the results are less reliable – as noted above – due to surface obstacles in form of dense vegetation. These measurements should be repeated in more favourable conditions if possible. Results obtained from the supposed cemetery site on the other hand reveal a highly magnetic background that allows only a rough analysis of the results.

Gradishte Site Survey

The surveyed area revealed a relative lack of interference from modern activities. Although old plough lines are visible on the whole area, they are more visible in the eastern part. In the space cleared in the western half, they were even clearly visible in the ground. What is also worth noting is the curved linear magnetic anomaly stretching in the centre – marking the presence of a modern communication tract and a small zone of point anomalies south of it (Fig. 4, A), probably a remnant of some modern use or scattered architectural remains from one of past archaeological seasons trenches. This zone of anomalies should be verified archaeologically, because it is also possible that these features are generated by subsurface architectural remains that form a cluster in this area. Beside these interference few general types of anomalies are present on the whole surveyed space – positive and negative anomalies forming linear disturbances and areas.

In the east part of the surveyed area a linear positive anomaly has been registered (Fig. 4, B) oriented on the north-south axis. This type of feature is normally produced by filled in ditches or other earthworks. Based on the information given by the excavation team, it is possible to potentially relate this anomaly to an old World War I trench that was laid across the top of the hill. The anomaly has a form typical for this type of feature, yet the source of the anomaly should be verified with excavation data.

The orientation of positive and negative linear anomalies is similar to the orientation of the walls documented in the north trench. This fact is the direct premise to consider these anomalies as potential indicators of the presence of walls and possible archaeological structures beneath the soil. Most of the linear anomalies outlined in the interpretation are negative, what would indicate that their source is less magnetic then the surrounding soil. Furthermore, positive linear anomalies were registered in their direct vicinity, indicating that there might be remains of structures built with different material next to each other and serving different purposes. Also worth noticing is a nearly circular positive linear anomaly west of the north trench (Fig. 4, C) and the vast rectangular negative linear anomaly in the west part of the surveyed area (Fig. 4, D). The sources of these anomalies should be verified to enhance the interpretation of the received results.

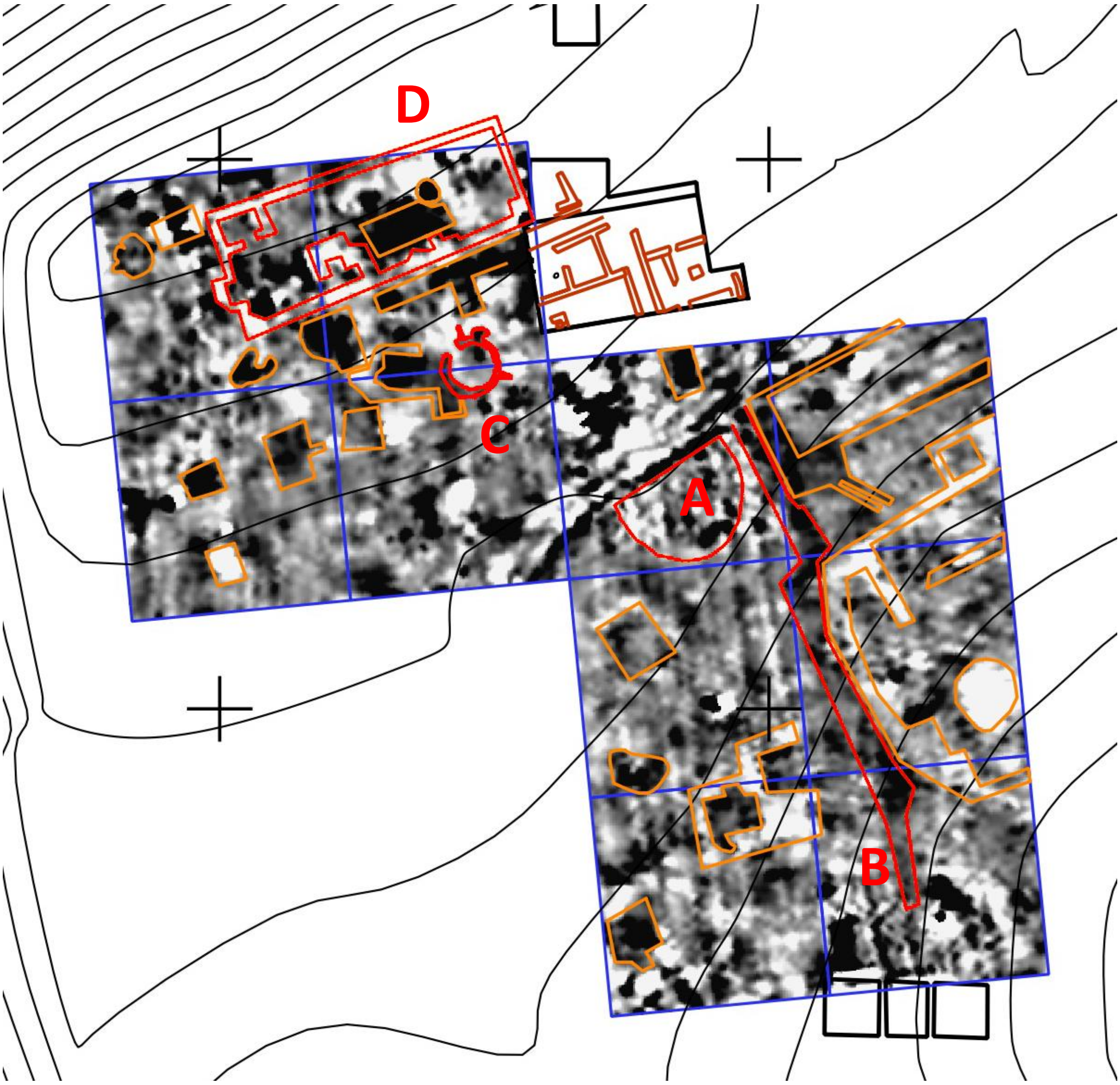

Fig. 4 – Section of the visualisation with marked outline of the mentioned features (-3/3nT, positive anomalies in black, negative in white, north up).

Beside the linear ones, there are positive and negative areas registered throughout the survey. They form dense clusters of point anomalies or alternatively clearly distinguishable zones. Positive zone anomalies are dominant in the results, yet negative anomalies also manifest in very compact forms. Positive zones are produced by material with higher magnetic properties than the surrounding. It might be either debris from structures, such as burned wood, bricks or roof tiles, either magnetic filling of pits. Negative zones might occur in places where there is an accumulation of non-magnetic material, f. ex. non-magnetic local stone that forms natural slabs, used as bricks in the excavated buildings. The sources of these two densely present types of anomalies should be studied, in order to reveal their origin. Verification of the structures causing the anomalies should help to enhance the understanding of the obtained results and the relation between subsurface structures behind the anomalies.

Fig. 5 – Results of the geomagnetic survey at the Gradishte site in 2015.

Fig. 6 – Results of the geomagnetic survey at the Gradishte site in 2015 overlaid on an orthophoto.

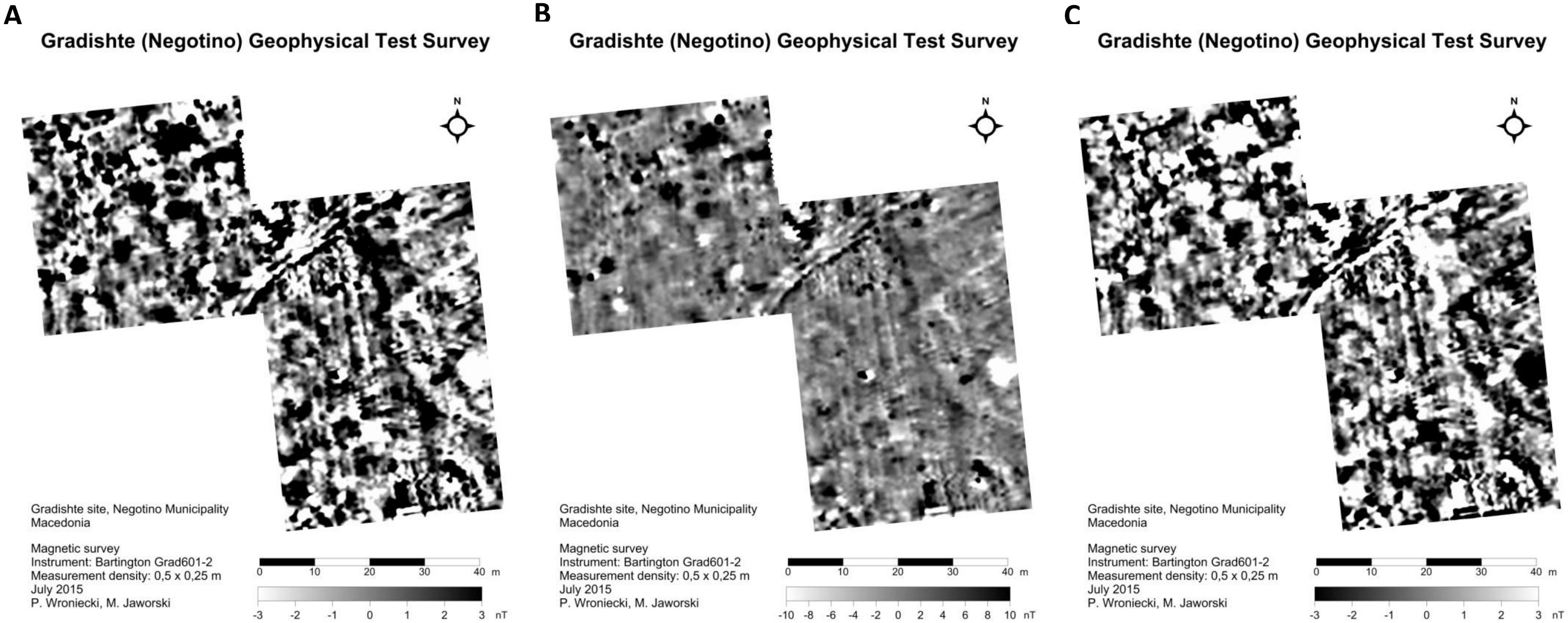

Fig. 7 – Examples of visualisations of geomagnetic survey results at Gradishte site in grayscale (A, B) and inverted grayscale (C) colormap.

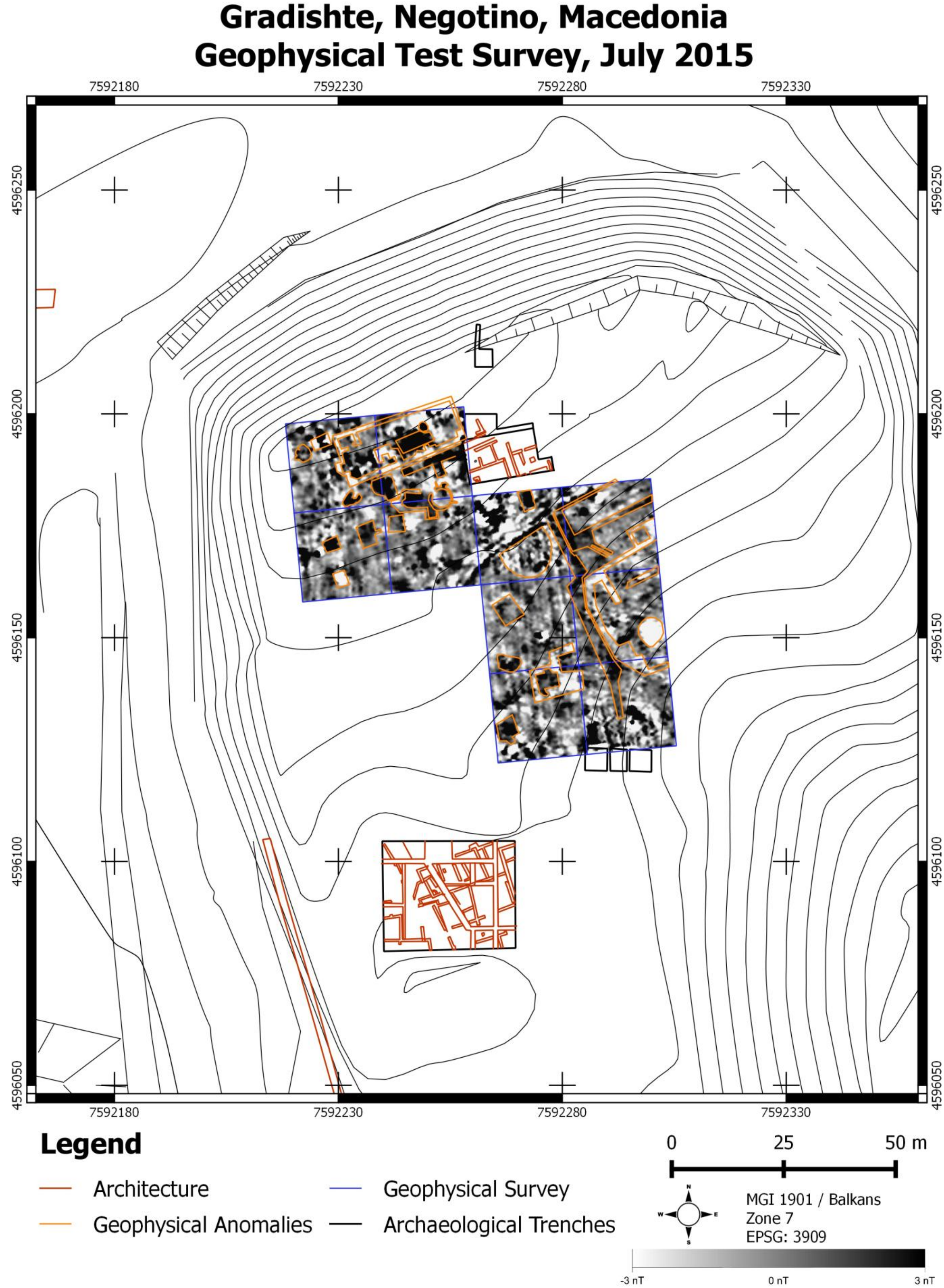

Fig. 8 – Interpretation of geomagnetic prospection results at Gradishte site.

Fig. 9 – Interpretation of geomagnetic prospection results at Gradishte site.

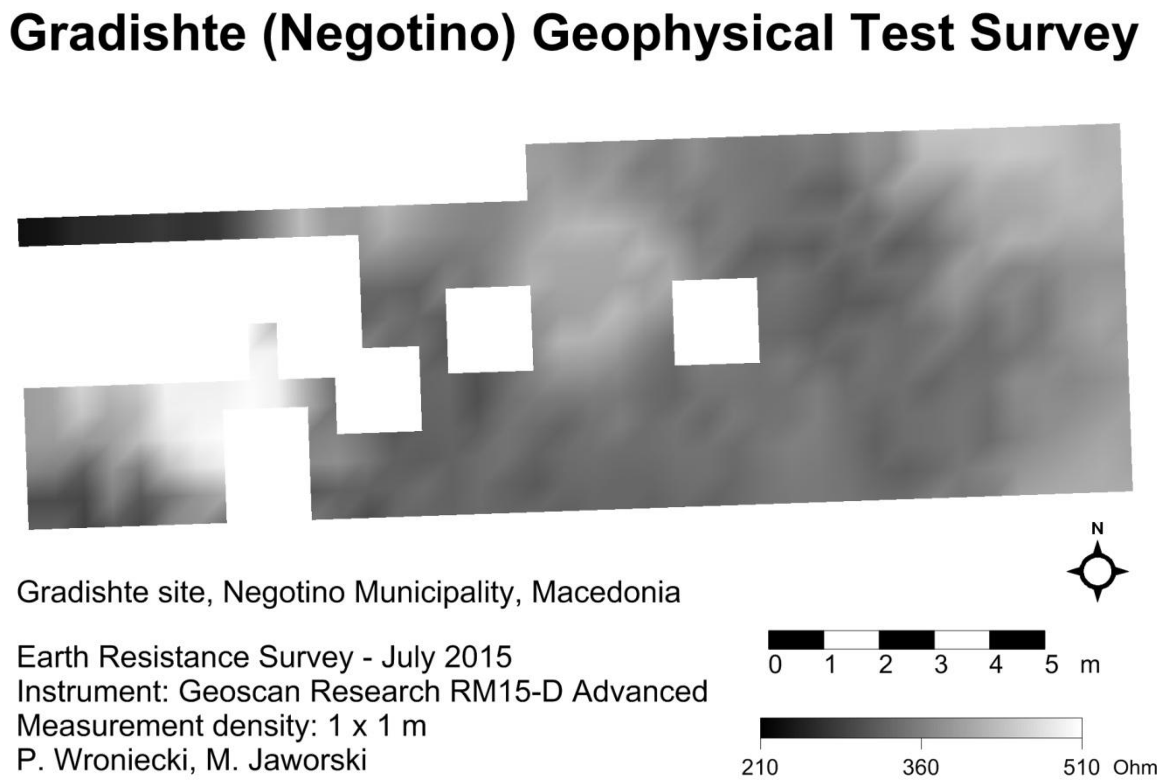

Fig. 10 – Visualisation of Earth Resistance test survey at Gradishte site in 2015.

Due to the weather conditions present before and during the fieldwork, earth resistance survey was limited to tests. Lack of moisture in the ground, as well as high temperatures resulted in two circumstances taking place which had a negative impact on the planned survey. First of all, lack of moisture did not allow the current to flow between probes. When it did, it was nearly impossible to distinguish the natural soil response from anomalies caused by subsurface archaeological features, as in such extremely dry environment they both produced high resistance values. Secondly, the long lasting heat and dryness turned the ground into a nearly impenetrable surface. The probes weren't able to punch through this crust, and that resulted in partial lack of measurement.

Having tested the application of this method on nearly a half of a polygon, the decision was made to abandon further measurements. Yet it is worth mentioning that if the survey was to be conducted in more suitable natural conditions, in less dry seasons perhaps, judging from the results of the magnetic survey and the depth of ancient walls in archaeological trenches, it would be theoretically possible to obtain results that potentially register archaeological features, especially architecture with higher detectability than magnetic prospection. Such survey should take place in spring or autumn, when the ground is moist and both conductivity is increased and the ground is easier to penetrate with probes.

Survey at the Supposed Cemetery Site

Interference from modern infrastructure is clearly visible on the results as a vast positive zone by the south edge and a series of dipole anomalies by the east one. The first results from the vicinity of a metal fence surrounding the adjecent football field (Fig. 11, A). The latter is generated by the road and probably underground pipes as a sewer drain was registered in the middle of the east edge of the surveyed area (Fig. 11, B).

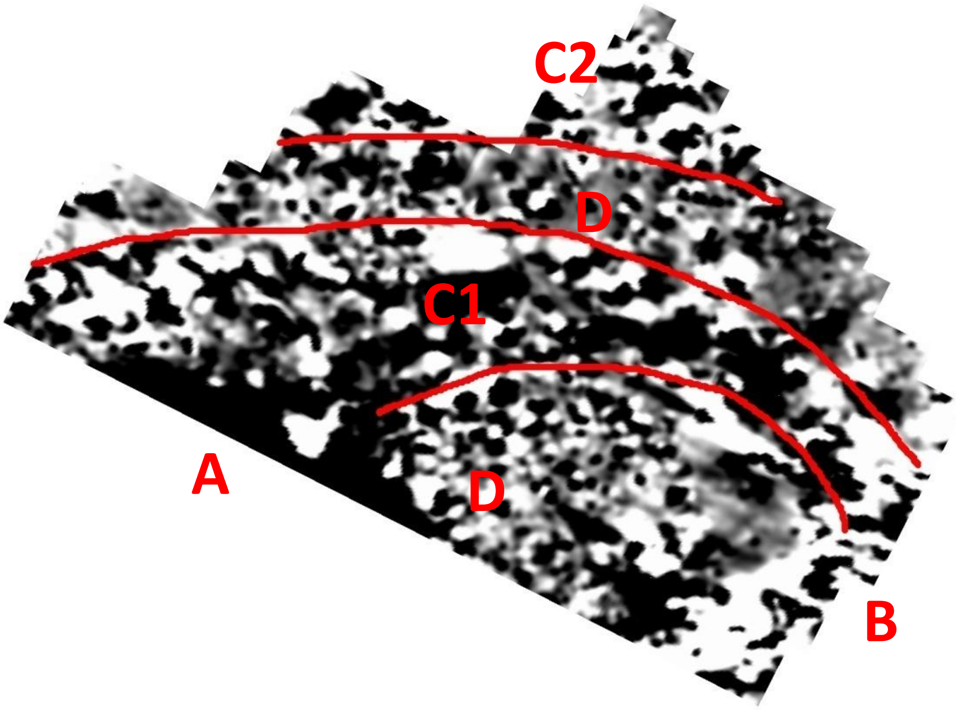

Fig. 11 – Section of the visualisation with marked outline of the mentioned features (-10/10nT, positive anomalies in black, negative in white, north up).

Dipole anomalies are present throughout the whole surveyed area, but in various densities. In broader dynamic ranges it is impossible to distinguish any other anomalies beside vast dipole zones (Fig. 11, C1, C2). In wider ones it is possible to notice zones of point anomalies, that fill the spaces between the highly dynamic dipole zones (Fig. 11, D). Smaller anomalies are probably generated by small objects with magnetic properties.

Due to high dynamic of the registered dipole anomalies it is impossible to distinguish any anomalies that might be related to archaeological features. Any archaeological fieldwork at this place should be done with reference to these results in order to provide additional information that might help form a key to new interpretations.

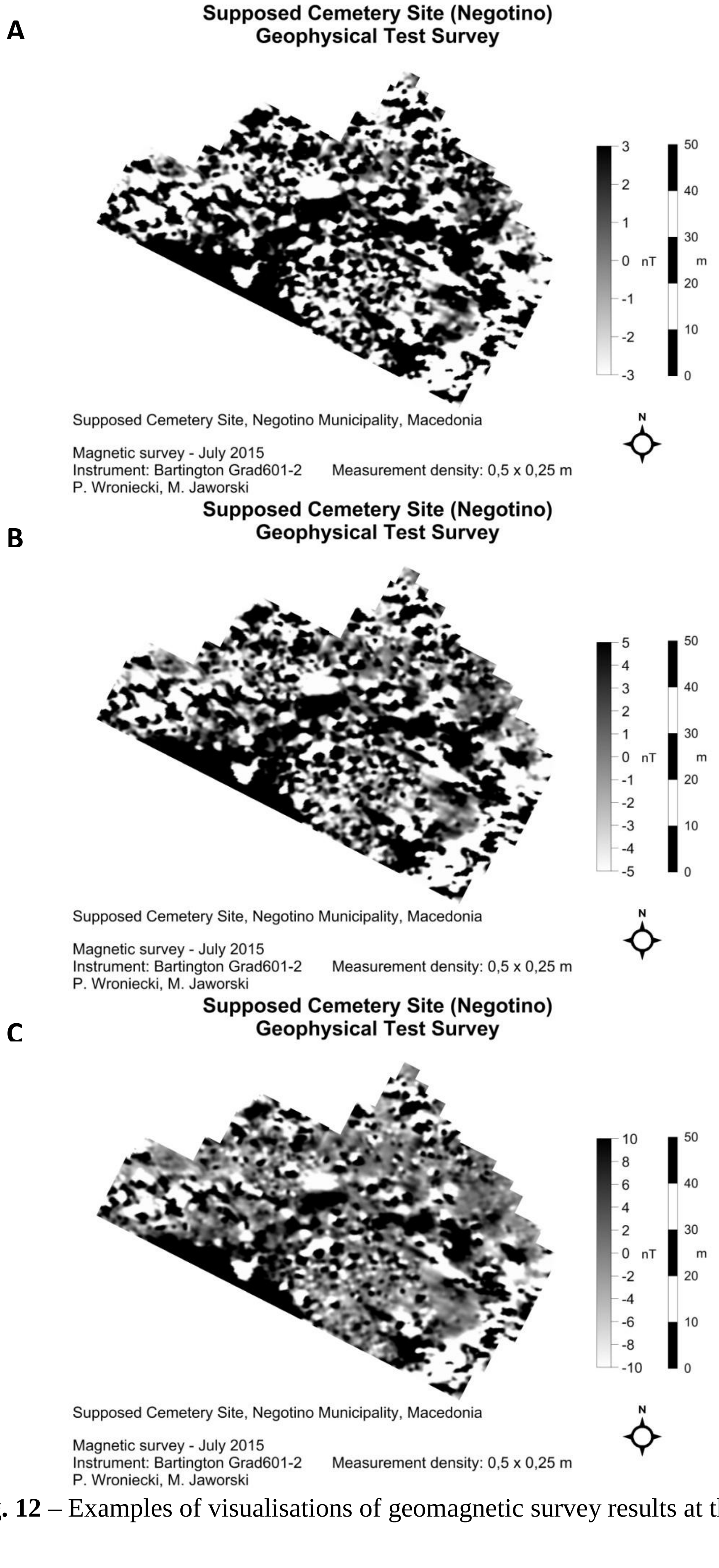

Fig. 12 – Examples of visualisations of geomagnetic survey results at the site.

CONCLUSIONS

The presented interpretation was based on results of the test survey in relatively unfavourable natural conditions, as far as accessibility of the terrain on the Gradishte site and general dry conditions for geoelectric survey are considered. Despite that, it was possible to obtain results of magnetic prospection that might indicate the presence of underground archaeological, presumably architectonical structures. The interpretation and conclusions were based on archaeological information, experience in archaeological prospection as well as additional information (spoken and digital) provided by the excavation team.

The effectiveness of methods

Magnetic prospection's effectiveness was slightly reduced on the Gradishte site, due to the presence of dense vegetation. Thick high grass and thistles had a visible impact on the results, which are less reliable and accurate in southern part of the surveyed area. Yet it was possible to detect a lasrge number of anomalies that might reflect the presence of architectural remains under the surface. At this point the impact of modern transformations, such as plowing and military activity, on archaeological structures and geophysical ability to detect them is unknown, but any fieldwork based on presented results should reveal the effectiveness of the method in the encountered conditions.

Presence of highly magnetic modern infrastructure on the supposed cemetery site was dominant enough to cover any traces of standard less magnetic archaeological features. It was possible to distinguish point dipole anomalies that were less magnetic than the modern interference, yet they are presumably caused rather by so called magnetic trash than archaeological artefacts.

Earth resistance survey has proven ineffective in the encountered conditions. This technique allows to identify archaeological features because they retain a different amount of water than the surrounding soil. But in an extremely dry and hot environment present in July it was impossible to obtain any results due to extreme decrease of conductivity.

Detection of structures

Despite the conditions the test survey on the Gradishte site proved to be effective enough to register magnetic linear and areal anomalies forming clearly distinguishable patterns. Both type of anomalies formed similarly shaped and outlined features. Presence of linear negative anomalies next to positive ones and interweaving of positive area anomalies with negative ones creates an image clearly indicating that there are strong magnetic anomalies present in a relative density at the site.

Integration of the geophysical test results with excavation documentation allowed to recognise a part of the presumed pattern behind the anomalies. If the above presented interpretation is correct in pointing out the outlines of disturbances that might be caused by archaeological features, then it was possible to register a portion of architectural remains of the ancient city. Depending on the depth and type of the feature generating the anomaly it is possible to say that there are linear objects, presumably walls or roads present in the results. Areal ones are clearly distinguishable as they form rectangular zones. These might be connected with filled pits and ditches, interiors of collapsed or demolished buildings or piled-up remains of such.

The most irregular outlined anomalies, like f. ex. the circular linear one or the zone with point anomalies or the anomaly of the supposed military entrenchment stand out from other types of anomalies. Their actual cause and relation with the ancient remains is an issue open for further research, as the shape and type of these anomalies needs archaeological verification.

Suggestions for further research

Knowing that the magnetic prospection on the Gradishte site proved to be effective in detection of anomalies that might originate from archaeological features the next steps in non-invasive archaeological prospection of the site should consist of expansion of the surveyed area and verification of the results. Knowing that the natural conditions are more favourable during spring or autumn, a different season should be chosen for continuation of the prospection. Spring should prove more effective for wide surface prospection due to decrease of vegetation cover after winter. Moisture retained in the topsoil should provide effective conditions allowing the repetition of earth resistance test and potentially even wide area prospection.

Extension of archaeological excavations to the areas where certain types of the anomalies were registered would allow to understand the origins and causes that stand behind them. Similar shaped anomalies but with the opposite values on the dynamic range might either relate to different building material and different types of construction. Recognition of the building material or other source of magnetic response would provide an archaeological key enhancing the present interpretation with new data.

After completing the magnetic survey and expanding it to the whole area of the hill-top other methods are to be considered. Earth resistance measurements can complement the magnetic data with information about the depth and presumed consistency of subsoil material in places of high and low resistance. Magnetic susceptibility could provide information where areas of intense past human activity were located, providing a hint into understanding other types of anomalies and both ancient use and transformation of the area through human occupation. Furthermore GPR (georadar) survey over selected areas, might result in revealing the extent of walls and underground structures on various depths. The selection of the methods and their application should seek to enhance the interpretative model, reveal the source of anomalies and types of archaeological or non-archaeological features behind them.

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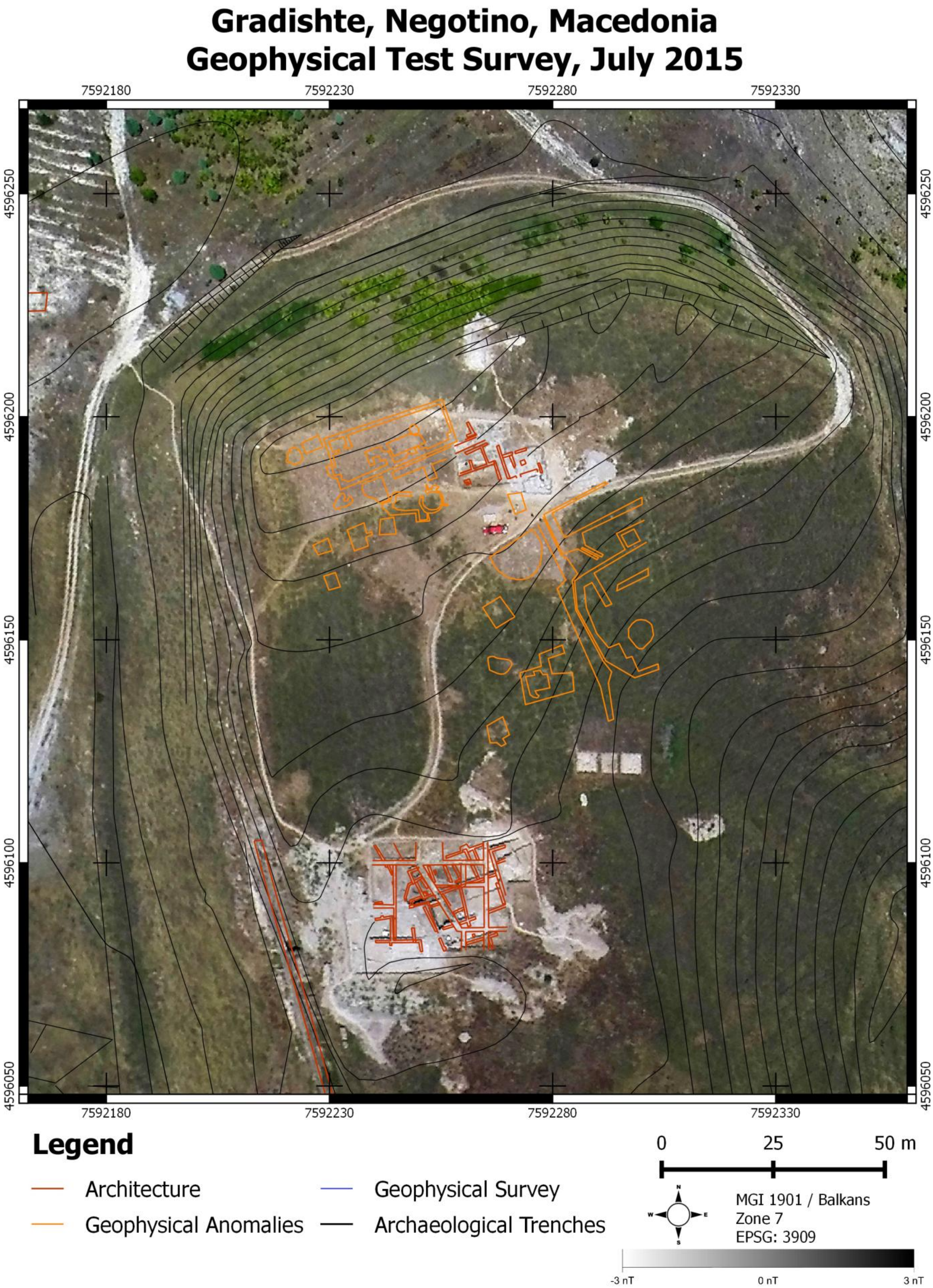

Fig. 13 – Interpretation of the geomagnetic survey results at the Gradishte site in 2015 overlaid on an orthophoto