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Prospect First – Dig Then! Investigations of Mining and Metallurgical Features in Kosovo

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Keywords

Magnetometer prospection, Electrical Resistivity Tomography, "Pürckhauer" drillings, mining, smelting

Abstract

Inspired by the Römisch-Germanische Kommission (RGK) in Frankfurt and the Archaeological Institute of Kosovo, the first mining archaeological/archaeometallurgical surveys were conducted in Kosovo in 2009-2011 by the Deutsches Bergbau-Museum Bochum (DBM) / German Mining Museum Bochum. We conducted the surveys mainly in cooperation with the Archaeological Institute of Kosovo. After the approval of two project phases by the DFG in 2012, five field campaigns were carried out (2013-15, 2017/18). The mining archaeologically oriented excavations were also carried out based on extensive prospection work by magnetometer prospection, geoelectric and pedological drillings. Initially used in different areas – magnetometer prospection and "Pürckhauer" drillings in settlement areas and on smelting sites, geoelectric investigations in mining areas - it became more and more clear that the combination of the methods would be a promising approach and added value for the clarification of features, also and especially in mining areas.

The specific combination of the methods makes it possible, particularly in the case of extensive fields of mining depressions such as those found in the Shashkoc/Janjevo area, to get ideas of their size and, above all, the shape of the shaft entrances, not just the depth, as initially planned. The shape of the mouth holes may be a very important indication of the age of the shafts, which in turn influences the planned excavations. Thus, unnecessary excavations can be avoided. Therefore, in the past two campaigns a whole series of mining depressions were investigated in this way. In order to evaluate and compare the measurement results, targeted excavations were then carried out in the upper areas of the shafts.

Although there are restrictive conditions such as different soil types, magnetic and electric disturbances and similar factors that may impede the measurement results, the combination of methods has provided considerable benefit and created a systematic working basis, future investigation can build on.

Introduction

In 2009 Kosovo became the focus of mining archaeological research at the Deutsches Bergbau-Museum Bochum (DBM) / German Mining Museum in Bochum. Starting from Roman Municipium Ulpiana near Graçanica southeast of Prishtina, the aim was to search for possible roman/antique mining traces in the wider vicinity in order to prove a connection between the settlement and its surroundings. The first surveys started between 2009 and 2011 in cooperation with the Römisch-Germanische Kommission (RGK) in Frankfurt and the Archaeological Institute of Kosovo in Prishtina (Gassmann, Körlin and Klein, 2011). Referring to these researches, the Deutsche Forschungsgemeinschaft (DFG) designed the mining archaeological and archaeometallurgical research by two stages, 2012-2015 (KO 4591/2-1) and 2017-2019 (KO 4591/2-3).

During the surveys it became evident that traces of old mining were preserved in large numbers in the Shashkoc and Janjevo district (an area of about 10 km^2), which were in use during several archaeological periods (Figure 1). The limited time frames allowed for only exemplary studies on elected sites. The principal purposes were to investigate the spatial and temporal extent of the mining area as well as dependent dressing, smelting and further processing. The analysis of the discovered ore, slag samples and end products characterize the de-

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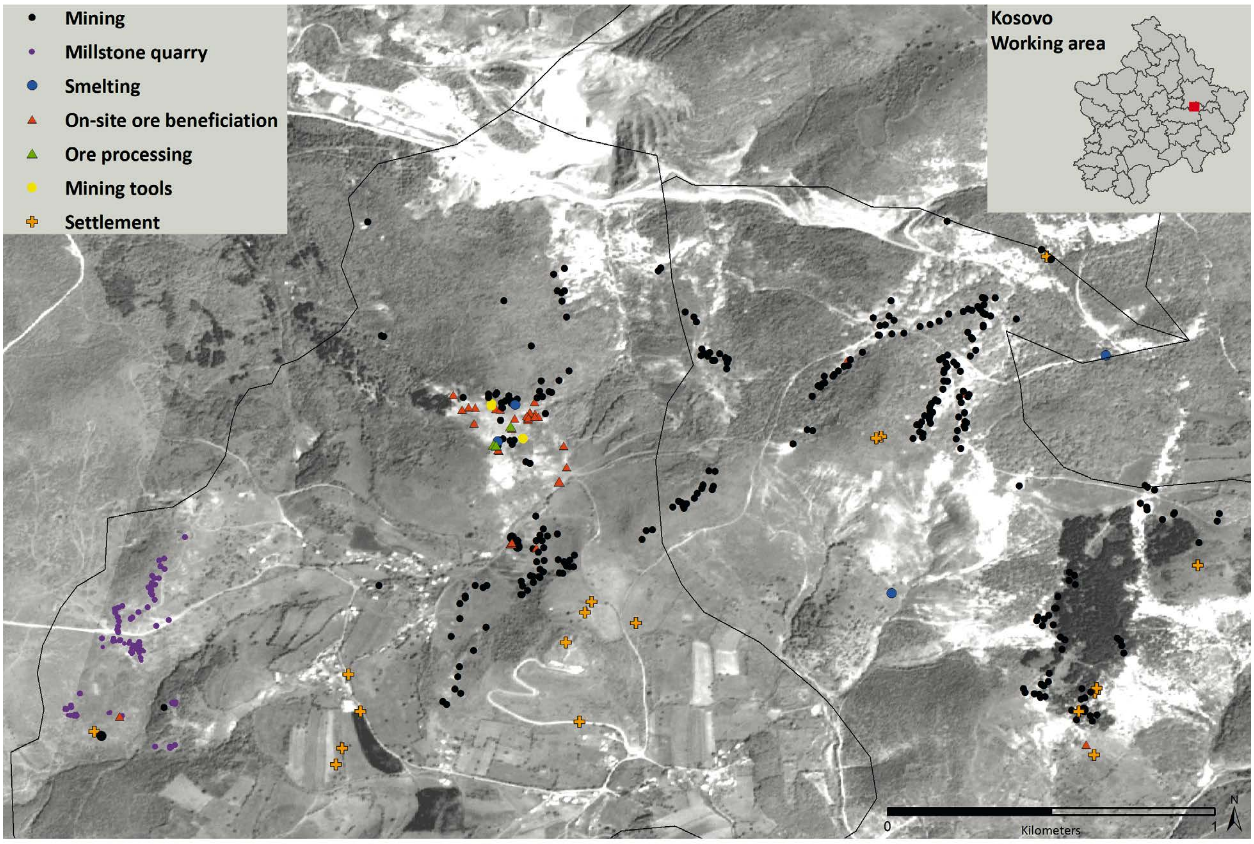


Figure 1. Map of the working area in Kosovo with the discovered traces of mining, ore beneficiation, smelting activities, settlements and millstone quarries in Janjevo and Shashkoc from the Roman Period to modern times. Illustration: B. Sikorski.

posits (Westner, 2017; Westner, et al., 2017). Secondly, questions concerning mining technology were supposed to be investigated, e.g. the toolkit used by the miners (Gezähe), the shape and size of the different galleries and shafts or the individual smelting steps (Gassmann, Klein and Körlin, 2015).

Different modern prospection methods, like aerial photo evaluation, magnetometer prospection and Electrical Resistivity Tomography (ERT) and additionally Pürckhauer drillings were carried out in the course of the project to find and characterize the remains of mining and processing (Ramani, 2016). Excavations followed at selected sites.

According to the research questions, in the beginning the different methods were used mostly separately of each other, depending on spatial and temporal conditions. Magnetometer prospection was used mainly in areas with settlement and smelting sites. Control Pürckhauer drillings mostly aimed at interesting anomalies. The 2D ERT measurements were used mainly in mining areas, in order to better estimate the depth of shafts (Körlin and Gassmann, 2016). In the course of time, however, it became clear that the combination of magnetometer and resistivity prospection, if necessary in addition with Pürckhauer drillings, led to a greater gain in knowledge than the sum of the individual results would have suggested. Especially the previously unusual combination 3D ERT measurements - magnetometer prospection allowed new insight in terms of the shape of the shafts. This may allow clues regarding the chronological classification of the shafts.

For reasons of time, not all measurements could be verified by excavations. After all, the measurements had been carried out in order to be able to investigate as many finds as possible in addition to the excavations. However, especially in the final phase of the project some of the sites investigated by magnetometer prospection and ERT were excavated in order to verify the obtained data. This allowed feedback and verification of the measurements, which were extremely important for the final evaluation.

Applied methods

Geophysical prospection uses the contrast of physical properties of archaeological soils and subsoil layers. Inhomogeneities such as from archaeological features cause anomalies e.g. of the Earth's magnetic field, the electric conductivity, gravitational field and seismic wave propagation. As early as in the 19th century, it was dis-

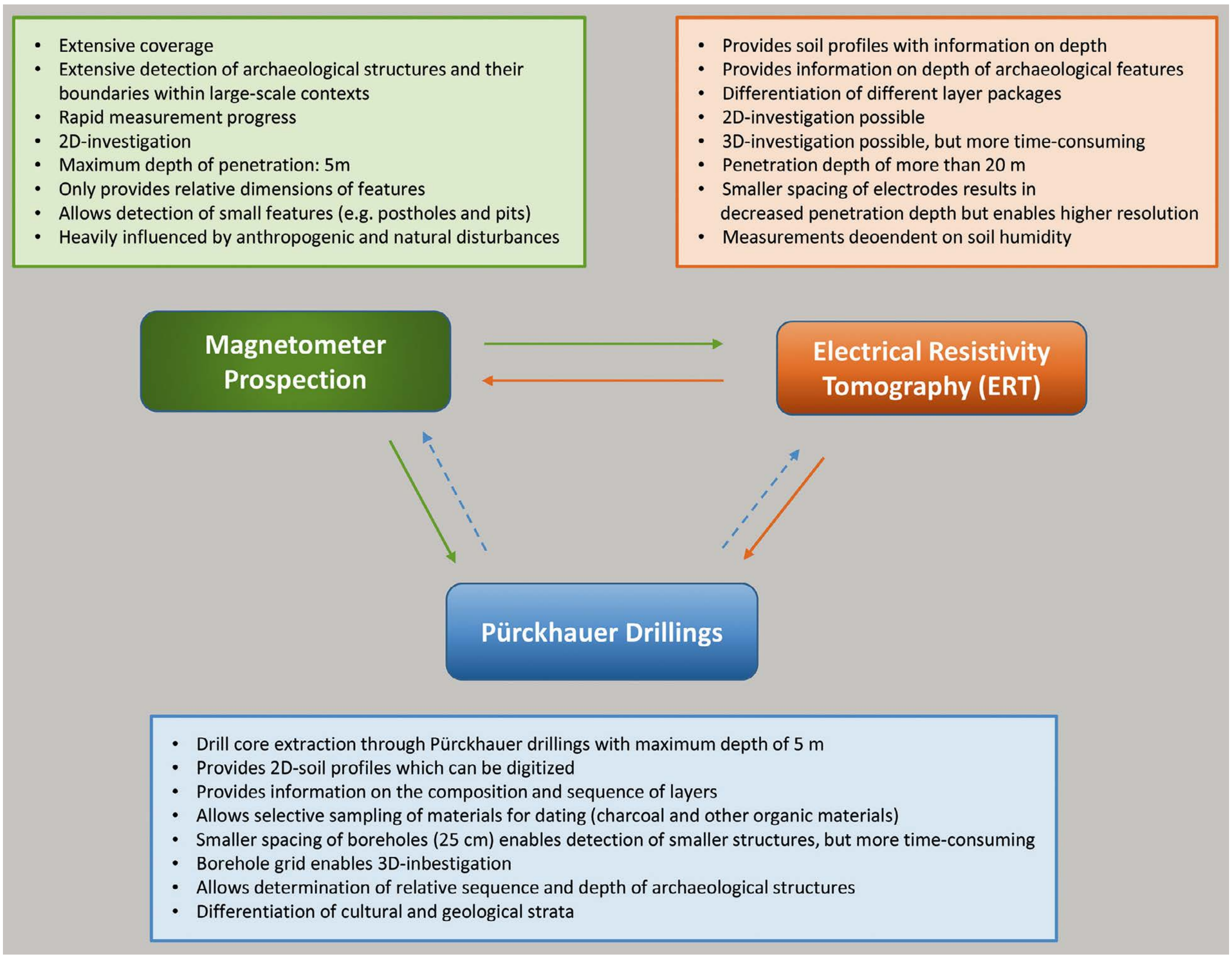


Figure 2. Workflow -The effective combination of modern prospection methods, in this case: magnetometer prospection, resistivity prospection and Pürckhauer drilling. Illustration: B. Sikorski.

covered that ceramics and fire clay are weakly magnetic (Folgheraiter, 1896).

Magnetic prospection was applied for the first time to archaeology in 1956 (Belshé, 1957; Aitken, 1958; Fassbinder, 2016). The frequently used geophysical prospection methods in archaeology are Magnetometer Prospection, Electrical Resistivity Tomography (ERT) and Ground Penetration Radar (GPR).

Archaeological prospection using geophysical methods allow for surveying structures of the near-surface subsoil without invading the soil and the archaeological structures. These methods are non-invasive and also offer the possibility to investigate large areas of interest quickly and effectively (Piro, 2009). A prerequisite for the meaningful application of geophysical methods is here a perceptible contrast between the structures/objects (anomalies) in the soil and their natural environment. For this project the combination of aerial photo and satellite imagery evaluation, magnetometer prospection, ERT, Pürckhauer drillings and sondages were used to complete the knowledge of the archaeological sites in the mining area Shashkoc/Janjevo (Figure 2).

Magnetic survey

Archaeological traces in the soil such as wall foundations, filled trenches or pits, fireplaces, smelting furnaces, slag heaps (Walach, 1998), and individual cremation burials change the soil layers at the surface, both physically and chemically (Linford, 2004; Fassbinder, 2009; Schmidt et al., 2015; Jordanova, 2017). The contrast between undisturbed soil and archaeological structures essentially determines the representation of magnetic anomalies (Lorra, et al., 1998).

For the measurements, two fluxgate gradiometers, a 1-channel system (Barthington) and a 5-channel system (Sensys) were used.

The measurements were performed within a measuring area (grid) of max. 30 × 30 m (Barthington) and 50 × 50 m (Sensys). The probe registers the vertical component of the magnetic field with an accuracy of 1 nT (nanotesla). With a line spacing between 0.25, 0.5 and 1 m, depending on the archaeological question, and the sampling (measuring point distance) between 8 and 10 per meter. For visualisation, each measurement point was converted into a pixel. The resulting graphic, also called magnetogram or greyscale picture provides the base for the archaeological interpretation. The magnetograms were evaluated by help of the Magneto (Sensys) and Geoplot (Geoscan Research 2001-2018) programmes. The obtained data were finally entered into the GIS system ArcGIS (Esri), and linked with other information, such as maps, our own surveys, aerial photographs, satellite pictures, excavation results etc. and then processed into different maps. With this information, the detected anomalies in the greyscale pictures could be classified into anthropogenic and natural anomalies, including settlement and mining structures like charcoal, fireplaces and kilns, geology and other structures. Some of them include a high temperature range with high nT (Nanotesla) values over 20 nT and more. In case of anthropogeny structures with a characteristic appearance, they could be interpreted as high temperature areas (Sikorski, 2024).

Heating the soil above a certain temperature (the so-called Curie-point) causes the disoriented lying magnetisable components to orient themselves according to the magnetic field that is present at the moment. After cooling, the orientation is frozen. As a result, the orientation deviates from the currently prevailing magnetic field (Dunlop and Özdemir, 1997; Hübner, 2005) as a dipole.

Resistivity prospection

Electrical Resistivity Tomography (ERT) is well suited for the investigation of mining traces in steep terrain or even in forested areas, because one of the advantages of this non-invasive geophysical method is the possibility to use it in topographically difficult terrain and in dense vegetation (Schrott and Sass, 2008). The Electrical Resistivity Tomography makes use of the electrical resistance of the subsurface to provide depth information about the area located directly below the measurement. Based on their resistance value, different subterranean materials can be delineated and archaeological objects can thus be distinguished from the surrounding subsoil. In order to be able to effectively plan an ERT, it is helpful if a magnetic prospection has already been carried out prior to the measurement, as this is helpful for investigating the approximate location and extent of the archaeological features. The geoelectrical measurement can then be carried out specifically at locations where depth information is desired. By combining the two methods, it is thus possible to obtain an approximate three-dimensional representation of the underground.

For the measurements, the measuring instrument GeoTom 200/100 RES/IP (1-channel or 4-channel) from GEOLOG2000 was used. 2D and 3D ERT was carried out. By applying the inverse modelling method, the RES2DINV (Loke, 1995; 2011a) programme generates a two-dimensional image which represents the different resistivity values by different colours and was used for the 2D ERT. RES3DINV evaluation programme (Loke, 2011b) was used for the 3D ERT.

Pedological drillings

Pedological drillings allow for pinpoint insights into the structure and depth of distinguishable geological and anthropogenic structures through the extraction and documentation of drill cores. Depending on the nature of the ground, different systems can be used. Widely used is the Pürckhauer driller, a metal tube open on one side, which is driven into the ground by means of a plastic hammer and, by means of a rotary movement, encloses a drill core, which remains enclosed in the metal tube and can be pulled out of the ground. For deeper boreholes drive rods/side markers can be used, to which extension pieces can be screwed.

By the installation of systematically catenaries, profiles can be reconstructed by exact recording and drawing implementation. The accuracy depends on the distance between the individual borehole points. By means of flat borehole grids, 3D reconstructions can also be generated. However, this requires a lot of time. The method is well suited for the recording of larger and medium-sized archaeological objects, even overlaps and the relative sequence of natural and artificial structures can be recorded. Post positions and other small structures are difficult to detect. Geophysical disturbance factors have no influence on the generated profiles.

Selected case studies

Settlement relics: Shashkoc, building

A building on the edge of the village of Shashkoc, just a few hundred meters south of the mining area, was already visible as an anomaly in aerial photographs. A first survey revealed late antiquity finds, so a large-scale magnetic prospection was conducted (Figure 3). Subsequently some Pürckhauer drillings and resistivity prospection could be carried out, concerning the anomalies of the magnetic prospection. Firstly, to prove the results and secondly to get more information about the structures.

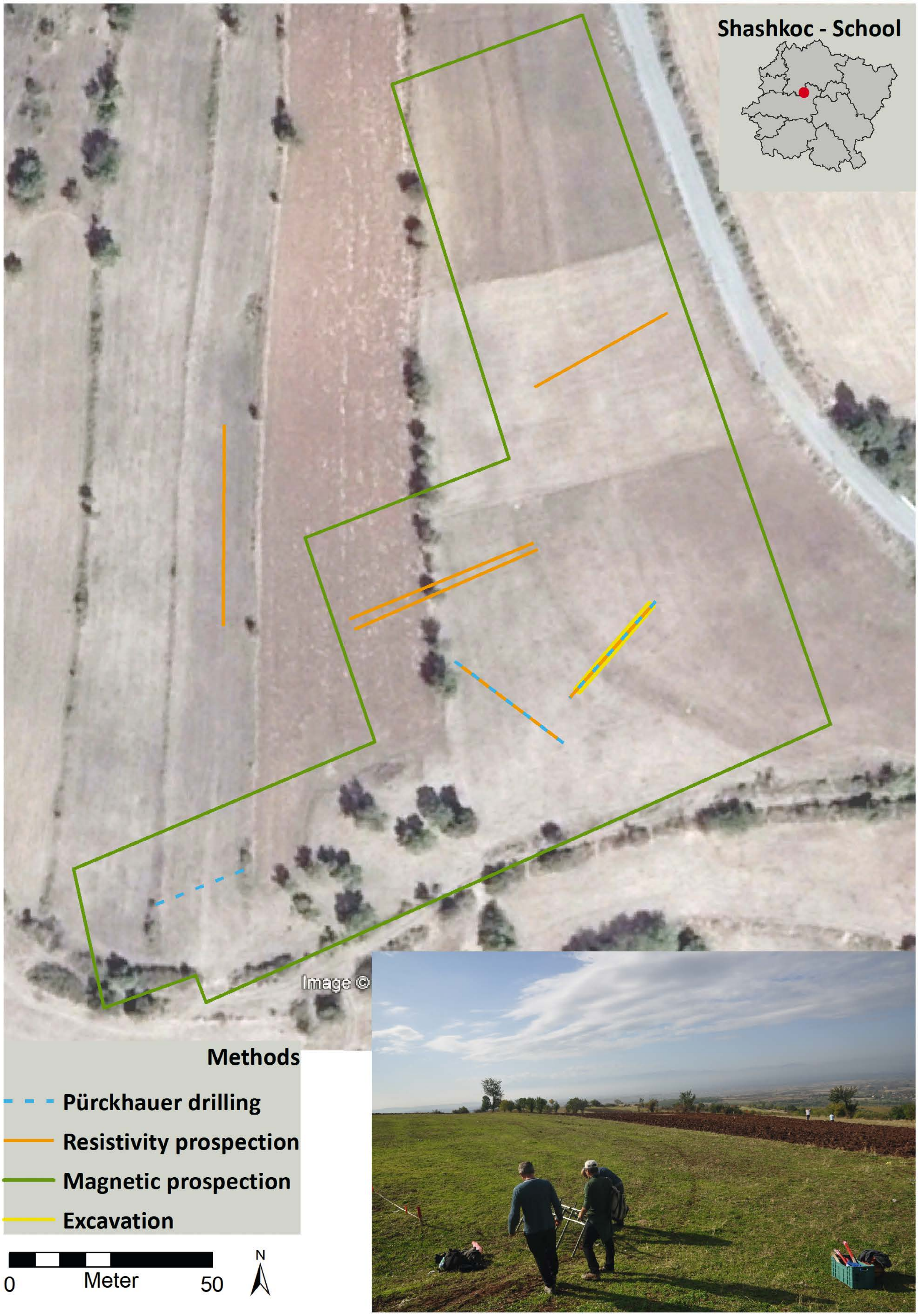


Figure 3. Shashkoc School, overview of all methods used at Shashkoc School: magnetometer and resistivity prospections, Pürckhauer drillings and excavation. The picture shows the measurement area. Magnetometer prospection and illustration: B. Sikorski; photo: DBM, B. Sikorski.

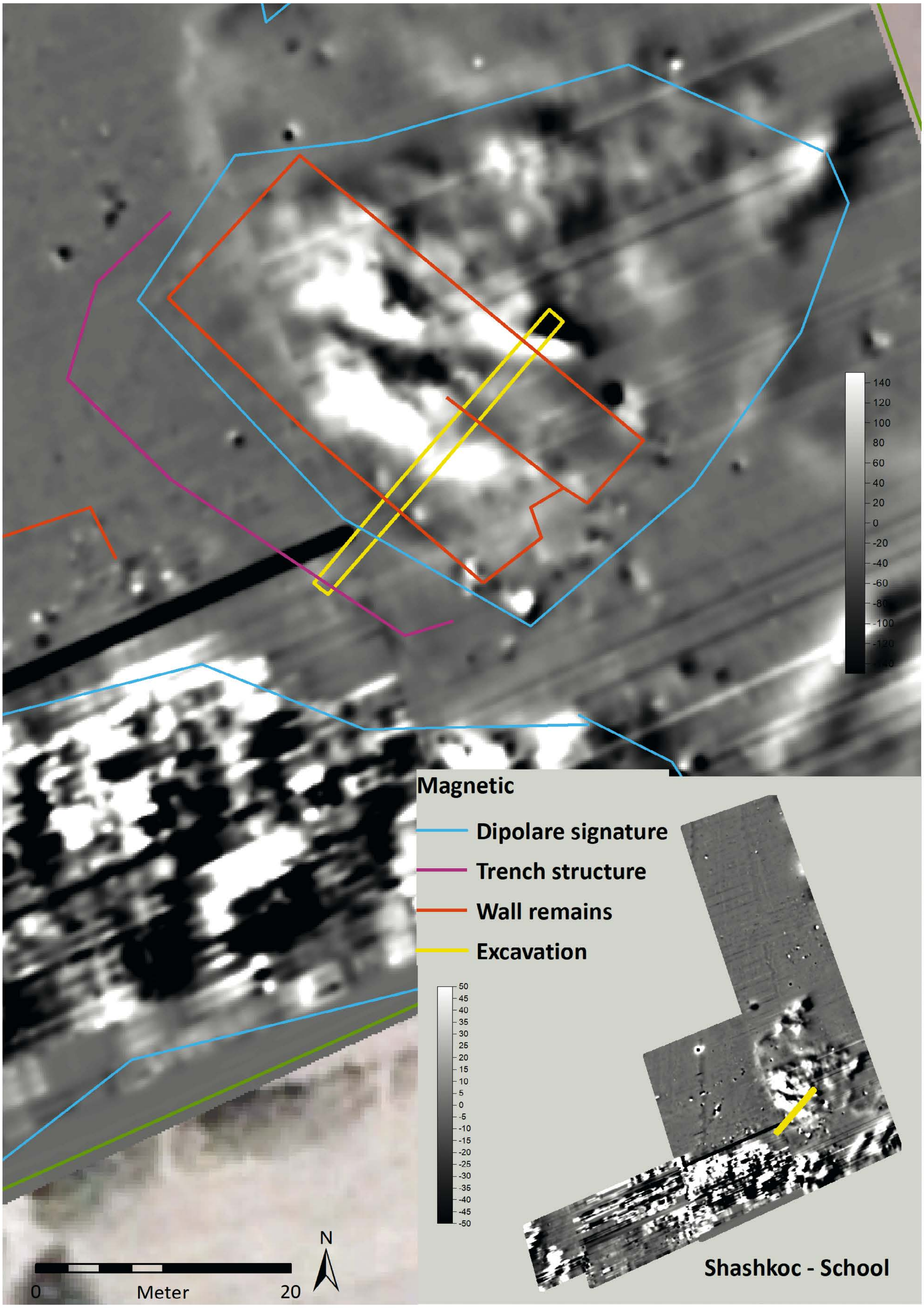


Figure 4. Shashkoc School, results of the magnetometer prospection. The greyscale image shows anomalies that could be interpreted as archaeological structures like wall remains and a trench structure. Magnetometer prospection and illustration: B. Sikorski.

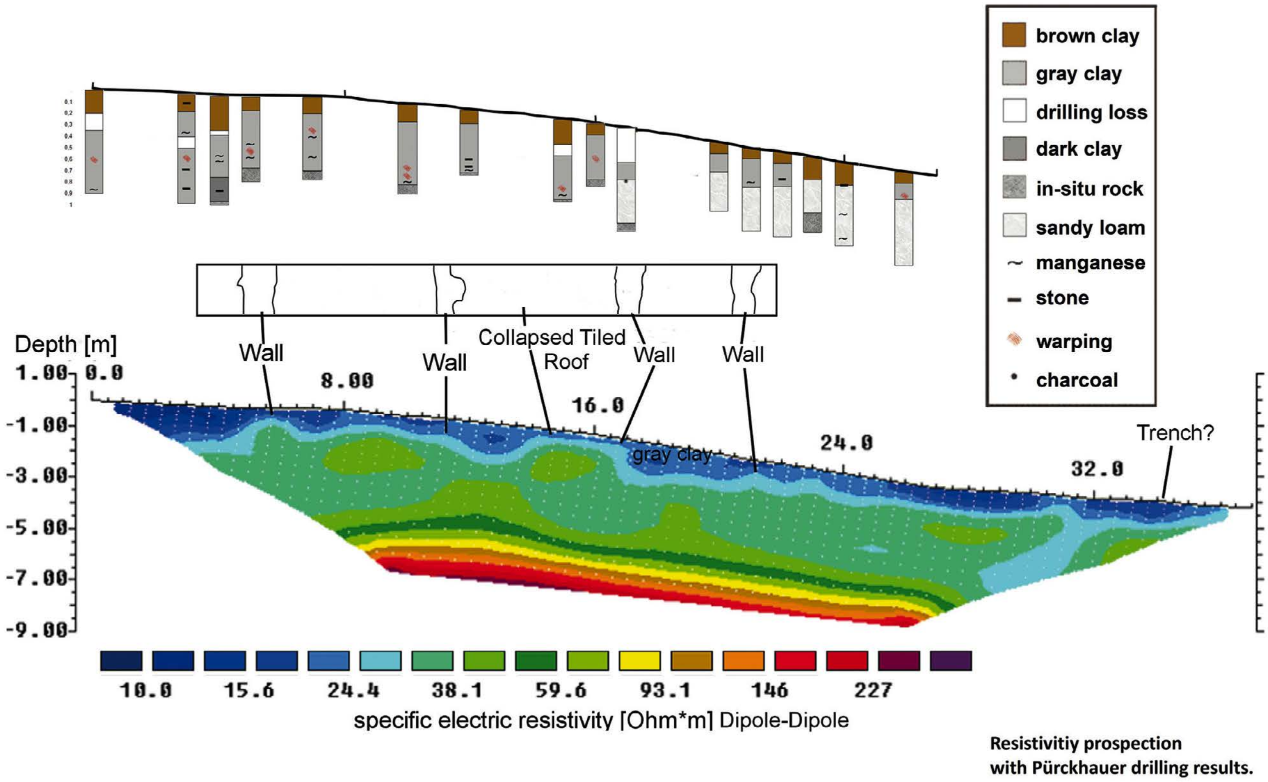


Figure 5. Shashkoc School, results of the resistivity prospection and Pürckhauer drillings. The resistivity prospection (profile) shows some of the wall structures (trench) of the building, confirmed by drillings. ERT: B. Matthes; drilling: G. Gassmann; plan: B. Matthes/B. Sikorski.

The results of the magnetic prospection show three linear anomalies, ca. 25 m long, running NW-SE, which can be interpreted as wall remains (Figure 4). Below this in a southwestern direction another linear anomaly, ca. 48 m long, can be identified as a ditch structure. It is indicated by strong magnetite precipitations (dipolar signature) along the whole anomalies. In the greyscale image, the building is about 16.4 m wide, about 25 - 32 m long and has several rooms of different sizes. To confirm the results of the magnetic prospection, resistivity prospection and Pürckhauer drillings were used along the entire anomaly. The results of the resistivity prospection match the results of the magnetic prospection and additionally those of the Pürckhauer drillings (Figure 5).

In the course of the resistivity prospection, identified structures can also be interpreted as wall remains and brick collapse. In the area of the profile situated down the slope (right), a pit-like structure with comparatively lower values can be seen. Supplemental Pürckhauer drilling provides data on the context and depth of the suspected building in order to prepare an archaeological excavation section. A main drill row was laid across the presumed building (see Figure 3). Different degrees of moisture penetration and obstacles such as stones in the drill profiles caused occasional loss of material. In the centre, under the partly capped topsoil, layers of debris were found which can be assigned to a collapsed building and extend to a maximum depth of 0.95 m. On the upper hillside, backfill layers were found which were deeper than the drilling depth of 1 m. There, structures may be suspected which indicate further finds in the subsoil outside the building. At the foot of the hillside, the sand content within the drill cores increased.

In the debris layers, which can be attributed to late antiquity, fragments of roof tiles tracing the core area repeatedly came to light. Larger stones were found especially in the vicinity of the wall remains, whose exact positions were recorded by the excavations. The most important result of the drillings was the maximum depth of the house find of about 1 m. A test trench through the entire feature could be realized within a manageable time frame (see Figure 3).

In addition to the results of combined prospection, a 28 m long and 1.4 m wide excavation section was then established along the ERT profile and drill catenary 1 and deepened to the surrounding soil (Figure 6). This revealed two outer walls and two inner walls. The results of the excavation confirm the results of the magnetic prospection, ERT and drillings. The walls had a uniform width of 80 cm (Körlin and Gassmann, 2016, p.202) and were generally preserved at a height of 20 -30 cm. The discovered pottery dates the building to the 4th century AD. Unfortunately, no further anomalies could be identified because the measurements were disturbed

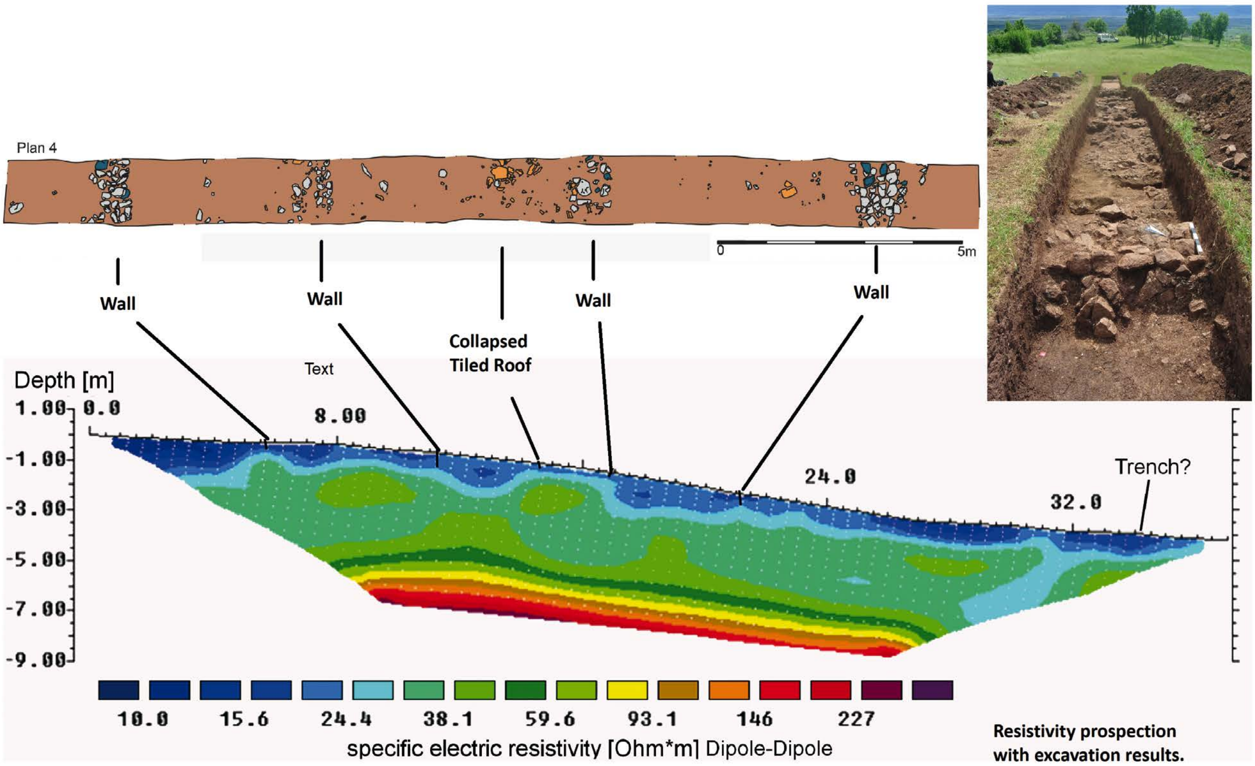


Figure 6. Shashkoc School, results of the resistivity prospection (profile) and excavation. Photo and drawing (planum) show the test trench through the building of the 4th century AD with the thick outer walls and thinner inner walls. The walls from the ERT match exactly with the wall structures that were found in the excavation. ERT: B. Matthes; drawing: B. Matthes, B. Sikorski; digitalisation: F. Schapals; illustration: B. Sikorski.

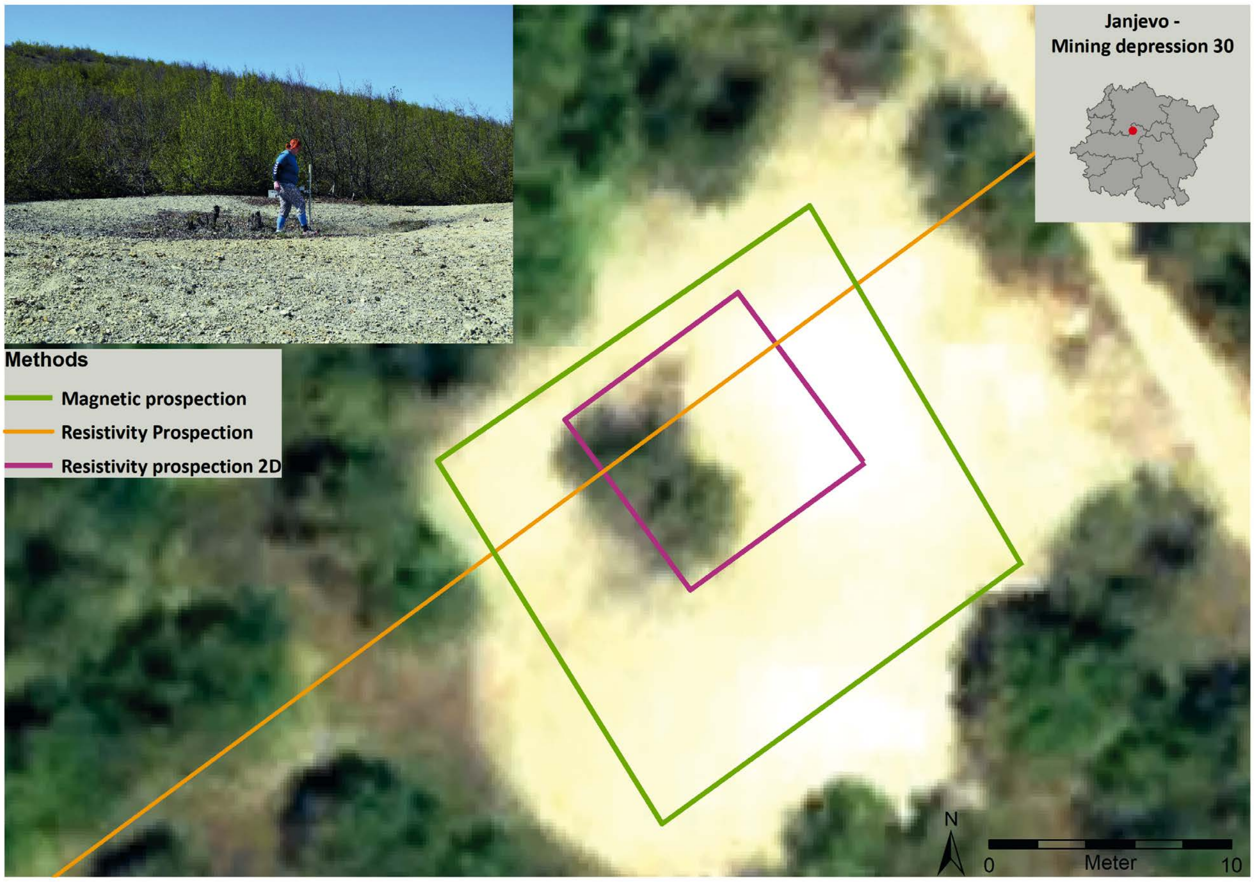


Figure 7. Janjevo, mining depression 30, overview with all methods: magnetometer and resistivity prospection plus two-dimensional resistivity prospection. Illustration: B. Sikorski; photo: archive DBM, G. Körlin.

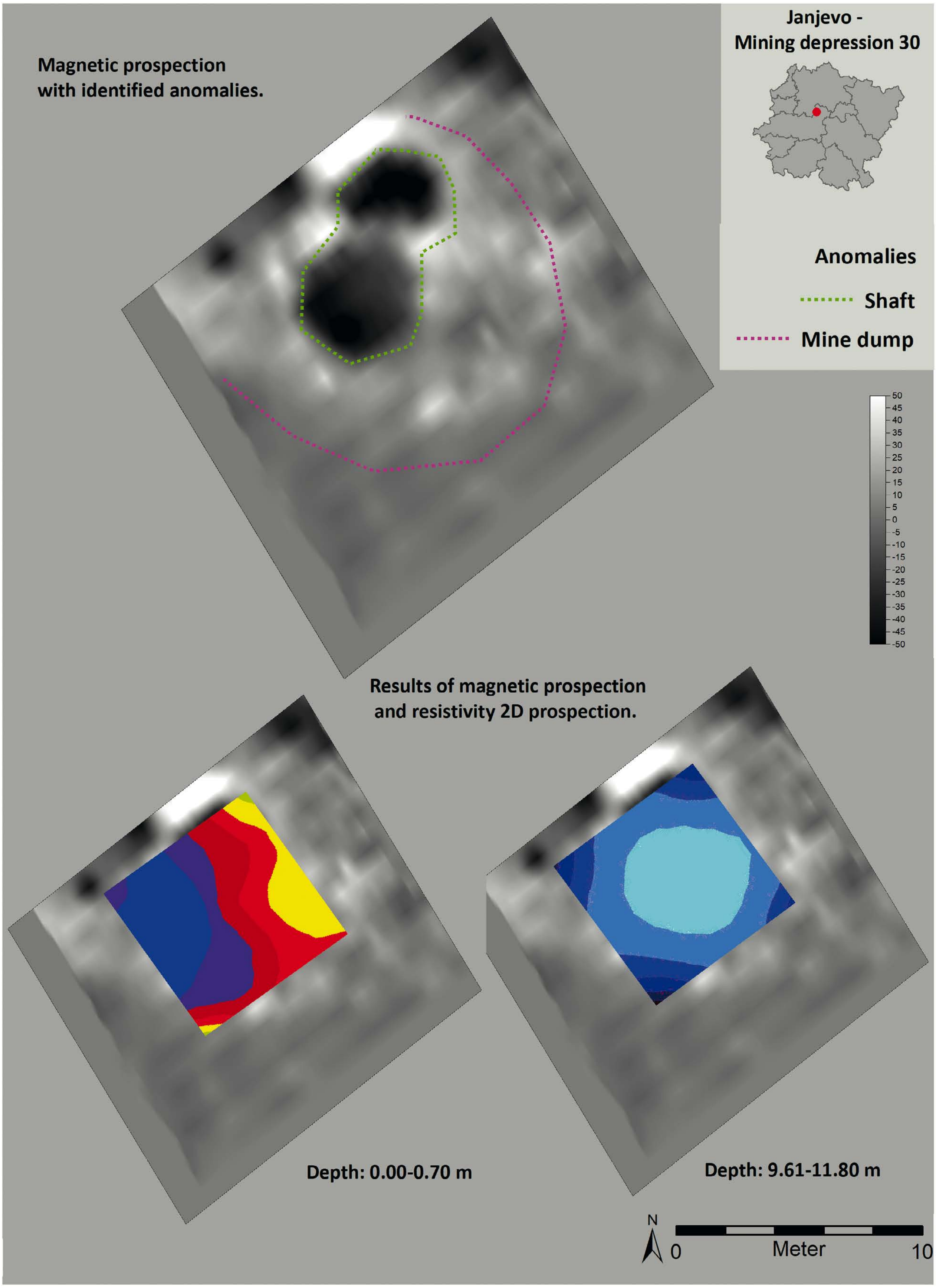


Figure 8. Janjevo, mining depression 30, results of the magnetometer prospection and resistivity 2D prospection in different depths. The shaft in the greyscale picture matches with the ERT results (depth: 9.61 - 11.80 m). Magnetometer prospection and illustration: B. Sikorski; ERT: B. Matthes.

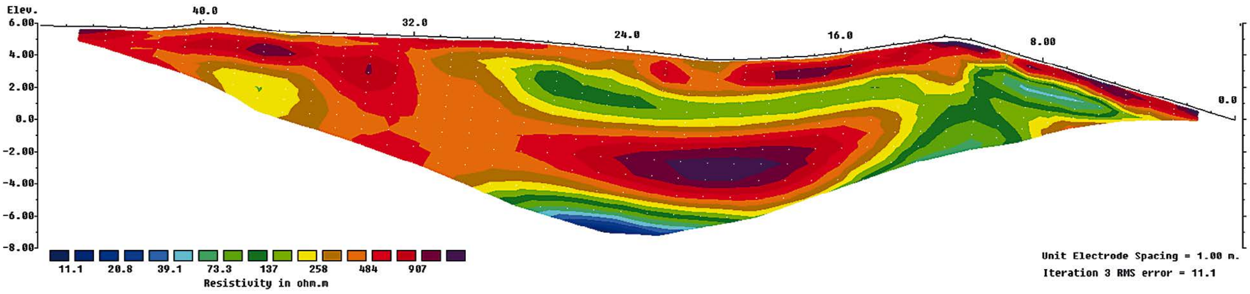


Figure 9. Janjevo, mining depression 30, results of the resistivity prospection (profile). The mining depression is on the scale between 20 and 22 m. ERT, illustration: B. Matthes.

by strong manganese oxide precipitations in the southern area of the measurements. They find expression by a strongly dipolar signature and overshadow all possibly still existing archaeological structures.

However, only three wall structures can be identified in the greyscale picture, which can be traced back to the immense disturbance caused by the iron oxide concentration (Faßbinder, 1994, p.8-9). Nevertheless, the results were good enough to identify an archaeological structure in conjunction with the resistivity prospecting and the Pürckhauer boreholes to enable accurate excavation.

Mining relics: Janjevo, mining depressions

The mining area extends between the present-day localities of Shashkoc and Janjevo. Well visible are shaft mining depressions (shaft pings), partly in rows following the ore veins. In addition, some mining entrances of small galleries or mines were found (Gassmann, Körlin and Klein, 2011, p.160). Many features, however, are probably overlaid and not visible due to the often closely adjacent and superimposed dumps. Mining extends over several neighbouring hills. In order to determine any chronological and other differences in shape, size or driving techniques, mining depressions and pits from all areas of the district were investigated (see Figure 1). Here, the geophysical measurements already provided information on the depth (ERT) as well as the shape (magnetic prospection and ERT) and size of the mining depressions. A selection is presented in the following.

Janjevo, mining depression 30

Mining depression 30 belongs to an apparently large and deep shaft with an annular heap. The dump is completely without vegetation and consists of comparatively very light-coloured rock. The colour of the rock indicates that it does not originate from the near-surface layers but from larger depths. The shaft has a large cone, which was overgrown with bushes on the inside (Figure 7).

In the greyscale image of the magnetic prospection, three anomalies can be seen which can be interpreted as archaeological structures (Figure 8). On the one hand it shows an approximately round, anomaly about 15 × 13 m, which can be interpreted as a dump body. Inside, two black anomalies are visible, which can be interpreted as a possible shaft or infill. The northern one with a size of ca. 3 × 3.50 m and the southern one with a size of ca. 5 × 4.5 m. Two more roundish anomalies of about 1.2 and 1.4 m in size, which can be interpreted as possible postholes, are also visible in the western area.

In the 2D ERT (Figure 9) the pile is clearly visible at approximately 32 m and the beginning of the shaft at around 24 m. The cross section/plan view of the 3D ERT shows results, which are also similar to the magnetic prospection (see Figure 8). The mine dump can be estimated to have a diameter of up to 15 m, and the black anomaly of the magnetic prospection can be recognized in a depth of up to 5 m in the ERT analysis, too. As a conclusion, it can be stated that the information of the magnetic prospection allows for identifying mining archaeological structures down to a depth of 5 m. Due to the recognizable dimensions of the shaft, which indicate rather recent mining, it was decided not to excavate it.

Janjevo, shaft 31

Shaft 31, with a mining dump in front of it, is also located on the main row of mining depressions in Janjevo, approximately 27 m north of shaft 30 (Figure 10).

The magnetogram shows some interesting anomalies (Figure 11). A black one, in the northeastern part of the picture, ca. 1.70 × 1.50 m large, can be interpreted as a shaft. The two white anomalies with high values (ca. 180 nT) were probably caused by the manganese ore that was also seen on the surface, like at the Shashkoc School site (see Figure 4).

The cross sections of the 3D ERT showed large differences of the resistivity values, whose interpretation is difficult. Here a long exposure could not be carried out,

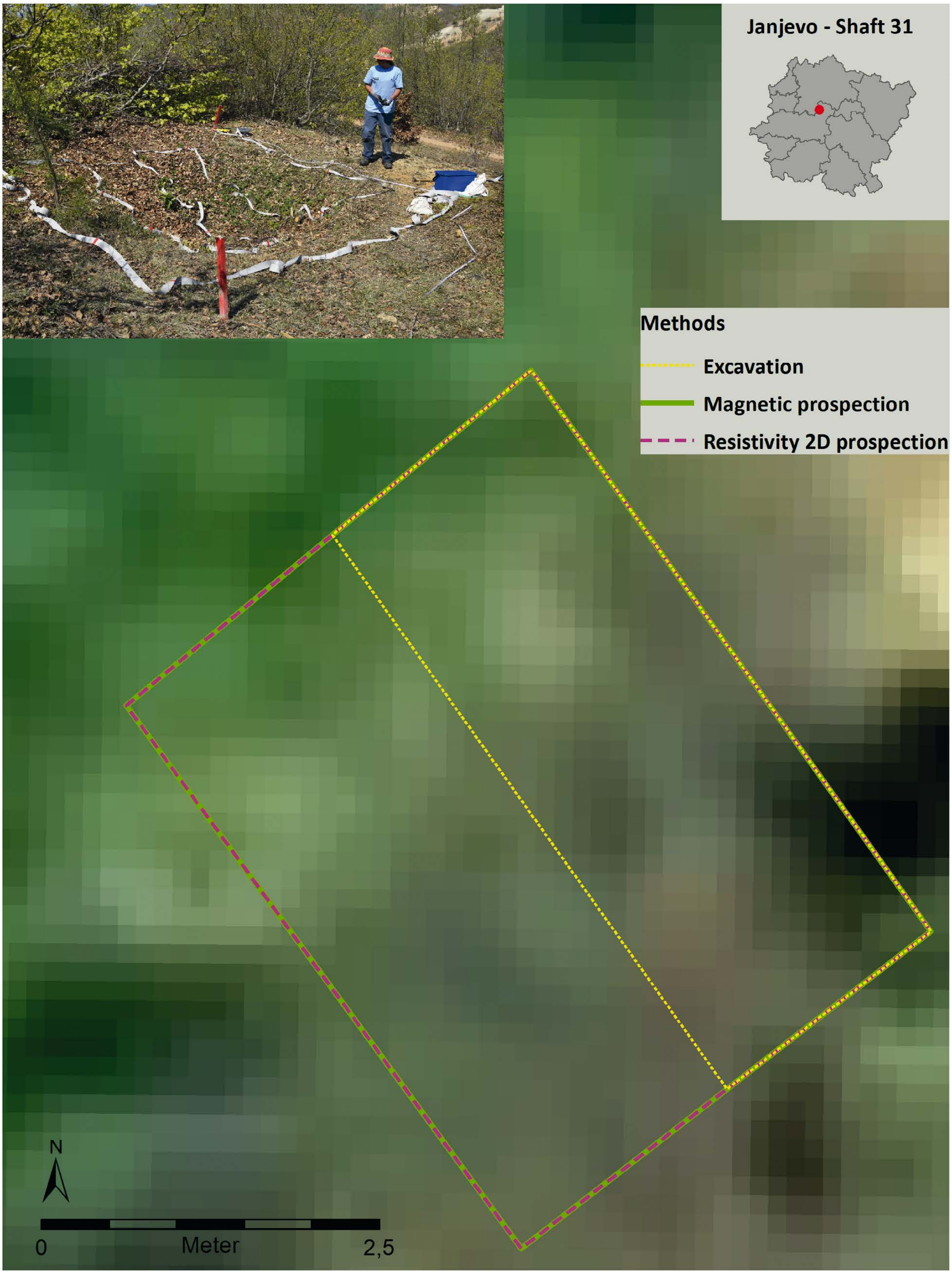


Figure 10. Janjevo, shaft 31, overview of all methods: magnetic prospection, resistivity 2D prospection and excavation. On the picture, you see Dr. B. Matthes at work with the ERT. Illustration: B. Sikorski; photo: archive DBM, G. Körlin.

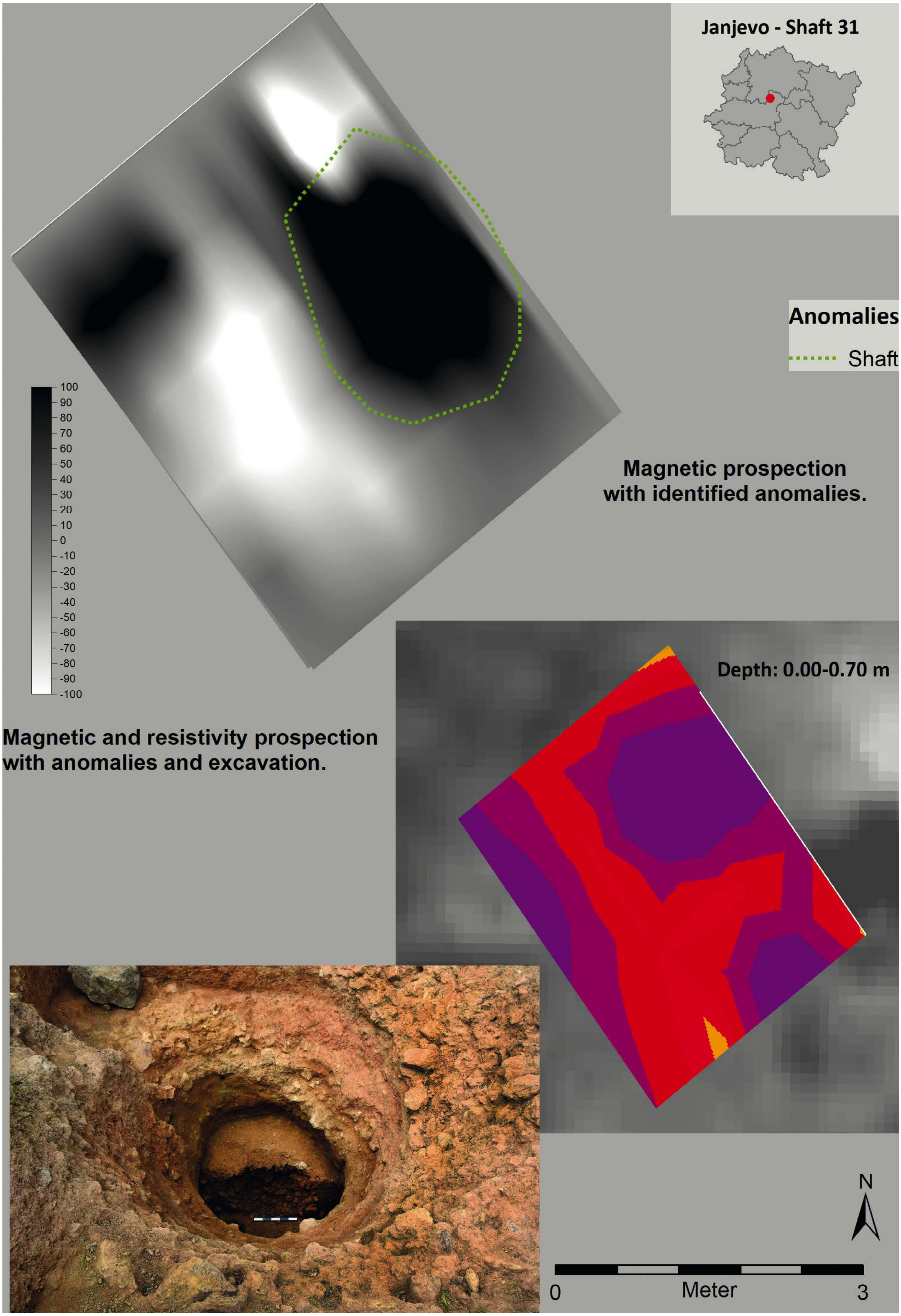


Figure 11. Janjevo, shaft 31, results of the magnetic and resistivity 2D prospection and excavation picture. On the picture, you see the view into the tapering shaft cone. Magnetometer prospection and illustration: B. Sikorski; ERT: B. Matthes; photo: archive DBM, G. Körlin.

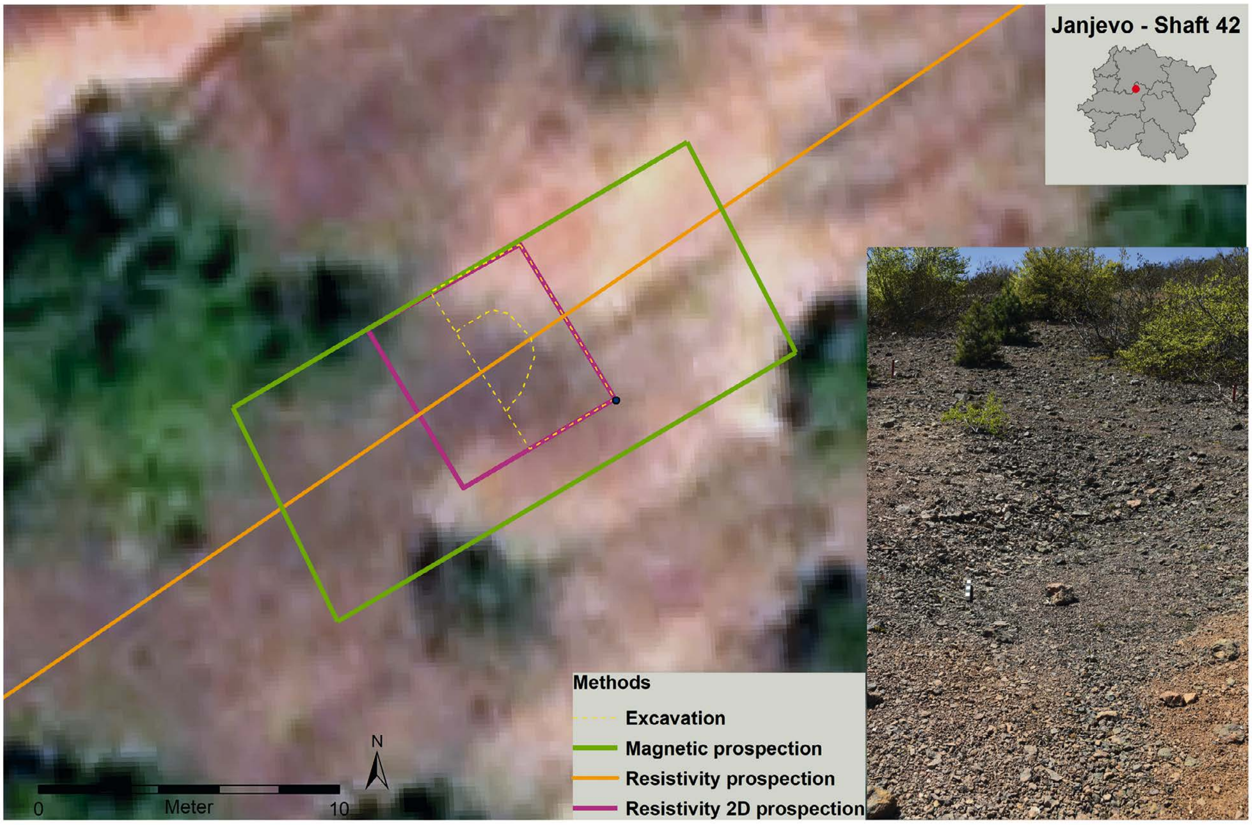


Figure 12. Janjevo, shaft 42, overview of all methods: magnetic and resistivity 2D prospection and excavation. The photo shows the mining depression/shaft 42 before the excavation. Illustration: B. Sikorski; photo: archive DBM, G. Körlin.

as it would not have been possible in sufficient length, due to the nearby path and the heavy vegetation.

To check these results, the shaft was excavated to a depth of 3.8 m (see Figure 11). The reasons for the dipole anomalies of the magnetic measurements could already be explained in the upper sections of the excavation trench. In some cases, larger chunks of magnetite were found, especially at the eastern edge of the excavation and the shaft.

At a depth of 0.85 m, the shaft cone had already been reduced to a diameter of 2.9 m. At a maximum depth of 1.3 m, the shaft was already completely in the existing rock. A strong reduction of the cone diameter can be observed at a depth of 1.7 - 1.8 m; at 2.2 m, the transition from the cone to the actual shaft takes place. At a depth of 2.6 m, the round-oval shaft had a "diameter" of 1.45 - 1.55 m.

The working faces were partly vertical, and in some cases they extended up to 40 cm. Up to the excavated depth of 3.8 m the main filling constantly consisted of stones with some sediment in between. This may indicate a targeted backfilling with rock debris, possibly mined material from the neighbouring mining depression, which is only 4 - 5 m away. Due to the nature of the surrounding rock, there are no signs of mining tools at the working faces. No datable finds were identified.

Janjevo, shaft 42

Mining depression 42 is a shaft with a round oval shape and a dump in the area of the main row of mining depressions, about 145 m north of shafts 30 and 31 (Figure 12).

The greyscale image of the magnetic prospection shows three anomalies that allow for archaeological interpretation. One anomaly of about 12 × 7.5 m, approximately round can be considered a dump structure. There are two round, black anomalies in the dump structure. One (North-East) has a size of about 3 × 3 m, and the second one (North-West) has a size of about 4 × 4 m, both could be interpreted as shaft structures, the North-Western one was further investigated (Figure 13).

3D ERT was carried out and shows a round anomaly. The structures match the magnetic prospection anomalies up to a depth of 5 m. Afterwards a 2D ERT was carried out through the centre of the mining depression. In this 2D ERT the shaft is visible between 18/19 and 23/24 m, a dump structure can also be seen (Figure 14). The results of the measurements could directly be compared to the western profile of the archaeological excavation.

To verify the results, the mining depression was excavated through a 5 × 3 m section down to a depth of 2.3 m, whereby the northern half was removed (see Figure 14). After only a short time, the cone of the shaft was clearly marked in the surrounding soil by an almost

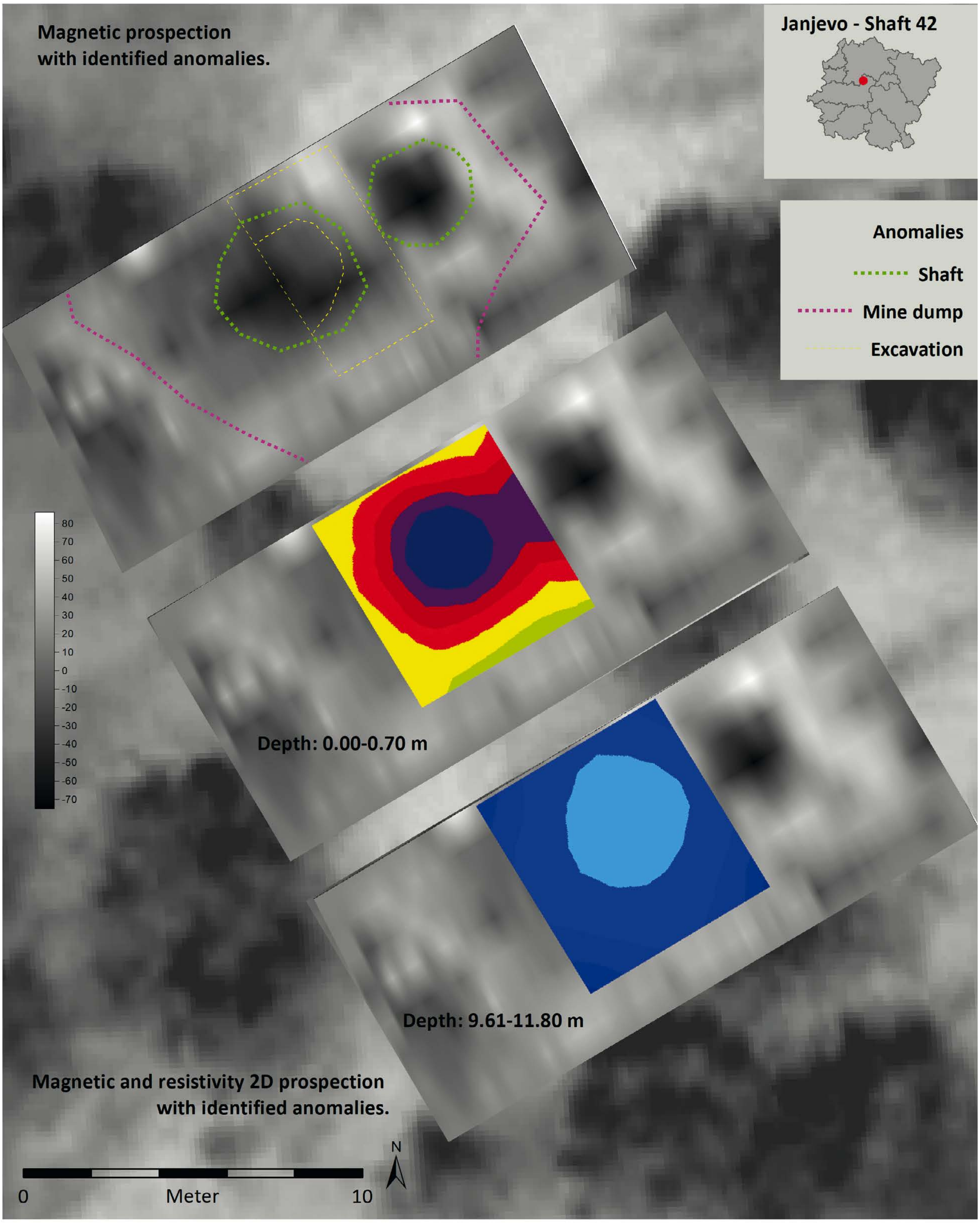


Figure 13. Janjevo, shaft 42, results of the magnetic and resistivity 2D prospection. Magnetometer prospection and illustration: B. Sikorski; ERT: B. Matthes.

semi-circular layer of clay without stones. Especially at the eastern edge, some larger boulders were located. At a depth of 1.2 m, the actual round shape of the shaft was more apparent, the surrounding rock retracted, and the cone merged into the actual shaft. The eastern border of the shaft could not be captured in the section. The profile shows a series of sediment layers of varying thickness; number and thickness indicate slow filling or sedimentation.

With a size of probably little more than 3 m, the diameter of the shaft at this level is comparatively large. The dimensions seem to indicate a modern rather than a Ro-

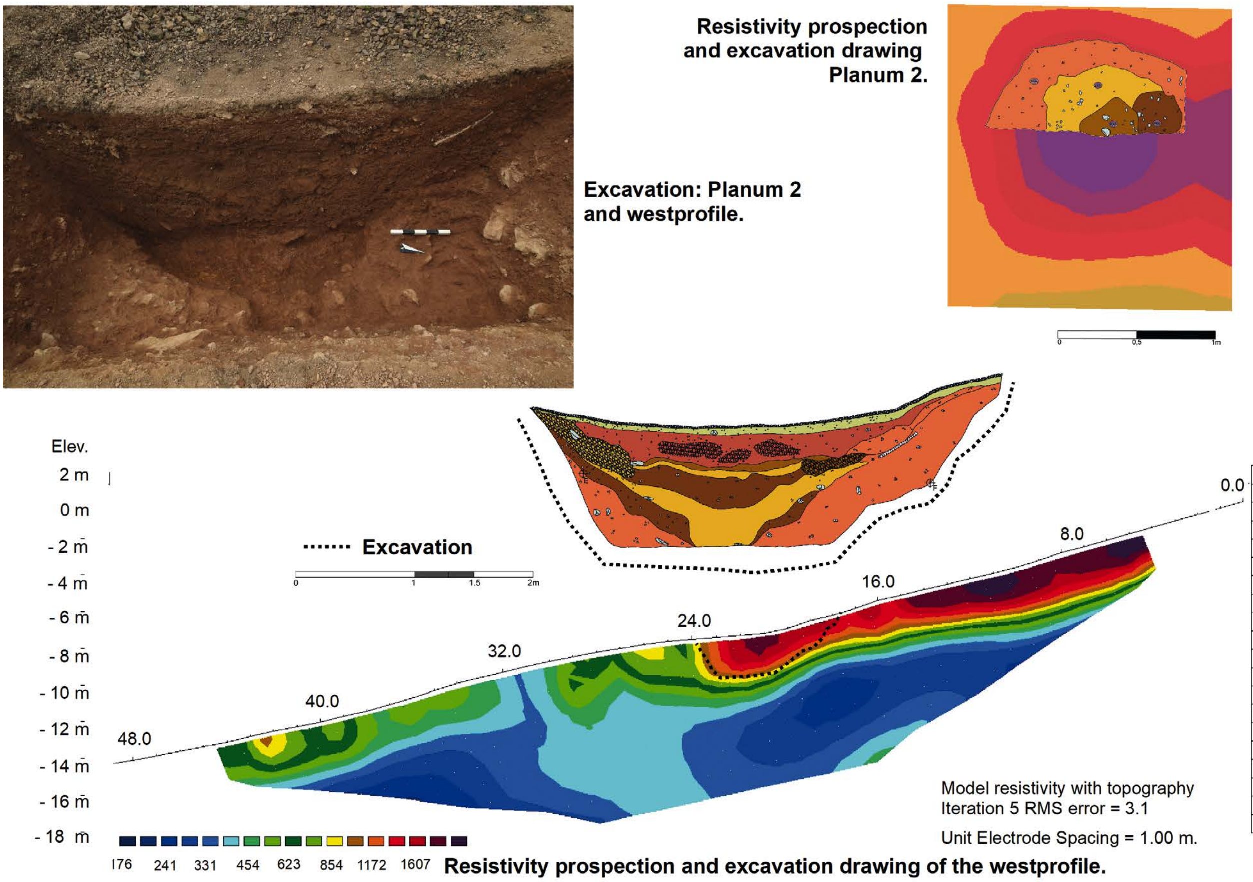


Figure 14. Janjevo, shaft 42, results of the resistivity prospection and excavation. In the marked area of the resistivity prospection (dark red area in the middle) the excavation was conducted. Photo and drawing: profile of the shaft cone. The figure on the right side shows the combination of the result of the resistivity prospection and the drawing of planum 2 in a depth of 2.3 m. ERT: B. Matthes; drawing and geodesy: top, K. Milkovic and L. Latzel, down, H. Arndt and L. Latzel; photo: archive DBM, G. Körlin.

man shaft. Datable finds could not be recovered. Due to weathering, clear signs of tool marks, which might provide indications for dating, could not be identified in this upper part of the shaft. The shaft is almost circular and thus confirms the geophysical measurements.

Janjevo, shaft 122

Shaft 122 comes from a larger shaft with a cone still clearly visible in the terrain and a ring-shaped dump surrounding it. A piece of arsenopyrite was discovered only a few meters away during the survey. The upper edge of the cone still was about 5 m in diameter and the depth was 1.2 m. The shaft is located on a hillside which is nowadays forested (Figure 15).

In the greyscale image of the magnetic prospection, two distinct anomalies are recognizable (Figure 16). There is a round-oval, black anomaly, almost 3.8 - 4.5 × 5 m in size, which can be interpreted as a shaft. All around, a "lighter" area is visible, which can be interpreted as a dump. In contrast to the other shafts, the total extent of this area does not seem to have been covered yet, as it is not so clearly visible in the greyscale image. A second distinct, black anomaly measuring approximately 2 × 1.3 m is located in the northwest of the measurement area. Here, the interpretation is difficult because it is different from the other anomalies. In the 3D ERT analysis (see Figure 16), both structures of magnetic prospection are clearly visible. Based on the depth information, it can be stated that the structure of the shaft can be observed in the magnetic prospection down to a depth of 5 m.

In the 2D ERT image at about 16 m, the structure of the shaft is visible, which seems to be backfilled with stony material at the surface. At a depth of about 2 to 4 m, structures with increased resistance values can be seen. However, it could not be clarified whether these are mining chambers or stone debris (Figure 17).

Here, too, an excavation to verify the geophysical prospection could be carried out after the measurements (see Figure 17). The filling of the shaft initially showed an oval discoloration in the section. At first, the working faces retracted only slightly, from approximately 1.4 m below the surface the transition from the shaft cone to the shaft took place, the working faces now ran vertically. The cross section remained round oval, with a length

Figure 15. Janjevo, shaft 122, overview of all methods: magnetic and resistivity (2D) prospection and excavation. The photo shows the mining depression and the ring-shaped dump of shaft 122 before the excavation. Illustration: B. Sikorski; photo: archive DBM, G. Körlin.

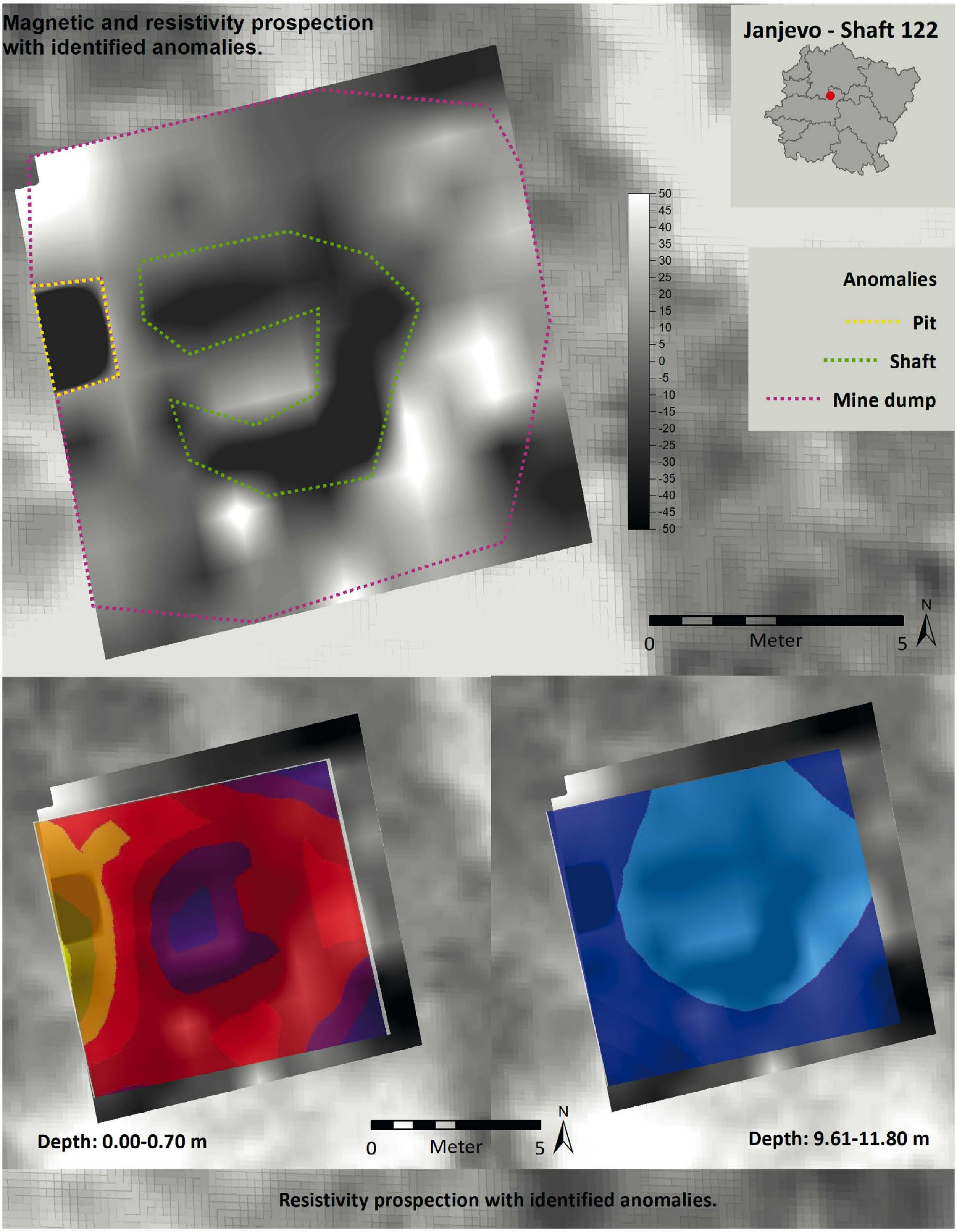
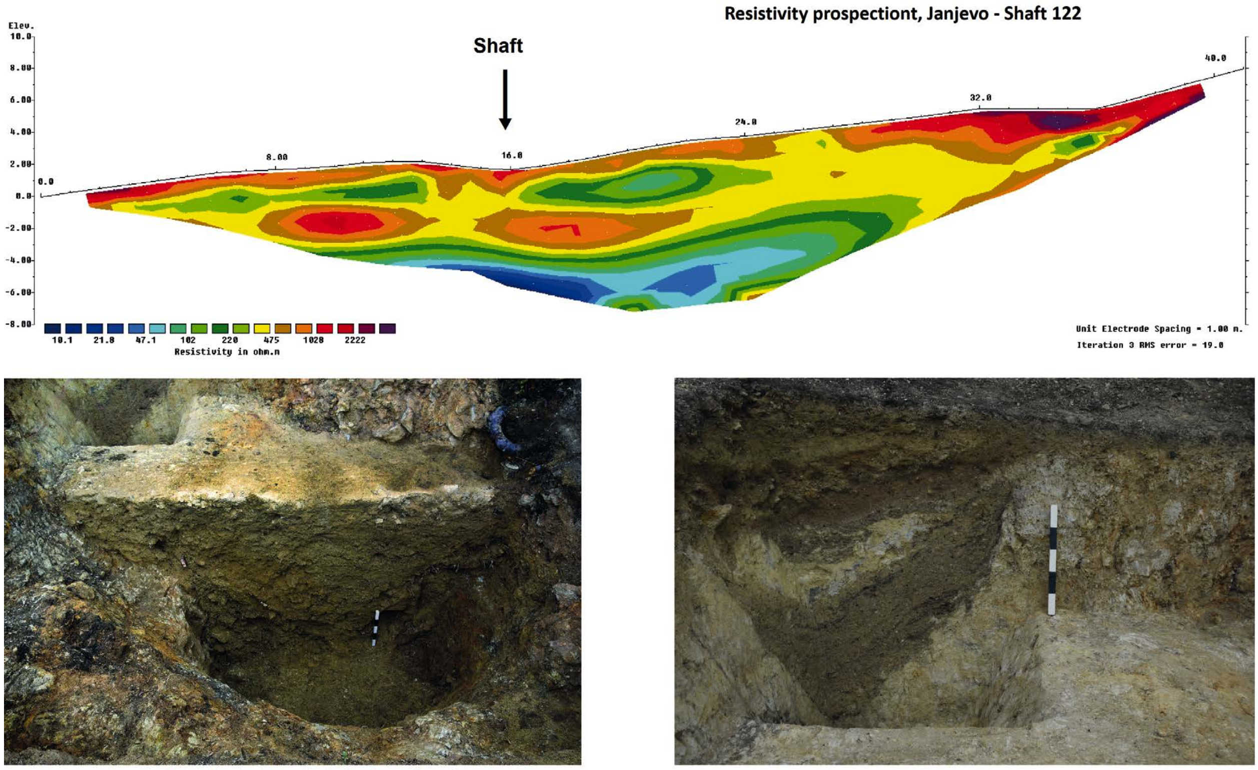


Figure 16. Janjevo, shaft 122, results of the magnetic and resistivity 2D prospection in different depths. Magnetometer prospection and illustration: B. Sikorski; ERT: B. Matthes.



Excavation shaft 122, shaft (in front) and v-shaped pit behind.

Excavation shaft 122, v-shaped pit.

Figure 17. Janjevo, shaft 122, results of the resistivity prospection (profile) and excavation. The shaft in the ERT matches perfectly with the excavation results. In the photos, you can see the profiles of the shaft on the left and of a pit on the right side. ERT: B. Matthes; illustration: B. Sikorski; photos: archive DBM, G. Körlin.

of about 2.3 m. Even at a depth of more than 2.5 m, the remains of a barbed wire were found, together with the huge diameter of the shaft a hint that the shaft dates back to the modern operating period.

Smelting relics: Mramor, furnace remains

In the small river valley that flows through Mramor, chains of slag deposits, indicating old smelting activities, line the river on both sides. Isolated finds of Roman relics in the wider surroundings gave reason to examine more closely a slag site on a slope in the valley of Mramor, about 1 km upstream from the village. However, later excavations did not yield any finds from the expected period. In the course of searching for usable material through the modern exposure of a slagheap, perhaps 50 m long and up to 20 m wide, an artificial outcrop was created there and served as the basis for our further investigations. Of particular interest was the upper edge of the slag dump and an artificially created terrace structure several meters above the dump, as at both positions associated smelting plants were to be expected (Figure 18).

Due to the heavy vegetation in the valley, existing aerial and satellite images could not provide any information. In order to define and open up specific excavation areas, smaller areas were investigated by geophysical prospection and Pürckhauer drilling where possible. However, the areas had to be prepared for the measurements with combined forces by cutting trees and cleaning the surface.

In the greyscale image of the magnetic prospection, some anomalies can be seen that make archaeological excavations at these sites seem reasonable. Especially the massively occurring high temperature areas caused by burned clay (all with values from 30 to over 100 nT), as already verified at other sites, were striking (Zeiler, Cichy and Sikorski, 2015).

The largest anomaly, with an extension of 10 × 10 m in the greyscale image, can be addressed as a slag dump, which is also well visible in the terrain (Figure 19). Adjacent to it is another dipolar high temperature area in the northeast. A white anomaly measuring about 2.8 × 2.3 m and a second black anomaly measuring approximately 3 × 0.8 m are visible. After comparison with the excavation results, both can be addressed as a channel, which is counted among the activities of metal smelting.

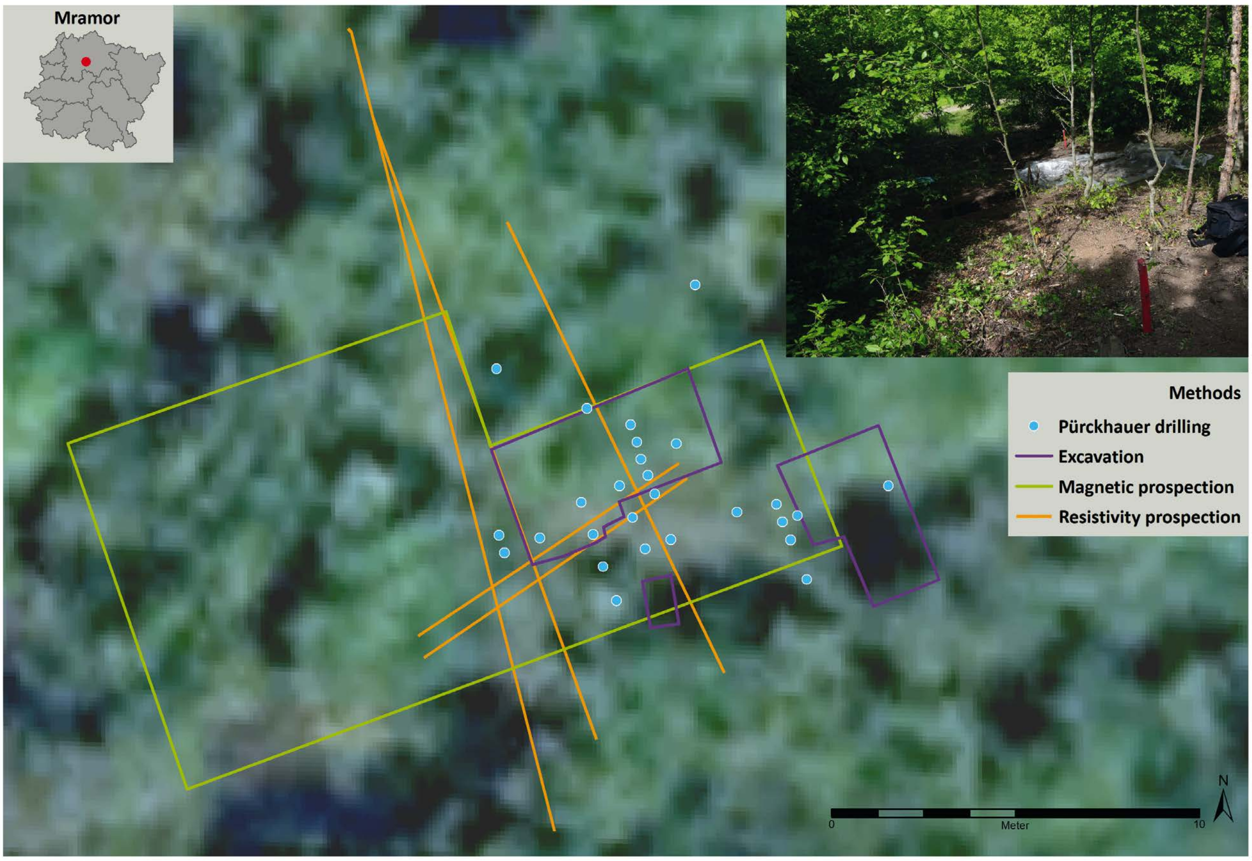


Figure 18. Mramor, smelting area, overview of all methods: magnetometer and resistivity prospection, excavation and Pürckhauer drillings. The photo shows a part of the smelting area. Illustration, photo: B. Sikorski.

To the southeast of this, a smaller white oval anomaly measuring about 0.5 × 1.3 m is visible in the greyscale image. On close inspection of the finding, a large block of slag from a furnace bottom could be localized, which explains the high nanotesla values at this location. Since the suspected furnace could not be located in the greyscale image, no further magnetic prospection was carried out because the area was very inaccessible. Nevertheless, the measuring device was used like a detector to locate further high temperature areas in the impassable terrain. On this basis, resistivity prospection and Pürckhauer drillings could then be used systematically.

In Mramor, five 2D ERT lines were carried out (see Figure 18). Measurement E44 clearly shows the dump structure between 11 and 12 m. In the range between 12.3 and 14.8 m, it runs along the later created southern profile of the archaeological excavation. In the range between 13.5 and 15 m, ERT profile E46 shows a channel-like structure whose location coincides exactly with the channel found during the excavation. Between 8.5 and 11 m, another channel-like structure was found, however outside the excavation area.

The Pürckhauer drillings confirmed the assumption that numerous high temperature indicators were located in the underground. Immediately above the slag dump, small heat reddened slate chips were found in all catenae, partly with some slag on top of slope debris of grey-brown clay, which was partly interspersed with unburnt slate chips. In the boring rods on the slope above, under humus slope debris, reddish clay with heat-reddened slate chips and occasionally charcoal was found, but nowhere conspicuously demarcated or depressed. It is not possible to reconstruct different features from these results; it rather appears to be a continuous layer of debris. The absence of slag in the drill cores was very noticeable. Since the bricked slate chips were also found in the catenae on the even higher situated artificial terrace, it was to be assumed that there was the source of the large-area influx. The beige-grey clay fillings with charcoal enclosures and a few reddish tiled slate chips that exceeded the drilling depth additionally obscured the findings (Figure 20).

Inspired by the many measurement values of high temperature indicators, a test trench was first made across the hillside immediately above the slag dump (see Figure 18). Especially on the west side some smelting detritus in the form of slag, furnace wall and some galena was found, but as yet no tangible feature. The scattering of finds probably came from further up from areas heav-

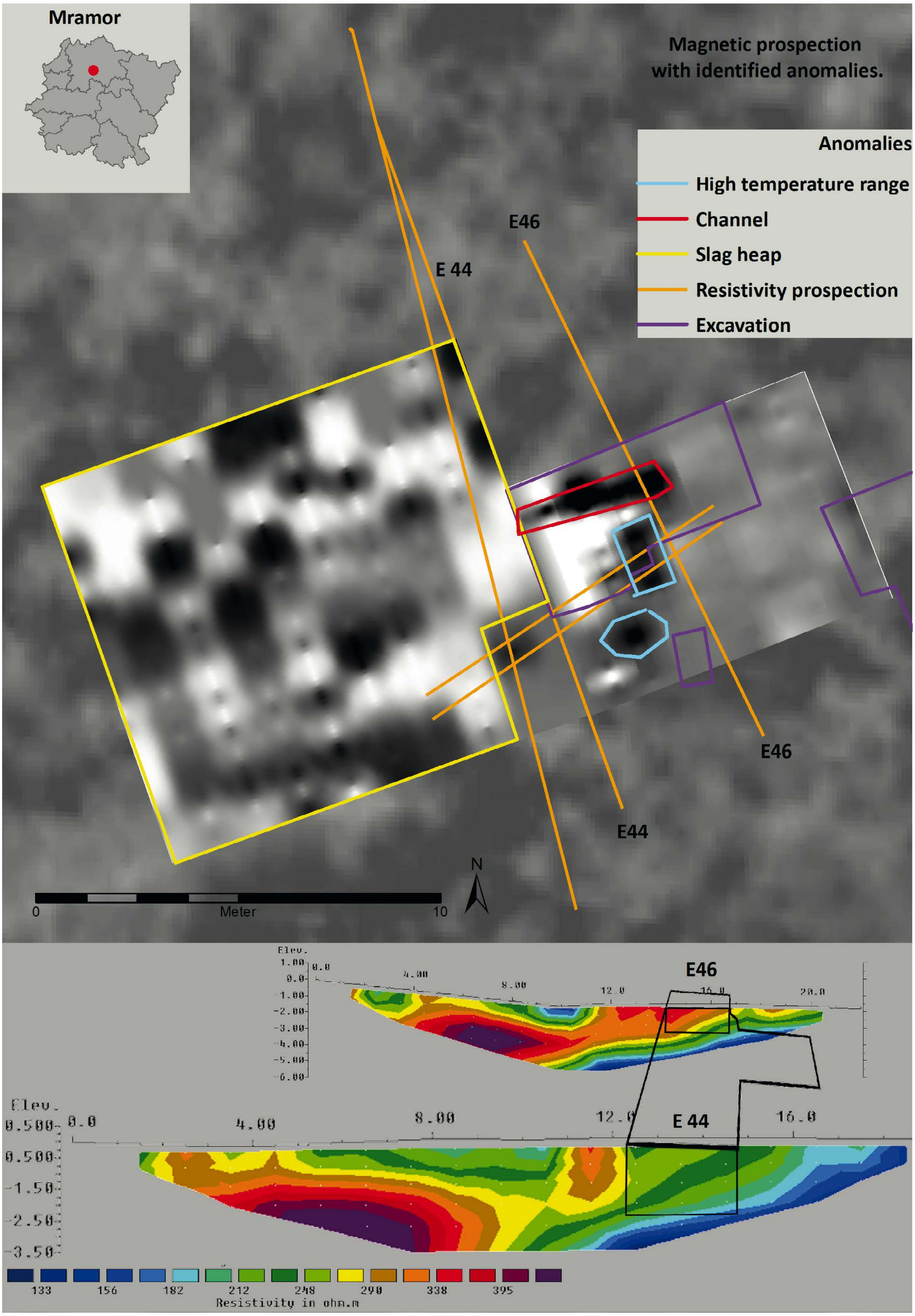


Figure 19. Mramor, smelting relics, results of the magnetometer and resistivity prospection (profiles). Measurement E 46 (upper profile) runs directly above the channel, measurement E 44 (lower profile) lies next to the channel and shows clearly deviating resistance values. Magnetometer prospection and illustration: B. Sikorski; ERT: B. Matthes.

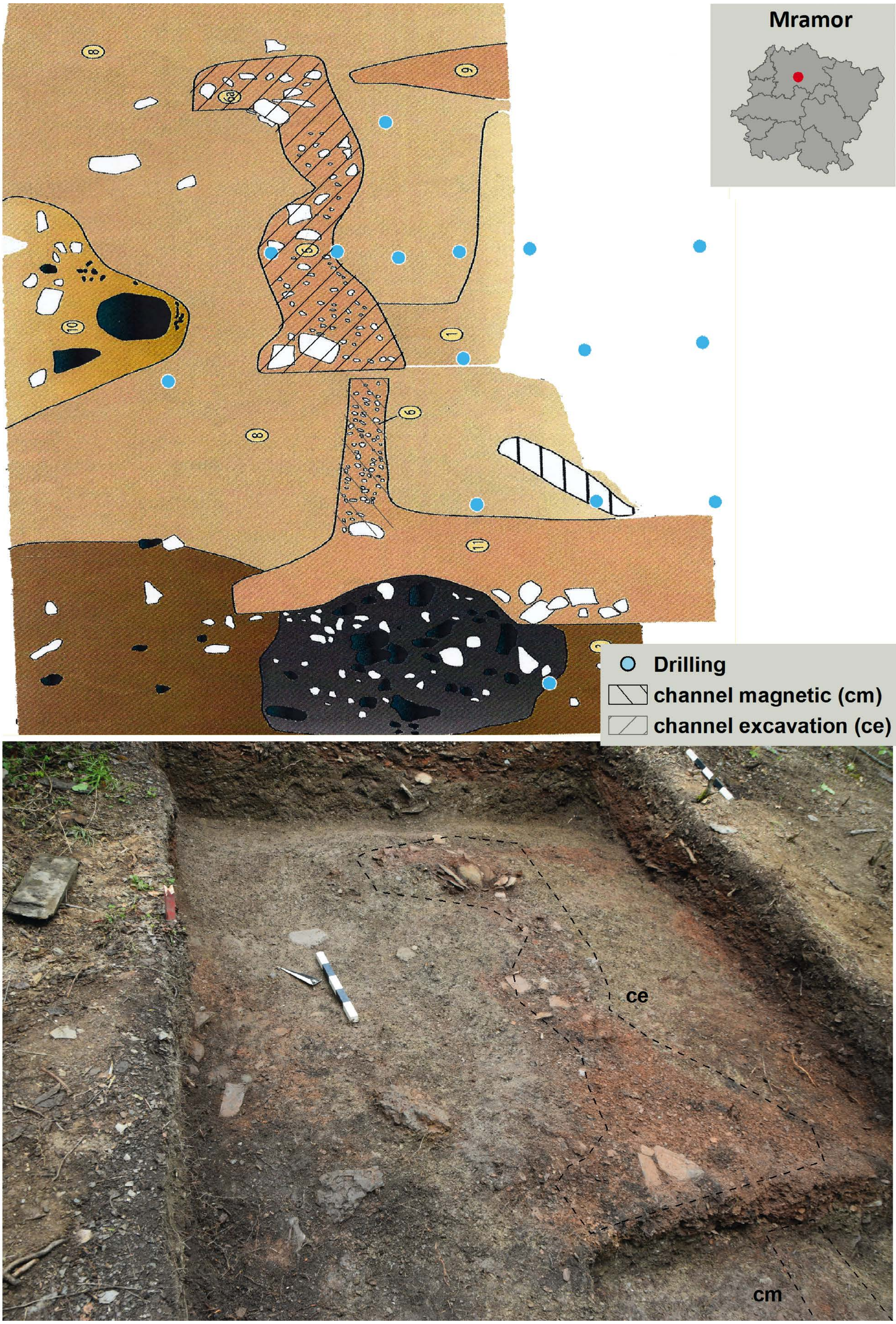


Figure 20. Mramor, smelting relics, results of the excavation, planum 3. The channel from the magnetometer prospection (see Figure 19) is well seen in the excavation drawing and in the picture (cm). Drawing: G. Gassmann; photo: B. Sikorski.

ily overgrown with brushwood. In the area of the higher situated artificial terrace structure a second trench was made and later extended to the south. As was to be expected due to the magnetic analyses, the high temperature areas were confirmed, however smelting slags, indicating a furnace location, were missing there. Rather, a clustered kiln complex for charcoal production existed there, overlaying the findings of metal production.

After the approximate clarification of the situation of the findings, an extension to the north was carried out on the west side of section 1, because especially there further high values as indicators of possible furnaces, which were detected in the search mode and confirmed by the drillings, were emerging. A flat channel was found in the extension area, which led vertically uphill from the uppermost foothills of the slag dump immediately adjacent to it. The excavation layers of heat reddened slate chips and charcoal of the kiln plant at the edges covered this channel, thus it is stratigraphically older. This was particularly evident in the northern profile. This could be a possible explanation, why this channel appears only vaguely in the magnetogram and only became apparent as a clear find after the excavation.

The interpretation of the magnetic prospection can be misleading, because the values interpreted as high temperature effects of kiln operation and presumed smelting are so similar to the slope debris slate material in the subsoil that they can be confounded. In the canal filling, smelting detritus was found in the form of furnace components, slags, ore and some raw lead, embedded in heat reddened slate chips and hillside clay. By way of magnetic measurements to the west of the channel, a large lump of slag could be detected next to other melt debris but appears to not be in-situ. The associated furnace site could not be located. It was probably detected by the deep reaching kiln pits and partially destroyed.

As a result, it can be stated that in combination with other prospecting methods it was possible to select specific areas for excavations at presumed smelting places, based on high nanotesla values of the magnetic prospections (see section magnetic survey). However, it was not possible to identify clear structures of a smelting furnace site, which could be connected to the downhill slag dump. However, the findings from the excavations, which were able to provide evidence of overlapping relics of differentiated high temperature areas, show the limits of the prospection methods used for interpreting the prospection results in the case of overlapping features. Only the excavations gave the full picture.

Results, outlook

In sum, it can be stated that the use of the method combination of magnetic prospection, resistivity prospection (ERT) and, depending on depth, in combination with Pürckhauer drillings, has achieved considerable benefit for mining archaeology. Depending on soil conditions or geological or modern disturbances, there were limitations in the applications, which should be considered accordingly. For most of the (disturbance-free) finds, especially the shafts, the shape and dimensions could already be determined this way without excavation. Depth determination by way of resistivity prospection depends on the possibility of being able to make a correspondingly long exposure, and therefore by nature it comes to its limits at some point. Since the shape and size of shafts can vary over time, only first impressions of the approximate chronological positions of finds can be obtained. Of course, this can vary from region to region, especially soil conditions have a great influence on the (reasonable) shape of shafts, and therefore verification by a series of excavations is indispensable. By the measurements or the knowledge of the different shapes and sizes, a reasonable selection of features, which should be examined more closely, can be made in advance. It should be noted that although the individual methods provide good results, it is only in combination that the archaeological picture of a site can be completed.

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