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GEOMAGNETIC RESEARCH OF THE ARCHAEOLOGICAL SITE ISAR MARVINCI, REPUBLIC OF NORTH MACEDONIA

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Abstract
In this paper the results of the geophysical investigation on the archeological site Isar-Marvinci are presented. The results show low changes in the magnetic field and the local gradient, as it is an archeological site where there are no buildings and structures built of baked bricks that cause larger magnetic changes in the magnetic field over 100 [nT] or more [nT]. Small anomalies of the magnetic gradient probably indicate graves that have been confirmed by illegal diggers, whose presence can be seen on the ground.

Key words: *Isar, geomagnetism, magnetic field, research*

INTRODUCTION

The archeological site of Isar, near the village of Marvinci, Valandovo (Norh Macedonia), is a settlement and a necropolis with a continuity from the VII century BC to the VI century AD. It is located next to the village, on its southwest side, on a very accessible hill with a great view of the Valandovo Valley and the valley of Vardar (Fig.1) [2, 4].

Figure 1. Part of the archeological locality Isar-Marvinci (near Valandovo).

In the earliest period of its existence, the settlement stretched over the area covered by Isar I and Isar II and it covered about 5 hectares. Isar I is actually the acropolis of the settlement, erected on a hill spacious enough for survival. The acropolis was reinforced with defensive walls and as such existed throughout the Hellenistic period. At that time, the area of Isar II (sector 5) was also inhabited - the remains of houses found in probe 6, with characteristic material, confirm this. Although no experimental excavations have been carried out, judging by the configuration of the terrain, we can assume that the western terrace of Isar II was protected by a defensive wall. From these two points the settlement gradually expands, so, during the Hellenistic period, the nearest terraces were also inhabited. Stratigraphic data indicate three or four living horizons, most of which were destroyed by collapsing. Over a longer period (from the end of V to the middle of the II century BC), the Southern necropolis was used for burial. The discovered graves with rich content give a clear picture of the changes in the way of burial and the burial ritual.

MATERIAL AND METHODS

Methodology

The geophysical-geomagnetic measurements were performed at the archeological site Isar, in the vicinity of the village Marvinci. The purpose of the research was to investigate a part of the site for which it is assumed that there are tombs that would show minimal changes in the geomagnetic gradient of the earth's magnetic field.

Having in mind the set task, appropriate geomagnetic surveys are designed with a given network of measuring points from the given plots. Knowing that in the researched space baked clays that cause bigger anomalies in the earth's magnetic field were not used, we still expected changes of small values of the gradient due to the inhomogeneity and incompatibility of the material from which the tombs are made.

For that purpose, a single-point height measurement was made with the sensor height of 1.5m and 2m on some plots to determine the gradient of the magnetic field. Characteristic places were chosen where a change in the gradient of the total vector of the earth's magnetic field could be expected. The terrain was divided and marked into 10 plots, while some plots were divided into two parts. For each plot, a strictly defined direction of movement, direction and correct placement of the sensor for measuring the anomalies of the earth's magnetic field were defined. The plots were marked with piles with marked profiles with a length of 50 m and a place with a mark of the measuring point. Thus, 10 plots were formed, consisting of several up to 21 profiles depending on the terrain and with 21 measuring points per profile, which means that for each plot we had from 200 to 441 measuring points. At each measuring point of the archeological site, a place was marked where the measurement of the total vector was performed. It was assumed that the distance of 2.5 m between the measuring points and the height of the measuring sensor of 1.5 m, would be a sufficient resolution for noticing some characteristic anomaly for the appearance of magnetic dipoles that would be formed if there was some inhomogeneity and different magnetism of the material.

In the Geomagnetic Surveys, instruments have been used for the geophysical surveys of the archeological site "ISAR". The measurements were made using three instruments - Geometrix and two Bison proton magnetometers. Figure 2 shows the two types of proton magnetometers.

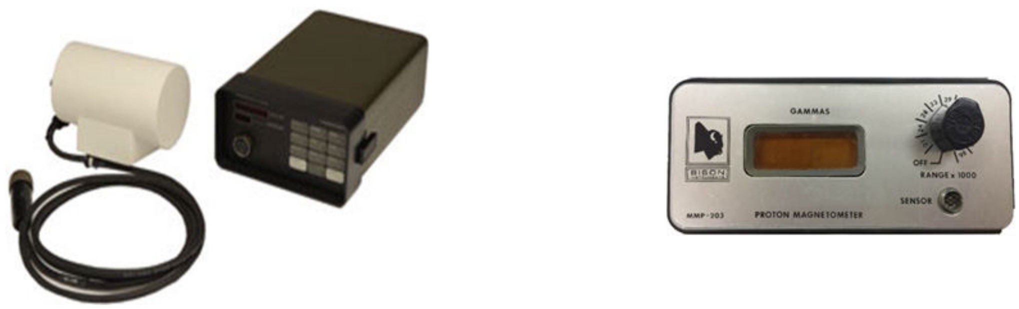

Figure 2. Geometrics (left) and Bison (right) proton magnetometers

Due to the nature of the tests in which they are used (determination of an archeological site), magnetic tests are based on the determination of the anomalous field, the registration of which would determine the presence of a structure with different density and characteristics in the geological complex.

To accurately determine the anomalous field, it was necessary to eliminate all other interferences on the registered magnetic field, and the most important correction was the daily variation of the earth's magnetic field [5].

On the territory of the Republic of North Macedonia on the mountain Plackovica, there is a functional magnetic observatory where the changes of the variation of the magnetic field of the X, Y and Z component for each second are monitored and digitally recorded.

In this way, the work of the geomagnetic observatory is simulated, i.e., a base line is made for the given space in the period of geomagnetic measurements. Figures 3 and 4 show the equipment that is in operation in the building of UGD on mountain Plackovica.

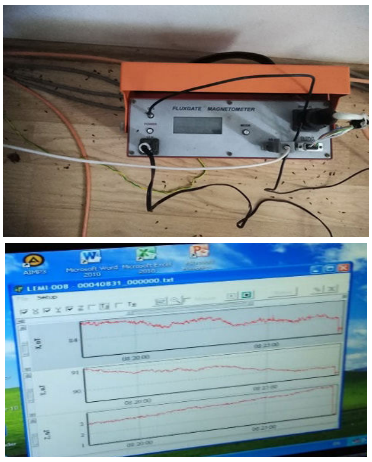

Figure 3. LEMI variometer and the record of the three components of the daily variation

Figure 4. Electromagnetic field measuring antennas

The data from the daily variation were also compared with the data from observatories in Serbia (Belgrade) and Greece (Athens), which globally do not differ much. On the days when the measurements were performed, the magnetic index was very small, almost k = 1, so that there were no major changes in the magnetic field, the correction was almost imperceptible.

Before interpretation the measured magnetic field is corrected for the daily variations registered by the variometers from the observatory in the same time interval; in our case, the values were corrected for some plots per second and for some per minute, depending on the data collection.

RESULTS AND DISCUSSION

Geomagnetic field maps of Plots 1 to 10

Results from the conducted measurements were processed and interpreted and the following maps were created [3].

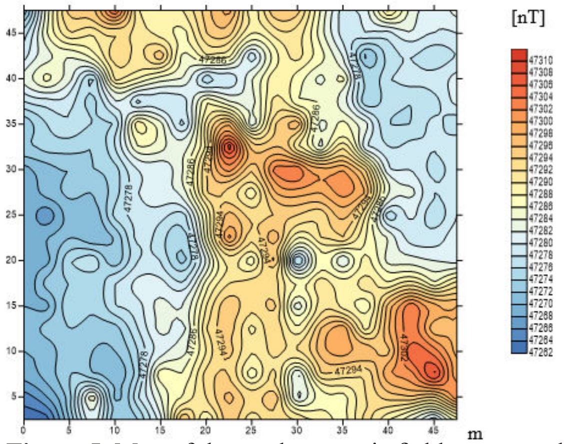

Figure 5. Map of the total magnetic field vector at the site Isar, Plot 1

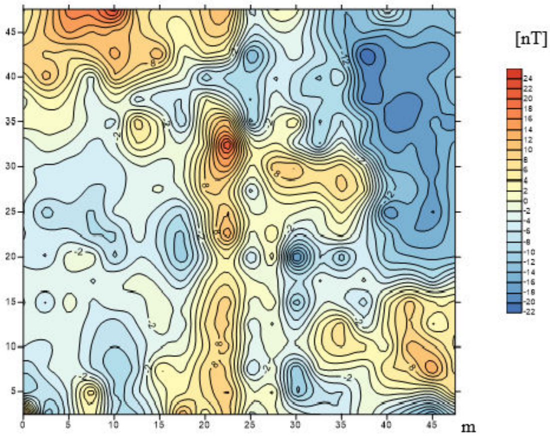

Figure 6. Map of the corrected geomagnetic gradient of local anomalies of the magnetic field at the site Isar, Plot 1

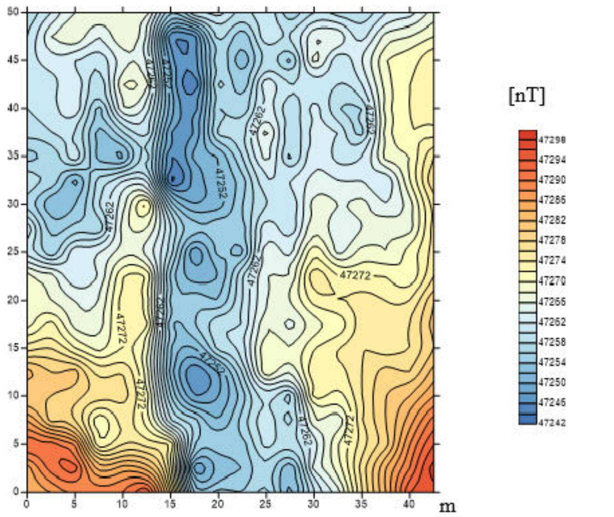

Figure 7. Map of the total vector of the magnetic field at the Isar site, Plot 2

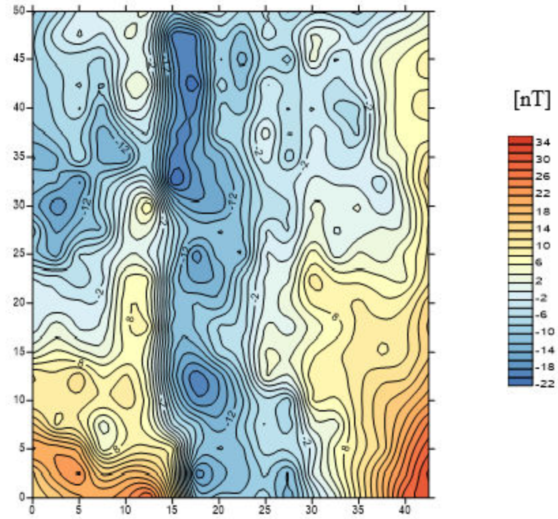

Figure 8. Map of the corrected geomagnetic gradient of the local anomalies of the magnetic field, Plot 2

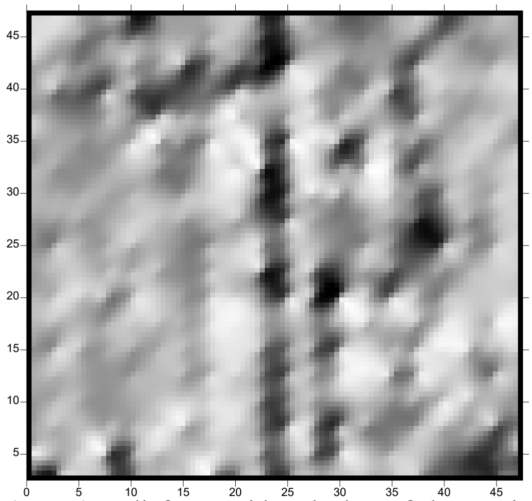

Figure 9. Relief map with a shadow of changes in the earth's geomagnetic field for plot 1

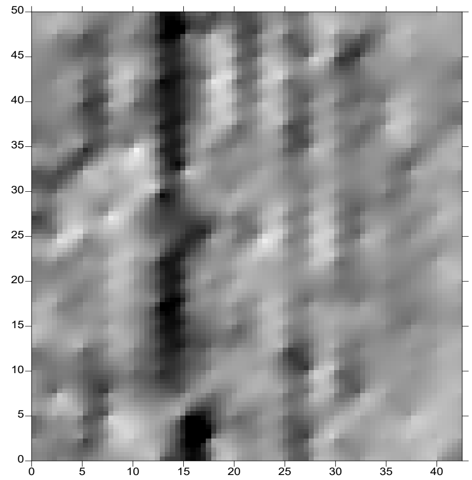

Figure 10. Relief map with a shadow of changes in the earth's geomagnetic field for plot 2

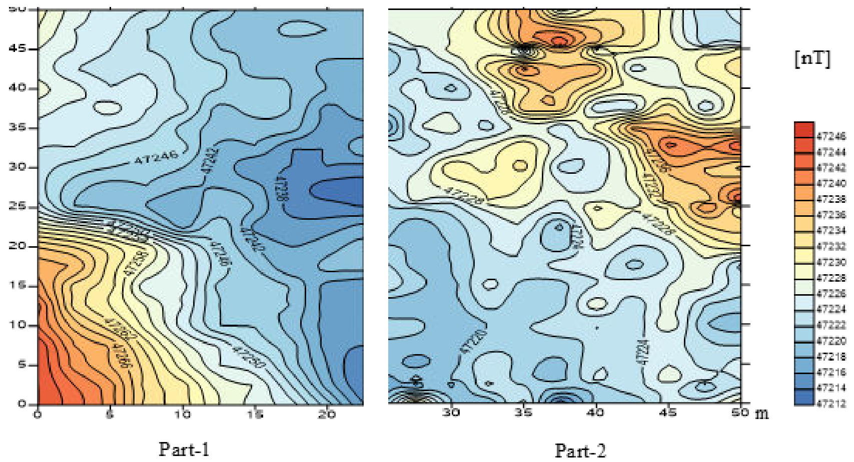

Figure 11. Map of the total vector at the Isar site, Plot 3, with the sensor positioned at the height of 2 m (part-1) and the height of 1.5 m (part-2)

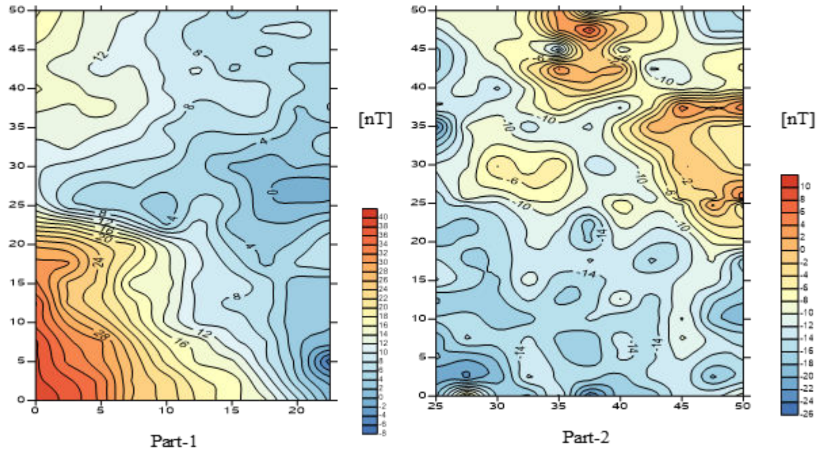

Figure 12. Map of the corrected geomagnetic gradient of the local anomalies of the magnetic field at the site Isar, Plots 3-1 and 3-2

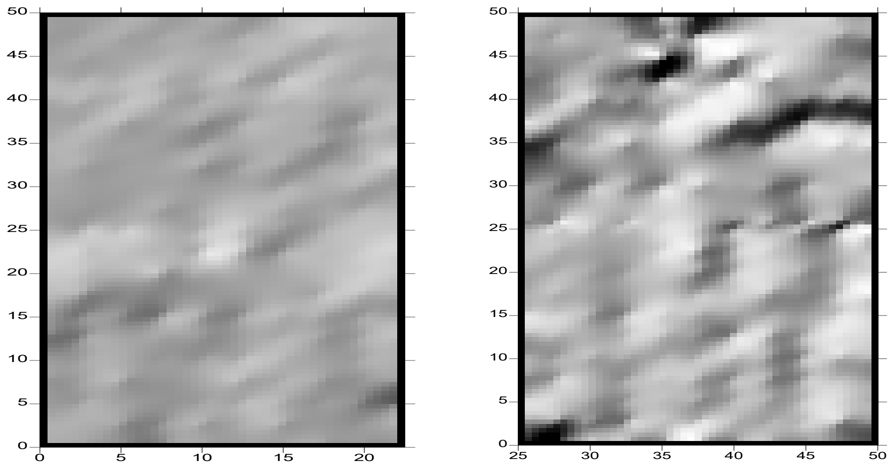

Figure 13. Relief maps with a shadow of the changes of the earth's geomagnetic field on plot 3, part-1 and part-2

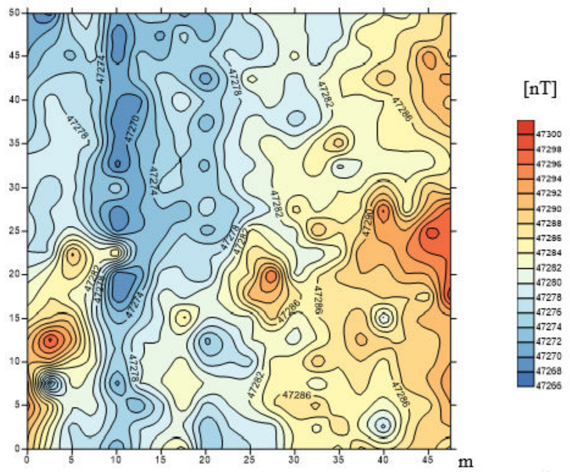

Figure 14. Map of the total vector of the magnetic field at the site Isar, Plot 4

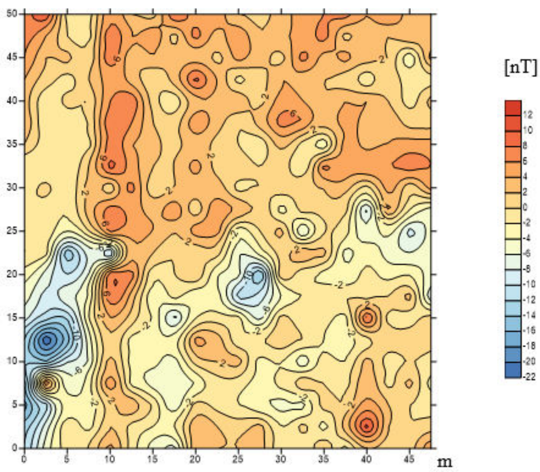

Figure 15. Map of the corrected geomagnetic gradient of the local anomalies of the magnetic field, Plot 4

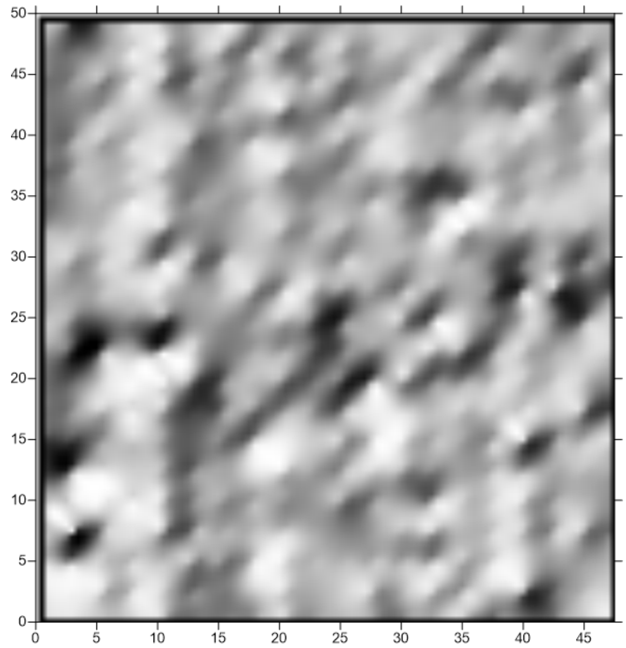

Figure 16. Relief map with a shadow of the changes of the geomagnetic field for plot 4

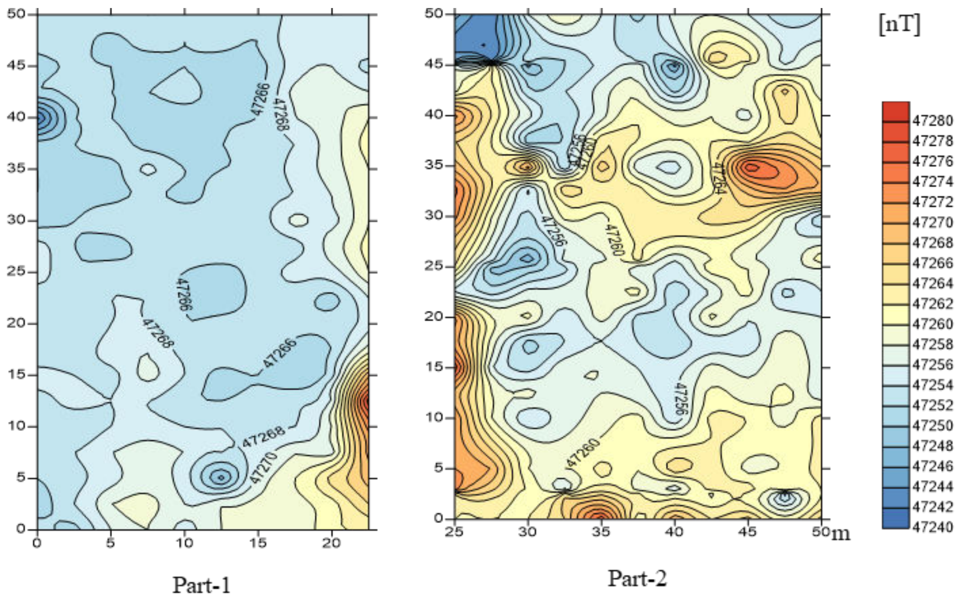

Figure 17. Maps of the total vector at the site, Plot 5, with sensor position
at the height of 2 m (Part-1) and the height of 1.5 m (Part-2)

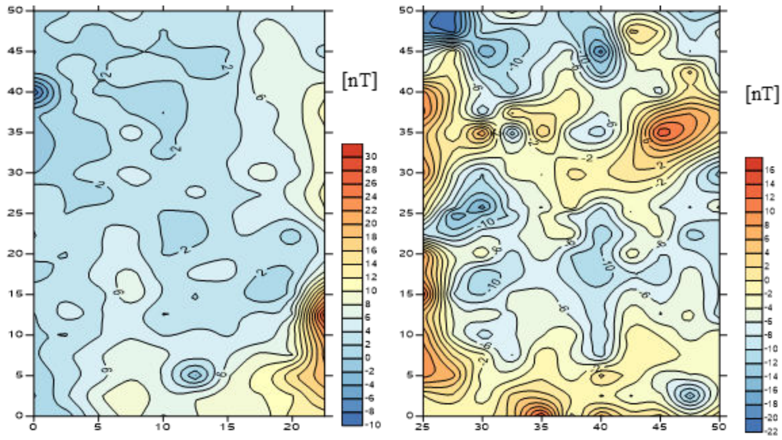

Figure 18. Corrected geomagnetic gradient maps of the total magnetic field vector at the site Isar, Plot 5-1 and 5-2

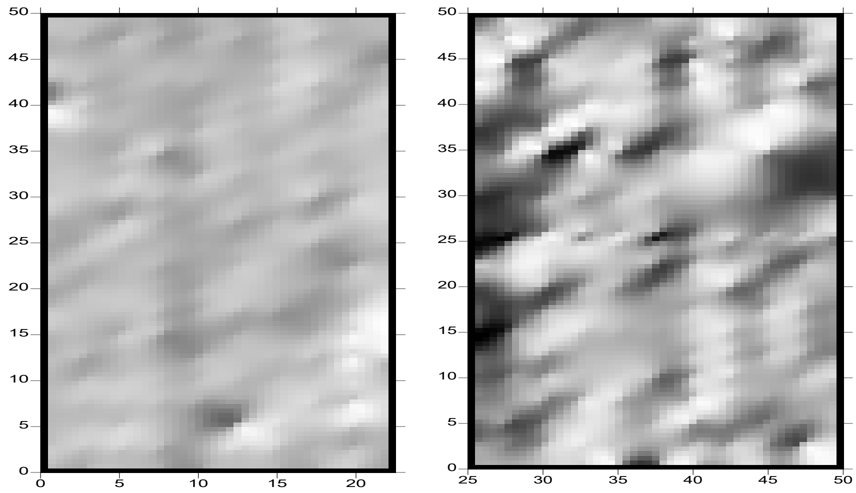

Figure 19. Relief maps with a shadow of the changes of the earth's geomagnetic field on plot 5, Part-1 and Part-2

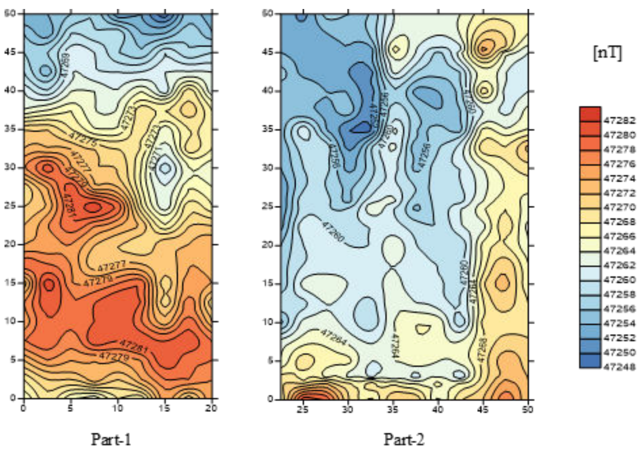

Figure 20. Maps of the total vector of the magnetic field, site Isar, Plot 6, with sensor position at the height of 2 m (Part-1) and the height of 1.5 m (Part-2)

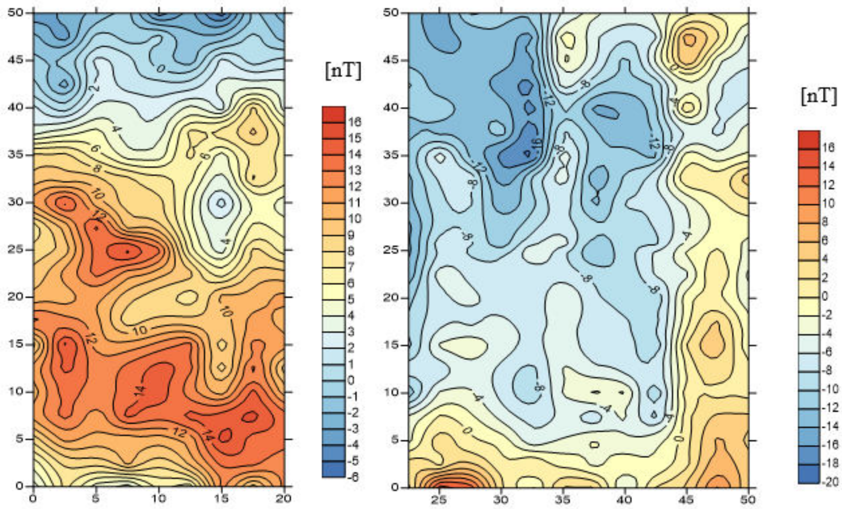

Figure 21. Maps Maps of the corrected geomagnetic gradient of the total magnetic vector of the magnetic field at the site Isar, Plots 6-1 and 6-2

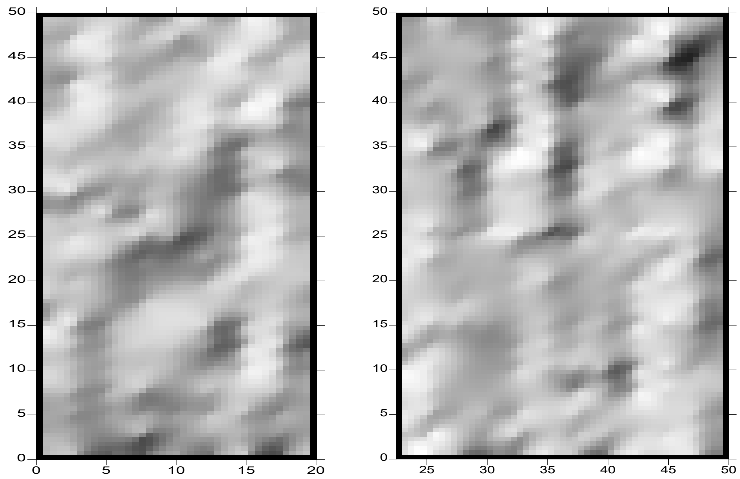

Figure 22. Relief maps with a shadow of changes in the earth's geomagnetic field of plot 6, Part-1 and Part-2

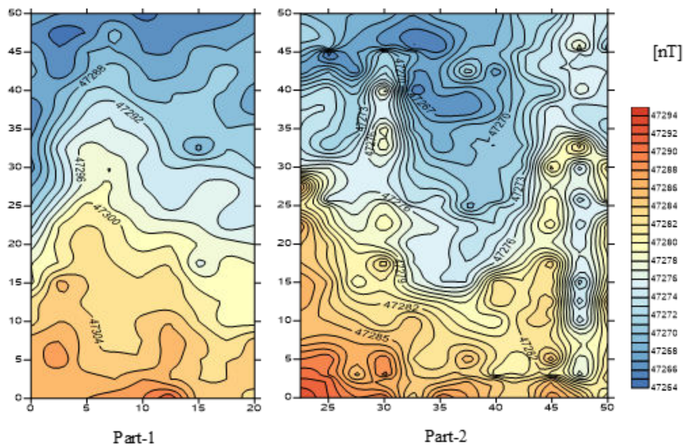

Figure 23. Map of the total vector of the magnetic field at the site Isar, Plot 7, with sensor position at the height of 2 m (Part-1) and the height of 1.5 m (Part-2)

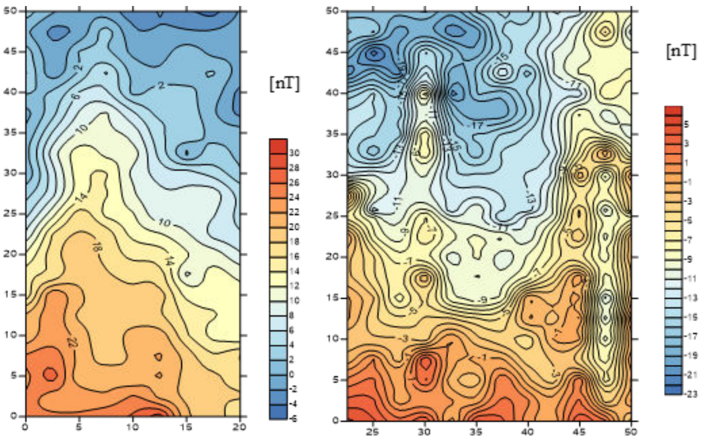

Figure 24. Map of the corrected geomagnetic gradient of the total magnetic vector of the magnetic field at the site Isar, Plots 7-1 and 7-2

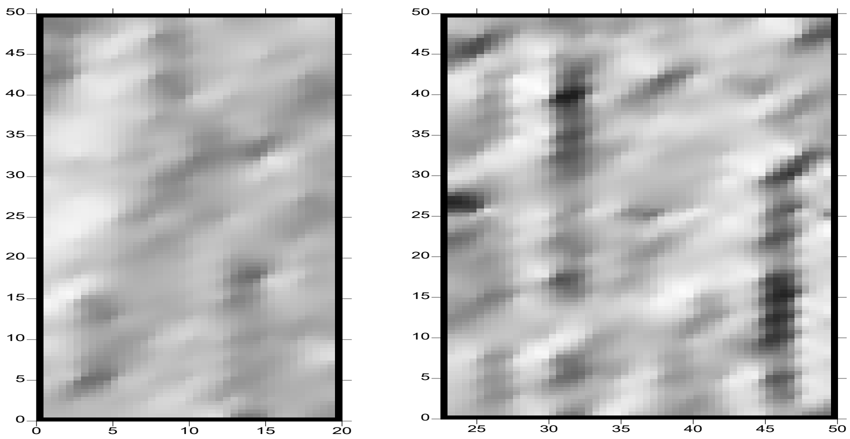

Figure 25. Relief maps with a shadow of the changes of the earth's geomagnetic field on plot 7, Part-1 and Part-2

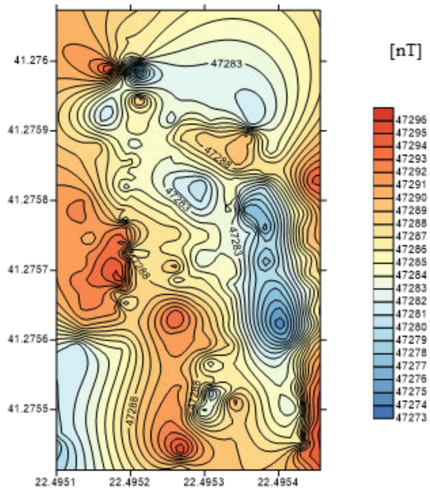

Figure 26. Map of the total vector of the magnetic field at the site Isar, Plot 8

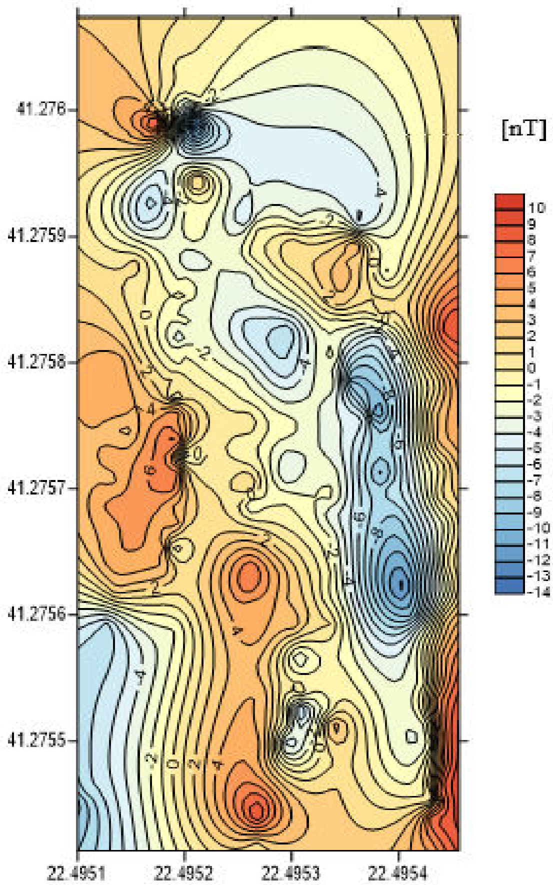

Figure 27. Map of the corrected geomagnetic gradient of the total vector of the magnetic field at the site Isar, Plot 8

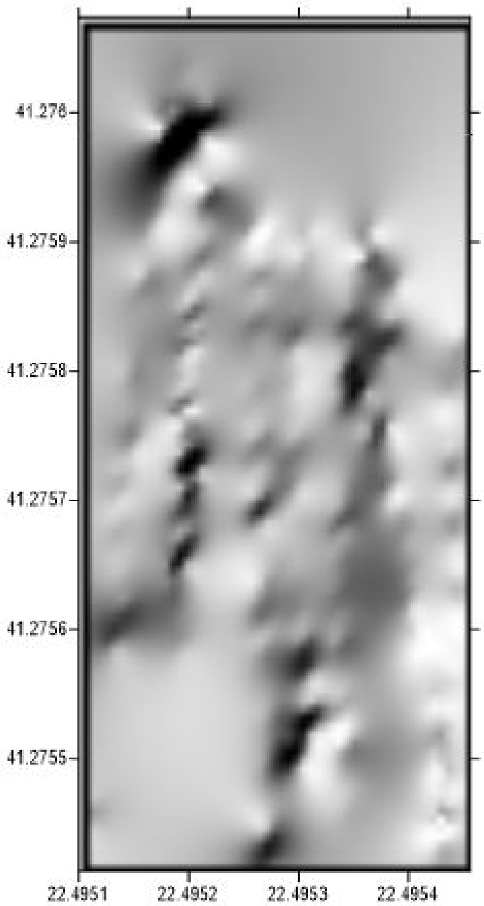

Figure 28. Relief maps with a shadow of the changes of the earth's geomagnetic field on plot 8

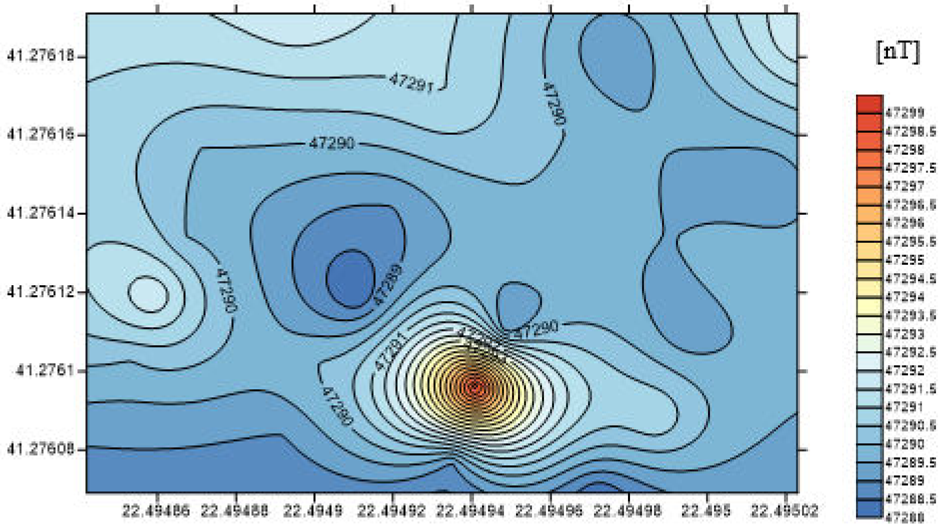

Figure 29. Map of the total vector of the magnetic field at the site Isar, Plot 9

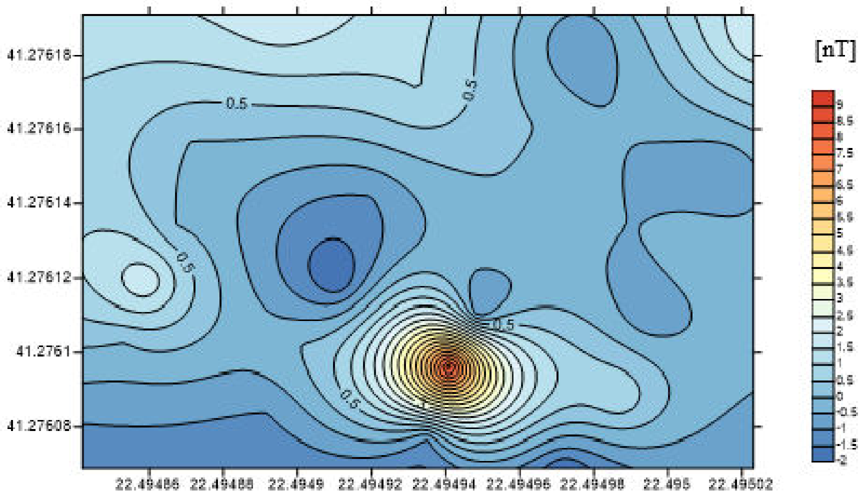

Figure 30. Map of the corrected geomagnetic gradient of the total vector of the magnetic field at the site Isar, Plot 9

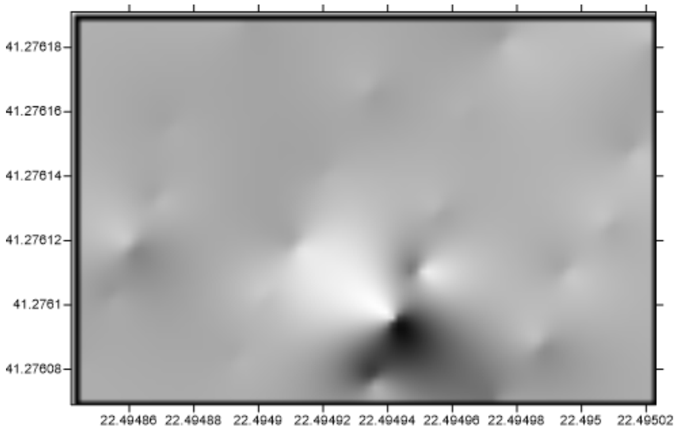

Figure 31. Relief map with a shadow of the changes of the earth's geomagnetic field at plot 9

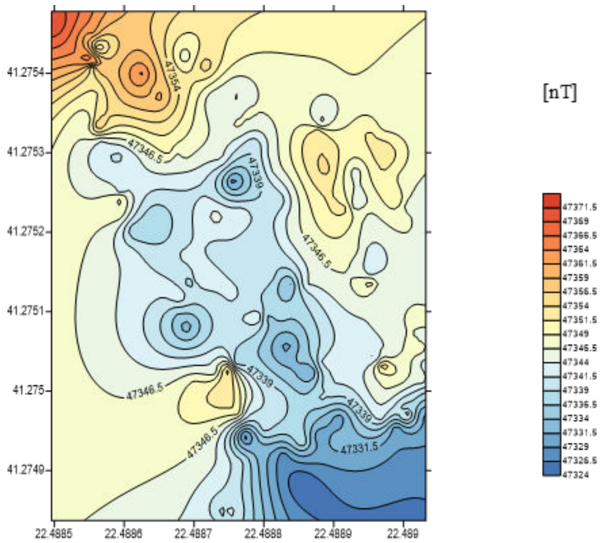

Figure 32. Map of the total vector of the magnetic field at the site Isar, Plot 10

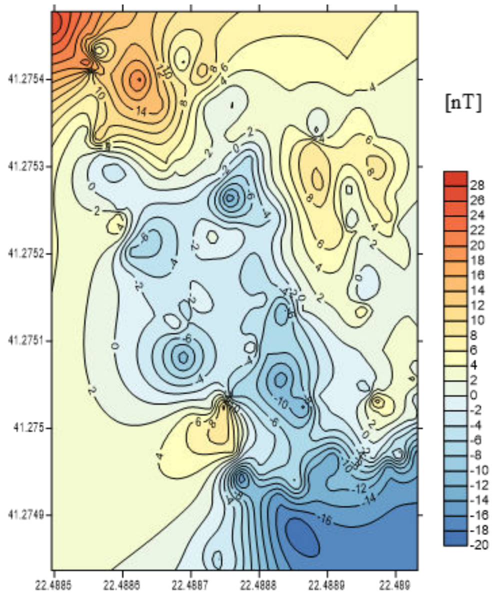

Figure 33. Map of the corrected geomagnetic gradient of the total vector of the magnetic field at the site Isar, Plot 10

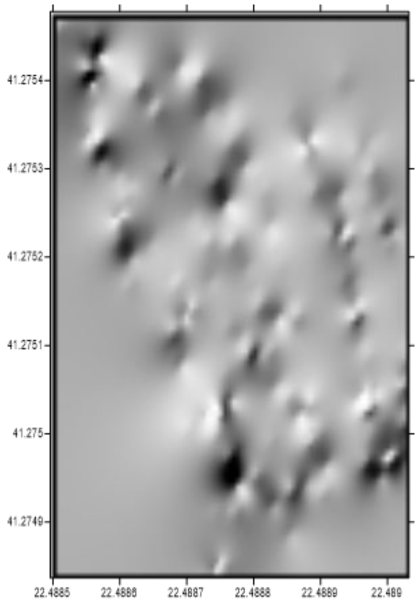

Figure 34. Relief map with a shadow of the changes of the earth's geomagnetic field at plot 10

DISCUSSION

Geomagnetic maps of the total magnetic field and gradient maps of the total vector of the magnetic field have been made, from where the increase or the decrease of the strength at a certain distance for each plot can be seen.

The isolines of the anomalous magnetic field regionalize the study space according to its magnetic characteristics. This type of data modeling allows direct prospecting of the examined space, so that the accuracy of the obtained model directly depends on the density and the number of geomagnetic profile survey lines.

From the research and analysis of the geomagnetic diagrams of the anomalous field it was concluded that the measurements at lower altitudes h = 1.5 m strongly expressed the close subsurface anomalies and therefore in the interpretation the measurements at the height of h = 2 m on some plots were used.

Figure 5 and Figure 6 show the maps of the total magnetic field vector and the gradient of the local anomalies at the Isar site, Plot 1. It can be seen that the gradient of the magnetic field anomalies ranges from -22 to 24 [nT] with a total of 46 [nT], and there several larger anomalies are noticed that may be of interest for research by making archaeological probes.

Figure 7 and Figure 8 show the maps of the total magnetic field vector and the gradient of the local anomalies at the Isar site, Plot 2. It can be seen that the gradient of the magnetic field anomalies ranges from -22 to 34 [nT] with a total change of 54 [nT], and several larger anomalies are also noticed here that may be of interest for research by making archaeological probes.

Figure 11 and Figure 12 show the maps of the total magnetic field vector and the gradient of the local anomalies at the Isar site, Plot 3. This plot is divided into two parts. One part of the plot is processed with a probe at the height of 2 m, Part-1, and the second part is processed with a probe at the height of 1.5 m. From the maps it can be seen that the gradient of the magnetic field anomalies ranges from -8 to 40 [nT] with a total change of 48 [nT] for Part-1. There is a larger change in the magnetic field compared to other plots. But it can be noticed that it is a change of the geological environment and not a local anomaly of the tomb, while in Part-2 some interesting anomalies can be distinguished even though the gradient is less than -26 to 10 [nT]. There are several anomalies forming dipoles that may be of interest for research by making archaeological probes.

Plot 4 is the same size, 50X50 m, as the previous plots. On the given maps, Figures 14 and 15 we can see the change of the magnetic field anomalies, where the gradient ranges from -22 to 12 [nT]. Here, too, some interesting anomalies can be identified for further research.

Plots 5, 6 and 7 with dimensions 50x50 m, just like plot 3, are divided into two parts. Part -1, where the height of the measuring probe is 2m and Part-2, where the height of the measuring probe is 1.5m. In Figures 17 and 18 we can see the changes in the magnetic field and the size of the gradient for plot 5, where it ranges from -10 to 30 [nT] for Part-1 and -22 to 16 [nT] for Part-2.

Figures 20 and 21 show the changes in the magnetic field and the size of the gradient for plot 6, where it ranges from -6 to 16 [nT] in total 22 [nT] for Part-1, and -20 to 16 [nT] in total 36 [nT] for Part-2.

Figures 23 and 24 show the changes in the magnetic field and the size of the gradient for plot 7, where it ranges from -6 to 30 [nT], a total of 36 [nT] for Part-1, and from -23 to 5 [nT], Part-2, a total of 28 [nT].

Plot 8 is 35X60 m in size, and the geomagnetic maps show a change in the magnetic gradient vector from -14 to 10 [nT], a total of 24 [nT]. On this plot, places for making archeological probes can also be identified (figures 26, 27).

Plot 9 is a smaller plot with dimensions of about 10x20 m, Figures 29 and 30, where only a small local anomaly of the magnetic gradient can be observed with the change of the magnetic field from -2 to 9 [nT], a total of 11 [nT], which not very interesting.

Plot 10, with dimensions of about 55X65 m, was the last one built. On the geomagnetic maps, Figures 32 and 33, the change of the magnetic gradient of the local magnetic field from -20 to 28 [nT] in total from 48 [nT] can be seen, so here several places of anomalies of the gradient of the magnetic field that would be interesting for archeology for making exploratory probes were noticed.

CONCLUSION

From all of the above, it can be concluded that 10 plots with a total area of about 2.3 ha from the archeological site Isar have been measured and analyzed.

The results show low changes in the magnetic field and the local gradient, as it is an archeological site where there are no buildings and structures built of baked bricks that cause larger magnetic changes in the magnetic field over 100 [nT] or more [nT]. Small anomalies of the magnetic gradient probably indicate graves that have been confirmed by illegal diggers, whose presence can be seen on the ground.

For a more accurate determination of the archeological construction, it is necessary to form a denser network with measuring points. In our case, the network was made of 2.5x2.5 m; from the presented results it can be concluded that if the network of measuring points was denser, there would be more reliable results in the field. Such measurements require a denser network of measuring points 0.5 to 1 m.

For better filtering of the data for determination of the changes of the magnetic gradient, a double-height measurement of the given points is required.

The measurements performed at lower altitudes indicate anomalies caused by factors that are less shallow and with lower intensity, while measurements at higher altitudes indicate bodies with greater mass and relatively deeper positions.

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ГЕОМАГНЕТНИ ИСТРАЖУВАЊА НА АРХЕОЛОШКИОТ ЛОКАЛИТЕТ ИСАР-МАРВИНЦИ, РЕПУБЛИКА СЕВЕРНА МАКЕДОНИЈА

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Резиме

Во трудот се прикажани резултатите од геофизичките истражувања на археолошкиот локалитетот Исар-Марвинци. Рзутатите покажуваат ниски промени на магнетното поле и локалниот градиент, каде станува збор дека се работи за археолошки локалитет каде нема градби и објекти градени печени тули кои предизвикуваат поголеми магнетни промени на магнетното поле и преку 100 [пТ] па и повеќе [nT]. Малите аномалии на магнетниот градиентот веројатно укажуваат на гробови кои се потврдени од дивокопачите по што се гледа и на самиот терен дека тие биле присутни..

Клучни зборови: *Исар, геомагнетизам, магнетно поле, истражување*