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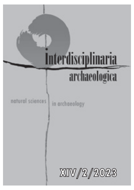

# The Results of Non-Invasive Studies Carried out at the Early Iron Age Fortified Settlement in Chotyniec in South-Eastern Poland

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*ABSTRACT*

The article presents the results of non-invasive studies carried out within the fortified settlement of Chotyniec, in south-eastern Poland. This site is the central and most important part of the so-called Chotyniec agglomeration, associated with the Scythian cultural circle. It is the westernmost enclave of this culture, which can be considered crucial for the interpretation of the situation in the Early Iron Age. Geophysical prospection was performed using three measurement methods: magnetic, electromagnetic (EM) and ground-penetrating radar (GPR). The magnetometer and electromagnetic tests covered the entire defensive structure along with the nearest facilities, and the ground-penetrating radar was used in selected parts of the settlement. The obtained results have revealed uneven effectiveness in the detection of archaeological features and layers. They were additionally verified in selected areas by the use of archaeological excavations.

## 1. Introduction

Chotyniec is located in south-eastern Poland, in the commune Radymno, in the district Jarosław. There are many archaeological sites within this locality, dating from the Neolithic to the Modern period. One of the most interesting ones is the place related to the Early Iron Age, represented by the fortified settlement with accompanying open settlements (Figure 1). This site has been systematically researched by archaeologists since 2008, initially in the frame of the construction of the A4 Motorway, and then from 2015 by researchers of the Institute of Archaeology at the University of Rzeszów (Czopek, 2019). These works have led to a radical change in the perception of the cultural situation during the Hallstatt period in south-eastern Poland. The preliminary results of these studies along with their interpretation have been systematically published (Czopek, 2019; 2020; Czopek *et al.*; 2017; 2020; 2021; 2022; Trybała-Zawiślak, 2019; 2020b; 2020a). There have also been considered selected categories of artefacts (Adamik-Proksa and Ocadryga-Tokarczyk, 2021; Burghardt, 2020) and the chronology of the site (Czopek and Krąpiec, 2020). In the presented paper, we want to show the methods and results of non-invasive studies carried out within the settlement and its immediate surroundings.

The aforementioned defensive structure, together with the entire system of open settlements, formed a functional settlement complex during the Early Iron Age. It covers an area of several dozen hectares, which excludes its survey with the use of invasive methods. As shown by the results of excavation conducted at the A4 Motorway, the Early Iron Age features often occur in clusters separated by empty space. What is more, the settlement with an area of over 30 ha, despite the involvement of considerable resources and time, is known only to a small extent (Czopek *et al.*, 2022). By the end of 2021, a total of about 0.77 ha of the discussed area was excavated, in various parts of the settlement, including both the fortification system and some selected places of the enclosure.

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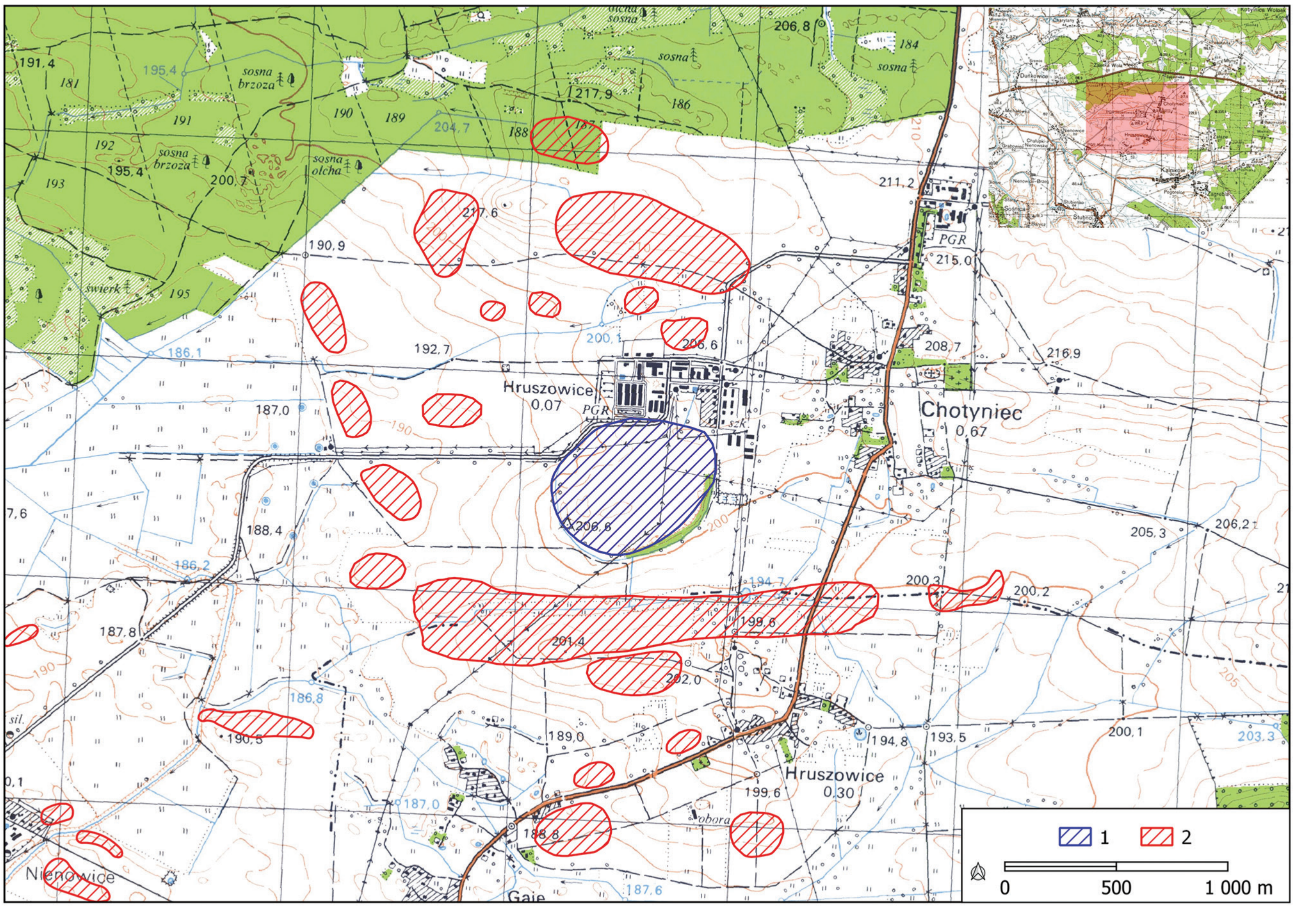


**Figure 1.** Location of archaeological sites dating back to the Early Iron Age. 1 – Chotyniec, site 1 (fortified settlement), 2 – open settlements.

The results of archaeological research carried out since 2016 at site number 1 in Chotyniec indicate that this area was a unique place in the Early Iron Age. Discovered here (for the first time in Poland) are traces of period(s) of stay of people of the Scythian cultural circle together with imports from Greek colonies – including wine in amphorae. This makes it one of the most important sites for the Hallstatt period in this part of Europe up to now (Czopek, 2019; 2020; Czopek *et al.*, 2021). The defensive structure itself is surrounded by earth ramparts, noticeable only relatively well in the southern and western parts (Figure 2). The outline of the embankment in the remaining parts can be reconstructed on the basis of airborne laser scanning (ALS) and analysis of the Digital Terrain Model (DTM) data, aerial photographs and the conducted excavation.

The fortified settlement is surrounded by extensive open settlements, which created the economic base and formed a political and social organism (Czopek *et al.*, 2020). However, it should be noted, as we know from the performed archaeological excavation, that only some of the area contains artefacts related to the Early Iron Age settlement. Observations show that immovable sources recorded in the course of excavations are not distributed evenly, creating more or less noticeable clusters, probably related to the functioning spatial organisation. The image of the sites created on the basis of surface collection surveys, even with quite precise tracking and collecting of artefacts, is often definitely different.

Examining the entire settlement complex with traditional methods is difficult to achieve. Moreover, such a struggle is pointless from the conservation point of view, assuming a need to preserve an intact historic structure for future generations. Therefore, as part of the project, it was important to implement various non-invasive research methods. Their use is also supported by a broader methodological context, in line with modern methods of archaeological documentation, aimed at maximising the information obtained about the past and ensuring the least possible destruction of the features and artefacts.

## 2. Site characterisation

The fortified settlement in Chotyniec is located in south-eastern Poland, occupying the western edge of the Tarnogród Plateau, also known as the Tarnogród Upland or the Lubaczów-Chyrów Plateau (Kondracki, 1978; Gębica and Jacyszyn, 2018). It is a physico-geographical unit that occupies the current areas of the Polish and Ukrainian border. Considering a more precise mesoregional division,

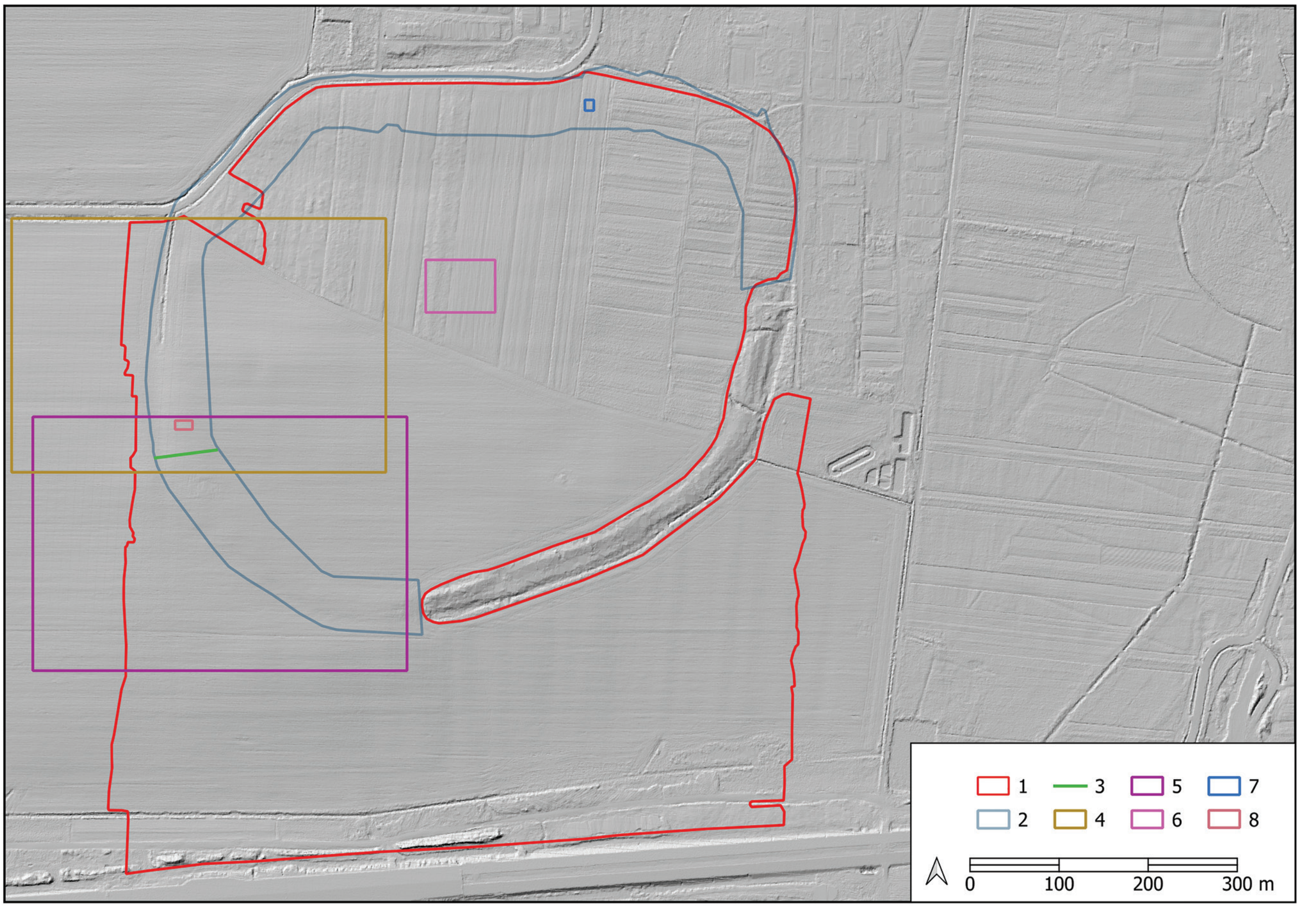


**Figure 2.** Chotyniec, site 1. The range of non-invasive tests: 1 – magnetometer and conductometer; 2 – the GPR; 3 – position of the GPR profile from Figure 3; 4 – The location of the place depicted in Figure 4.1; 5 – The location of the place depicted in Figure 4.2; 6 – The location of the place depicted in Figure 7; 7 – The location of the place depicted in Figure 10; 8 – The location of the place depicted in Figure 11; presented on the numerical terrain model (data source: Central Office of Geodesy and Cartography).

we can indicate that it is located on the Krakowiec Ridge, between the Wisznia and Szkło rivers. To the west of the settlement there is the Lower San Valley and the Wisznia Valley. In terms of geomorphology, the discussed site is composed of podzolic and pseudopodzolic soils with silty formations. In the northern part, brown, loamy and sandy soils occur. This is confirmed by the recorded profiles within archaeological excavation trenches, where a sequence of silty deposits (about 30 cm thick) is usually noted, covering dense loamy deposits in the roof part, and sandy in some areas, up to 110 cm thick, below which there are sands of glacial origin.

Geophysical research was carried out at different times depending on the implemented method. The research using a magnetometer in the northern part of the settlement was carried out at the end of August 2019, whereas in other areas it was from the beginning of December 2019 to the end of January 2020. Electromagnetic research was carried out from the end of August to the beginning of December 2019, while the prospection using GPR was performed in January 2020. Thus, it is visible that in the case of all the methods, variable humidity and temperature conditions, along with the diversified geological structure, have a smaller (magnetometer) or greater impact on the obtained results (electromagnetics and GPR).

## 3. Materials and methods

Geophysical works in Chotyniec were commenced after the first non-invasive surface surveys and excavations, and additionally, a detailed surface plan was prepared. The first studies showed a relative difficulty in locating places for further invasive research within the settlement. The repeated field survey with systematic walking in various conditions did not allow the researchers to indicate the presence of artefacts on the surface. The first excavations were carried out at the beginning in the southern zone of the settlement, *i.e.*, the place where the rampart is partially noticeable. Their aim was to check and verify the chronology of the site, initially dated to the Early Middle Ages or Modern period. As shown by the results of the C14 study, this complex is much older and should be dated to the Early Iron Age (Czopek *et al.*, 2017). This information together with the next season of research, which provided, *inter alia*, the first Greek amphora discovered in Poland, allowed the scholars to intensify fieldwork

(Czopek *et al.*, 2021). In the course of their implementation, an important element was to conduct non-invasive research, which in the first place covered the entire fortified settlement as the key element for a complete cluster of sites.

One of the important elements in this endeavour was choosing the right method or methods to maximise the information obtained. There are several factors that should be considered when planning work of this nature. The first quantifier, and one of the most important, is the scope of the research. As a rule, the larger the area covered by the prospection, the more complete the potentially received image will be. More extensive research has a positive effect on the possibility of interpreting and assessing the obtained results. This requires, however, the use of mobile (and therefore more expensive) data collection systems, and the post-processing period is longer. It is also necessary to take into account a large collection of data, *i.e.*, potential features and other anomalies visible over a larger area, which can sometimes obscure the picture and make it difficult to identify elements that are the source of the researchers' interest.

One of the most important criteria for assessing the collected data is the time in which it was collected. Optimally the work should be carried out in the most similar conditions possible. One of the most important factors influencing the obtained results, their analysis and comparison is the degree of humidity of the tested surface. In the case of a quick prospection, performed with the use of mobile systems or smaller in scope, this condition can be more easily fulfilled, which makes the obtained results comparable.

Another important factor to consider is the selection and employment of appropriate methods. It should be emphasised that there is no single, optimal method for non-invasive prospection. An effective research program must take into account, *inter alia*, the specificity of the surveyed sites and their type, *e.g.*, settlements or cemeteries. If settlements are surveyed, it is necessary to consider whether we can expect traces of additional structures (wooden, stone) or architectural remains (walls, basements, foundations). In the discussed case, non-invasive tests were the next stage, preceded by the excavation. Thanks to establishing a chronological framework and general analogies to other objects related to the Scythian cultural circle, it was possible to select optimal methods that allow the researchers to maximise the obtained effects. Therefore, reviewing available research methods, the following three were selected: magnetic, electromagnetic and ground-penetrating radar.

The first method is one of the most frequently used in the field of archaeology (Herbich, 2003), especially in a case of prehistoric and protohistoric sites. It results from its advantages, such as high mobility, which allows it to cover quickly a large area by the use of multi-probe systems. It also lets the explorers capture a wide range of potential archaeological features and structures, such as wooden or brick structures, places associated with thermal treatment (manufacture zones, furnaces, hearths, lime pits, *etc.*), utility pits, buried ditches, roads, moats and even individual features, *e.g.*, postholes. Moreover, it favours the assessment of a settlement's range (to some extent) and the distinction of feature clusters and their spatial distribution (Oniszczuk *et al.*, 2020; Schmidt, 2019). However, this method has its limitations and cannot be used in an area with a highly-developed infrastructure, *e.g.*, asphalt roads, utilities, modern buildings (Mackiewicz *et al.*, 2019).

In the course of the tests, a Sensys magnetometer was used, consisting of FGM 650/3 fluxgate gradiometers, placed in a non-magnetic and non-disturbing frame, set perpendicularly to the tested plane. The FGM650 probes consisted of two uniaxial magnetometers spaced vertically at a distance of 650 mm and with a measuring range ±8,000 nanotesla (nT). The geomagnetic field has an equal effect on both sensors – the lower and the upper ones. The lower sensor additionally registers anomalies caused by subsurface sources of the magnetic field, including archaeological features (Aspinall *et al.*, 2008). The difference in measurements on the upper and lower sensors allows the size of the anomaly and its nature to be determined (Bartington and Chapman, 2004; Fassbinder, 2016).

Their positioning and alignment in one plane also allow the influence of short-term changes in the geomagnetic field to be eliminated. Measurements are performed passively, which means that the device itself does not generate its own field, but records the physical properties of the surveyed area. During the prospection, the researchers used five gradiometers placed 50 cm apart from each other. The measurement profiles were carried out in parallel, alternately in the scope of 2.5 metres with the measurement at a frequency of 2 cm. The total area surveyed with the use of the magnetometer was 58.5 ha (Figure 2). The research results were presented using magnetograms in 256 shades of grey on a scale from 5 to –5 nT.

The second survey method, carried out with the use of a conductometer, is based on the measurement of the apparent conductivity which can be converted into soil resistivity (Ω·m) in an artificially created electric field (Clark, 2001; Bonsall *et al.* 2013). Although this method can be used alone, it should usually complement the magnetometer tests. In this way it enables the recognition of the ground geology and enables the detection of architectural remains at various depths. Measurement disturbances may be caused by excessive and uneven over-drying or dampness of the soil studied as well as modern infrastructure, *e.g.*, road or utility networks. In the discussed study, the CMD-Mini Explorer conductometer (Bonsall *et al.* 2013; http://www.gfinstruments.cz/version_cz/downloads/CMD_Short_guide_Electromagnetic_conductivity_mapping-20-04-2020.pdf, accessed 13.10.2023), manufactured by GF Instrument, was used. The tests were carried out within a grid of parallel profiles distributed 1.5 m apart, with a measuring step of about 0.2 m, depending on the operator's speed of movement. Two pairs of coils spaced at different distances were used in the prospection, ensuring soil penetration at two levels: 0.5 and 1 m. The parameters measured by the electromagnetic conductivity meters were then normalised and recalculated. The results of conductivity (mS/m) and resistivity of the

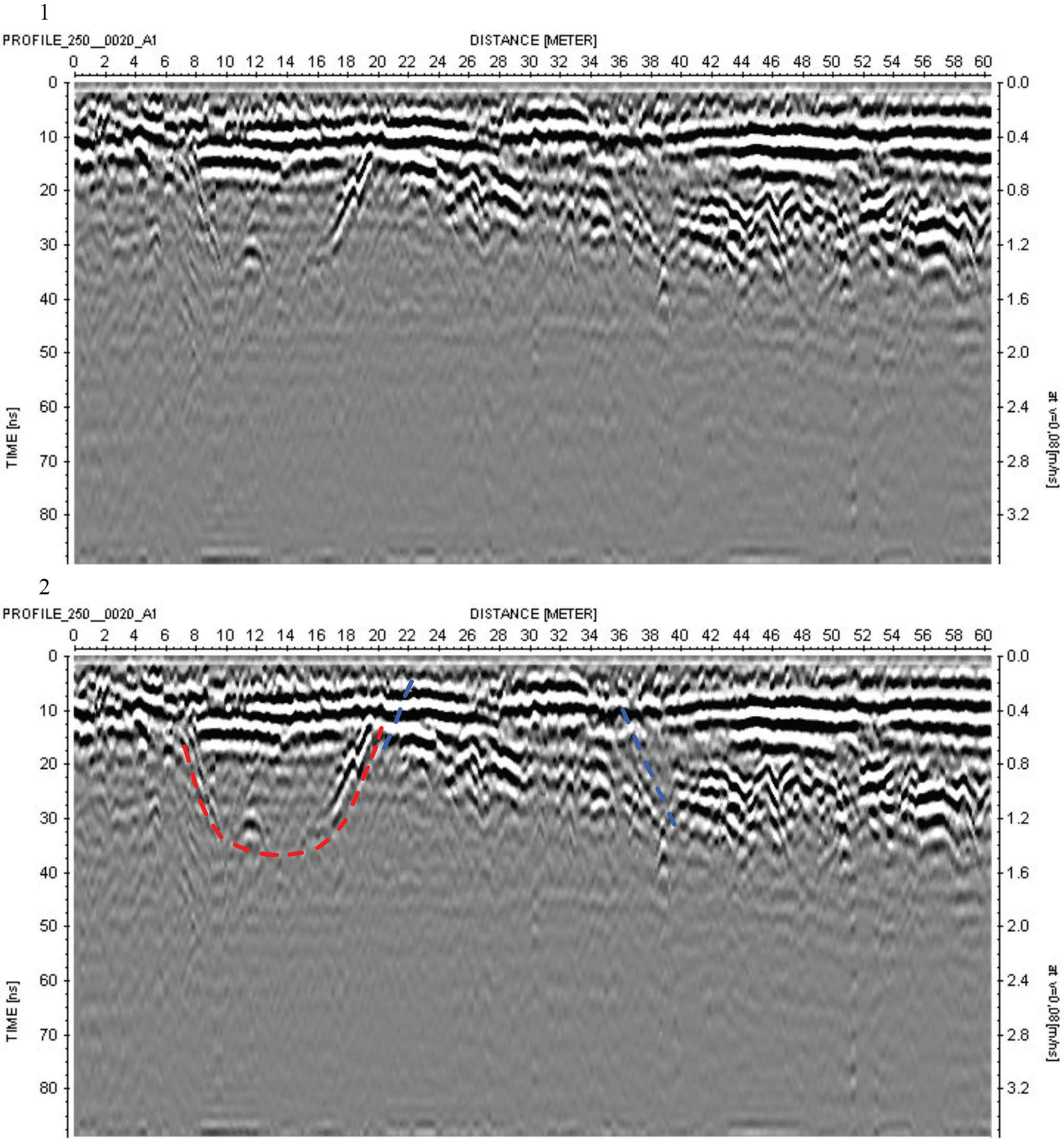


**Figure 3.** Chotyniec, site 1. 1 – Cross-section (profile) of the GPR survey with visible anomalies; 2 – interpretation of the profile: red dashed line – the likely trace of a ditch; blue dashed line – a rampart.

tested features were presented on colour maps. The total area of the performed studies by means of the conductometer was approximately 58.5 ha (Figure 2).

Due to the unfavourable terrain conditions (see chapter "site characterisation"), the least extent of prospection was used in the case of the ground-penetrating radar, which transmits electromagnetic waves and measures the energy and velocity of the reflected pulses (Conyers and Goodman, 1997; Kazunori *et al.*, 2012). As for research aimed at detecting anthropogenic features, especially historic ones, their construction is important. The more the feature you are searching for differs from the environment in which it is placed, the more effective its detection will be. It results from the different permittivity of materials, which is described by the dielectric constant. Additionally, the measurement is influenced by such factors as electrical conductivity (mS/m), the damping factor (dB/m) or the speed of the electromagnetic wave (cm/s), and their configuration may significantly hinder the effective distinction of anthropogenic features (Kazunori *et al.*, 2012).

Another important factor that affects the detection capabilities of features is the dependence resulting from the configuration of the measuring device itself. The most important parameters that affect the operation of the system include the frequency of the antenna (Annan, 2009). Depending on the needs and products, antennas with a frequency of 10 MHz to over 2.5 GHz are used. The antenna frequency translates into two factors, *i.e.*, the depth and resolution of the measurement, which determine the obtained results. Nominally low-frequency antennas, such as those within the operating range of 25 to 200 MHz, allow deep cross-sections to be obtained (depending on the geology of the ground) from 30 to 6 metres, but with low resolution. On the other hand, antennas operating in the range of 200 to 750 MHz create cross-section images from 6 to 1.5 metres, but with a higher and very high (even several centimetres) resolution of the tested features. Antennas with frequencies above 800 MHz are usually used in shallow engineering, where it is necessary to obtain very accurate images with a small thickness. Similarly, low frequency antennas are generally used in geology and environmental research, whereas the others are a wide range of products that are used in various fields of engineering and archaeology (Daniels, 2004; Sala *et al.*, 2012).

It is worth mentioning that the type of antenna (its frequency) is a kind of compromise between the depth and the detail (resolution) of the image obtained. Shallower measurements are more detailed and are better suited for detecting smaller, less noticeable features (Sala *et al.*, 2012). Ground-penetrating radar prospecting can be used within modern infrastructure (such as asphalt, pavement, gravel roads) and does not require direct contact with the ground. In archaeology, it is particularly effective in detecting architectural relics (*e.g.*, stone and brick foundations, paving or floors, and buried or cut features) that do not have magnetic properties, which results directly from the physical differences between the detected feature and the ground where it is located.

In recent years, the use of the ground-penetrating radar method has been steadily increasing in archaeology, which has improved the effectiveness of feature detection (Trinks *et al.*, 2010). During this research, the two-channel ProEX GPR was used, produced by Mala GeoScience, together with a shielded antenna with a frequency of 250 MHz. Under favourable conditions (humidity, type of substrate) it can penetrate the ground up to a maximum of 5 meters with a resolution of 0.05 to 0.5 m. Measurement data were prepared in the form of cross-sections and time profiles (Goodman *et al.*, 1995), and the surface area in which the research was performed covered approximately 9 ha (Figure 2).

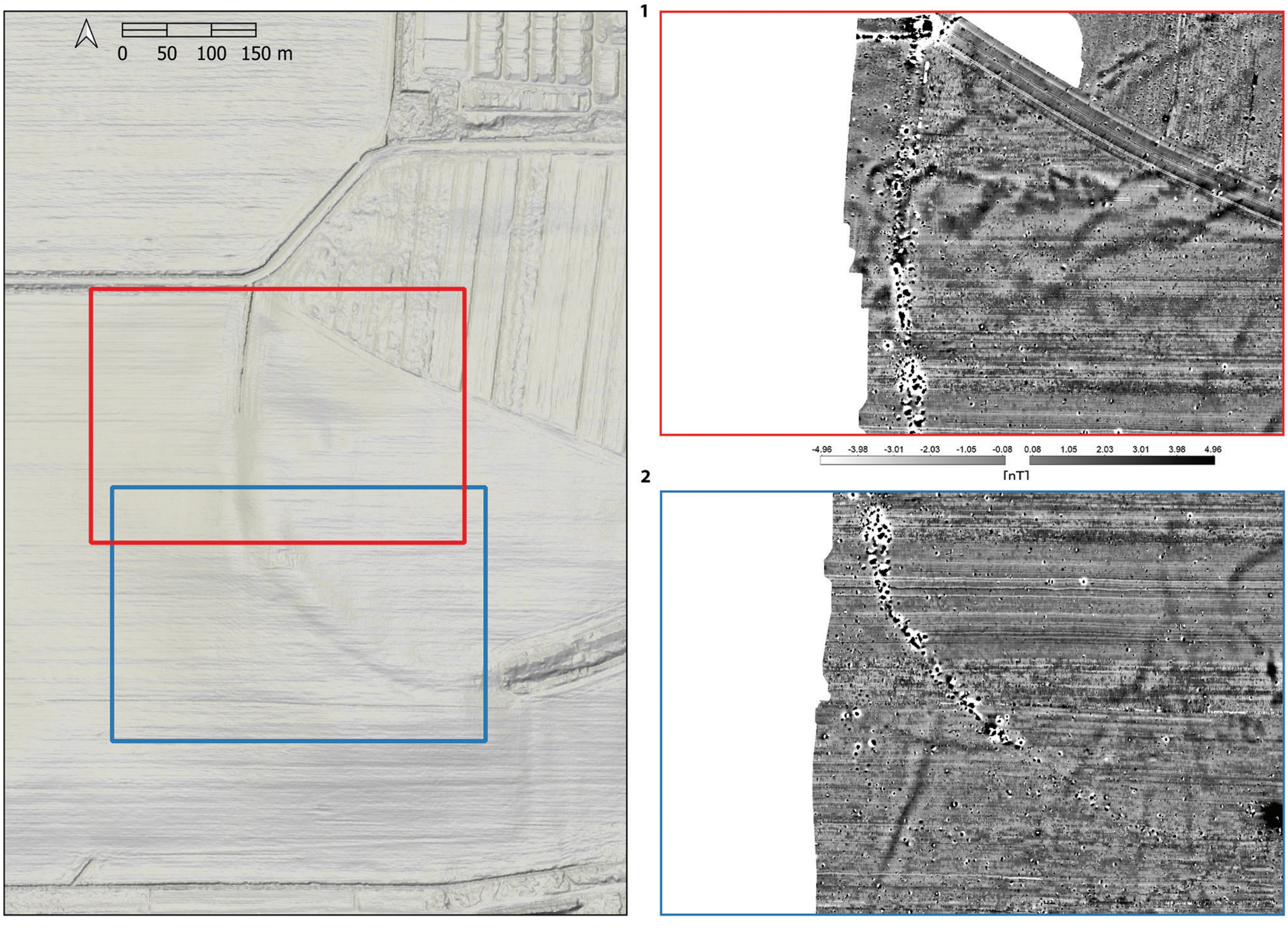


**Figure 4.** Chotyniec, site 1. Zonal system of dipolar anomalies located in the south-western (1) and western (2) parts of the settlement.

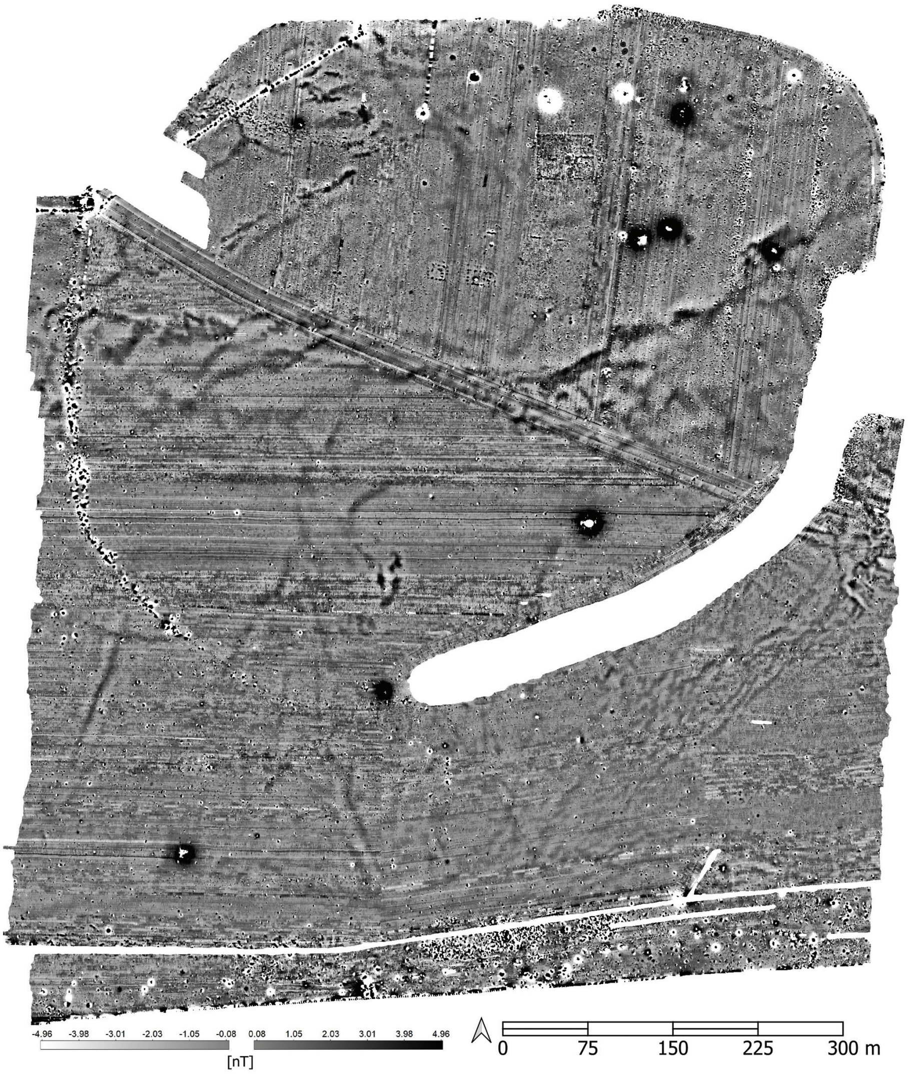
## 4. Results

The research performed by means of a magnetometer with the use of a mobile system made it possible to recognise a large area in a relatively short time, providing valuable information about the features existing within the site, which, it is worth emphasising, do not manifest themselves, for example, in the presence of movable artefacts on the surface. Their verification is planned both by performing further geophysical surveys and at selected points using invasive methods. Similar goals were set for the prospection made with a conductometer, where more emphasis was placed on the location of the rampart, especially in its currently invisible parts. What is more, the use of ground-penetrating radar was mainly carried out in the survey of traces of additional structures in the defence system.

The results of ground-penetrating radar research are generally not very representative, which is probably due to the insufficient contrast of electrical properties between the search target and the surroundings. Additionally, the possibility of observation, mainly on the basis of vertical cuts (profiles) and a small horizontal area, made it difficult to assess the recorded images. In the vast majority of them, no clear anomalies that could be associated with archaeological features were observed. Only in the western part of the settlement could two structures be distinguished in the profiles (6–8 m and 19–20 m in profile) with the depth of the deposition difficult to unambiguously determine (Figures 2.3 and 3.1). They also do not have regular, parabolic shapes, which makes it quite difficult to establish the exact position of the wave inflection. Nevertheless, the profiles show a repeating pattern of the arrangement of two anomalies, between which there are horizontally arranged layers, which may confirm the existence of a backfilled ditch (Figure 3.2). Their location fits well with the image obtained in the magnetometric studies (Figures 2.4, 2.5, 4.1 and 4.2).

It is not possible to analyse in detail all the magnetograms made over a large surface (Figure 5) in this short article. To put it briefly, within them, we can distinguish several types of magnetic anomalies, the registration of which is a result of such factors as the shape and structure of the feature, its orientation, depth of deposition or the physical parameters

**Figure 5.** Chotyniec, site 1. Map of measurements made with a magnetometer, presented in grey scale, in the measuring range from -5 to +5 nT. 1–4 – The location of anomalies depicted in Figures 6.1–6.4.



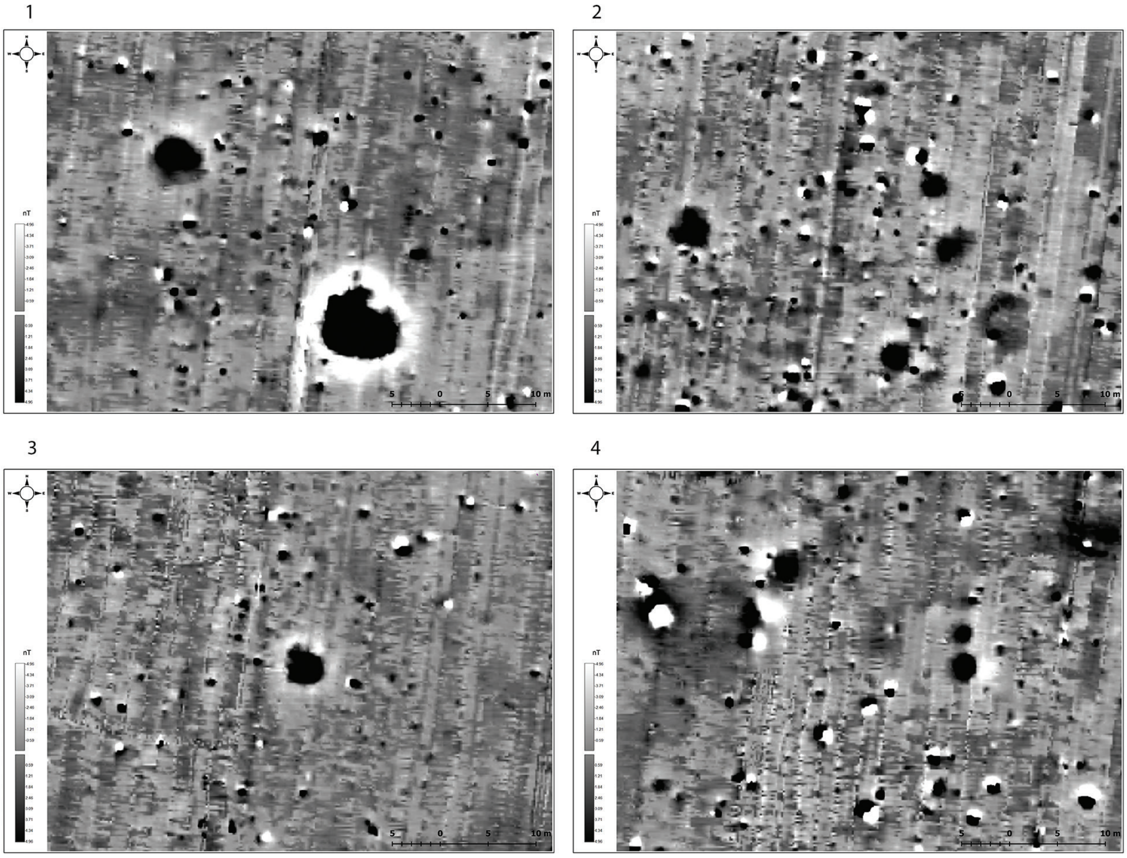


**Figure 6.** Chotyniec, site 1. Examples of positive anomalies interpreted as remains of archaeological features.

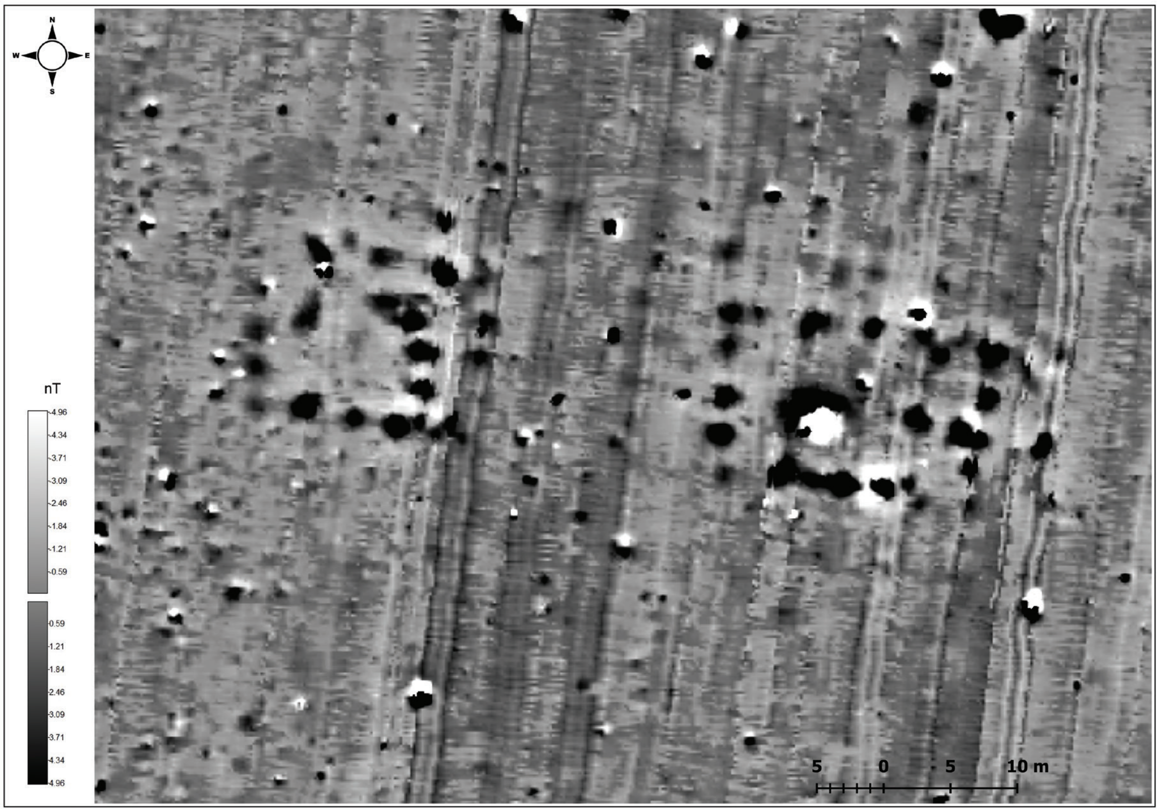


**Figure 7.** Chotyniec, site 1. Regular arrangement of positive anomalies; possibly the remains of a posthole structure.

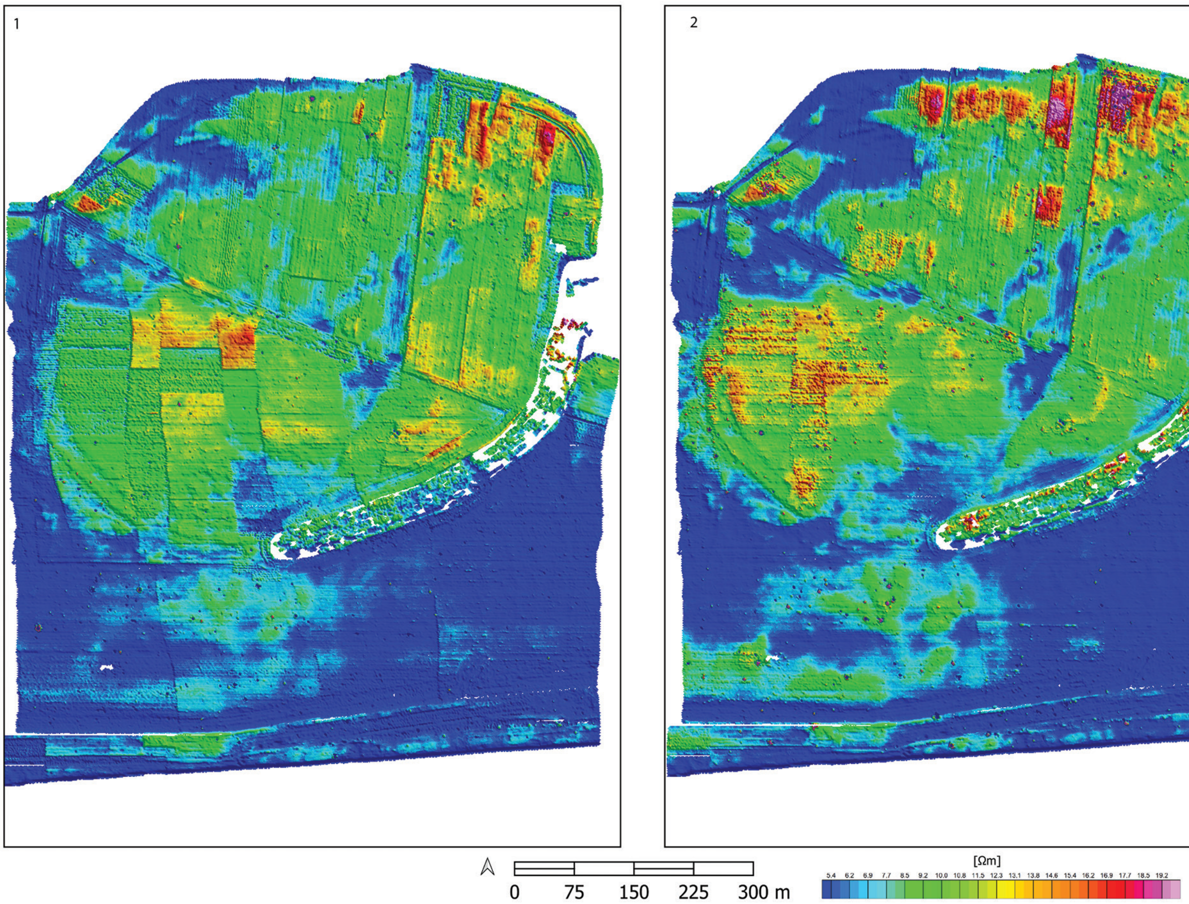


**Figure 8.** Chotyniec, site 1. Colour maps showing the results of the measurements made with the conductometer: 1 – down to a depth of 0.5 m; 2 – down to a depth of 1 m.

of the place where it is located (Aspinall *et al.*, 2008). There are three main groups of registered anomalies: positive, positive with a circular negative reaction, and dipolar anomalies. Sometimes the above-mentioned point anomalies create linear or zonal systems. As for the interpretation in the context of archaeological research, the first two groups are the most important, which can usually be traces of archaeological features (Sala *et al.*, 2012).

The distinct area is a zone of dynamic dipolar anomalies in the south-western and western part of the settlement in the fortified settlement (Figure 4.2). It is located just beyond the range of the damaged rampart, whose course at this point is reconstructed on the basis of data from airborne laser scanning (Figure 4.1). The linear system repeating the course of the rampart is interpreted as the existence of a buried and levelled ditch at this point, which could hypothetically constitute an element of the defensive structure – a moat.

In the northern part, within the enclosure, there are single, clearly visible anomalies with oval, regular shapes and positive values – from ca. +8 to +14 nT. They can be interpreted as potential traces of features (utility pits, hearths) related to the prehistoric use of the settlement. In this zone, there are also clear thermoremanent anomalies (value ca. +31 nT) with a circular negative reaction (ca. –10 nT), which may indicate a very strong burnout of the substrate, *i.e.*, the existence of structures in the form of, for example, hearths or stoves (Figures 5.1 and 6.1–6.4). Similar anomalies, revealing the remains of this type of features, are known from magnetometric studies and excavations of the western fortified settlement in Bielsko (Orljuk *et al.*, 2016). In the entire area subjected to prospecting, there are single dipolar anomalies, which can be considered as numerous contemporary and Modern period metal objects in the subsurface layers of the studied area. The obtained magnetogram clearly shows the lack of visible structures to the south of the settlement. Probably in the Early Iron Age, the depression that used to exist here must have been marshy and difficult to access.

The group of point anomalies with mostly positive values (from ca. +10 to +20 nT) is a set of one of the most interesting elements noticeable in the results of the magnetometric prospection. They have a quadrangular arrangement, creating a zone with a dimension of 55×15 m, evoking an obvious association with a building that existed in the past (a single structure or consisting of two separate parts) based on the posthole structure (Figures 2.6 and 7). Additionally, within it, in the eastern part, there is also an anomaly, which could indicate the existence of, for example, a hearth resulting from the values noticed. It should be noted that this is the only such distinctive and large feature within the settlement,

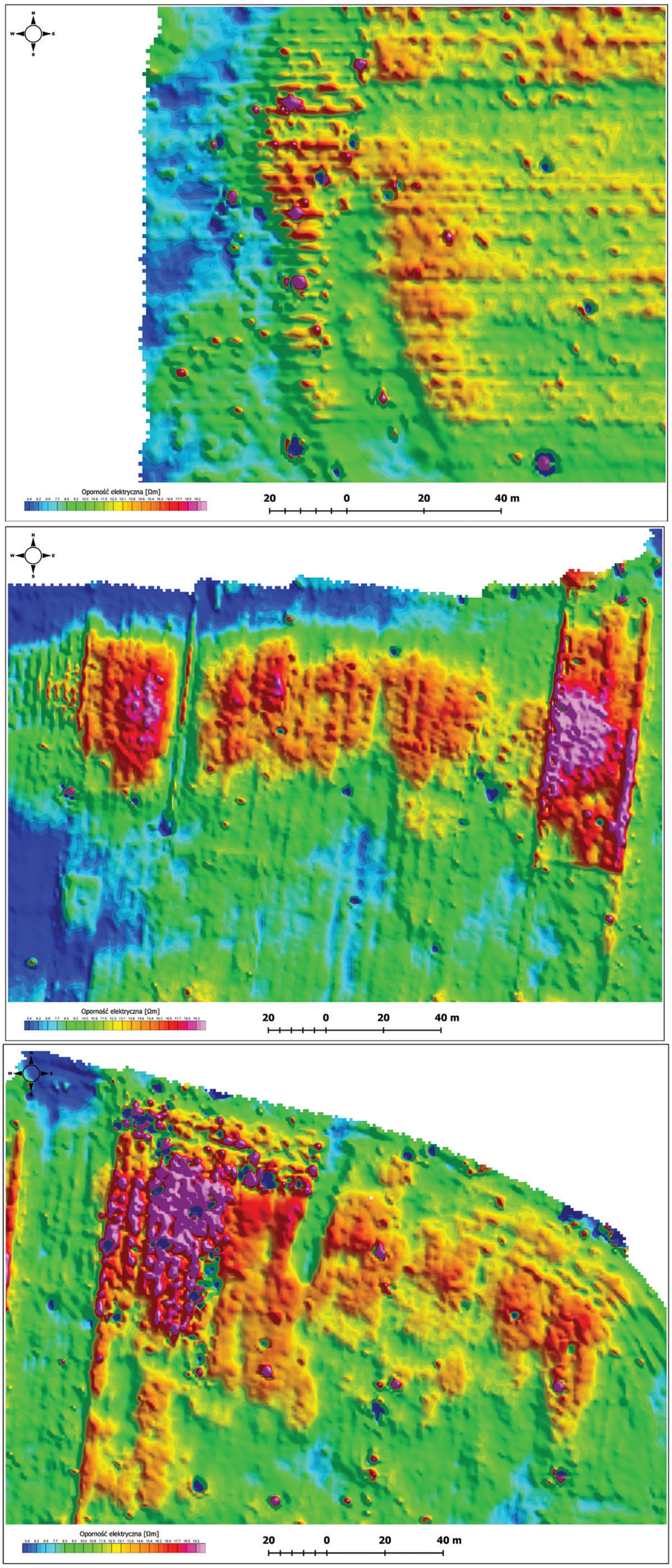


**Figure 9.** Chotyniec, site 1. Examples of zones of increased ground resistance, suggesting the existence of anthropogenic interference in this place.

additionally located in close vicinity (about 90 m) to the *zolnik* (also called the "ash hill", cult object with traces of cyclical libation rites with quite complicated stratigraphy, with layers containing, among others, animal bones, fragments of ceramic vessels, including imported Greek amphorae and charcoal), completely excavated on this site (Czopek, 2020; Czopek and Krąpiec, 2020; Trybała-Zawiślak, 2020a).

Unfortunately, the studies carried out by means of the conductometer were performed in unequal soil moisture conditions (see section "site characterisation"), which adversely affected the obtained image, especially in shallower soil layers (Figure 8.1). The reading of the results (in the measurement of conductivity and resistivity) was also influenced by weather factors, contemporary deep ploughing or the type of crops. Therefore, more favourable in the analysis are measurements from depths of more than one metre (Figure 8.2), where the influence of the aforementioned factors is marginal. On the other hand, it does not allow the capture of many shallower archaeological layers that occur just below the contemporary humus layer. In the entire area, the resistivity (apart from local disturbances induced by iron objects) did not exceed 20 Ωm, which indicates that the structure of the investigated complex was mainly made of clay. The distribution of resistance also points out the existence of areas of varying moisture content, which may be caused by different clay densities (more or less dense), and indirectly by anthropogenic interference in their structure (Figures 8.1 and 8.2).

What is more, zonal systems of increased resistance are also clearly visible, especially in the northern part of the settlement, which may indicate the existence of elements related to the rampart structure (hardening and levelling of the terrain). They disappear to a large extent in the north-western and partially western parts, which could suggest a discontinuity of the rampart structure caused by the necessity of communication openings (Figures 9.1–9.3).

## 5. Discussion

The non-invasive tests performed were verified in selected places by archaeological excavations. The results from these allow for a better understanding and interpretation of the non-invasive tests and for the planning of future activities.

Verification of the measurements of electrical resistivity, which suggested the existence of openings in some parts of the ramparts, was not confirmed. The established trenches in the north-west part indicate the existence of similar structures that were examined in other parts of the rampart (Czopek *et al.*, 2022). The situation is similar in the northern part

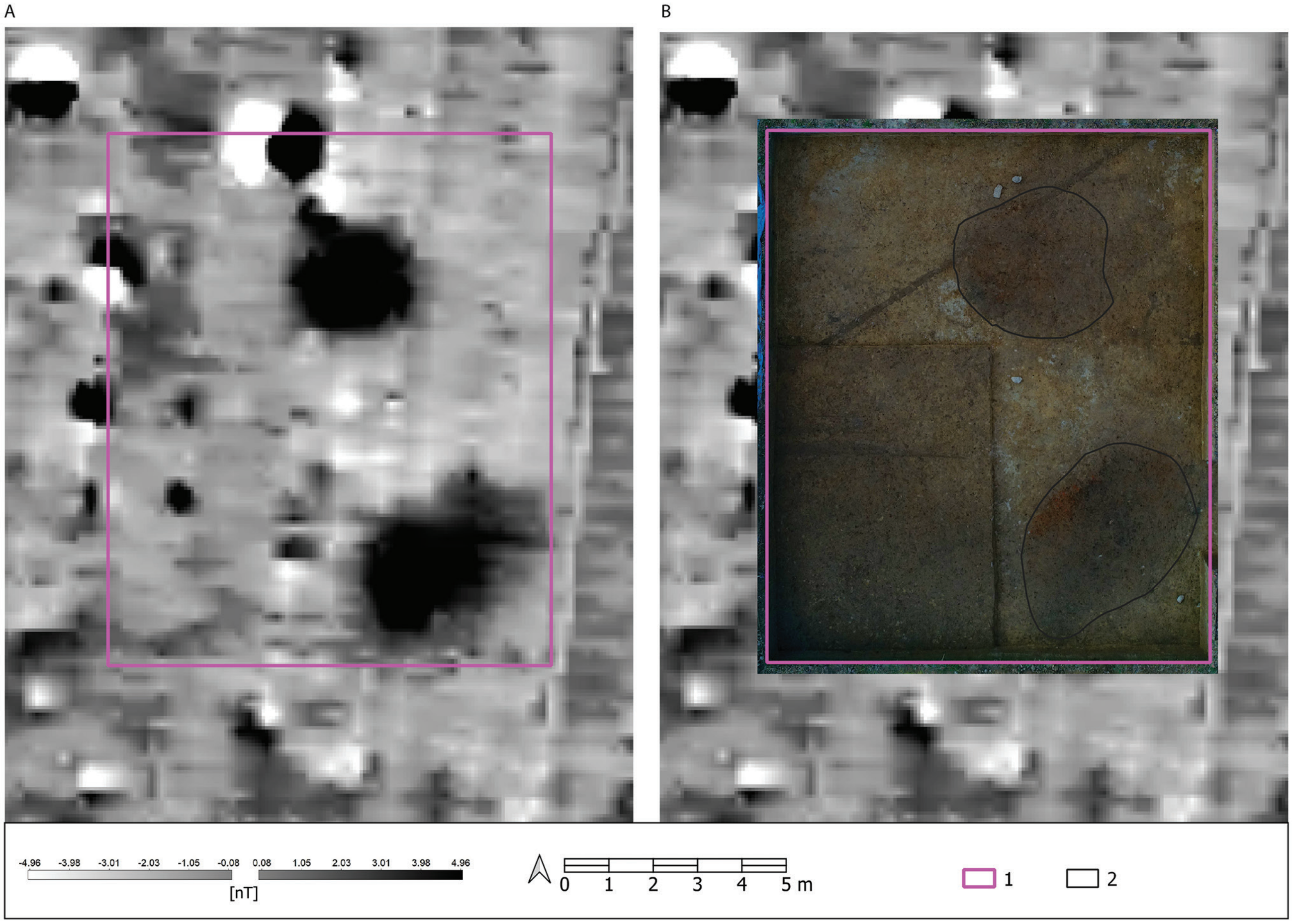


**Figure 10.** Chotyniec, site 1. Verification of anomalies determined with a magnetometer (1) and archaeological features uncovered in their place (2).

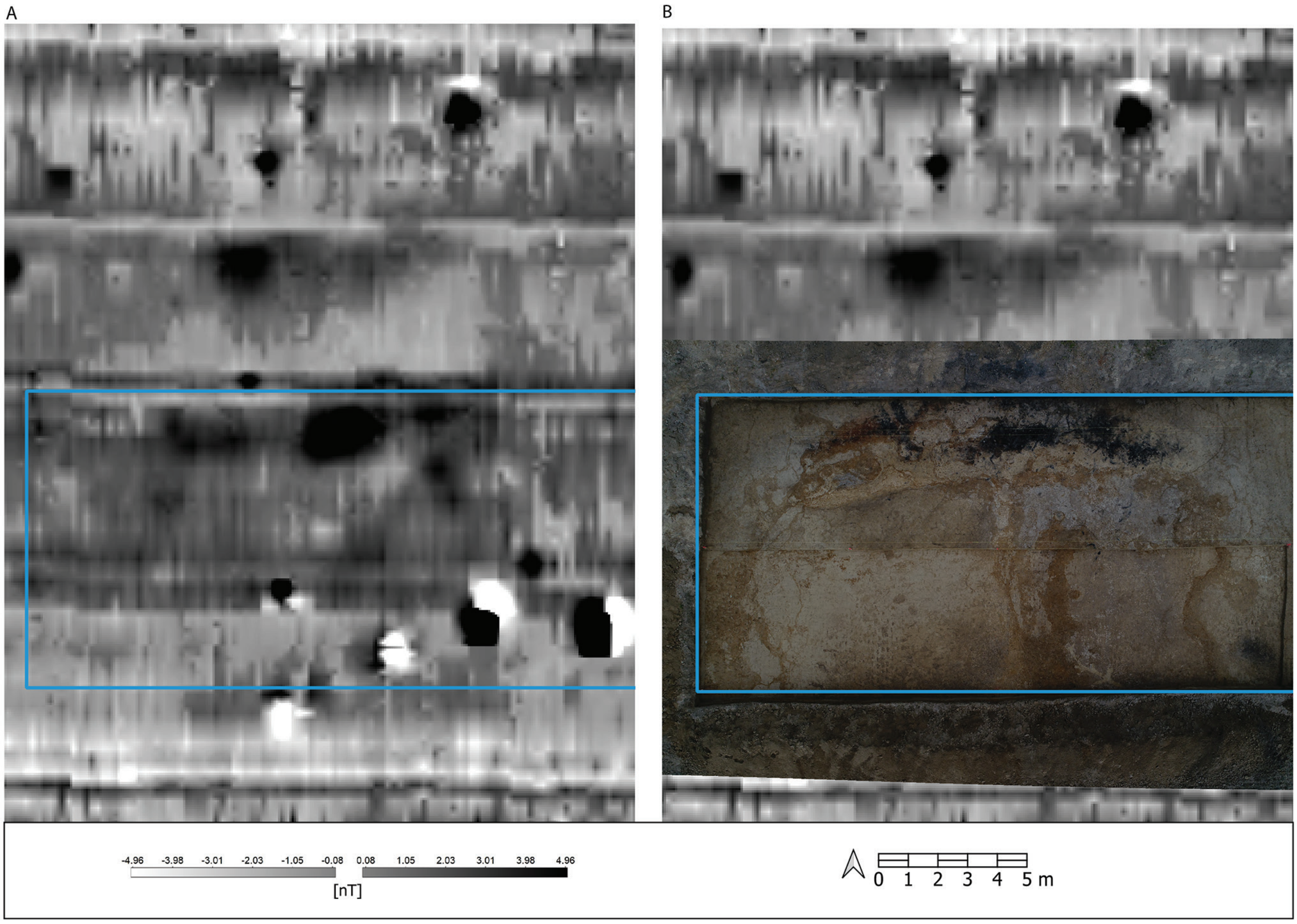


**Figure 11.** Chotyniec, site 1. Anomalies discovered with the use of a magnetometer and an established excavation trench (1) for verification; 2 – results of archaeological excavation with a visible burnt layer.

of the settlement, where a levelling of the surface could be expected on the basis of the image from the conductometer, but it is not confirmed in the stratigraphic situation observed in the excavations (Czopek *et al.*, 2022). It seems that in our case the discussed method is not reliable and does not allow for a correct assessment of the possible occurrence of layers or archaeological features. This observation, *i.e.*, the relatively low usefulness of this method in strictly archaeological applications, especially prehistoric ones, agrees with the general observations and limitations of this method (Oniszczuk *et al.*, 2020; Schmidt, 2019).

Research excavations carried out in the western part of the settlement, at the place of the ground-penetrating radar research, confirmed the existence of a ditch buried at a depth of 1.5 metres. Within its filling, contemporary metal objects were present especially in large numbers at the top, which was reflected in the magnetogram. Therefore, not only the conductometer, but also the ground-penetrating radar provided unsatisfactory test results in this particular case. This is the effect, on the one hand, of the geological structure of the test area (clay damping waves) and, on the other, a slight difference in the filling (humus mixed with subsoil clay) between the background and the tested features. Additionally, the used antenna with medium central frequency generates an image with a lower resolution, especially in the near-surface zones where the occurrence of archaeological objects and layers is to be expected.

The most reliable and scientifically valuable results were obtained by means of the tests performed with the use of a magnetometer. What is more, verification of selected places by invasive methods usually confirmed the validity of the interpretation and assessment of the recorded anomalies. It is also worth mentioning that their shape is often largely analogous to documented archaeological features.

In order to illustrate it better, it is useful to present the results of the research obtained in 2020. Based on the image received from the magnetometer, a trench with an area of 100 m$^2$ was excavated in the locality of two noticeable anomalies (Figures 2.7 and 10.A). During the excavation, the two features were clearly marked with dimensions: the first, 3.4×2 m, and the second, 4.4×3 m (Figures 2.7 and 10.B). In their filling, apart from pottery sherds, numerous lumps of burnt clay were discovered, which contributed to a good record during magnetometer tests. Likewise, very positive results were obtained from excavations within a separate structure of a quadrangular outline, where the presence of distinct sets of postholes was found. Their fillings were enriched with numerous clay lumps, which were probably structural elements of the load-bearing walls. What is more, the excavation in the western part of the fortified settlement, at the place of a heavily damaged rampart, also gave a positive result. In the recorded positive anomaly (Figures 2.8 and 11.A) within the established trench, the existence of burnt layers (a damaged wooden structure) was found, the outline of which (Figures 2.8 and 11.B) is similar to what we can observe in the magnetogram.

## 6. Conclusion

Archaeological research within the Chotyniec agglomeration has always been assumed to be a project focused on long-term studies. From the very beginning, the researchers decided to implement the most modern methods possible and seek to improve them. The results of the non-invasive tests presented above fit perfectly into this trend. They were made on the basis of various geophysical methods, which allow for the assessment of their effectiveness in the course of detecting archaeological features and cultural layers. Additional verification in the form of excavations is another important element that allows for a better understanding and description of the results both in the local and in the broader context of research on other fortified settlements in the forest-steppe zone. Therefore, they make a significant contribution to the understanding of the internal structure and spatial organisation of the defensive facilities of the Scythian cultural circle. The survey of the entire available area of the settlement and its immediate surroundings does not find analogies to other investigative work of this type, which in exceptional cases only covered a part of the hillfort (*cf.* Zöllner *et al.*, 2008; Orljuk *et al.*, 2016).

Verifying excavations confirmed that in the case of the aforementioned research program focusing on the recognition of Early Iron Age settlements, the best results are obtained from magnetometer tests. Initial hypotheses resulting from measuring the resistivity (despite the high engagement and large area) were not confirmed in the studied areas. Similarly, ground-penetrating radar studies did not provide good results, although in a single case (see Figure 3.2), potential locations for a filled ditch (?) and a levelled rampart (?) could be indicated.

The performance of non-invasive research allows for the completely new identification and visualisation of archaeological sites. A wide range of prospection that does not destroy layers and features, give a better context and a different interpretative perspective, and not one based solely on archaeological excavations and movable artefacts (Sala *et al.*, 2012).

The experience gathered during the implementation of the research project investigating the Scythian agglomeration in Chotyniec in south-eastern Poland has shown that a well-carried out, non-invasive prospection may constitute a crucial element of the research. The obtained results enable (by the selection of the most prospective places or those exposed to the fastest destruction) a better planning of invasive tests and their reduction to the necessary minimum. On the basis of the above, new questions and research issues can be formulated, as well as becoming a valuable supplement to traditional archaeological research.

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## References

ADAMIK-PROKSA, J., and OCADRYGA-TOKARCZYK, E., 2021. Problem chronologii zolnika z grodziska w Chotyńcu i tworzących go poziomów użytkowych w świetle badań nad klasyfikacją i datowaniem szpil. *Przegląd Archeologiczny*, 69, 147–169.

ANNAN, A.P., 2009. Electromagnetic principles of ground penetrating radar. In: H.M. Jol, ed. *Ground penetrating radar: Theory and applications*, Amsterdam, Oxford: Elsevier, pp. 3–40.

ASPINALL, A., GAFFNEY, C.F., and SCHMIDT, A., 2008. *Magnetometry for archaeologists*. Lanham, Maryland: AltaMira Press.

BARINGTON, G., and CHAPMAN, C., 2004. A high-stability fluxgate magnetic gradiometer for shallow geophysical survey applications. *Archaeological Prospection*, 11, 19–34.

BURGHARDT, M., 2020. Classification and chronology of the collection of arrowheads from the ash-hill found in the hillfort of the Scythian Cultural Circle in Chotyniec, site 1, Jarosław district. *Przegląd Archeologiczny*, 72(2), 327–355.

BONSALL, J., FRY, R., GAFFNEY, C., ARMIT, I., BECK, A., and GAFFNEY, V., 2013 Assessment of the CMD Mini-Explorer, a New Low-frequency Multi-coil Electromagnetic Device, for Archaeological Investigations. *Archaeological Prospection*, 20(3), 219–231.

CLARK, A.J., 2001. *Seeing beneath the soil: Prospecting methods in archaeology*. London: Routledge.

CONYERS, L.B., and GOODMAN, D., 1997. *Ground-penetrating radar: An introduction for archaeologists*, London: AltaMira Press.

CZOPEK, S., 2019. An enclave of the Scythian Cultural Circle in South-eastern Poland. *Przegląd Archeologiczny*, 67, 119–148.

CZOPEK, S., 2020. Znaczenie odkryć w Chotyńcu (południowo-wschodnia Polska) dla interpretacji procesów kulturowo-historycznych na zachodnim Wołyniu i Podolu (Ukraina) we wczesnej epoce żelaza. *Archeologia Polski*, 65, 67–114.

CZOPEK, S., and KRĄPIEC, M., 2020. The cult area (zolnik) from the hillfort of the Scythian cultural circle in Chotyniec near Radymno (south-eastern Poland) in the context radiocarbon dating. *Radiocarbon*, 62(6), 1599–1611.

CZOPEK, S., TRYBAŁA-ZAWIŚLAK, K., and TOKARCZYK, T., 2020. Chotynieckaja aglomeracija skifskogo kulturnogo kruga i je znachenie dlja interpretacii kulturnych svjazej rannego zeleznogo veka na pograniche centralnoj i vostochnoj Evropy. *Stratum Plus*, 3, 259–276.

CZOPEK, S., TRYBAŁA-ZAWIŚLAK, K., and TOKARCZYK, T., 2022. Gorodiste u Chotynci v doteperisnich doslidzenjach. *Archeologija i dav na istorija Ukraini*, 1(42), 105–114.

CZOPEK, S., TRYBAŁA-ZAWIŚLAK, K., TOKARCZYK, T., OCADRYGA-TOKARCZYK, E., BURGHARDT, M., ADAMIK-PROKSA, J., and RAJPOLD, W., 2017. Pierwsze sprawozdanie z weryfikacyjnych badań na grodzisku z wczesnej epoki żelaza w Chotyńcu. *Materiały i Sprawozdania Rzeszowskiego Ośrodka Archeologicznego*, 38, 291–306.

CZOPEK, S., TRYBAŁA-ZAWIŚLAK, K., TRĄBSKA, J., TRYBALSKA, B., ADAMIK-PROKSA, J., BURGHARDT, M., OCADRYGA-TOKARCZYK, E., TOKARCZYK, T., and RAJPOLD, W., 2021. The first finding of a Greek amphora in Poland. *Prähistorische Zeitschrift,* 96(1), 156–172.

DANIELS, D.J., 2004. *Ground Penetrating Radar.* 2nd ed. London: The Institution of Electrical Engineer.

FASSBINDER, J., 2016. Magnetometry for Archaeology. In: A. Gilbert, P. Goldberg, V. Holliday, R. Mandel, and R. Sternberg, eds., *Encyclopedia of Geoarcheaology*. Dordrecht: Springer, pp. 499–514.

GĘBICA, P., and JACYSZYN, A., 2018. Charakterystyka geomorfologiczna i pokrywa glebowa dorzecza Wiszni. In: S. Czopek, K. Trybała-Zawiślak, N. Wojceszczuk, O. Osalczuk, D. Bobak, P. Gębica, A. Jacyszyn, W. Pasterkiewicz, D. Pawliw, W. Petehyrycz, M. Połtowicz-Bobak, and A. Wacnik, eds., *Przemiany kulturowo-osadnicze w dorzeczu rzeki Wiszni w epoce brązu i we wczesnej epoce żelaza w kontekście zmian prahistorycznej i wczesnośredniowiecznej ekumeny*. Rzeszow: Wydawnictwo Uniwersystetu Rzeszowskigo, pp. 47–70.

GOODMAN, D., NISHIMURA, Y., and ROGERS, J.D., 1995. Time Slices in Archaeological Prospection. *Archaeological Prospection*, 2, 85–89.

HERBICH, T., 2003. Archaeological prospection. *Archaeologia Polona*, 41, 5–15.

KAZUNORI, T., JAN, I., HOLGER, P., and SEIICHIRO, K., 2012. Basics and Application of Ground-Penetrating Radar as a Tool for Monitoring Irrigation Process. In: K. Manish, ed., *Basics and Application of Ground-Penetrating Radar as Problems, Perspectives and Challenges of Agricultural Water Management a Tool for Monitoring Irrigation Process*. London: IntechOpen, pp. 154–180.

KONDRACKI, J., 1978. *Geografia regionalna Polski*. Warszawa: Wydawnictwo Naukowe PWN.

MACKIEWICZ, M., FURMANEK, M., WRONIECKI, P., and MYŚLECKI, B., 2019. Badania geofizyczne w rozpoznaniu neolitycznych i wczesnobrązowych krajobrazów archeologicznych Śląska. In: M. Furmanek, ed. *Pierwsi rolnicy i hodowcy na Śląsku. Dialog interdyscyplinarny*. Wrocław: Uniwersytet Wrocławski, pp. 191–213.

ONISZCZUK, A., MISIUK, Z., MAKOWSKA, A., WRZOSEK, J., and SEKUŁA, M., 2020. Standardy prowadzenia badań archeologicznych Cz. 1. Badania nieinwazyjne lądowe. *Kurier Konserwatorski*, 17, 1–50.

ORLJUK, M., ROLLE, P., ROMENEC, A., ULRICH, B., and COLNER, CH., 2016. Mikromagnitnaja semka Bolshogo Belskogo gorodista skifskogo vremeni, Poltavskaja oblast. *Geofizicheskij Zurnal*, 38(5), 25–39.

SALA, R., GARCIA, E., and TAMB, R., 2012. Archaeological Geophysics – From Basics to New Perspectives. In: I. Ollich-Castanyer, ed. *Archaeology, New Approaches in Theory and Techniques*. Rijeka: IntechOpen, pp. 133–166.

SCHMIDT, A., 2019. Onderzoeksrapport. De toepassing van geofysische prospectie methoden in de archeologie. In: E. Meylemans, and P. Smedt, eds. *The use of Geophysical Prospection methods in Archaeology.* Brussels: Flanders Heritage Agency Scientific Institution of the Flemish Government, 23–34.

TRINKS, I., JOHANNSON, B., GUSTAFSSON, J., EMILSSON, J., FRIBORG, J., GUSTAFSSON, C., NISSEN, J., and HINTERLEITNER, A., 2010. Efficient, Large-scale Archaeological Prospection using a True Three-dimensional Ground-penetrating Radar Array System. *Archaeological Prospection*, 17, 175–186.

TRYBAŁA-ZAWIŚLAK, K., 2019. *Wczesna epoka żelaza na terenie Polski południowo-wschodniej – Dynamika zmian i relacje kulturowe*. Rzeszów: Uniwersytet Rzeszowski.

TRYBAŁA-ZAWIŚLAK, K., 2020a. The Chotyniec Agglomeration and its importance for interpretation of the so-called Scythian finds from Southeastern Poland. *Sprawozdania Archeologiczne*, 72(2), 88–116.

TRYBAŁA-ZAWIŚLAK, K., 2020b. The fortified settlement in Chotyniec (south-eastern Poland) as part of the military system of forest-steppe Scythia. *Ido Movement for Culture. Journal of Martial Arts Anthropology*, 20(4), 55–63.

ZÖLLNER, H., ULLRICH, B., ROLLE, R., MAKHORTYKH, S., and ORLYUK, M., 2008. Results of Geophysical Prospection in the Scythian Settlement of Belsk (Bol'šoe Belskoe Gorodišče). In: A. Posluschny, K. Lambers, and I. Herzog, eds. *Layers of Perception Proceedings of the 35th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA) Berlin, Germany, April 2–6, 2007.* Bonn: Kolloquien zur Vor- und Frühgeschichte, 10, pp. 25–29.