Interdisciplinary research of the Early Iron Age iron production centre Cvinger near Dolenjske Toplice (Slovenia)

Interdisciplinarne raziskave železarskega središča Cvinger pri Dolenjskih Toplicah iz starejše železne dobe

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Izvleček

Prazgodovinski kompleks Cvinger pri Dolenjskih Toplicah leži na strateški točki na prehodu med Dolenjsko in Belo krajino. Tukaj odkrite najdbe so imele pomembno vlogo pri opredelitvi mlajšega halštatskega obdobja v jugovzhodnih Alpah. Prav tako pomembno je odkritje železarsko-talilniškega območja.

V zadnjih letih pa je bil Cvinger predmet interdisciplinarnih raziskav, ki so povezale sodobne tehnike daljinskega zaznavanja, kot so zračno lasersko skeniranje in geofizikalne meritve, s tradicionalnimi arheološkimi metodami. Rezultati so pripeljali do novih dognanj o celotnem kompleksu, vključno z natančnejšo datacijo talilniškega območja, pridobljeno z metodo arheomagnetnega datiranja.

Ključne besede: Dolenjska; starejša železna doba; gradišče; železarsko-talilniško območje; talilne peči; interdisciplinarne raziskave; arheološka geofizika; arheomagnetno datiranje

Abstract

The prehistoric complex of Cvinger near Dolenjske Toplice occupies a strategic position between the regions of Dolenjska and Bela krajina. It has yielded important finds for the understanding of the Late Hallstatt period and holds the largest known iron-smelting area in the region.

In recent years, several interdisciplinary research campaigns took place at Cvinger, combining modern remote sensing techniques, such as airborne laser scanning and geophysical surveys, with more established archaeological methods. Importantly, the results have brought new understanding about the whole complex, including the chronological refinement of the iron smelting area thanks to archaeomagnetic dating.

Keywords: SE Slovenia; Dolenjska region; Early Iron Age; hillfort; iron smelting area; iron smelting furnaces; interdisciplinary research; archaeological geophysics; archaeomagnetic dating

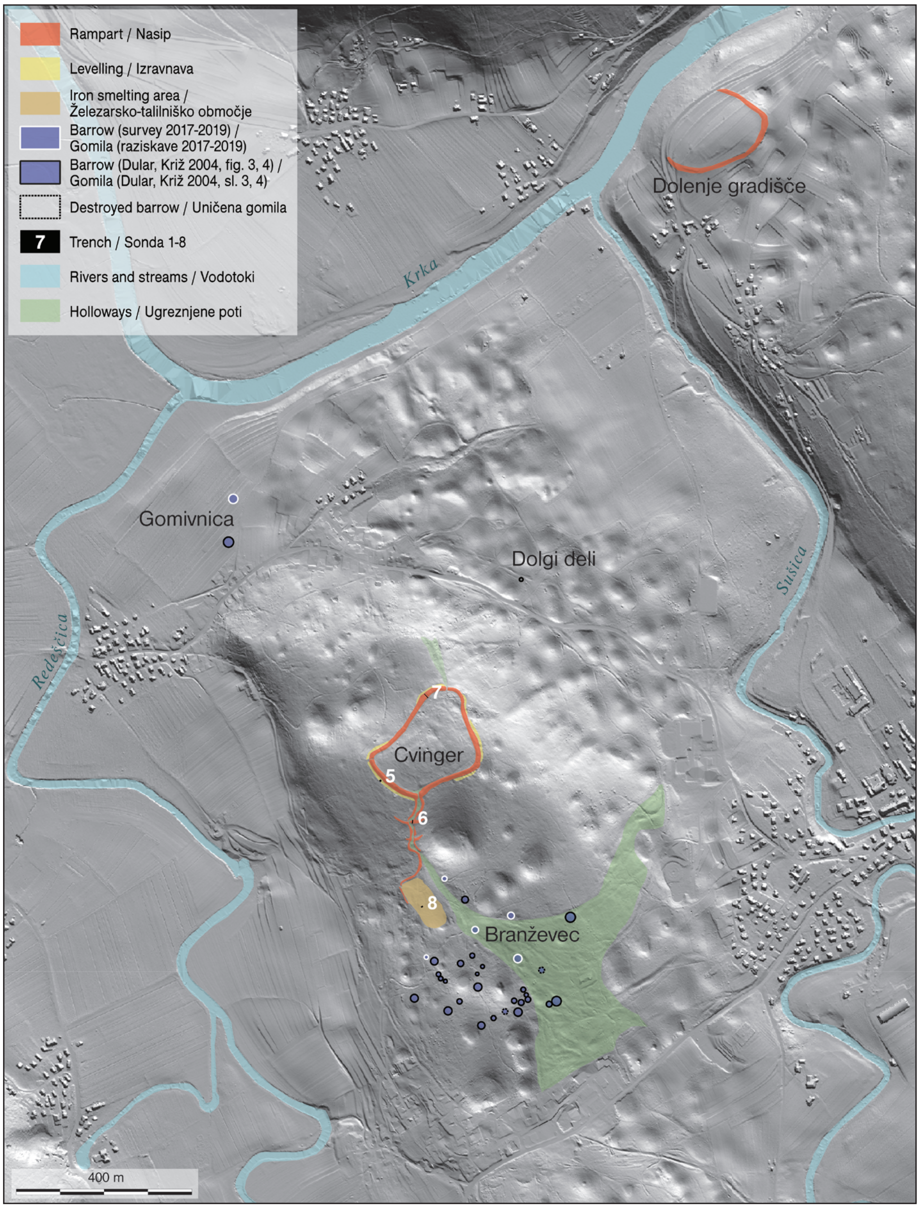

Fig. 1: Cvinger near Dolenjske Toplice and its surroundings on a shaded DTM.
Sl. 1: Cvinger pri Dolenjskih Toplicah z okolico na senčenem DMR-ju.

INTRODUCTION

The prehistoric complex of Cvinger near Dolenjske Toplice occupies a limestone hill between the modern towns of Meniška vas and Dolenjske Toplice in the Dolenjska region (SE Slovenia). It consists of a hillfort (Cvinger), three barrow cemeteries (Branževec, Dolgi deli and Gomivnica) and an iron-smelting area (Branževec). The settlement holds a strategic position, which enables a visual control of the surrounding lowlands, with key routes running across this landscape. To the north of the complex lies the Krka river valley, one of the most important waterways of the region. At this specific area, the river changes its direction, from NW-SE to SW-NE, and its shape, from a narrow valley in the north to a broader plain to the east towards Novo mesto. In addition, the valleys of the Radešca and Sušica streams branch off and run towards the south, connecting the Dolenjska and Bela Krajina regions, both integral parts of the Dolenjska Early Iron Age (EIA) group (*Fig. 1*).

The history of research of the archaeological complex at Cvinger goes back to the end of the 19th century. It is thoroughly presented by Dular and

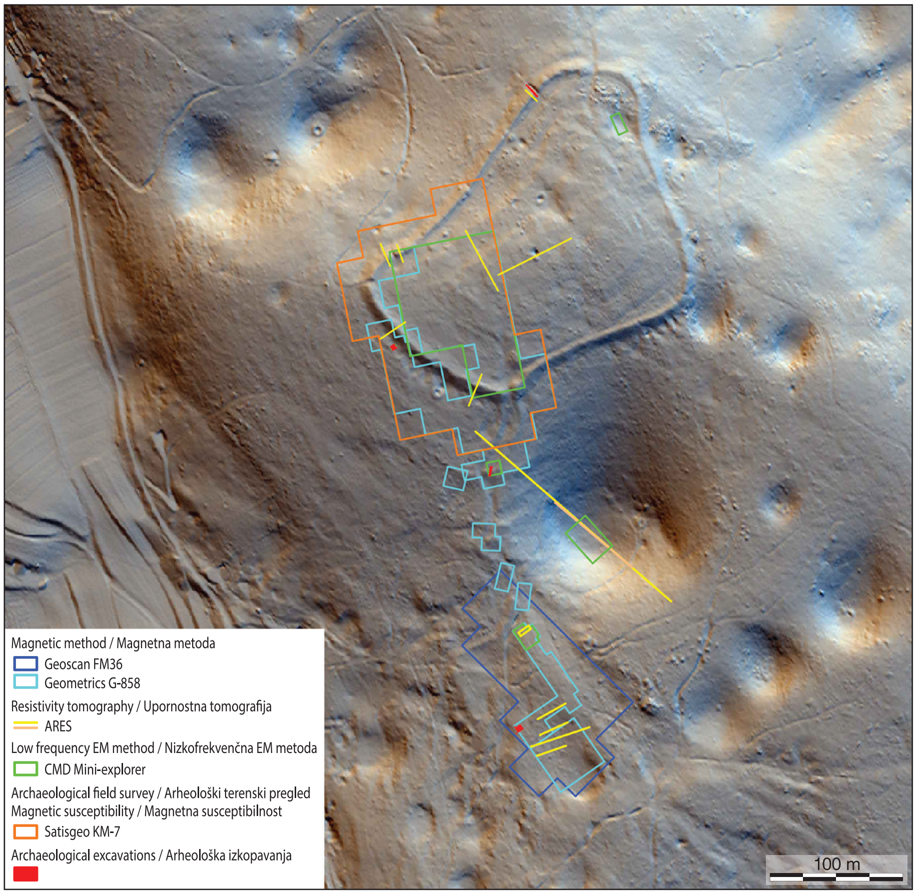

Fig. 2: Cvinger near Dolenjske Toplice. Overview of the main part of research activities carried out between 2014 and 2019.
Sl. 2: Cvinger pri Dolenjskih Toplicah. Pregled večjega dela raziskav med letoma 2014 in 2019.

Križ (2004); a short summary is presented here. The first investigator of the site was Jernej Pečnik, who excavated seventeen barrows in 1898 and 1899, one at Dolgi deli and the others at Branževec to the south of the hillfort (Teržan 1976, 393–413, Pl. 1–93; Dular, Križ 2004, 209–210). His work was supervised by Josef Szombathy from Vienna, who initiated the research of the settlement. They excavated 18 trial trenches in 1899, some on the rampart and the majority in the interior of the hillfort. These excavations yielded important data regarding the construction of the fortification and they present one of the first attempts of systematic settlement research in the region. Later, in the 1930s, W. Schmid also excavated in the settlement, but little is known about his work (Teržan 1976, 413, Pl. 92–93; Dular, Križ 2004, 209–215). The finds from the barrows, as well as from the Schmid's research of the settlement, were integrally published. The grave finds in particular had an important role in refining of the EIA chronology for the region (Teržan 1976, 385–413, Pl. 1–93).

Significant for the current knowledge about the Cvinger complex is the fieldwork of Križ between the years of 1986 and 1991. He lead several campaigns, excavating six trial trenches on the hillfort and one on the adjacent iron-smelting area (Dular, Križ 2004). The latter was subsequently prospected with geophysical methods, presenting the first study of this kind in Slovenia (Mušič, Orengo 1998).

The current research shows that the first occupational phase of Cvinger can be dated to the Late Bronze Age (Ha B). At that time, the settlement was already surrounded by a rampart constructed out of wood and soil, which was destroyed in a fire. After a hiatus, the hillfort was fortified by a dry stone wall in the Late Hallstatt period, most probably in the late 6th century BC. It remained occupied until the end of the Late Hallstatt period, that is until the end of the 4th century BC (i.e. the Certosa fibula and Negova helmet horizons) (Teržan 1976, 385–393; Dular, Križ 2004, 215–228, 231–232).

Recent research campaigns on Cvinger near Dolenjske Toplice complex started in 2014 as a part of the ENTRANS project and continued after 2017 as a part of the Iron-Age-Danube project. In the first step of our research we employed the airborne laser scanning (ALS) in order to build the base document of the site and the broader area around it. The preliminary desk-based analysis of the ALS data revealed a range of features, showing that the landscape surrounding the hillfort is more complex than previously thought. Features identified in the ALS data study were then combined with field observations and refined by a large scale multi-method geophysical measurements (magnetic method, low-frequency electromagnetic method, electrical resistivity tomography, and magnetic susceptibility of surface layers), as well as an intra-site surface collection (*Fig. 2*) (Mušič et al. 2015; Črešnar, Burja, Vinazza 2017; Horn, Mušič, Črešnar 2019). To provide valuable information on certain landscape features and/or probable archaeologically relevant geophysical anomalies, a series of trial trenches were excavated in selected locations. As the research is still in progress, some of the results presented here need to be considered as preliminary.

THE HILLFORT AND ITS LANDSCAPE

Although a thorough study of the site was presented before (Dular, Križ 2004), a detailed analysis of the ALS data produced some additional findings. It led us to the recognition of some previously unidentified or not fully understood features and offered a broader picture of the landscape around and the hillfort structures.

The hillfort has an irregular trapezoidal form, with the interior consisting of several settlement terraces, sloping gently from the centre in all directions. Its form is influenced by the karstic landscape with several dolines that are partly incorporated in the fortification. It is completely surrounded by the remains of an impressive 730 m long rampart, the ruins of which are up to approx. 11 m wide and have an average height difference of 0.5 m towards the inside and of 3 m to the outside.[1] The outside of the rampart is accompanied by a shallow depression or levelling of the terrain (*Fig. 3*). Its course cannot be followed clearly around the entire perimeter of the settlement; however, it was assessed with different ALS data visualizations. It is most obvious on the south-western side of the settlement, where it was further investigated by two ERT profiles and the trial Trench 5 (*Fig. 2*). The ERT profiles showed that the upper soil layers, as well as part of the limestone ground, were removed/lowered in the areas around the rampart. The Trench 5, excavated inside this depression, did not yield any further conclusive information. After the removal of turf and humus only a layer of transported material eroded from the rampart covered the solid limestone, partly interrupted by natural clays. The levelling can be understood as an anthropogenic feature, resulting from the removal of building material, i.e. earth and limestone, for the erection of the rampart and the dry stone wall, and not as a defensive structure.

Two entrances, one to the south and one to the north, originally led into the settlement.[2] The embanked approach path indicates that the southern entrance was more important, although there is a clear holloway leading towards the northern entrance as well, extending into the interior of the settlement.

The approx. 180 m long embanked approach path[3] leads to the settlement from the smelting area on the saddle called Branževec. It makes a series of slight turns and combines with two transverse features with a maximum width of 8.5 m and 6.5 m respectively (see below). They seem to have functioned as additional reinforcement of the fortification, as the transverse wall closest to the hillfort path narrows from 4–5 m to 2.5 m[4] (*Fig. 3*).

The rampart partially extends around the northern side of the iron-smelting area. The latter can be clearly recognized by the different surface texture on the digital terrain models (*Fig. 3*). It covers an area of approx. 0.6 hectare. This area was detected by surface finds of slag and burned clay. It was first excavated already in the late 1980's and surveyed

[1] The average values were calculated from 39 profiles over the rampart on the DTM from all around the settlement. The minimum/maximum values are 0.1/1.6 m towards the inside and 1.7/4.7 m to the outside.

[2] Other entrances lead into the settlement today, but they are of modern date.

[3] The distance here is considered a walking distance along the path and not air distance between two points.

[4] The width of the path is an approximation from 12 measurements along the path.

by geophysics a few years later (Dular, Križ 2004, 228–230; Mušič, Orengo 1998).

From the iron-smelting area to the east, south-east and south we can identify a broad corridor of commingled holloways (*Fig. 3*). This corridor, as already observed elsewhere (e.g. Mason, Mlekuž 2016, 104–109; Mlekuž, Črešnar 2014), is connected to the barrows in the Branževec area, which seem also to border this corridor (*Fig. 3*). Although no direct evidence for the dating of the holloways exists, it is very probable that they originate in the time of all the other identified features, i.e. in the Early Iron Age.

Additionally, a basic landscape study of the three barrow cemeteries, known after their location names as Branževec, Dolgi deli and Gomivnica was conducted. The largest barrow cemetery at Branževec was researched in 1898–1899 and altogether 16 barrows were excavated (Teržan 1976, 393–413, Pl. 1–93; Dular, Križ 2004, 209–210). The grave finds were later used for the previously mentioned modification of the Late Hallstatt period chronology of the Dolenjska region (Teržan 1976, 391–393). Locations of 26 barrows were published[5] (Dular, Križ 2004, 209–210); however, the ALS study combined with field observations indicates that there might be more possible barrows in the area (*Fig. 3*).

The location of the barrow excavated by Pečnik at Dolgi deli, north of the hillfort, is only known by the plot number[6] (Teržan 1976, 395–396, Pl. 1–3; Dular, Križ 2004, 210). With the analysis of the ALS derived DTM we have tried to estimate the area of the barrow more accurately. As a natural dolina dominates the southern part of the plot and barrows at Cvinger seem to have generally omitted this type of landscape, it is most probable that the barrow was located in the central or northern part of the plot, where the terrain is more even. Also, the surface there shows signs of mayor modern interventions, which might have completely erased all the remains of a former barrow (*Fig. 1*).

A possible cemetery at Gomivnica was proposed, based on the chance find of a bronze arm ring, ceramic fragments and cremated remains in 1979,[7] followed by field observation (Dular, Križ 2004, 210–211, Fig. 3). The results of the analysis of the DTM confirmed a possible heavily ploughed-out barrow in the suggested location and identified another barrow approx. 70 m to the north[8] (*Fig. 1*).

FIELD RESEARCH BETWEEN 2017 AND 2019

Settlement

Considering the settlement, we have researched the karstic abyss in the centre of the settlement as well as the fortifications, i.e. the rampart and the embanked approach path.

Cvingerska jama abyss

In the central part of the settlement, there is a vertical karstic abyss, the so-called Cvingerska jama, which was mentioned for the first time in the 1900 and sketched out by A. Müllner in 1909 (Pršina 2017, 107–108). The first modern research followed in 1982, when the abyss was documented by cavers and registered in the cave cadastre of Slovenia. Soon after, in 1986–1987, the first archaeological research took place, when approx. 10 m^3 of material was removed from the area just below the entrance, but no archaeological material was retrieved (Dular, Križ 2004, 212; Pršina 2017, 109–110).

The latest research campaign of 2016 and 2017 was executed in cooperation with the Novo mesto caving association (*Jamarski klub Novo mesto*). The intention was to clear the continuation of the entrance part of the shaft of modern material and compare the situation with Müllner's sketches from 1909, which pointed to a wide hall at the bottom of the shaft. Large amounts (over 20 m^3) of material were transported out of the shaft. At a depth of approx. 10 m, we stopped the removal of material as the abyss splits into two shafts. One of them allowed penetration into the deeper parts of the system without removing the remaining debris still covering a part of the entrance shaft. Moving forward to the next parts of the abyss and exploring if humans entered it before it became the

[5] Most of the barrows already published could also be identified on the DTM and in the field. Besides that, the already published dimensions are very much comparable with the ones obtained by the recent study.

[6] Plot. nr. 3411 k. o. Podturen.

[7] Plot. nr. 3835 k. o. Podturen.

[8] The remains of the previously identified barrow are most probably stretching over two plots (plot. nr. 3834 and 3835 k. o. Podturen) as does the newly identified barrow (plot. nr. 3829/2 and 3830 k. o. Podturen).

focus of the campaign in 2017. The team of cavers entered the newly discovered parts of the abyss using technical equipment. They finally reached a depth of over 51 m (the depth was corrected from 53 [Pršina 2017] to 51 m: revisional measurement, pers. comm. M. Pršina). However, below the existing cap of debris, consisting of earth and fallen rock, at a depth of approx. 15 m, no signs of human presence were observed.

The work consisted of documenting the research inside and outside the shaft. All the material removed was inspected and the vast majority of the finds; ceramic, bone and metal, were determined as modern. Only a few rounded fragments of prehistoric pottery were found, however, all in layers recently washed into the shaft by water. Although some debris are still present in the upper part of the shaft, which could also include archaeological remains, the observations are leading us to an assumption, that the entrance of the abyss was much smaller, completely blocked or did not even exist in the time of the prehistoric inhabitation. Therefore, the Cvingerska jama abyss most probably has no archaeological significance.

RAMPART AND WALL

Excavation of Trench 7

Trench 7 cut the rampart in a place recently damaged by a forest track. Although the excavations were limited, the whole section of the rampart from the interior of the settlement to its foot was exposed (*Figs. 3; 4*). The remains, described below, do not represent intact stratigraphy, as the forest track partly damaged the layers all the way to the limestone bedrock.

The geological base in Trench 7 was formed from solid limestone (SE 7026) and an archaeologically sterile clayish layer (SE 7027). These were covered by several clayish layers (SE 7017, 7018, 7020 and 7023), two of them (SE 7018 and 7020) also containing a moderate number of archaeological finds. These layers correspond well with those belonging to the first phase of the fortification, as recognized by Dular and Križ in their Trench 1 (Dular, Križ 2004, 215–217, App. 1). The layers SE 7017 and 7020 seem also to have been partly removed and manipulated during the erection of the defence wall (SE 7009, 7010, 7010a), which was in part resting also on a clayish layer mixed with stones (SE 7009a). The approx. 1.5 m thick wall was built with an inner (SE 7009) and an outer (SE 7010) face, made of bigger stones, whereas the core of the wall was filled with smaller stone material (SE 7010a).

On the inner side of Trench 7, the first layer above the archaeologically sterile soil (SE 7027) was SE 7018, which was partly covered by layer SE 7023, the lowest layer, understood as a part of the settlement fortification. It was cut by a posthole (SE 7021/7022), which could be part of the fortification. We must also be aware of a thin clayish layer 7024 and a layer with signs of burning (SE 7019) covering it. It is possible that these layers are connected to the destruction of the first fortification, as observed in other trenches (Dular, Križ 2004, 217–220). It seems that the next settlement layer (SE 7016) was already connected to the phase of the dry stone wall, as are also both the others (SE 7015, 7013), which are leaning on the lower part of its construction (SE 7009a). The settlement layers included typical finds such as baking lids, pieces of burned wall plaster and a spindle whorl. The uppermost layers (SE 7002, 7008) can be understood as wall ruins.

On the outside of the wall, several sloping layers were recognized. The lower layers (SE 7012 and 7014) represent the covering of the base of the dry stone wall (SE 7010). The layer SE 7003 includes bigger stones, probably from the wall and can be understood as a layer of ruins of the fortification. It can be most probably also connected to the layer SE 7028, excavated at the foot of the rampart, whereas the sloping layers SE 7004 and 7006 can be attributed to the later (modern) destruction of the rampart by the forest activities inside the forest track.

The unearthed finds from the settlement layers did not include any typologically distinctive forms, which could be used for more precise dating and add to the interpretations already presented about the fortification and its chronology (Dular, Križ 2004, 215–221, 230–232).

Electrical resistivity tomography (ERT) of the rampart

Trench 7 was one of the first profiles with electrical resistivity tomography conducted on a prehistoric rampart in Slovenia, where comparative results from an ongoing excavation were available. In Slovenia, electrical resistivity tomography has been used in prehistoric studies only in the recent

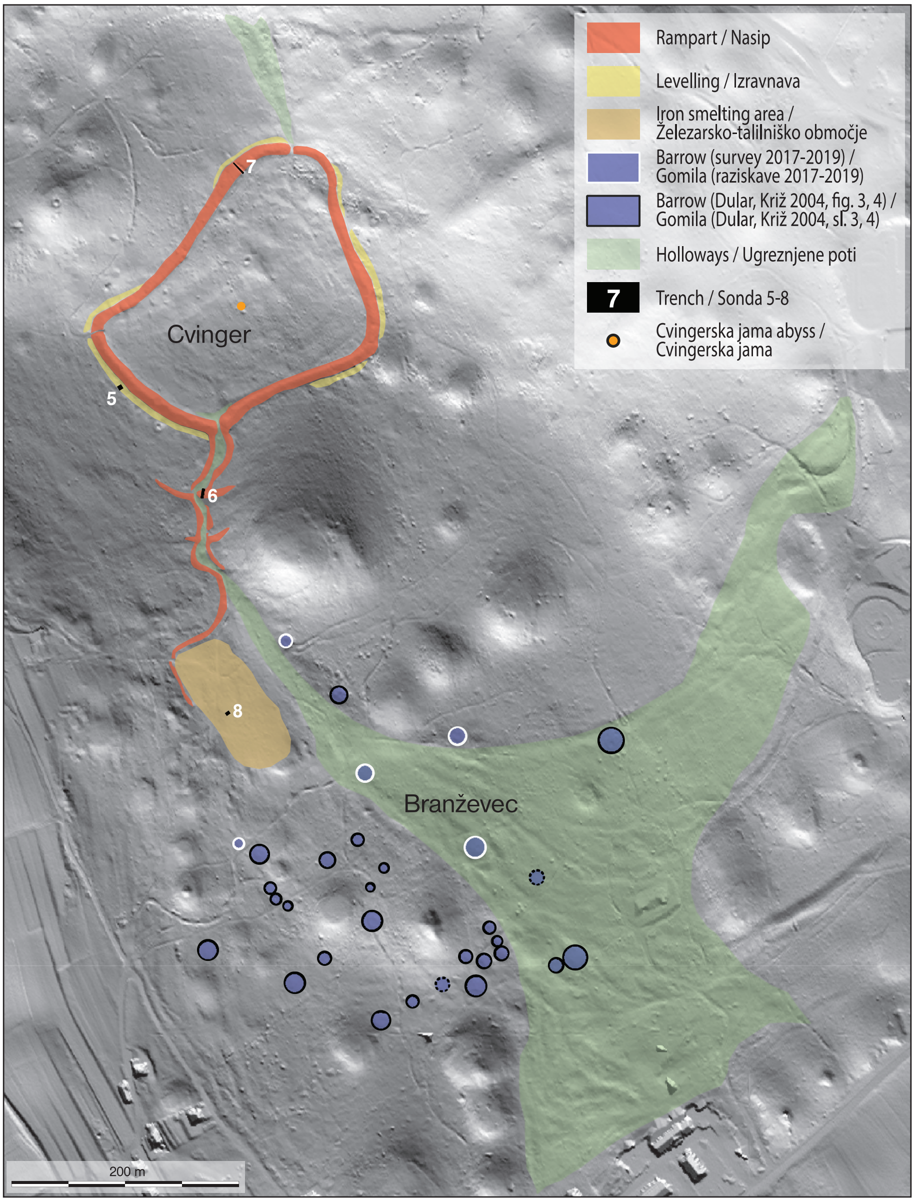

Fig. 3: Cvinger near Dolenjske Toplice with immediate cultural landscape on a shaded DTM.
Sl. 3: Cvinger pri Dolenjskih Toplicah s kulturno krajino v neposredni okolici na senčenem DMR.

years; however, the basic principles and some possibilities of its applications have already been presented (Mušič et al. 2015; Mušič et al. 2018; Horn et al. 2018a; 2018b; Horn, Mušič, Črešnar 2019).

In order to examine the structure of the settlement rampart and to allow direct comparison with the profile/cross-section of above described Trench 7 (*Fig. 4*), we set a profile (ERT 6) only 1.5 m away and parallel to the trench (*Figs. 3–5*). We used the dipole-dipole electrode array and an electrode spacing of 0.3 m.

Inversion resistivity model ERT 6 shows a very good correlation with the profile of Trench 7 (*Figs. 4; 5*). Knowing the shape of the solid bedrock and thickness of soil changes over very short distances in the karst environment and given it was measured 1.5 m away from the already open trench, we have to allow some minor differences in material (and thus also resistivity) distribution between the two.

Defence dry stone wall ruins are defined with high resistivity values (*Fig. 5:* [A, A1, A2: 200–1000 Ωm]) with approx. 4 m in length and up to 1 m depth (corresponding to layers SE 7002, 7008, 7009, 7010) and are separated from the settlement layers below with slightly lower, but still high resistivity values (*Fig. 5:* [B1: 200–400Ωm]) of layers SE 7013, 7015, 7016. Behind the rampart inside the settlement two resistivity areas can be

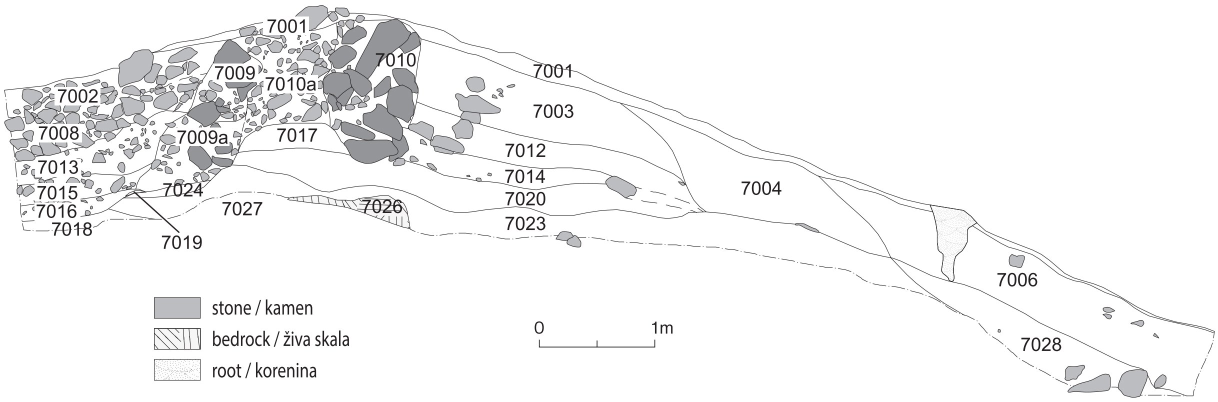

Fig. 4: Cvinger. Section of Trench 7, cutting the remains of the rampart.
Sl. 4: Cvinger. Presek sonde 7, izkopane čez ruševine obzidja.

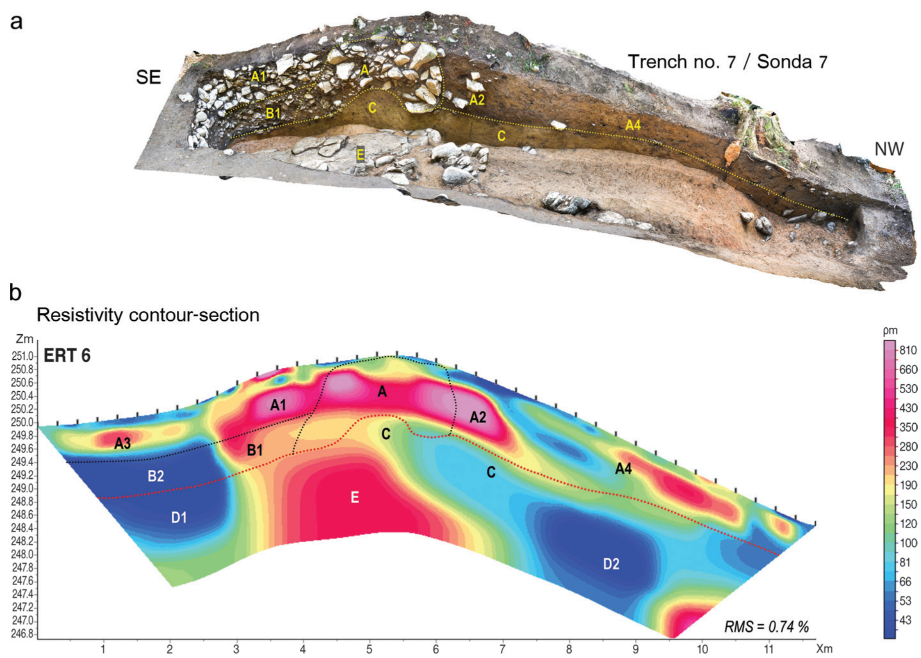

Fig. 5: Cvinger. 3D model of Trench 7 (a) in comparison with the nearby inversion resistivity model ERT 6 (b) (see also *Figs. 2; 3; 4*).
Sl. 5: Cvinger. 3D model sonde 7 (a) v primerjavi z bližnjim inverznim upornostnim modelom ERT 6 (b) (glej tudi *sl. 2; 3; 4*).

recognised – a higher resistivity area A3 (up to 300 Ωm), most probably corresponding to the stone debris and very low resistivity area B2 (~30 Ωm), which is a continuation of the B1 layer and corresponds to the wetter clayey sediment, which very likely contains archaeological material. This low resistivity anomaly continues deeper, down to 2 m below the surface, in the area marked D1. The first 2.5 m of the ERT profile length was not excavated, so the border between the interpreted archaeological layers and geological base (red dashed line) in this section is extrapolated from the known border in the profile of Trench 7 (*Fig. 4:* SE 7016/7018); thus, it could also be deeper regarding resistivity distribution (it can continue to the area D1), or shallower as well. On the outer slope, there are high resistivity areas (A4: 40–350 Ωm) of redeposited clayey layers mixed with debris belonging to the covering of the base of the stone wall (*Fig. 4:* 7012, 7014) and the wall ruins (*Fig. 4:* SE 7003, 7006, 7028). There is also a low resistivity area, belonging to a redeposited clayish layer, probably also influenced by recent activities around the forest track (*Fig. 4:* SE 7004). A low to medium resistivity layer (C: 70–200 Ωm) beneath the defence wall ruins corresponds to archaeologically clayey sediment (*Fig. 4:* SE 7017, 7020) and archaeologically undisturbed layer (*Fig. 4:* 7027). The high resistivity anomaly (E: ~400 Ωm) reflects the solid limestone bedrock (*Fig. 4:* SE 7026). Very low resistivity anomalies in geologic base (D1 and D2: ~30 Ωm) indicate the presence of narrow steep depressions in the obviously severely weathered limestone bedrock, filled with clayey sediments with higher moisture content.

EMBANKED APPROACH PATH

The embanked approach path leading to the hillfort's main entrance (*Figs. 1; 3*) is a structure with no appropriate comparisons in the region. The only similar structure is the much shorter (20 m) simple linear embanked approach path at the entrance to the Vinkov vrh hillfort, which lies not far away toward the north above the Krka valley (Dular, Tecco Hvala 2007, 183–184, 341, Fig. 104; 263).

Our primary aim was to investigate the feature, recognized in its whole complexity only with the analysis of the DTM. With a trench we cut the second transverse feature, which closes the path and probably represents an important point of this fortification element (*Fig. 3*).

Excavation of Trench 6
(*Figs. 6; 7*)

The geological base in Trench 6 was formed from solid limestone (SE 6016 = 6009), which presented also the basis on which the dry-wall was built. Only under the main outer wall face we have recognized the foundation of the wall (SE 6021), whereas the rest of the wall was placed directly on the limestone bedrock. The dry-wall construction, with a width of approx. 4 m, had an outer face (SE 6006) and an inner face (SE 6010), as well as additional intermediate lines made of bigger stones (SE 6012 and 6015). The intermediate areas were filled with loose smaller stones and soil (SE 6011, 6013 and 6019). It has to be emphasized, that only the outer face of the wall could be followed in several layers of construction, whereas the inner face and both of the intermediate lines were preserved only in one complete layer. The outer face also included a possible niche in its eastern part.

The earliest feature on the inner side of the wall was a layer with pieces of iron slag and animal bones (SE 6018) filling up a natural depression in the limestone bedrock (SE 6016 = 6009). Most of the excavated area behind the wall was covered by a succession of rather thin layers; the clayish layer SE 6008, including a larger amount of charcoal, and the layer SE 6004 above it, yielding atypical pottery fragments. Both layers can be understood as remains of former open surfaces on the inner side of the wall.

The excavation of Trench 6 did not yield enough evidence to show the reconstruction of the wall. The one possible niche, recognized in the outer face of the wall, has parallels in the Stična type fortifications, not however at Cvinger (Dular, Križ 2004, 216–217). Also interesting are the intermediate lines of bigger stones. They were preserved only in one layer and have no suitable parallels; therefore, we cannot draw any conclusions whether they were only building elements influencing the stability of this very wide dry stone construction, or they also indicating its original form. Besides that, the amount of stone discovered at the location is very limited; therefore, a high stone structure is not very probable and a stone/wood construction is more likely.

IRON-SMELTING AREA AT BRANŽEVEC

Magnetic survey

We have applied magnetic survey (magnetometer and magnetic susceptibility) (*Fig. 2*), as it was successfully used for identifying iron-smelting sites at this location and beyond (Mušič, Orengo 1998, 157–186; Abrahamsen et al. 1998, 61–70; Powell et al. 2002, 651–665; Vyncke et al. 2014, 109–113). It is the most appropriate geophysical technique to identify strong magnetic anomalies generated by Early Iron Age furnaces with or without slag pits and other archaeological remains associated with iron-production activities, e.g. waste material deposits. The magnetic responses of different iron slag forms always produce a wide range of magnetic anomalies. The exceptional variability of magnitudes and shapes of magnetic anomalies may be basically connected to different portions of differently magnetic iron mineral types. Besides

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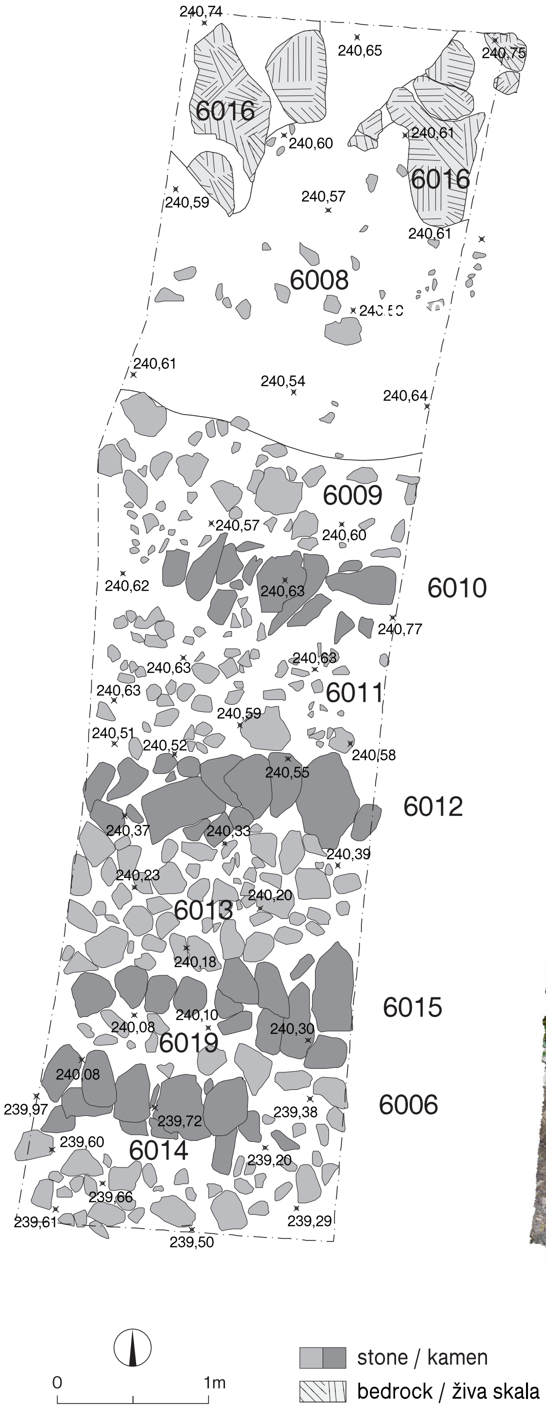

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Fig. 6: Cvinger. Plan of Trench 6, cutting across the second transverse wall of the embanked approach path to the hillfort (see also *Fig. 2*).
Sl. 6: Cvinger. Načrt sonde 6 čez drugi prečni zid utrjene pristopne poti do gradišča (glej tudi *sl. 2*).

Fig. 7: 3D model of Trench 6, cutting across the second transverse wall of the embanked approach path to the Cvinger hillfort (see also *Fig. 3*).
Sl. 7: 3D model sonde 6 čez drugi prečni zid nasipa za pristopno pot do gradišča Cvinger (glej tudi *sl. 3*).

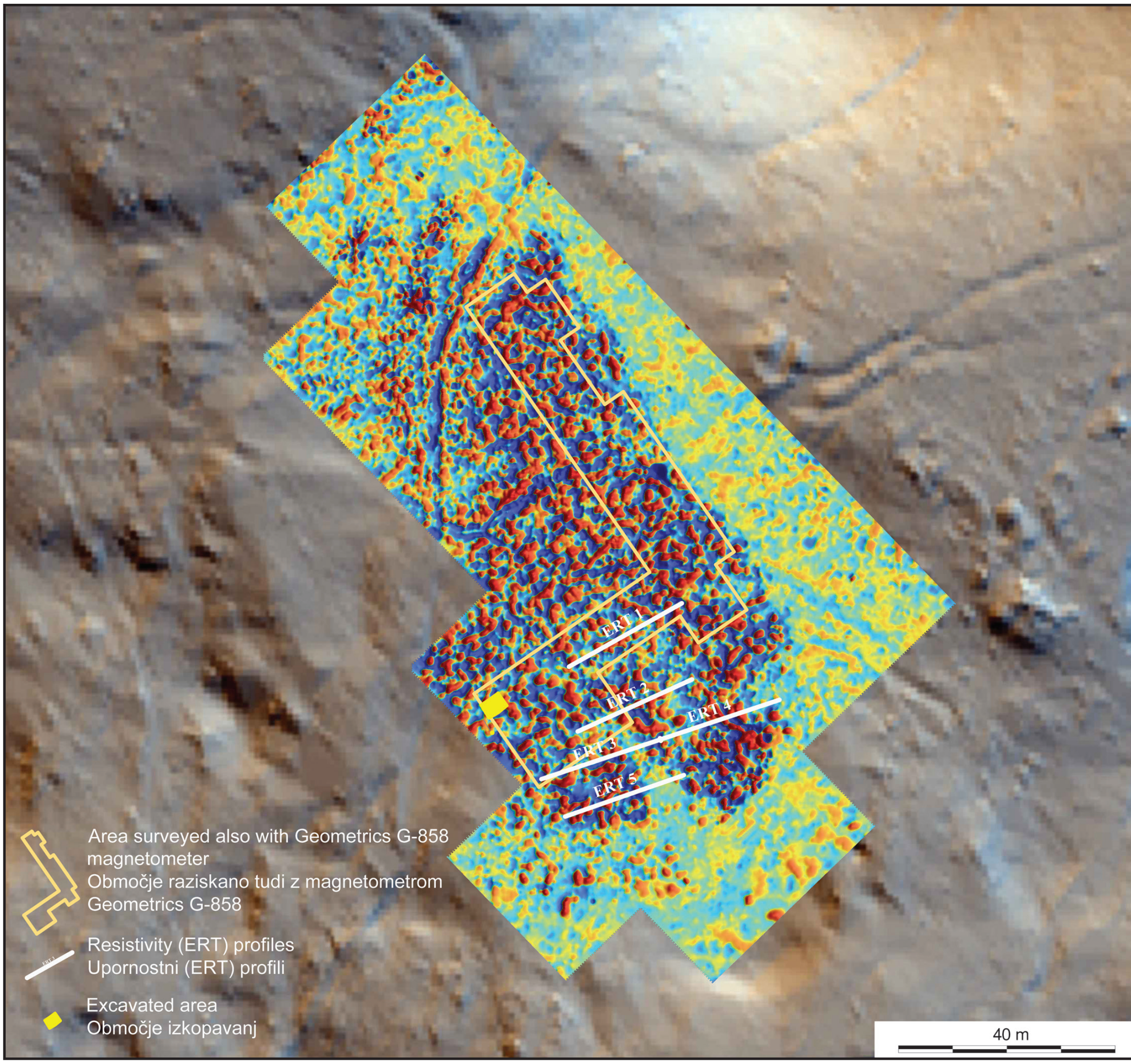

Fig. 8: Branževec. Results on first magnetic prospection obtained by Fluxgate gradiometer *Geoscan FM36* (see Mušič, Orengo 1998) after applying Gaussian filter in colour scale display using Histogram equalization. Dynamics: -62.31/+74.48 nT/m.

Sl. 8: Branževec. Rezultati prve magnetne prospekcije, pridobljeni s pretočnim gradiometrom *Geoscan FM36* (glej Mušič, Orengo 1998) po uporabi Gaussovega filtra v barvnem prikazu z uporabo histogramskega izenačevanja. Razpon prikazanih vrednosti: -62,31 /+74,48 nT/m.

the iron mineral composition, depth, dimensions and geometry of the iron-production remains can also significantly contribute to the magnitude and shape of anomalies. Strong magnetic anomalies from waste slag deposits frequently blur the magnetic responses of individual furnaces. Therefore, only the case sensitive, adapted examination can assure reliable identification of individual structures (Powell et al. 2002, 651–665).

At Branževec a geophysical survey using a total field magnetometer (*Geometrics G-858*) in (pseudo)gradient mode was undertaken. Magnetic measurements in this configuration generally amplifies the weak magnetic anomalies of induced magnetization at shallow depths in favour of long-wave magnetic anomalies caused mostly by the magnetic susceptibility differences in karstic limestone bedrock (*Fig. 8*). As this magnetometer consists of two separate sensors, it allows the observation of magnetic field readings separately on the top and the bottom sensors. The analyses of single sensor data presents a more refined approach for specific archaeological contexts such as iron-production sites (Tabbagh 2003, 75–81).

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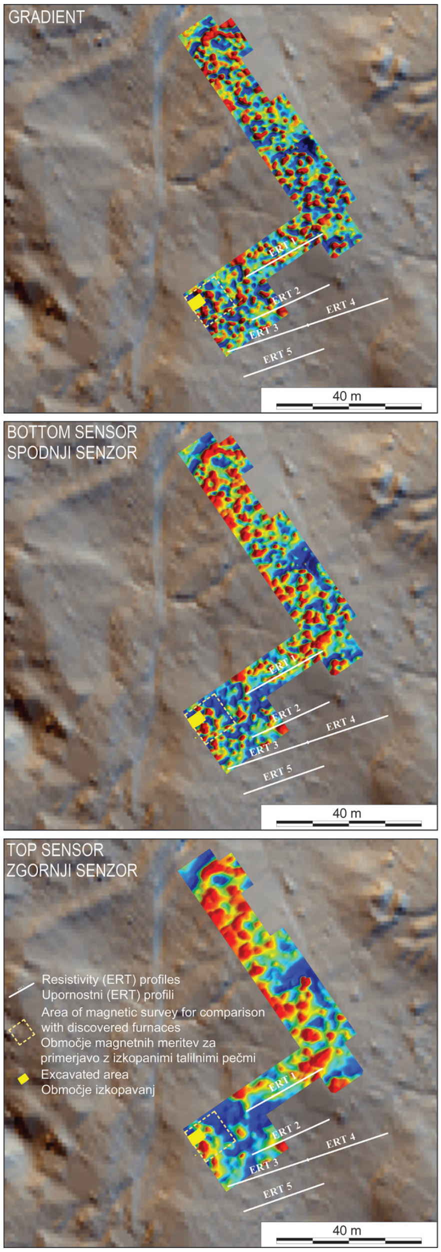

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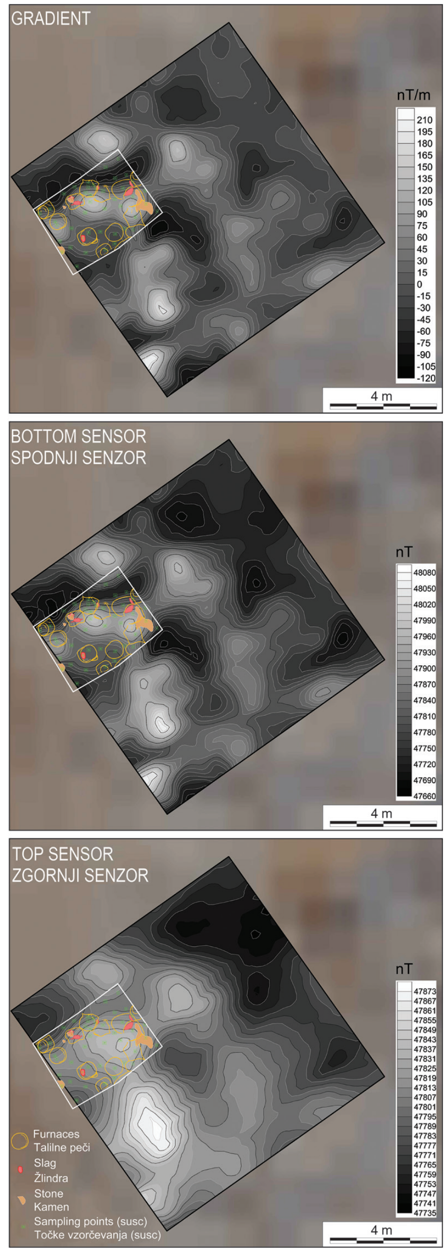

Such measurement procedures are normally supported by diurnal magnetic field changes corrections using a base magnetometer. If single sensor measurements are acquired in a short period of time when the diurnal magnetic field changes are rather small, a base magnetometer is not necessary. For smaller diurnal variation corrections, adequate processing steps are suggested (Tabbagh 2003, 75–81). In our case, the diurnal variations were surprisingly small. Therefore, no additional corrections were required, and processing steps resembled those used for gradient mode (*Fig. 9*). The magnetometer used attained a resolution of 0.1–0.2 nT/m in measuring the total magnetic field density, with an acquisition at a rate of 5 Hz along the 0.25–0.5 m spaced transects. The height of the bottom sensor above the ground was approx. 0.3 m and the distance between vertically positioned sensors was 0.7 m. The readings were interpolated to a sample interval of 0.25 m in both directions using the cubic "spline approximation to the sinc function" (Engels, Stark, Vogt 1988, 225–236) and smoothed by Gaussian filter (Nixon, Aguado 2008). The magnetic maps were created using Histogram equalization adjustment (see for instance: Acharya, Ray 2005). In this way, the total magnetic field readings can be better distributed on the histogram to enable insight into weaker, discrete magnetic

←←
Fig. 9: Branževec. Results on magnetic prospection applying total field magnetometer *Geometrics G-858* in gradient mode and single sensors without any corrections of diurnal magnetic field changes. Gradient and total magnetic field data after applying Gaussian filter and colour scale display using Histogram equalization. Dynamics: −268.68 /+104.84 nT/m (gradient); 47577/47954 nT (bottom sensor); 47736/47870 nT (top sensor).
Sl. 9: Branževec. Rezultati magnetne prospekcije z uporabo magnetometra totalnega magnetnega polja *Geometrics* G-858 v gradientnem načinu in s posameznimi senzorji brez popravkov dnevnih variacij Zemljinega magnetnega polja. Podatki o gradientnem in totalnem magnetnem polju po uporabi Gaussovega filtra v barvnem prikazu z uporabo histogramskega izenačevanja. Razpon prikazanih vrednosti: −268,68 /+104,84 nT/m (gradient); 47577/47954 nT (spodnji senzor); 47736/47870 nT (zgornji senzor).

←
Fig. 10: Branževec. Comparison of the magnetic method results obtained by caesium magnetometer *Geometrics G-858* in gradient mode and single sensors with the excavated remains of furnaces (*Fig. 12*). According to theoretical background on magnetic method, furnaces are located approx. half the distance between the highest positive and lowest negative parts of magnetic anomalies. Mean values of magnetic susceptibility: 5.54×10^{-3}SI (furnace); 15.44×10^{-3}SI (slag); 0.07×10^{-3}SI (stone); 1.14×10^{-3}SI (archaeologically undisturbed soil).
Sl. 10: Branževec. Primerjava rezultatov magnetne metode, pridobljenih s cezijevim magnetometrom Geometrics G-858 v gradientnem načinu in s posameznimi senzorji z izkopanimi ostanki peči (*sl. 12*). Glede na teoretično ozadje magnetne metode se peči nahajajo približno na polovici razdalje med najvišjimi pozitivnimi in najnižjimi negativnimi deli magnetnih anomalij. Srednje vrednosti magnetne susceptibilnosti: $5,54 \times 10^{-3}$SI (peč); $15,44 \times 10^{-3}$SI (žlindra); $0,07 \times 10^{-3}$SI (kamen); $1,14 \times 10^{-3}$SI (arheološko intaktna tla).

anomalies. Basically, this histogram manipulation allows for areas of lower contrast to gain a higher contrast. Histogram equalization accomplishes this by effectively spreading out the most frequent intensity values (Acharya, Ray 2005). Results of a previous magnetic survey using Fluxgate gradiometer *Geoscan FM36* (Mušič, Orengo 1998, 157–186) also contributed additional information obtained from Histogram equalization. Namely, the height of gradiometer above the ground was only approx. 0.1 m with a strong influence of slag fragments beneath the topsoil. By making relatively weaker magnetic responses of high frequency visible it becomes evident which parts of an iron-smelting complex are covered by slag fragments and other strongly magnetic waste material in relatively larger quantities (*Fig. 8*) in comparison with caesium magnetometer results (see for instance: Dirix et al. 2013, 233–247).

The comparison of the magnetometry survey obtained by caesium magnetometer and the excavated remains (*Fig. 12*) of the furnaces shows, in general, a good spatial correlation between archaeological objects and magnetic anomalies (*Fig. 10*). According to the theoretical background on magnetometry, furnaces are located approx. half the distance between the highest positive and lowest negative parts of magnetic anomalies (see e.g.: Telford, Geldart, Sheriff 1990). Even on the high-resolution results of gradient measurements (min=−117 nT/m; max=+299 nT/m; sd=35), we cannot clearly identify the individual furnaces, because the magnetic anomalies of adjacent furnaces at short distances overlap. In some situations, younger furnaces have been dug into older ones, but they also differ in the depths at which they occur. It is therefore obvious that the situation on the iron-smelting area is even more complex than it was discernible from magnetic method results. From these results it can be concluded that the total number of furnaces is much larger than the number estimated solely from magnetometer survey. This problem can be at least partly solved by applying 3D magnetic modelling as it was described in the previous publication on the magnetic survey at Branževec (Mušič, Orengo 1998). Magnetic gradient and bottom sensor (min=47647 nT; max=48143 nT; sd=54) give quite similar results but single sensor results are in general clearer because they incorporate less high-frequency noise, which is an inherent characteristic of surveys in gradient mode. While gradient mode and bottom sensor enable high resolution and recognition of magnetic anomalies, generated by small clusters of furnaces, top sensor (min=47730 nT; max=47880 nT; sd=24) gives insight into the areas with the strongest magnetic response. The latter can be the consequence of very well preserved furnace remains and/or large quantities of deposited slag (*Fig. 10*).

Electrical resistivity tomography survey

To be able to further investigate the type of archaeological sediments in the iron-smelting area (furnaces, bigger waste depositions or else) electrical resistivity tomography (ERT) was also employed.

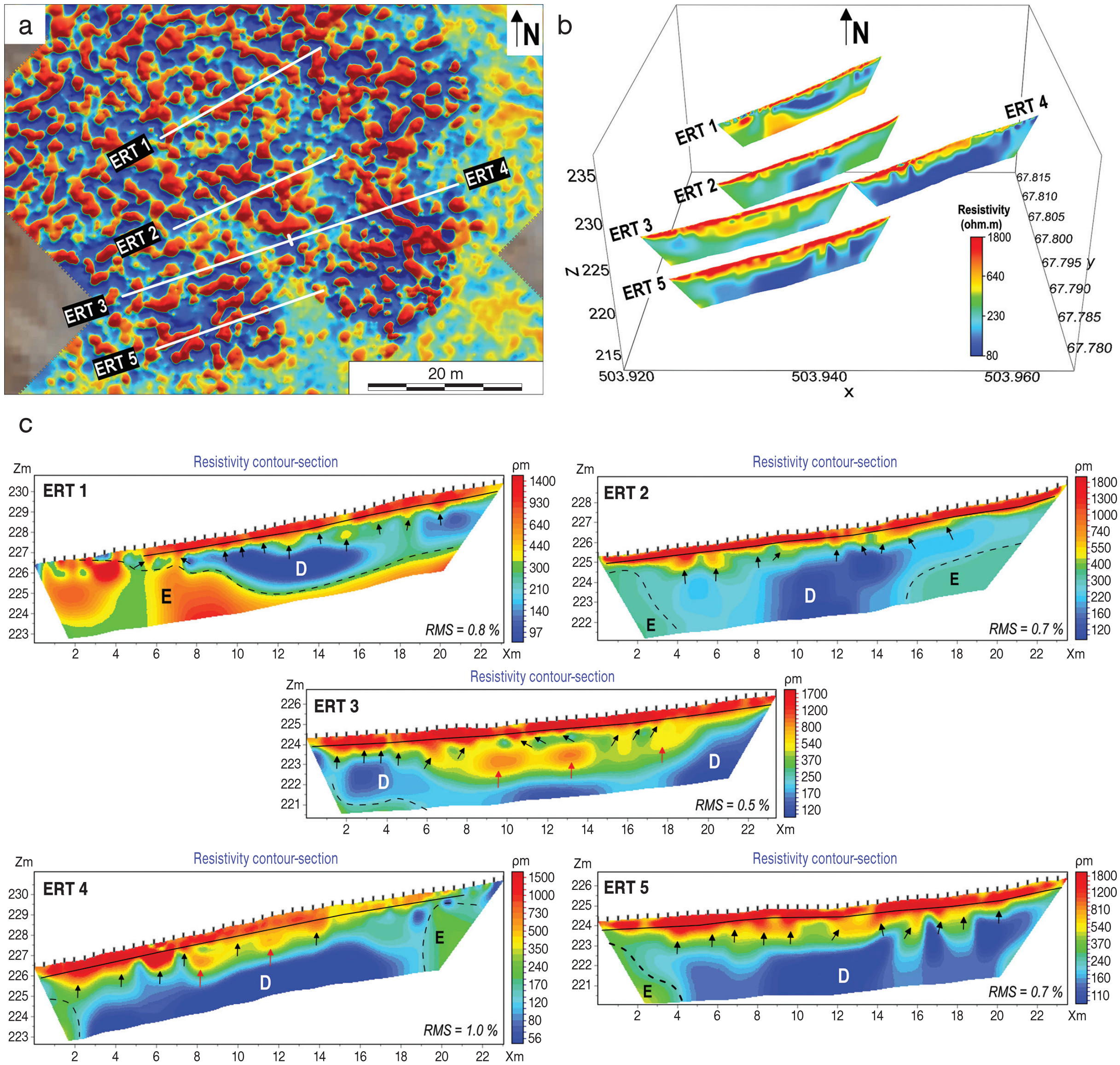

Fig. 11: Branževec. Magnetic anomaly map (gradient mode) with shown positions of the ERT lines 1–5 (**a**), combined with inversion resistivity models ERT 1–5 shown in 3D view (**b**) and with their more detailed explanations (**c**).
Sl. 11: Branževec. Karta magnetnih anomalij (gradientni način) s prikazanimi položaji linij ERT 1–5 (**a**) v kombinaciji z inverznimi modeli upornosti ERT 1–5 v 3D pogledu (**b**) in z njihovimi natančnejšimi razlagami (**c**).

For the possible recognition of individual furnace remains, estimation of the total thickness of archaeologically disturbed layers and depth to the solid bedrock (limestone) we have measured five ERT profiles at the southern part of the iron-smelting area as shown on *Figs. 2* and *11*. According to the previous research (Mušič, Orengo 1998; Dular, Križ 2004) the furnace remains discovered at the northern part of the iron-smelting area lay 0.5–0.6 m below the topsoil (mixed with humus, iron slag and burnt clay). Their radii reached between 0.5–0.9 m and heights of 0.3–0.4 m (below topsoil). According to the recent excavation at the western part of the iron-smelting area (*Fig. 12*) furnace remains lie approx. 0.4 m below the topsoil, are 0.6–0.7 m wide and are up to 0.4 m deep.

Considering this information a 0.5 m electrode spacing was applied with a 48-electrode system, resulting in the profiles lengths of 23.5 m and depth reach of approx. 4 m with the applied Wenner-beta electrode configuration. The latter is in fact a reduced version of the dipole-dipole electrode array (e.g. Loke 2013), with better sensitivity to the lateral changes in subsurface resistivity, which

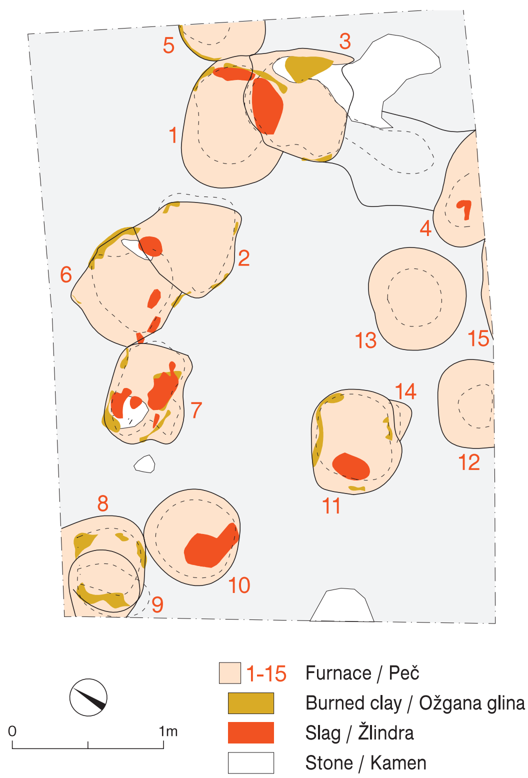

Fig. 12: Branževec. Trench 8 with the remains of furnaces (1–15), excavated in the southern part of the iron-smelting area (see *Figs. 3; 8–10*).
Sl. 12: Branževec. Sonda 8 z ostanki peči (1–15), izkopana v južnem delu železarsko-talilniškega območja (glej tudi *sl. 3; 8–10*).

makes it better in resolving vertical artefacts such as furnaces and depressions in limestone bedrock. Its data acquisition time is 3–4-times faster than for dipole-dipole at the expense of lower resolution and lower depth reach. After adding topography information, all the pseudo sections were inverted using the focused inversion (Portniaguine, Zhdanov, 1999; *Zond geophysical software, 2016*[9]).

We have located the five profiles (ERT 1–5) in the midst of the highest magnetic anomalies in the southern part of the iron-smelting area (*Fig. 11a*). Based on the resistivity distribution on inversion models ERT 1–5 (*Fig. 11c*) we can define a high resistivity topsoil layer (dashed black line) at an approximate depth 0.5 m. Below that line, multiple small oval-shaped high resistivity anomaly disturbances are defined (black arrows)

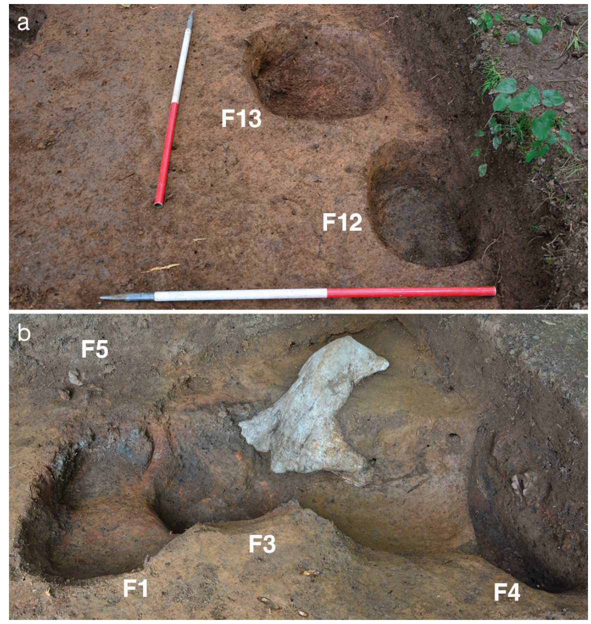

Fig. 13: Branževec. Simple furnace remains without any remains of superstructures (F12, F13) (**a**); and more complex remains pointing to the probable use of domed furnaces (F1, F3) (**b**).
Sl. 13: Branževec. Ostanki preprostih peči brez ostankov nadgradnje (F12, F13) (**a**); in kompleksnejši ostanki, ki verjetno kažejo na uporabo kupolastih peči (F1, F3) (**b**).

down to depths up to approx. 1 m. These might reflect the remains of furnaces. While profiles ERT 1 and ERT 2 show no significant disturbances below this depth, on ERT 3 and ERT 4 medium to high resistivity anomalies are also present up to the depth of approx. 2 m (red arrows), which can indicate archaeologically disturbed layers, i.e. stone debris or burnt clay deposits.

Deeper, medium resistivity anomalies on ERT 5 can be probably attributed to the unrealistic distortion of the shallower anomalies (black arrows), which are common with Wenner-beta electrode configuration. Low resistivity areas (D) can be interpreted as clayey sediments, and most probably can be considered as archaeologically undisturbed below 1 m depth on profiles ERT 1 and ERT 2 and 2 m on ERT 3 and ERT 4. High to medium resistivity areas (E) represent the solid limestone bedrock on ERT 1 and weathered limestone blocks on ERT 2–5.

Excavation of Trench 8

The results of the recent caesium magnetometer study (*Figs. 8; 9*) were used to choose the location

[9] ZONDRES2D – Program for two-dimensional interpretation of data obrained by resistivity and induced polarization methods. (n.d.). Zond geophysical software. – Saint-Petersburg 2001–2016.

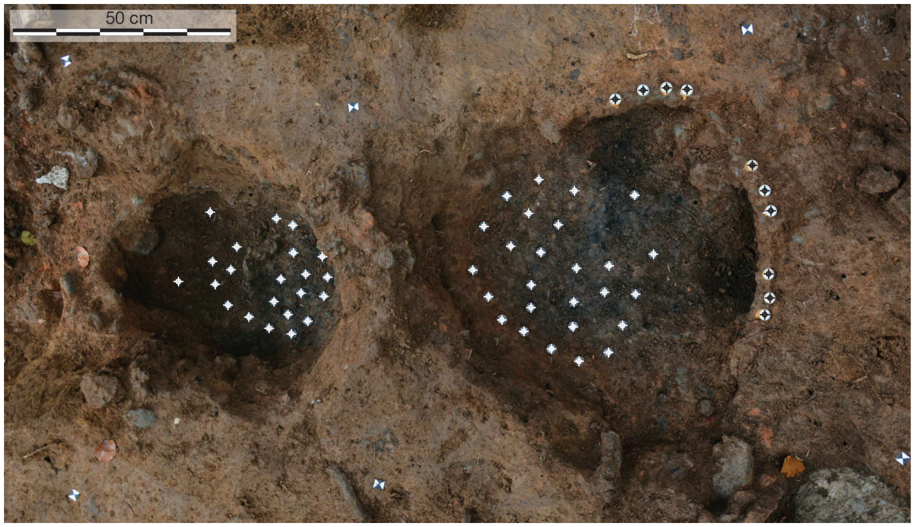

Fig. 14: Branževec. Sample positions (CVG 1, samples 1001–1036) from furnace base deposit (F1: SE 8024) and the clay lining (F1: SE 8022) of Furnace 1 (**a**). Sample positions (CVG 2, samples 2001–2014, 2017–2024) from furnace base deposit (F2: SE 8023) of Furnace 2 (**b**).
Sl. 14: Branževec. Položaji vzorcev (CVG 1, vzorci 1001–1036) iz spodnje plasti (F1: SE 8024) in stene peči (F1: SE 8022) peči 1 (**a**). Položaji vzorcev (CVG 2, vzorci 2001–2014, 2017–2024) iz spodnje plasti peči 2 (F2: SE 8023) (**b**).

of the trial Trench 8 (*Figs. 1–3*). It was located in the southern part of the iron-smelting area, approx. 70 m away from trench excavated by Križ in the northern part, which yielded remains of 12 slag-pit furnaces (Dular, Križ 2004, 228–229, Figs. 3; 4; 36). Our basic aims were to investigate whether other parts of the smelting area show similarly dense occurrence of furnace remains, if they belong to the same type and if the remains are similarly poorly preserved. Besides that, we wanted to get the best possible data for their correlation with the contemporary magnetometer survey, which was planned to be used for a more relevant interpretation of the whole smelting area. Therefore, a location was chosen that showed various ranges of magnetic anomalies and could offer possible interpretations for many of the observed anomalies.

Although the excavated remains are not yet fully studied, some initial conclusions can be drawn. The excavation of the test trench (3 × 4 m) yielded remains of possibly 15 furnaces (*Fig. 12:* F1–15) and a great amounts of smelting remains, including limonite iron ore, roasted ore, partly reduced ore and various types of slag (Črešnar, Burja, Vinazza 2017, Fig. 4). The excavated furnaces can be generally divided into two types. The simpler ones (F4, F9–10, F12–15) were only lightly burned round or oval pits (*Fig. 13a*), filled with a mixture of earth, charcoal as well as pieces of burned clay and slag (mostly <10 cm). A more complex type (F1–3, F5–8, F11) presents round or oval furnaces, with heavily burned thick walls (5–10 cm) (*Fig. 13b*). They were filled with large pieces (<50 cm) of burned clay and slag as well as charcoal. Furthermore, the complex remains most probably present furnaces in which the slag was not trapped for the entire time of the smelting process but was at least partially removed. This assumption is supported by the strongly fired furnace walls, which also suggest that the furnaces were used multiple times.

When searching for the form of the furnaces, most of them lack any parts of the superstructure. Nevertheless, furnaces F1, F3 and F6 were preserved enough to interpret them as domed and not shaft type (cf. Cleere 1972, Fig. 11) as proposed previously. However, not all the burned clay material from the furnace remains have been studied to the detail that would allow us to draw final conclusions on the forms of the furnaces.

The furnaces were clustered in four distinct groups with an empty central space or corridor. Furnaces in the groups were built one after the other, and partly reused the existing empty space of the former furnace. Such a case is the group in the northeast where furnaces F5 and F3 were without a doubt cut when furnace 1 was built and the slag from the furnace ran into the emptied and reused bottom part of the deeper furnace F3 (*Fig. 13b*).

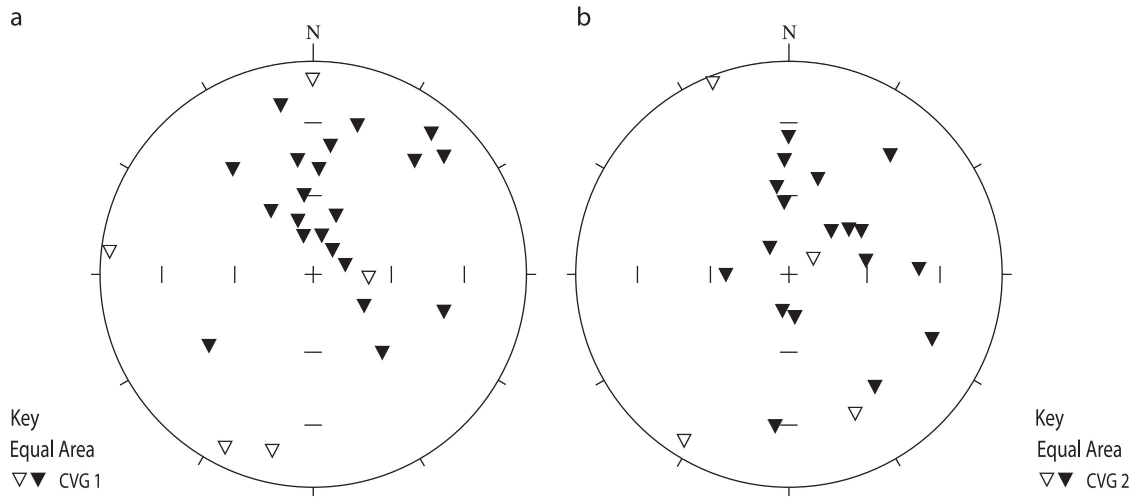

Fig. 15: Branževec. Archaeomagnetic directional data from the tube samples taken from the base deposits of the Furnace 1 (CVG1) (**a**) and Furnace 2 (CVG2) (**b**). The full symbols represent normal inclination values and outlined symbols represent reversed inclination values.
Sl. 15: Branževec. Arheomagnetni podatki usmeritev remanentnega magnetnega polja iz cevastih vzorcev, odvzetih iz spodnjih plasti peči 1 (CVG1) (**a**) in peči 2 (CVG2) (**b**). Polni simboli predstavljajo normalne vrednosti inklinacije, prazni pa obratne vrednosti inklinacije.

ARCHAEOMAGNETIC DATING OF THE IRON-SMELTING FURNACES

Archaeomagnetic dating can be a suitable dating technique when iron-bearing clay material has been fired to above c. 400°C and has remained *in situ*. The unearthed iron-smelting furnaces excavated in Trench 8 at Branževec iron-smelting area (*Fig. 12*) offered the opportunity to employ this dating technique. Thus, archaeomagnetic studies were carried out on two iron-smelting furnaces in Trench 8. The main reason for the analysis was the dating of the furnaces, as it might add important knowledge about the use of the iron-smelting area. The site is lacking in any datable pottery or metal finds, and the radiocarbon dating of charcoal was affected by the Hallstatt plateau and has therefore a very broad time-span (Dular, Križ 2004, fn. 40).

Archaeomagnetic dating utilises knowledge of past changes in the Earth's magnetic field to date archaeologically fired materials such as fired clays and ceramics (McIntosh, Catanzariti 2006; Pavón-Carrasco et al. 2015). The fundamental principles of the method rely on two phenomena. Firstly, the geomagnetic field changes significantly on archaeologically relevant timescales of decades and centuries, and secondly, iron-bearing oxides within soils and clays under certain conditions can record and retain a magnetic remanence, which reflects the past geomagnetic field from the time of the last firing. Archaeomagnetic dating is well-established in Europe (Hervé, Chauvin, Lanos 2013; Batt et al. 2017) and regularly utilised for dating fired archaeological structures, i.e. furnaces, kilns or hearths (Aidona et al. 2018; Casas et al. 2018). Palaeosecular variation curves (PSVC) mainly cover country-specific areas and facilitate archaeomagnetic dating for those countries where there is enough data.

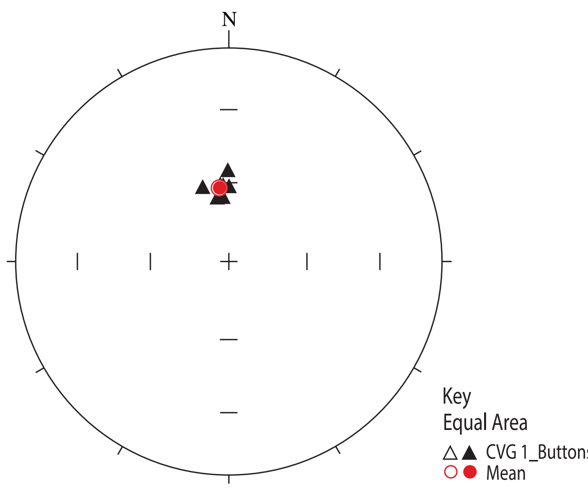

Fig. 16: Branževec. Archaeomagnetic directional data from the button samples taken from the clay lining of furnace 1 (CVG 1).
Sl. 16: Branževec. Arheomagnetni podatki usmeritev remanentnega magnetnega polja iz gumbastih vzorcev, odvzetih iz glinene obloge peči 1 (CVG 1).

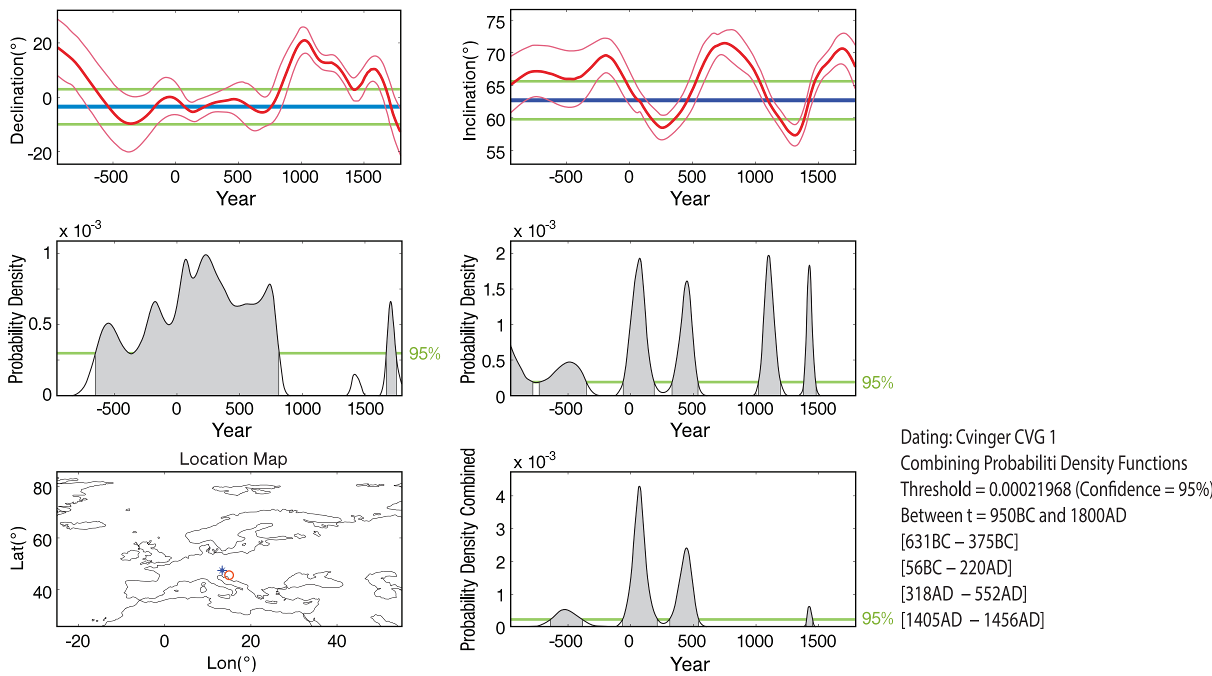

Fig. 17: Branževec. Summary of the calibration data for the clay lining of furnace 1 (CVG 1) using the Austrian PSVC (Schnepp, Lanos 2006) and the *Matlab* programme developed by Pavón-Carrasco et al. (2011). – *Top row:* master secular variation curves for the observation site (red bold curves with red error bands) of the declination (*left*), inclination (*right*) and the undated archaeomagnetic direction (blue line). – *Middle row:* the individual probability density functions for the declination (*left*), inclination (*right*). The green lines indicate the 95% probability threshold. – *Bottom row:* map with locations of the research area (red circle) and of the master secular variation curve (blue star) (*left*); combined probability density (declination and inclination) marked with the green line of 95% probability (*right*) and archaeomagnetic dating 95% probability ranges (*far right*).
Sl. 17: Branževec. Povzetek kalibracijskih podatkov za steno peči 1 (CVG 1) z uporabo avstrijske krivulje preteklih časovnih sprememb usmeritve magnetnega polja (PSVC) (Schnepp, Lanos 2006) in programa *Matlab*, ki so ga razvili Pavón-Carrasco et al. (2011). – *Zgornja vrsta:* temeljna krivulja preteklih časovnih sprememb usmeritev magnetnega polja za območje raziskav (rdeči krepki krivulji z rdečimi pasovi, ki prikazujejo interval pričakovanih odstopanj) za deklinacijo (*levo*), inklinacijo (*desno*) in časovno neopredeljena usmeritev (modra črta). – *Srednja vrsta:* funkcija gostote verjetnosti za deklinacijo (*levo*) in inklinacijo (*desno*). Zeleni črti označujeta 95 % prag verjetnosti. – *Spodnja vrsta:* zemljevid s prikazom območja raziskav (rdeč krog) in lokacije temeljne krivulje preteklih časovnih sprememb usmeritev magnetnega polja za območje raziskav (modra zvezda) (*levo*), združena gostota verjetnosti za deklinacijo in inklinacijo, z zeleno črto, ki označuje 95 % prag verjetnosti (*desno*), in razponi datacij 95 % verjetnosti, pridobljeni z arheomagnetnim datiranjem (*skrajno desno*).

There were three aims, which this analysis sought to investigate. Firstly, if the material was fired *in situ* and to a high enough temperature to acquire a thermoremanent magnetisation (TRM). Secondly, to ascertain if there was a difference between the samples taken from the base deposits of the furnaces and the furnace wall samples. Finally, determine if a date for the last firing event could be established through calibration with the nearest applicable PSVC.

Across the two furnaces (*Figs. 12; 13b*) a total of 58 samples were taken and orientated with a north seeking magnetic compass (*Fig. 14*). The first furnace (F1: sample CVG 1) had some of the clay lining preserved (SE 8022) which was sampled using the button method (10 samples). The remaining samples were taken from the base deposits of the two furnaces using the tube method (48 samples: 26 from SE 8024 and 22 from SE 8023).[10] The sampling protocols from Clark, Tarling, Noël (1988) and Trapanese, Batt, Schnepp (2008) were followed.

[10] The full archaeomagnetic analysis of these two furnaces can be found in: S. E. Harris, C. M. Batt, M. Črešnar, M. Vinazza, *Dating Early Iron Age sites in the SE Alpine region: first archaeomagnetic data for Slovenia. Physics of the Earth and Planetary Interiors* (in preparation).

Analysis of all the archaeomagnetic samples at the University of Bradford's Archaeomagnetic Dating Laboratory showed large discrepancies between the base deposit samples and the samples originating from the clay lining. Despite the base deposit samples containing sufficient magnetic minerals to record a TRM the two sample sets from the floor of the two furnaces exhibited large scatter in the data set (*Fig. 15*). The presence of reversed inclination values (open triangle symbols in *Fig. 15*) is not a possible record of the geomagnetic field for this geographical location in the Holocene. This in conjunction with the large α_{95} values (14.0° and 15.4° respectively which are well above the recommended value of 5.0° (Hervé, Chauvin, Lanos 2013), show that the base deposits are in our case not suitable and do not retain a stable remanence of the past geomagnetic field. The samples were not considered for further analysis due to the clear likelihood that these deposits were not fired sufficiently.

The archaeomagnetic samples from the clay-lining of the first sampled furnace (F1, sample CVG 1) displayed a set of data with higher precision (*Fig. 16*). The archaeomagnetic analysis showed that the material from the clay lining had been fired to a high enough temperature to reset the archaeomagnetic signal. The archaeological direction obtained from the clay linings is a record of the geomagnetic field from the last time the furnace cooled down, i.e. the last time it was used.

While Slovenia does not have its own calibration curve the nearest applicable PSVC is the Austrian dataset (Schnepp, Lanos 2006) and the introduction of errors by comparing over such a distance has shown to be minimal (Casas, Incoronato 2007). The calibrated archaeomagnetic date range at 95% confidence which is most in concordance with the archaeological evidence is 640–370 BC for furnace CVG 1 (*Fig. 17*). The additional date ranges are due to the geomagnetic field displaying the same behaviour at more than one point in the past (Batt 1997).

The second furnace (F2, samples CVG2) failed to provide a date. The archaeomagnetic analyses of the base deposit material from both features showed large scatter in the data sets. There are various possible explanations for that. Firstly, it could suggest that the material sampled was not fired to sufficiently high temperatures. Secondly, the deposits on the base of the furnace could have been moved/mixed after the cooling down, when later furnaces were erected or might be as a result of post-depositional processes; it was noted that roots had heavily bioturbated some of the contexts.

CONCLUSIONS

This short overview of research at Cvinger near Dolenjske Toplice complex in the recent years is not a summary of all the results of our work, for several analyses are still in progress. However, it summarizes some of new findings. On the one side, the novelties are concerned with the whole archaeological complex and on the other side with the methods used and combined in the presented interdisciplinary approach (*Fig. 2*).

The first step of the research was the analysis of the ALS data. Therewith we gained new data about all parts of the Cvinger complex. Firstly, we could recognize a levelling/shallow depression around the settlement fortification (*Figs. 1; 3*), which can be most probably understood as signs of material acquisition (soil, stone) for the erection of the rampart. Furthermore, an approx. 180 m long embanked approach path, leading to the settlement from the iron-smelting area on the saddle called Branževec was recognized.

The observation of the terrain texture helped us also to delineate the perimeter of the iron-smelting area, which measures around 0.6 hectares. Also, additional knowledge about the barrow cemeteries was gained (*Figs. 1; 3*). A more accurate position of the previously excavated and levelled barrow at Dolgi deli was proposed, a new barrow was recognized in the fields at Gomivnica and five possible additional barrows were recognized at the main barrow group at Branževec.

Cvinger is also an important archaeological site for the application of multi-method geophysics and the development of new research approaches. Although other methods were used, the focus here lies in the magnetometry and electrical resistivity tomography (ERT). Two case studies presented are important beyond the site of Cvinger as they open new possibilities for researching on the one hand fortifications of hillforts and on the other fortified sites as well as iron-smelting areas.

As shown above, the ERT method based on resistivity distribution inside ramparts can identify approximate dimensions and depths of defence dry stoner wall ruins and other features as embankments etc. (*Fig. 5b*). However, as also demonstrated, due to the absence of the electrical contrast in the same type of material we cannot (for now) further differentiate between the in-situ wall remains and the collapsed parts of a defence wall. Although not discussed further, other parts of the rampart at Cvinger and elsewhere were also studied and the ERT method is more than comparable with the results of previous excavations. The huge advantage is however, it is non-destructive, replicable and much less time consuming than archaeological excavations.

New information also came from the research of the iron-smelting area on the Branževec saddle. Geophysical survey using a total field magnetometer (*Geometrics G-858*) (*Fig. 9*) was performed at selected parts of the previously surveyed area by the Fluxgate gradiometer (*Geoscan FM36*) (*Fig. 8*) (Mušič, Orengo 1998, 157–186). It was conducted in the (pseudo)gradient mode with the separately displayed single sensor measurements that ensured more refined magnetograms. The more reliable evidence about furnaces and clusters of furnaces was also ensured also by a greater distance of the lower sensor from the surface, as this reduced the effect of the slag on the surface and the shallowness below it.

Magnetic gradient and bottom sensor gave similar results but single sensor results are in general clearer because of less high-frequency noise. Gradient and bottom sensor measurements enable high resolution and recognition of magnetic anomalies, generated by small clusters of furnaces, while the top sensor gives insight into the areas with the strongest magnetic response.

The comparison of the magnetic survey results obtained by caesium magnetometer and the excavated furnaces (*Fig. 10*) shows, in general, good spatial correlation but almost without clearly identified individual furnaces because the magnetic anomalies of adjacent furnaces, which were often even built one over the other (*Fig. 13*), at short distances overlap. Therefore, the total number of furnaces is much larger than it can be estimated from magnetic method results.

We have shown that the remains of furnaces can also be investigated by ERT. They are manifested on ERT inversion models as small (up to 1 m deep), oval-shape, medium to high resistivity anomalies, below the approx. 0.5 m thick high resistivity surface layer (*Fig. 11*), which is consistent with the results of archaeological excavations.

The combination of these methods is highly important for investigations of further probable iron-smelting areas, which have already been discovered, but are known only by single furnaces or simply finds of iron-smelting waste.

Archaeological excavations of trial trenches at Cvinger were in all cases embedded into the interdisciplinary approach. Therefore their results are important not only for the rather limited areas of the trenches, but broader areas, researched with other methods (ALS, geophysics) as well as for verification of methodology in this interdisciplinary approach.

One of the archaeological trenches (Trench 6) was positioned on the second transverse rampart, which is a part of the embanked approach path, recognized on the ALS data (*Fig. 3*). The excavation yielded remains of a dry stone wall with a width of approx. 4 m, which is unique fortification element in the broader region (*Figs. 4–7*).

Important data also comes from the Trench 8, excavated in the iron-smelting area, following the results of geophysical investigations. Remains of 15 furnaces were unearthed with a variety of styles representing simple and complex stratigraphy, often cutting earlier furnaces (*Figs. 12; 13*). Furthermore, the complex remains most probably represent furnaces in which the slag was not trapped for the entire time of the smelting process but was at least partially removed. In addition, some better preserved remains point to the use of domed furnaces and not (only) shaft furnaces. That is an important new discovery, which will have to be investigated further and compared to other already researched furnace remains.

One of the furnaces (F 1) was also successfully sampled for archaeomagnetic dating (*Figs. 14–16*), which was performed at the University of Bradford's Archaeomagnetic Dating Laboratory. The calibrated archaeomagnetic date range at 95% confidence, which is most in concordance with the archaeological evidence, is 640–370 BC (*Fig. 17*). That is important as the smelting area is lacking in any datable pottery or metal finds, and the radiocarbon dating of charcoal was affected by the Hallstatt plateau and has therefore a very broad chronological timespan (Dular, Križ 2004, fn. 40).

The successful archaeomagnetic study of one of the iron-smelting furnaces from Cvinger shows that it is possible to obtain a date for its last use and that the precision of the date range is an improvement on that possible from radiocarbon dating. Future archaeomagnetic studies within Slovenia, particularly in the 1st millennium BC, have the potential to introduce a new method to aid the dating of sites or contexts lacking other datable material in this region.

Although not crucial for understanding of the site, one of the main actors of a series of different myths, was the karstic abyss, called Cvingerska jama, located in the centre of the hillfort (*Fig. 3*). Our research showed that the entrance of the abyss was much smaller, completely blocked or did not even exist in the time of the prehistoric inhabitation of the settlement. Therefore, the Cvingerska jama abyss most probably has no archaeological significance.

Although this article only presents an overview of the research conducted at Cvinger, it has revealed the potential that Cvinger and its surroundings still hold for future research. Having this said, we must not forget about other sites in its vicinity, e.g. Dolenje Gradišče (*Fig. 1*), and potential sites in the lowlands around Cvinger, where several prehistoric sites have been identified, however none of them was systematically studied.[11]

[11] In an area of less than 2.5 km away from Cvinger there are six known or potential archaeological sites entered into the database *RKD* – Register of immovable heritage of Slovenia (*RKD = Register kulturne dediščine,* Ministrstvo za kulturo RS) [https://gisportal.gov.si/portal/apps/webappviewer/index.html?id=df5b0c8a300145fda417eda6b0c2b52b].

Acknowledgements

The authors thank first and foremost the colleagues who were collaborating with us on the research of the Cvinger complex, namely Luka Pukšič, Dejan Udovč, Miha Mihelič, Manca Omahen Gruškovnjak, Igor Medarić, Filip Matijević, Petra Basar and Jernej Umek as well as Bryan Hanks with his team of the University of Pittsburgh (ScienceProHeritage project, ARRS, BI-US/18-19-088). We would like to thank also colleagues who have previously researched the Cvinger complex and shared their knowledge us, namely Janez Dular, Borut Križ and Philip Mason. Furthermore, we would like to thank regional conservators, who inspected our work, Tina Britovšek and Uroš Bavec from the ZVKDS, OE Novo mesto. Besides that do our thanks go also to Marko Pršina (ZVKDS) for his enthusiastic support, the Novo mesto Caving club and the Municipality of Dolenjske Toplice as well as to all the other colleagues, who participated at our work, and very importantly our students from the Oddelek za arheologijo, Filozofska fakulteta, Univerza v Ljubljani, and Erasmus students many of whom spent their fieldwork practicum at Cvinger. Helen McCreary is also thanked for measuring some of the archaeomagnetic samples at the University of Bradford. The authors would also like to thank the reviewers for their comments, which we feel have helped us to improve the paper.

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Interdisciplinarne raziskave železarskega središča Cvinger pri Dolenjskih Toplicah iz starejše železne dobe

Povzetek

V prispevku je predstavljen zgoščen pregled rezultatov interdisciplinarnih raziskav, izvedenih v zadnjih letih na arheološkem kompleksnem najdišču Cvinger pri Dolenjskih Toplicah. Novosti na eni strani dopolnjujejo dosedanja arheološka spoznanja o Cvingerju (Dular, Križ 2004), ki ga z naborom že uveljavljenih sodobnih metod lahko raziskujemo celoviteje tudi na neinvaziven oz. nizko invanziven način. Opravljene raziskave so lahko spodbuda za nadaljnje uvajanje interdisciplinarnega pristopa na kompleksnih utrjenih prazgodovinskih najdiščih dolenjskega krasa. Poudarek je predvsem na uporabi nedestruktivnih metod, tj. zračnem laserskem skeniranju in različnih geofizikalnih meritvah, a so seveda v vseh primerih ključnega pomena za razumevanje rezultatov teh metod zlasti rezultati arheoloških izkopavanj (*sl. 2*). V prispevku so predstavljeni rezultati (arheo)magnetne datacije talilnih peči, izkopanih na železarsko-talilniškem območju na ledini Branževec pod gradiščem.

Z analizo podatkov zračnega laserskega skeniranja (ZLS) smo pridobili nova spoznanja o notranji ureditvi naselbine s terasiranjem, poteku obrambnih struktur in manjših pregrad ter o vrtačah, umetno oblikovanih izravnavah in seveda številnih gomilah. Pri tem kaže poudariti, da smo izstopajoče površinske oblike na prikazih ZLS v vseh primerih preverili tudi na terenu. Ob že znanih terasah v notranjosti naselja in okopu, ki v celoti obdaja naselje, smo na njegovi zunanji strani prepoznali izravnavo terena, ki na jugozahodni strani najdišča prehaja v plitek jarek (*sl. 1; 3*). Gre za nezvezno, na več mestih prekinjeno in različno široko negativno topografsko obliko, ki ji ne pripisujemo obrambne funkcije, verjetneje gre za posledico obsežnega odstranjevanja zemljenega in kamninskega materiala za gradnjo okopa in zidu okoli naselja.

Gradišče je nekoč imelo dva vhoda, severnega in južnega, vsi drugi današnji prehodi skozi okop so nastali v novejšem času. Glavno vlogo pripisujemo južnemu vhodu, ker smo pred njim v obdelanih podatkih ZLS prvič v celoti zaznali kompleksno, na obeh straneh utrjeno dohodno pot v dolžini okoli 180 m in širini 4–5 m. Ta pot vodi od železarsko-talilniškega območja na Branževcu v naselje in na tej razdalji večkrat zavije, ob tem pa se na dveh mestih nanjo navezujeta prečna okopa (*sl. 1; 3*).

Uspelo nam je natančneje zamejiti tudi železarsko-talilniško območje na podlagi očitnih razlik v teksturi na prikazih ZLS. Zavzema okoli 0,6 ha veliko območje, ki je na severnem delu zamejeno še z nizkim nasipom.

Pregledi ZLS območij vseh treh grobišč prav tako prinašajo nova spoznanja (*sl. 1; 3*). Izkopano in izravnano gomilo na Dolgih delih smo poskušali nekoliko natančneje locirati. Na njivskih površinah pri Gomivnici, kjer je bila doslej znana le ena gomila, smo v njeni neposredni bližini prepoznali še eno. Na območju osrednjega gomilnega grobišča na Branževcu pa smo nekoliko natančneje locirali že veliko prej dokumentirane in opredeljene gomile in jim dodali še pet drugih, ki smo jih zaznali v okviru te raziskave (glej tudi Dular, Križ 2004, 208–212).

Analize podatkov ZLS in ogled najdišča smo na razmeroma obsežnih območjih dopolnili z geofizikalnimi raziskavami (*sl. 2*). Rezultate teh raziskav smo upoštevali pri izboru lokacij za testne sonde. Raziskave na Cvingerju so tako primer interdisciplinarnega pristopa za utrjena arheološkega najdišča na dolenjskem krasu, kjer so geofizikalne meritve že zaradi kompleksnosti naravnega okolja izjemno redke. Čeprav so bile že prej uporabljene različne metode, je bil tokrat poudarek na magnetni metodi in električni upornostni tomografiji (ERT). V prispevku predstavljena primera obravnavata uporabnost teh metod pri ugotavljanju arheoloških ostankov in nista pomembna zgolj za Cvinger, temveč širše, saj uvajata nove rešitve za raziskave obrambnih struktur (*sl. 4; 5*) in železarskih kompleksov tudi drugje v podobnih okoljskih kontekstih (*sl. 8–11*).

Z izkopom testne sonde 7 prek glavnega okopa okoli naselbine (*sl. 3; 4*) smo preverjali primerljivost rezultatov izkopavanja na tem delu z razmeroma kompleksno stratigrafijo z rezultati, pridobljenimi z metodo ERT. Meritve s to metodo, ki temelji na porazdelitvi upornosti do določene globine, smo opravili na odseku, oddaljenem 1,5 m od

roba arheološke sonde. Prepoznali smo približne dimenzije in globine ruševin obrambnega zidu, kulturne plasti in nasutja pred obzidjem, globino matične geološke podlage itn. (*sl. 5*). Vendar pa za zdaj še ne moremo razlikovati med ostalinami zidu *in situ* in ruševino zidu zaradi odsotnosti električnega kontrasta pri isti vrsti materiala.

Z metodo ERT so bili preiskani še drugi deli okopa na Cvingerju in utrdbene strukture na nekaterih drugih najdiščih, ki pa jih na tem mestu nismo vključili v razpravo, a so rezultati tudi v teh primerih dobro primerljivi z izsledki izkopavanj (Horn, Mušič, Črešnar 2019). Velika prednost metode ERT je v tem, da je povsem nedestruktivna, ponovljiva in precej manj zamudna, kot so arheološka izkopavanja. Ta metoda lahko v prihodnje močno olajša raziskave utrdbenih struktur in pripomore k primerni izbiri lokacij za arheološka izkopavanja obrambnih struktur.

Geofizikalne metode so imele pomembno vlogo tudi v raziskavi železarsko-talilniškega območja na sedlu Branževec. Na izbranih delih območja, ki je že bilo raziskano s pretočnim gradiometrom (*Geoscan FM36*) (Mušič, Orengo 1998, 157–186), so bile izvedene geofizikalne meritve z magnetometrom totalnega polja (*Geometrics G-858*) (*sl. 8–10*). Glede na zastavljene arheološke cilje so meritve, izvedene v (psevdo)gradientnem načinu, in analize rezultatov meritev na spodnjem in zgornjem senzorju dale preglednejše magnetograme (*sl. 9; 10*). K bolj izpovednim podatkom o posameznih pečeh oz. skupinah peči je prispevala razmeroma velika oddaljenost spodnjega senzorja od površine (pribl. 30 cm), kar je zmanjšalo magnetni učinek žlindre na površini in plitvino pod njo. Magnetni gradient in meritve na spodnjem senzorju so dali glede opredeljevanja peči podobne rezultate, vendar so ti na splošno jasnejši zaradi manjšega deleža visokofrekvenčnega šuma meritev s posameznimi senzorji blizu površja. Gradientne meritve in meritve na spodnjem senzorju zagotavljajo dobro ločljivost in s tem prepoznavanje magnetnih anomalij na mestih posameznih peči oz. majhnih skupin peči, medtem ko magnetne meritve na zgornjem senzorju omogočajo boljši pregled nad območji z najmočnejšimi magnetnimi anomalijami (*sl. 9; 10*).

Primerjava rezultatov magnetne metode, pridobljenih s cezijevim magnetometrom, in izkopanimi pečmi kaže na splošno dobro prostorsko korelacijo (*sl. 10*), vendar pa posamezne peči niso jasno opredeljene. Razlog je v tem, da ležijo peči na tem območju zelo blizu druga drugi in se tako magnetne anomalije sosednjih peči prekrivajo ali pa so mlajše peči vkopane v ostaline starejših in se njihovi magnetni učinki seštevajo (*sl. 9; 10; 12*). Zaradi navedenih spoznanj lahko upravičeno zaključimo, da je skupno število peči mnogo večje, kot je mogoče oceniti le na podlagi na magnetogramih vidnih izrazitih magnetnih anomalij.

Preizkusno smo metalurško območje ob tem preiskali še z metodo ERT. Na inverznih modelih ERT-profilov smo peči prepoznali kot majhne, do 1 m globoke ovalne anomalije s srednjo do visoko upornostjo pod pribl. 0,5 m debelo površinsko plastjo z visoko upornostjo (*sl. 11*). To je skladno z rezultati arheoloških izkopavanj.

Kombinacija obeh metod je dala pomembne rezultate, ki so lahko ključni za nadaljnje raziskave podobnih železarsko-talilniških območij tudi drugje. Številna potencialna najdišča so namreč že bila ugotovljena, a doslej z njih večinoma poznamo le posamezne peči ali najdbe odpadnih produktov železarstva.

Arheološka izkopavanja na Cvingerju so bila v vseh primerih vključena v interdisciplinarni pristop in pomenijo del celote, kjer uporabljene metode dopolnjujejo druga drugo. Rezultati izkopavanj torej niso pomembni le za razlago arheoloških vsebin na izkopanih območjih, temveč pomenijo izhodišče za razlago veliko širšega prostora, od koder so na voljo zgolj rezultati neinvazivnih metod. Izsledki izkopavanj tako prispevajo ključne podatke za razlago rezultatov nedestruktivnih metod.

Arheološka sonda 6 je tako pripomogla k razjasnitvi dela utrjene pristopne poti, prepoznane na prikazih ZLS (*sl. 3*). Umeščena je bila na enega od prečnih okopov. Izkop je razkril ostanke približno 4 m širokega kamnitega zidu. Čeprav je bil slabše ohranjen, je bilo mogoče jasno prepoznati njegovo zunanje in notranje lice, grajeno iz večjih kamnov, ob tem pa sta bili odkriti še dve liniji večjih kamnov v notranjosti zidu. Vmesni prostori so bili zapolnjeni z manjšimi kamni (*sl. 6; 7*).

Mesto arheološke sonde 8 je bilo na železarsko-talilniškem območju izbrano na podlagi analize rezultatov geofizikalnih meritev. Z njo smo poskušali zajeti karseda različne oblike in jakosti magnetnih anomalij. Odkrili smo ostanke petnajstih peči, ki so se razlikovale po obliki in razporejenosti. Ene so stale bolj osamljeno, ob jami za žlindro pri njih tudi nismo odkrili ostankov nadgradnje. Druge so imele bolj zapleteno zgradbo in so bile pogosto vkopane druga v drugo (*sl. 12; 13*). Pri večini smo ugotovili, da ne gre za tip peči, v katerih je bila žlindra ves čas taljenja ujeta v jamici pod pečjo, temveč da je vsaj delno iztekla oz. je bila odstranjena. Poleg tega nekateri bolje ohranjeni ostanki kažejo na uporabo kupolastih, in ne (le) jaškastih peči (*sl. 13*), kot se je domnevalo doslej (Dular, Križ 2004, 228–230).

Na eni od peči (peč 1) je bila uporabljena magnetna datacijska metoda, ki se je izkazala za uspešno (*sl. 14–17*). Analiza je bila izvedena v laboratoriju za arheomagnetno datiranje Univerze v Bradfordu. Umerjena datacija zadnje uporabe peči, ki je s 95-odstotno zanesljivostjo opredeljena v čas 640–370 pr. n. št., se ujema s predhodnimi arheološkimi dognanji (*sl. 17*). Uspešnost te metode za datacijo je še toliko pomembnejša, ker na območju taljenja ni bilo kronološko indikativnih keramičnih ali kovinskih najdb, uporabnost radiokarbonskega datiranja oglja pa je zaradi t. i. halštatskega platoja, v katerega razpon sodi, omejena (Dular, Križ 2004, str. 229, op. 40). To je pri nas prva tovrstna raziskava, ki odpira široke možnosti za datiranje žgane gline v najrazličnejših arheoloških kontekstih (ognjišča, kurišča, ostanki pogorišč, različne peči, kovaška ognjišča itn.), zlasti če ni na voljo drugih arheoloških ostalin ali najdb. Osnovni pogoj za uspešno rabo te datacijske metode je, da so vzorčeni arheološki ostanki v primarni legi oz. *in situ*.

Arheološke raziskave smo izvajali tudi v sodelovanju z jamarji Jamarskega kluba Novo mesto, in sicer v kraškem breznu, poimenovanem Cvingerska jama, ki leži sredi naselja (*sl. 3*). Čeprav samo brezno ni ključnega pomena za razumevanje najdišča, je bilo za raziskovanje zanimivo zato, ker se je okoli njega spletlo kar nekaj zgodb o neodkritih zakladih. Spoznanje, do katerega smo prišli pa je, da je bil vhod v brezno v času prazgodovinske poselitve bodisi precej manjši ali popolnoma zaprt oziroma ga morda sploh ni bilo. V preiskanem delu brezna, ki je bilo 51 m globoko,[1] namreč ni bilo arheoloških najdb (Pršina 2017).

Pričujoči članek predstavlja kratek in zgoščen pregled dela raziskav na Cvingerju pri Dolenjskih Toplicah v letih 2017–2019 in izpostavlja potencial, ki ga ima cvingersko gradišče s svojo okolico za sedanje in prihodnje raziskave. Pri tem ne kaže zanemariti bližnjih najdišč, kot so Dolenje Gradišče tik nad reko Krko (Horn et al. 2018) in druga potencialna prazgodovinska najdišča v nižinskem delu okoli Cvingerja, od katerih še nobeno ni bilo sistematično raziskano.

[1] Revidirana globina jame s 53 m (Pršina 2017) na 51 m je posledica revizije meritev; osebna komunikacija M. Pršina, Jamarski klub Novo mesto.

Illustrations: Fig. 7 (prepared by: Jernej Umek, PJP d. o. o.).

Slikovno gradivo: Sl. 7 (izdelava: Jernej Umek, PJP d. o. o.).

The research was in the years 2013–2016 conducted in the framework of the ENTRANS (*Encounters and transformations in Iron Age Europe*) project, which was led by Ian Armit. The project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 291827. The project was financially supported by the HERA Joint Research Programme (www.heranet.info) which is co-funded by AHRC, AKA, BMBF via PT-DLR, DASTI, ETAG, FCT, FNR, FNRS, FWF, FWO, HAZU, IRC, LMT, MHEST, NWO, NCN, RANNÍS, RCN, VR and The European Community FP7 2007–2013, under the Socio-economic Sciences and Humanities programme. In the following years 2017–2019 the research and other activities were conducted in the framework of the Iron-Age-Danube project, led by Marko Mele from the Universalmuseum Joanneum Graz. The project was co-financed by the Interreg Danube Transnational Programme.

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