Electric Resistivity Tomography and Magnetic Susceptibility Measurements at the Baden Culture Site Stavenice-Úsov (Czech Republic)

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ABSTRACT

Electric resistivity tomography (ERT) is a well-known geophysical method for the identification of archaeological features. It was applied at the Middle Eneolithic fortified site Stavenice-Úsov in Central Moravia (Czech Republic) to reconstruct the shape and structure of a local rampart and, if possible, identify additional settlement features in addition to those revealed by archaeological excavation. Simultaneously, mass magnetic susceptibility (χ_{mass}) was measured in selected settlement layers and fills in order to distinguish settlement and post-settlement strata and contexts destroyed or otherwise influenced by fire. The results of ERT measurement indicate that artificial terrain modifications took place on the northern, south-eastern and possibly south-western slopes of the hill. Magnetic susceptibility values indicate that the fortification, and in all probability also other settlement features, had been destroyed by fire.

1. Introduction

Along with tree logging on the northern slope of an unnamed hill between the villages of Úsov and Stavenice (Olomouc region, Czech Republic) at an altitude of 312 m and coordinates N 49°47′08.89″, E 16°59′31.21″, a rescue excavation took place in 2012 and 2013 (Daňhel 2014; Daňhel in press). This site is located in the southern part of the Hanušovice Highlands at the foot of the Mohelnice Furrow. The bedrock at the site is formed by Culmian greywackes, siltstones and shales (Paleozoic), covered by Quaternary deposits, primarily loessic loam and colluvial sediments (Koverdynský 1996).

A number of archaeological features (*i.e.* pits, structures, hearths, *etc.*; Binford 1964) dating from the Boleráz phase of the Baden Culture of the Middle Eneolithic (Podborský 1993) were unearthed at the site earlier (Daňhel 2014; Daňhel in press). This would date the settlement between 3325 and 3027 cal BC (Horváth *et al.* 2008). Two earthen, and possibly the wooden ramparts on the northern (N) slope of the hill, finished with a stone pavement rank among

these features. The fortification work was also identified by magnetometry and aerial prospection on the mild south-eastern (SE) slope of the hill (Daňhel 2014), where it had been levelled by Modern Age field tilling and made partially visible by crop marks. Part of the same fortification is in all probability distinguishable as a terracing modification on the south-western (SW) slope of the same hill (Figure 1).

As the excavations of 2012 and 2013 could not cover the entire area affected by forest clearance, a non-destructive geophysical measurement was carried out in the unexcavated area in June of 2013 and November of 2014 in order to discover additional potential settlement features and verify the spatial continuation of the rampart. Selected settlement strata have been sampled for magnetic susceptibility measurement to confirm or reject their anthropogenic origin and identify potential burned sediments.

2. Methods

Out of the range of geophysical methods used in archaeological prospection, geoelectrical methods constitute an important tool for distinguishing archaeological features from original, undisturbed ground. Electric resistivity

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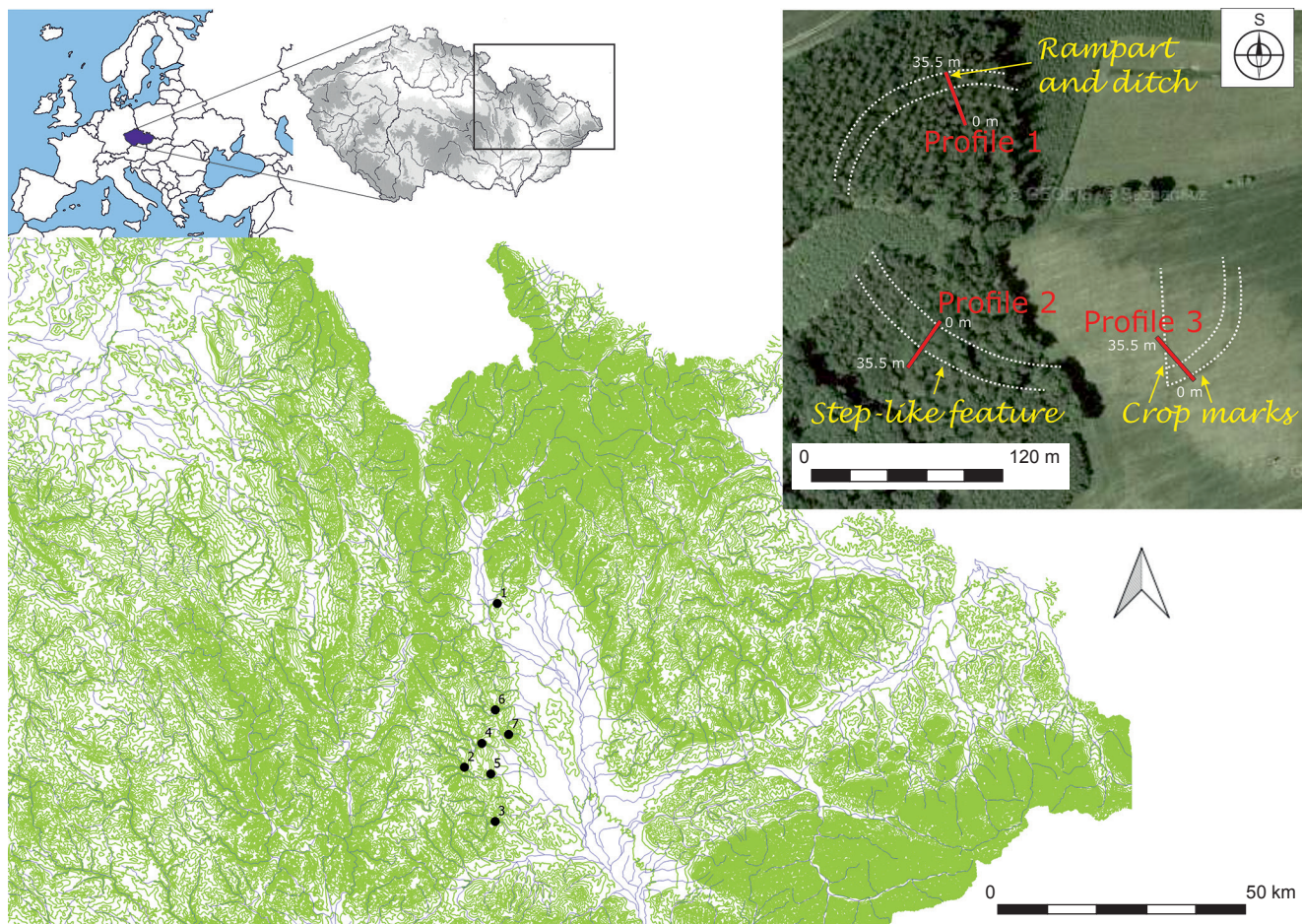
Figure 1. Location of the site at Úsov within the Czech Republic, position of the three ERT sections made by the authors and the probable location of the Eneolithic fortification (dotted line) as indicated by aerial photography, archaeological excavation (Daňhel 2014) and terrain observation. Nos. 1–7 indicate the fortified settlements of the Lower to Middle Eneolithic in Central Moravia (according to Šmíd 2007): 1 – Úsov, 2 – Stínava, 3 – Otaslavice, 4 – Bílovice, 5 – Ohrozim, 6 – Rmíz, 7 – Slatinky.

tomography (ERT) is based on the detection of variations in resistivity of rocks and subsurface materials (Kampke 1999). The method is frequently used both in sedimentology for differentiating high-resistivity sands and gravels from low-resistivity loams and clays (*cf.* Matys Grygar *et al.* 2013) and in archaeology (*i.e.* Negri, Leucci 2006; Cardarelli, Di Filippo 2009; Tsokas *et al.* 2009). It is assumed that certain archaeological features, above all stone walls and rubble, behave as resistivity anomalies. If their resistivity values differ from their surroundings, they can be easily detected. It should be mentioned, moreover, that the resistivity values of subsurface soil and colluvial sediments are affected by water saturation (Besson *et al.* 2004). During dry seasons, soil particles contain a small amount of water and the subsurface layers appear as highly resistive.

Measurement by ERT is relatively precise, fast and a wide range of electrode arrangements can be selected from. Reliable results can be expected in particular in shallow subsurface structures. ERT measurement was realized in Stavenice-Úsov using ARES geoelectrical system (GF Instruments, Czech Republic) to discover the shallow subsurface situation on the northern, south-western and south-eastern

slopes of the hill. Three ERT sections were carried out, all localized by a GPS device Ashtech Promark 500. Preceding the measurements, a series of electrodes connected with a multi-core cable were introduced into the ground using the Schlumberger array, with the electrodes spaced at 0.5 m. This minimum spacing is necessary to acquire the high resolution of the underlying ground. The northern and south-western sections were made in one day in June of 2013 to minimize the influence of weather conditions (precipitation) on the differences between single measurements. Although the third, south-eastern section was made in the autumn of 2014, the resistivity values seem to be similar to those from the other two sections. The length of the acquired sections was 35.5 metres in all cases. The maximum depth reached by the measurement, which depends on the length of the section, was approximately 7 metres in the central part of each section. Raw measurement results were processed by the RES2INV software (Geotomo, Malaysia), using the least squares inversion method. One of the aims of this study was to confirm the suitability of ERT method for distinguishing cultural sediments and anthropogenic impact into the bedrock from the underlying, original subsoil. Furthermore,

the results were compared with cultural features discovered during rescue excavation.

Additionally, soil samples were acquired from the fills of three settlement features for low field magnetic susceptibility measurement. Samples were acquired from stratigraphic units (s. u.) from within two settlement features as well as from the body of the upper rampart on the northern slope. The samples were then oven-dried for 8 hours at a temperature of 60°C and subsequently measured for mass magnetic susceptibility (χ_{mass}) with laboratory kappameter KLY-4 (AGICO Ltd., Czech Republic) with a magnetic field intensity of 300 Am^{-1}, operating frequency of 920 Hz and sensitivity of 3×10^{-8}. Mass-specific data expressed in cm^{3}g^{-1} were used. Differences in the magnetic susceptibility values of the single strata often reveal varying settlement intensity in different archaeological features. In archaeological features occupied at a certain moment, magnetic grains concentrate as a result of firing of sediments and objects (Marwick 2005) so that magnetic susceptibility values tend to be elevated.

3. Investigation results

3.1 ERT measurement

"Section 1", carried out on the northern slope of the hill 10 m east of the excavated archaeological probe (Daňhel 2014), revealed the presence of three principal resistivity units. The measured resistivity values vary in the range of 10–400 Ωm. The surface unit extending to a depth of about 50 cm is characterized by high resistivity of between 100–300 Ωm, in the lower end of the section even 400 Ωm. The underlying unit consists of a homogenous resistivity domain with extremely low resistivity values (ca 10–40 Ωm), this horizon has a thickness of 1–3 metres. The lowermost layer reveals medium to high resistivity values (ca 100–400 Ωm) and is more heterogeneous. This may be a consequence of different rock types of Culmian facies (Figure 2). The most interesting

part lies between 20 and 26 metres of the section where the lower high-resistivity layer shows two step-like features, located about 1 m under the present surface, of possibly an anthropogenic origin.

"Section 2" on the steep SW slope of the hill showed a pattern similar to Section 1, but there is a greater range in resistivity values from 20 to 600 Ωm. The surface layers are highly resistive (300–600 Ωm) which may be caused by an admixture of rock debris in the colluvial sediments. The underlying unit reveals similar resistivity values as in the first section, but the thickness of this unit is lower (about 1 m) and indicates resistivity values of between 20–55 Ωm. The bottom high resistivity unit lays only about 1–1.5 metres below the surface (Figure 3). The resistivity values here, however, are highly variable and vary between 50 and 500 Ωm. Terrain modification between 24 and 32 m of the section is not supported by rescue excavation, is less clear than in Section 1 but still distinctive and plainly visible with the naked eye.

As for "Section 3" on the mild SE slope, it was positioned so as to cut through three crop-mark lines, possibly indicating the lines of prehistoric fortification (Figure 1; *cf.* Daňhel 2014). The overall resistivity values measured here were similar to those in sections 1 and 2, within a range of 18 to 350 Ωm (Figure 4). The resistivity of the upper layers (between 0–3 metres of thickness) is highly variable (18–350 Ωm), whereas the underlying layer, evidenced between 12 and 24 m of the section, is more homogeneous (150–300 Ωm). The upper part is dotted with high-resistivity anomalies, the most distinguished between 1 and 10 and then between 25 and 30 metres of the section. In the first case, lower on the slope, the resistivity values reached a maximum of about 350 Ωm, whereas in the second case the values were slightly lower, of about 300 Ωm at most. A low resistivity feature appeared at 24 metres of the section, whereas there was a mix of higher and lower resistivity features between 11–21.5 metres.
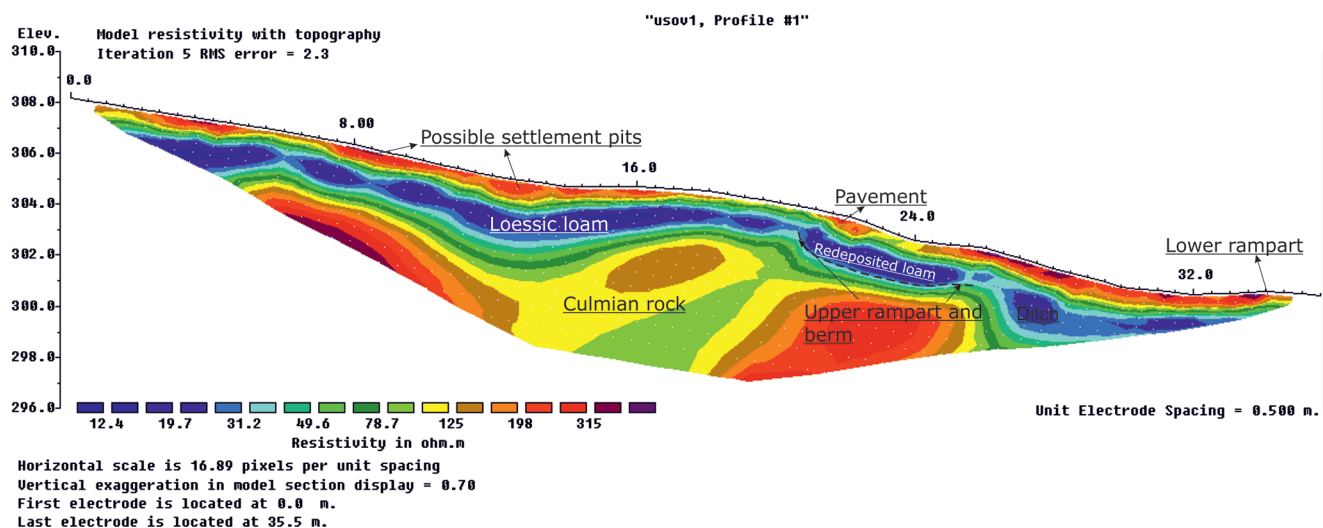

Figure 2. ERT Section 1 on the northern slope of the hill at Stavenice-Úsov.
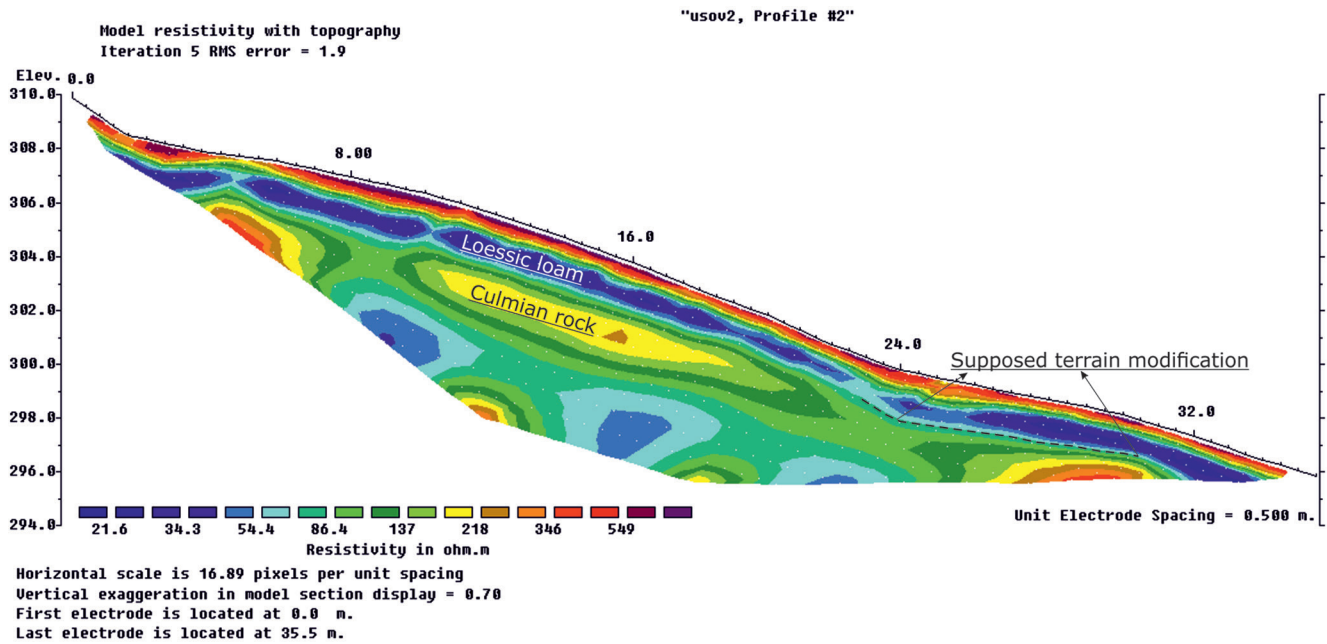
Figure 3. ERT Section 2 on the south-western slope of the hill at Stavenice-Úsov.

3.2 Magnetic susceptibility measurement

Mass-specific magnetic susceptibility (χ_{mass}) of different strata and settlement fills was measured in three archaeological features: in the settlement feature (hut?) n. 13, in the sequence of strata in square n. 23 and in the earthen rampart on the N slope. Lithologically, light to medium brown and yellow sandy soils prevail in the partially cemented infills. The magnetic susceptibility values are shown in the pictures with a diagram on the right side (Figure 5). A description of the different layers is presented in Table 1. In the feature n. 13, high χ_{mass} values were observed in layers nos. 161 and 159. The remaining layers (nos. 136, 139, 148, 160) reveal lower χ_{mass} values of between 9.59×10^{-10} and 4.83×10^{-9} cm³g⁻¹.

Magnetic susceptibility measurement in square n. 23 has shown that both the undisturbed soil (n. 101) and the most cultural and post-settlement layers have relatively low χ_{mass} values of between 7.19×10^{-10} and 1.04×10^{-8} cm³g⁻¹. The exception is layer n. 235 with the χ_{mass} value of 5.56486×10^{-7} cm³g⁻¹.

The values of magnetic susceptibility of the fills of the rampart are also elevated (2.15×10^{-7}–4.74×10^{-7} cm³g⁻¹), similar to the burned layer n. 235 from square n. 23.

4. Discussion

ERT measurements identified three principal electric resistivity layers in both Section 1 and Section 2, one at a depth of about 0–0.5 m below the present-day surface, another at a depth of 0.5–3 metres and the last one below
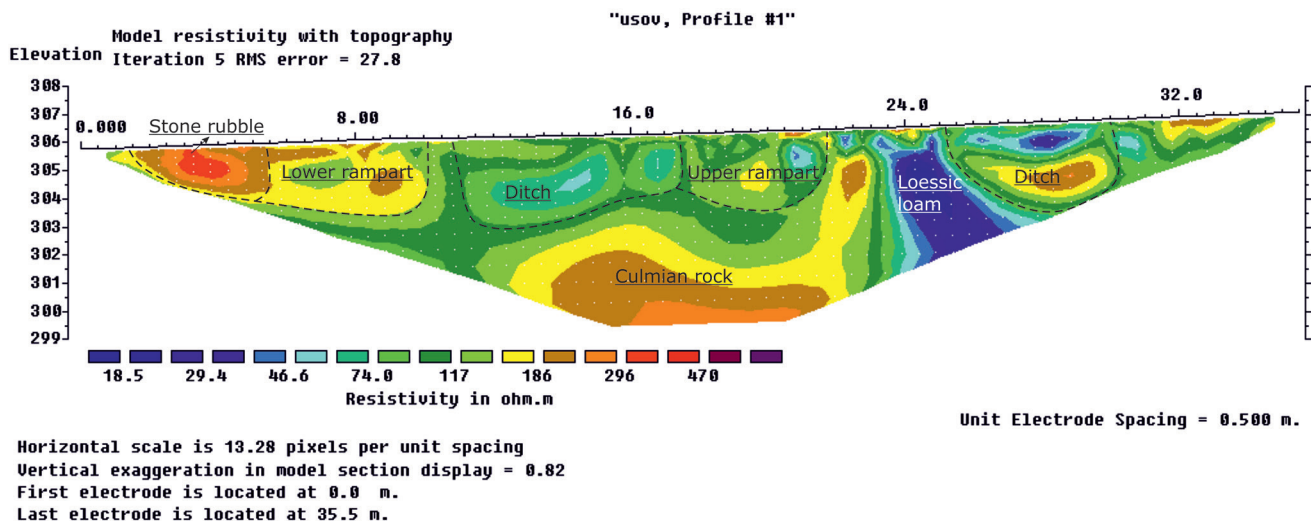

Figure 4. ERT Section 3 on the south-eastern slope of the hill at Stavenice-Úsov.

Table 1. Characteristics of the layers with the measured magnetic susceptibility (χ_{mass}) values.

	Stratigraphic unit	Description	Magnetic susceptibility
Square n. 23	s.u. 141	medium brown, firm, sandy soil, with burnt clay	3.00786×10^{-09} SI
	s.u. 164	dark greyish red, loose, sandy soil, with burnt clay	1.04229×10^{-08} SI
	s.u. 233	light greyish brown, loose, sand, with burnt clay	3.42761×10^{-09} SI
	s.u. 234	dark brownish grey, firm, sandy soil	1.15391×10^{-09} SI
	s.u. 235	dark red orange, cemented, sandy soil	5.56486×10^{-07} SI
	s.u. 101	light brownish yellow, firm, loessic soil	7.19280×10^{-10} SI
Square n. 15, feature n. 13	s.u. 159	middle brown, firm, sandy soil, with burnt clay, carbons, pottery	6.11032×10^{-07} SI
	s.u. 136	light brown, firm, sandy soil, with burnt clay, pottery, carbons, stones	1.67803×10^{-09} SI
	s.u. 160	middle greyish brown, firm, sandy soil, with burnt clay	4.83082×10^{-09} SI
	s.u. 161	light brown, compact, stones up to 3 cm in size, with soil	6.24434×10^{-07} SI
	s.u. 139	light grey, firm, clayey soil, with patches of loessic soil, carbons, stones	9.59419×10^{-10} SI
	s.u. 148	middle to light brown, firm, clayey soil, with patches of loessic soil	1.79463×10^{-09} SI
Rampart	s.u. 900	stone blocks up to 0.5 m in size, cemented with soil	2.39415×10^{-07} SI
	s.u. 252	dark yellow, cemented, sandy soil	4.73582×10^{-07} SI
	s.u. 118a	middle yellow, cemented, sandy soil	3.52832×10^{-07} SI
	s.u. 118b	middle yellow, cemented, sandy soil	2.89938×10^{-07} SI
	s.u. 101	light brownish yellow, firm, loessic soil	2.15210×10^{-07} SI

this level. It seems probable that the lowermost unit, with resistivity values between 100–400 Ωm, can be interpreted as Culmian siltstones, shales and greywackes in accordance with the geological map whereas its low-resistivity (ca 10–40 Ωm) cover is made up of loam with a loess component which covers most of the hill (Koverdynský 1996) and which made up the lowermost stratigraphic unit for most of the unearthed archaeological features (Daňhel 2014). It is well known that increased conductivity (low resistivity) is typical for loessic sediments (Rinaldi, Cuestas 2002). The top level is in all probability partially formed by stone rubble as it is again more resistive. Values of around 100 Ωm are probably related to soil whereas rubble and pit fills are more resistive (200 Ωm).

Figure 5. Archaeological sections and magnetic susceptibility (χ_{mass}) values of the sampled layers.
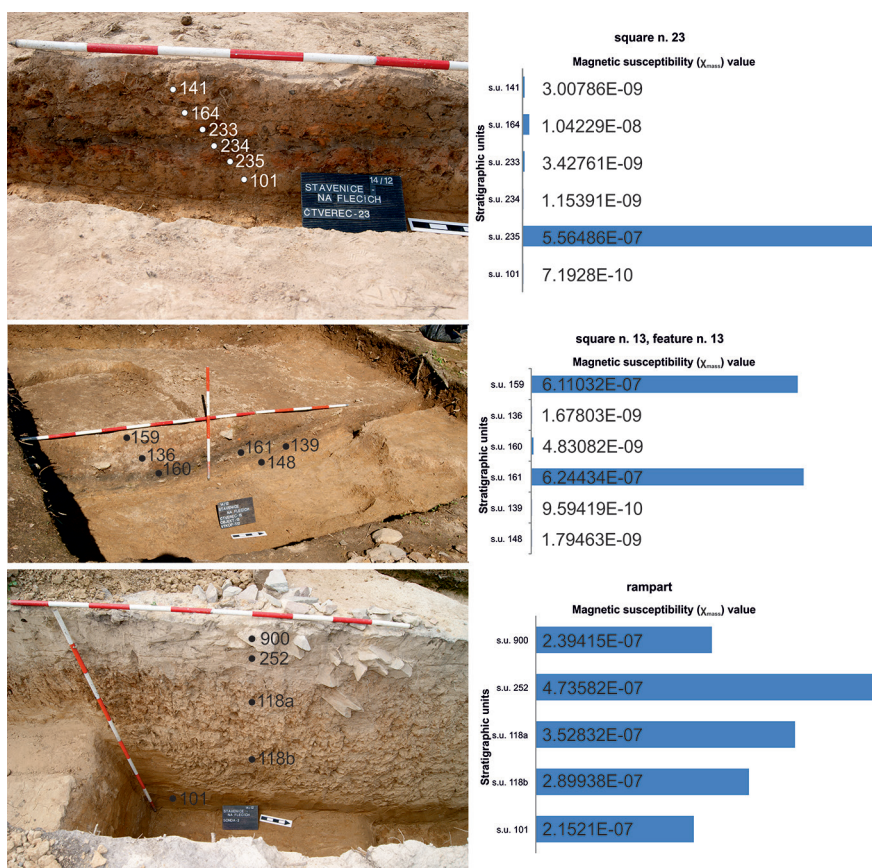
The step-like feature in the northern, lower part of Section 1 (between 20.5 and 25.5 metres) is in all probability of anthropogenic origin. It could be identical with the structure identified by archaeological excavation some 10 metres to the west (Figure 5, bottom) and can be interpreted as a remnant of the upper fortification rampart and berm (see below for analogies), with the rampart body fallen over the berm following the downfall of the settlement. At 25.5–26 metres, there is another vertical step, possibly a fortification ditch placed in front of the rampart (Figure 2). The northernmost part of the Section 1 in all probability reached part of the lower rampart as well, identified by archaeological excavation in 2013 (Daňhel, in press), indicating that at least two lines of defensive ramparts were constructed in Úsov.

Resistivity values of the *in situ* loam higher on the slope and the redeposited loam, which forms the body of the Eneolithic rampart (Daňhel 2014) do not differ. As the magnetic susceptibility values (and archaeological probe situated 10 m to the west) also indicate the anthropogenic origin of the rampart (see below), it has to be conjectured that the ERT method fails, in this case, to distinguish between two different kinds of sediments, *i. e.* a slope sediment and an artificial infill. This is probably due to post-depositional processes which lead to similar water saturation, and thus conductivity, of both sediment types.

Remnants of a stone pavement discovered by archaeological excavation on the northern slope (Daňhel 2014) are also evident in the ERT Section 1 (Figure 2). This structure forms a sharp resistivity anomaly (about 400 Ωm) and can be observed at about 22 m of the section. The pavement probably topped the rampart to form some kind of pathway.

There is also a step-like feature in the south-western ERT Section 2 (Figure 3), between 24 and 30 metres. Although its artificiality is not as clear as in the case of the northern slope and its age is uncertain as no excavation was performed here, it in all likelihood formed part of the Eneolithic fortification as well as stretching over a significant part of the SW slope and seemed to connect with the fortification lines on both the N and SE slopes (see below).

ERT Section 3 in all probability detected three fortification lines on the SE slope of the hill, indicated earlier by aerial photography (Figure 1). The outermost line of the fortification seems to have been formed by a ditch and a rampart (1–10 m of the section). The former had been filled with a high-resistivity material, possibly stone rubble, in its lower part (between 1–5.5 metres of the section; Figure 4). It is possible that stone wall may have formed part of the Eneolithic rampart and collapsed into the ditch at a later point. The maximum depth of the ditch is 2 metres below the present-day surface although Modern-Age tillage may have made it significantly shallower than it originally was.

The low resistivity (46–100 Ωm) anomaly between 11 and 17.5 metres in all probability represents another ditch, part of a second fortification line. Its depth is about 2 m again. The anomaly immediately next to it (between 17.5 and 21.5 metres of the section) with slightly higher resistivity values (up to about 200 Ωm) probably represents a second

rampart. It would seem that, similarly to the situation on the northern slope, two fortification lines had been constructed on the SE slope (*cf.* Daňhel, in press).

The third anomaly, situated higher on the slope between 25 and 30 metres of Section 3, is filled with high-resistivity (up to 300 Ωm) material in its lower part whereas the upper part of the fill is low resistive (<50 Ωm). The most probable interpretation of this feature is a third fortification ditch running in N-S direction as indicated by crop marks (Figure 1). This ditch is not parallel to the two former ones so that their contemporaneity is less certain. It should be emphasized that no data are available for the dating of these three fortification lines although the Middle Eneolithic age of at least the two outer lines is the most plausible here as they connect well with the fortification systems on the N and SW slopes. Lastly, the low-resistivity anomaly at 24 m of Section 3 is best interpreted as the natural loamy sediment cover, unearthed in several archaeological probes on the northern slope as well.

As for the magnetic susceptibility measurement, the χ_{mass} values of undisturbed natural sediments seem to be within the order of $\times^{-10}$ or $\times^{-9}$ SI units. Although anthropogenic strata do not necessarily have higher χ_{mass} values, only three types of deposits on the site have shown positive anomalies. First are fills and strata of a reddish color, in all probability burnt by intensive fire (s. u. 159 and 235) as indicated by burnt clays and carbons. Second are two stratigraphic units in settlement feature n. 13, namely gravelly layer n. 161 below a dark settlement horizon (n. 160), the former probably the remnant of a hearth. Magnetically highly susceptible unit n. 159 then probably dates back to the post-settlement period and may have originated during a forest fire. Lastly, there is the rampart body where all the sampled stratigraphic units show elevated χ_{mass} values. These high magnetic susceptibility values indicate that the rampart was probably subject to fire. It is well known that clay minerals in the ground, when heated above 250°C (easily reached by a combustion of organic material), may transform into ferrimagnetic minerals (Kapper *et al.* 2014), mainly magnetite and maghemite.

The process or reasons behind the burning of the fortification rampart are unclear although two hypotheses seem the most probable:

Burning of the fortification took place along with the violent destruction and downfall of the settlement. In this (and the latter) case, a certain or even a significant part of the fortification must have been constructed of wood.

Burning of the rampart body took place along with its construction in order to somehow improve its defensive properties.

The latter hypotheses was also held for certain Dacian (4th–3rd century BC) fortifications in SW Romania, where, however, the burning had in all probability taken place elsewhere in order to manufacture adobe, later used for the construction of the fortification (Zirra 2011). The variety in the 2nd hypothesis would explain the absence of charcoals in the fortification body in Úsov but is otherwise improbable as no adobe was used here. The first hypothesis is thus more

plausible as the burning of loessic loam probably would not have improved the properties of the fortification in any way. The absence of charcoals in the body of the rampart may be best explained by post-depositional processes, *e.g.* washing out or mechanical destruction/slope redeposition of organic material.

The presence of defensive ditches (verified meanwhile by archaeological excavation on the N slope; Daňhel 2014) and a probable wooden palisade allows us to look for analogies in other similarly dated hillforts in Central Moravia. One of them is the Rmíz hillfort (Figure 1) of both the Funnel Beaker Culture and Baden Culture (Šmíd 2007), 22 km to the SSE, where an originally stone fortification, supplemented by a fortification ditch, was gradually substituted by wooden components in the course of the Lower to Middle Eneolithic (*i.e.* 3500–2600 BC; Podborský 2006). One of the Funnel Beaker Culture defensive walls in Rmíz was accompanied by a berm and a ditch, a combination quite possible on the northern slope at Úsov as well.

Similarly to Rmíz, several fortification lines were discovered by both archaeological excavations, magnetometry (Daňhel 2014), on the basis of crop marks, and now through ERT at the Stavenice-Úsov hillfort. On the N and SE slope there seems to have been at least two parallel fortification lines constructed, formed by two ramparts with stone elements and one (N) or two (SE) fortification ditches. The probable fortification works had taken place on the SW slope as well, although here no defensive ditch was evidenced. If all these fortification works were contemporaneous, which seems probable, they encircled the top of the hill where the Eneolithic settlement was concentrated (Daňhel 2014).

Apart from Úsov and Rmíz, more Lower to Middle Eneolithic fortified sites in Central Moravia are known from Bílovice, Ohrozim, Otaslavice, Slatinky and Stínava (Šmíd 2007; see Figure 1), the two former ones dating from the same period as the Stavenice-Úsov hillfort, *i.e.* the end of the Funnel Beaker Culture and the beginnings of the Baden Culture from the turn of the Lower/Middle Eneolithic. The settlement in Úsov, in any case, indicates that the end of such hillforts may have been violent as indicated by the probable burning of the fortification ramparts.

5. Conclusion

Geophysical prospection at the Stavenice-Úsov Middle Eneolithic site has revealed a number of artificial terrain modifications, the most significant of them encountered on the northern slope of the hill. Based on the ERT measurement, terrain levelling before the heaping of the fortification rampart in the Eneolithic disturbed the local strata up to a depth of 2 metres so that overlying sediments were most likely redeposited. Similarly, significant terrain modifications took place on the SE slope of the same hill where three probable defensive ditches were identified by ERT. Artificial terrain modifications are less pronounced on the SW slope although even here prehistoric terrain levelling

cannot be excluded. It seems probable that a significant part of the hillfort was encircled by a system of ditch-and-rampart defensive lines.

Magnetic susceptibility positive anomalies were identified both higher on the northern slope in the burnt fills of the settlement pits and in the rampart body, so that the latter was probably destroyed by fire. This would indicate that a wooden construction originally formed part of the Eneolithic fortification.

The investigation has revealed the potential of both ERT and magnetic susceptibility measurement in archaeological research. The advantage of the former lies in its swiftness, easy use and low cost in comparison with archaeological excavation whereas the latter proved useful for the identification of cultural, particularly burnt, stratigraphic units.

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