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Geophysical Survey and Changes in the Use of the Cultural Landscape

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A B S T R A C T

The results of detailed and large-scale geophysical measurements in archaeology have been steadily increasing for years. The growth in measured data has also increased the need for processing and interpretation; in archaeology, this primarily means the archaeological interpretation of the measured data. However, the information contained in geophysical data includes a substantial volume or area of data of varying size or thickness of some different natural or modern anthropogenic origin (beyond archaeological interest). Like the archaeological situations themselves, these must also be identified and demarcated. The presented article consists of a wide range of case studies in which the result of a specific applied geophysical method includes both the desired interpretations of archaeological features and the differentiation and warning of other anomalies, the origin of which may or may not be unambiguous or related to the post-deposition processes of archaeological features. The purpose of selecting several different examples of results in our paper is to point out that there are many more consequences of anthropogenic activity hidden beneath the surface of the terrain of the contemporary cultural landscape than just those that archaeologists have in their viewfinder. Other anomalies in specific environments may be of natural origin or related to various geological, pedological or hydrological changes in a site's natural environment. This should be dealt with by the alternative differentiation of anomalies of various probable origins; the interpretive descriptions, diagrams or maps should not just focus strictly on the anticipated subsurface relics of the archaeological features and situations, as these are not there alone.

1. Introduction

Non-destructive geophysical methods are used primarily for the targeted detection, identification or verification of particular archaeological features and/or activities as well as entire sites. The choice of a suitable geophysical method, or a combination of several methods, is based on the given prospecting conditions as well as the requirements for distinguishing specific archaeological features and situations. More, or also less, anticipated results are then most often presented to archaeologists in the form of two-dimensional maps of the measured physical parameter changes (in some cases vertical or horizontal sections or three-dimensional images), the aim being the best possible depiction of the sought or verified archaeological situation. However, other archaeological contexts and possibly other situations may also be detected in the actual data and displayed results. While many of these correspond to various intentionally-sought relics of anthropogenic activities (archaeological situations), still others may reflect different (sometimes former, but more usually later, modern and recent) anthropogenic activities that are seen as disruptive from the archaeologist's point of view, as well as many changes in the land use or natural conditions of a site. The result of any (archaeo-) geophysical prospecting is in fact the sum of all these changes, with the heterogeneity of the measured data still increasing in the conditions of multicultural situations and the repeatedly-changed terrain of archaeological sites. In this respect there is great similarity with the explanation of the cultural landscape in terms of a palimpsest – as used in aerial archaeology (see, for example, Crawford, 1953; Cowley and Gilmour, 2005; Johnson, Ouimet, 2018; Kostyrko and Kiarszys, 2019). From the perspective of our field experience, this is reflected both in the magnetometer or electromagnetic data – and in

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another way in the result of the resistivity measurement or radar. Only some of these manifestations can be reliably distinguished as expressions of certain archaeological situations, but additional evidence of anthropogenic activities usually makes the results very difficult to read and frequently leads to ambiguous interpretations. In short, there are many subsurface and surface traces of anthropogenic activities in our intensively-exploited cultural landscape.

2. Objectives

The main objective here is above all to draw the attention of archaeological readers (archaeologists and also archaeologists working with geophysical instruments and interpreting geophysical data) to the fact that the variability of the results of geophysical measurements depends not only on the number of subsurface archaeological situations, but increasingly on the extent and intensity (for an archaeological site) of subsequent (later) anthropogenic activities and the potency of changes to the landscape. While even these can be documented today, they also need to be intentionally monitored in the geophysical results of many examined archaeological sites in various environmental conditions (Kvamme, 2003; Campana, 2009; De Smedt *et al.*, 2017; Cuenca-García *et al.*, 2018; Křivánek 2019b). Using selected examples of geophysical measurements supplemented by the relative temporal interpretation of the origin of identified situations (Figure 1), we illustrate the diversity of measured data and the very different sources of various anomalies that are a reflection of the numerous changes and superpositions in the archaeological landscape. The four selected examples are based on the results of magnetometer measurements, with two of the examples being based on the results of geoelectric resistivity measurements and the other two examples using the separate results of radar measurements. Despite the fact these are different geophysical prospecting methods (in terms of principle, method of measurement and monitoring of physical properties), we can observe the influence of changes in the cultural landscape in all the mentioned examples of results. Landscape changes also influence the interpretation possibilities of the geophysical data in their various extent and form. On the other hand, the methodological differences of the chosen geophysical methods also depend on the archaeological situations and the individual survey questions resolved at specific sites. These are therefore explicitly mentioned in each individual example.

3. Examples

3.1 Magnetometer measurement

Employed apparatus: five-channel fluxgate Magneto-arch gradiometer, Sensys (Germany), measurement density: 0.5×0.2 m, sensors FMG650B (gradient length 0.65 m), precision of results <0.2nT, positioning of data in relative coordinates (points of measured grid system 50×50 m georeferenced by GPS).

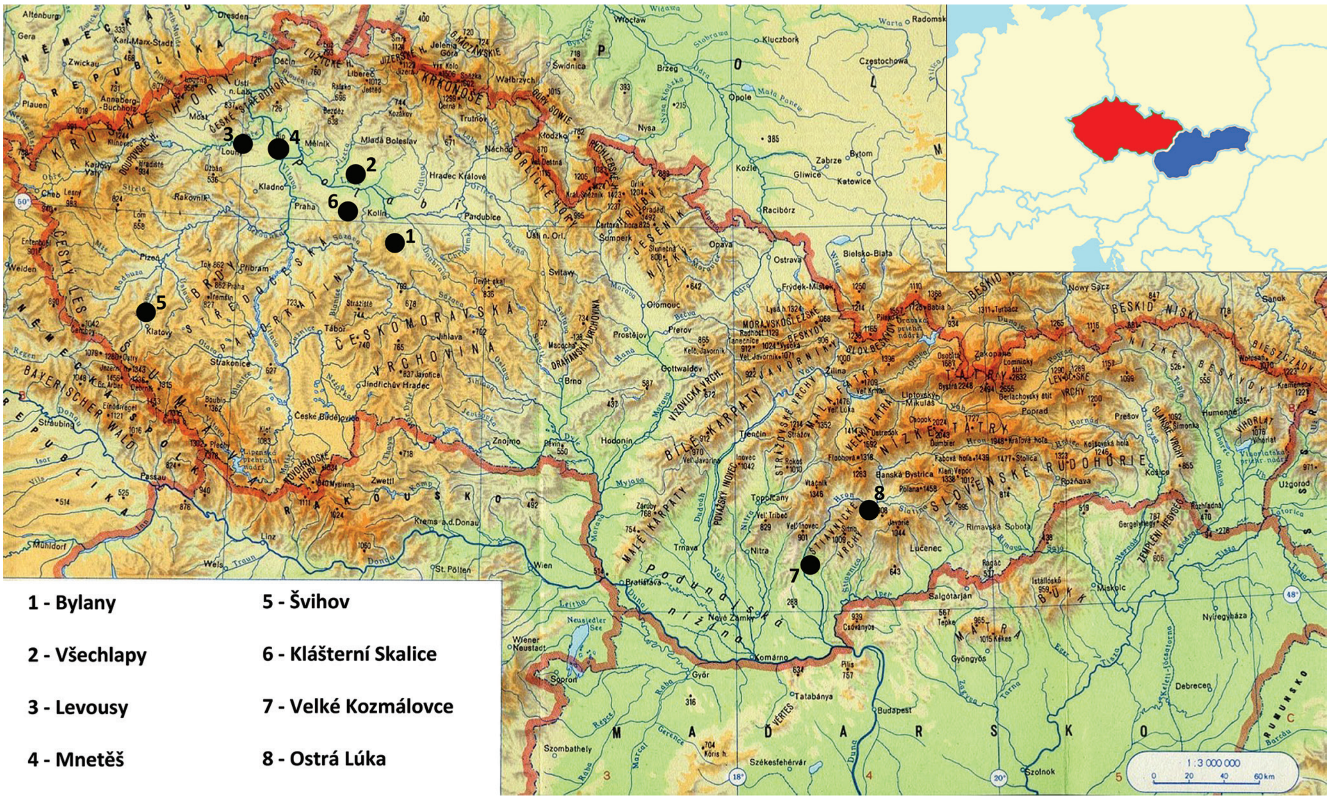


Figure 1. Map of the Czech Republic and Slovakia with the location of surveyed archaeological sites discussed in this paper.

3.1.1 *Bylany (Kutná Hora district) – Neolithic area with roundel ditched enclosures*

Main survey objective: Verification of the extent, intensity and state of subsurface preservation of situations at Neolithic roundels.
Surveyed area: c. 10.35 ha.
Geology: Quaternary loess and loess clays, southern edge of area with fluvial alluvial sediments.
Pedology: brown soil luvic (HNl).

The location of the three verified roundels in the north-western part of the extensive and long-investigated archaeological site of Bylany can serve as an example of archaeological terrain in which multiple changes and landscape uses are recorded. Some of these settlement features can also be distinguished in the results of extensive geophysical measurements. In addition to the succession of several activities from different Neolithic periods (different phases of the Linear and Stroke Pottery culture), albeit in multiple distinct spaces, it is necessary to consider the modern manifestations and consequences of anthropogenic

Figure 2. Bylany, Kutná Hora district. The result of a magnetometer survey over the area of the Neolithic ditched enclosures (a) and an interpretative diagram of the likely origin of the strongest magnetic anomalies (b).

interventions in the field (associated with previous archaeological excavations) and changes in agricultural fields cultivated for many years. Archaeological excavations were conducted here in several stages (Zápotocká, 1983; Pavlů, 1995) and, in direct connection with their results, several phases of magnetometer surveying were also carried out to verify the continuation of the ditched enclosures (Faltysová and Marek, 1993; Majer, 1995). However, three triple Neolithic roundels were only fully verified and demarcated by surface magnetometer measurements in the years 2012–2013 and 2019 (Křivánek, 2014; 2015b; 2019a). Of course, this result must also have included earlier anthropogenic activities (such as local soil erosion, ploughed-out modern field roads, terraces, field borders and also recent archaeological trenches) that are all disruptive for the employed method (Figure 2a).

Interpretation: In an attempt to distinguish the magnetic anomalies of various origins and dating, we can consider the remnants of narrow grooves running in a north-south direction and signs of rows of postholes as the relics of archaeological situations (magnetic anomalies between +2 and +5 nT; green in Figure 2b). The evidence of these relics corresponds to the results of individual archaeological test pits, where in the places of the later roundel an intensive settlement was originally established with rows of long houses from different phases of the Linear Pottery culture, and also from early phases of the Stroked Pottery culture (Zápotocká, 1983; Pavlů, 1995). It was only after the demise of the settlement that the terrain was probably used in the late phase of the Stroked Pottery culture to gradually build the first large and less-regular, triple-ditched enclosure (red in Figure 2b). In the case of two inner, parallel, circular ditches, four regularly-spaced entrances were distinguished (though only on two that are archaeologically unverified can we still see their original deviation with shorter grooves). However, magnetometer surveys have repeatedly confirmed two triple Neolithic roundels in superposition in this part of the site (magnetic anomalies varying between +1 and +6 nT). The second triple-ditched enclosure has a fully circular ground plan and it probably had three entrances, though one part of the outer ditch was not built (purple in Figure 2b). In addition to the different shape of the probably unfinished roundel, a later dating of the enclosure (thus far without archaeological verification) is indirectly supported by the detail of the superposition of the two roundels. The magnetic linear anomalies of the smaller triple roundel disrupt the outer arc of the linear magnetic anomaly of the large roundel. The third triple-ditched enclosure (with magnetic anomalies between +2 and +6 nT) was identified later and has a fully-circular ground plan with four entrances (dark purple in Figure 2b). As a result of the magnetometer survey over the entire area, we also registered a large number of anomalies and disturbances already related to ongoing natural processes and modern anthropogenic activities. The first category includes a longer-term process of soil erosion (accelerated by ploughing and field changes) above the second circular roundel (yellow in Figure 2a). The southern part of the roundel, already situated on a steeper slope, shows weak and fragmented magnetic anomalies. Other disruptive manifestations of anthropogenic origin can be recorded locally over the area of the large irregular roundel and also the triple roundel of the third confirmed in 2019. The older ones include fragments of linear anomalies (with magnetic anomalies between +1 and +2 nT) caused by later ploughed-up sunken field paths or parcels (brown in Figure 2b). Their continued presence in the 19th century or in the first half of the 20th century is also confirmed by maps of the stable cadastre and old aerial images. We must consider the latest disruptive magnetic anomalies to be the accumulation of dipolar anomalies of probable small pieces of metal arising during the archaeological excavations or the subsequent backfilling of test pits (many small bipolar anomalies +/– 5–15 nT; cyan in Figure 2b). Some areas or long lines of test pits above the verified parts of the large roundel can be distinguished in the results of the magnetogram to this day. On the other hand, due to these numerous modern-to-recent interventions in the natural terrain of the site, we can no longer identify any relics of the archaeologically-confirmed inner palisade.

Main result: The presence of three triple roundels, as well as the locally variable intensity of settlement, was verified over the entire area. However, the condition of the individual situations is greatly influenced by soil erosion on the sloping terrain, the intensity of agricultural activity, and also by various interventions in the landscape relief.

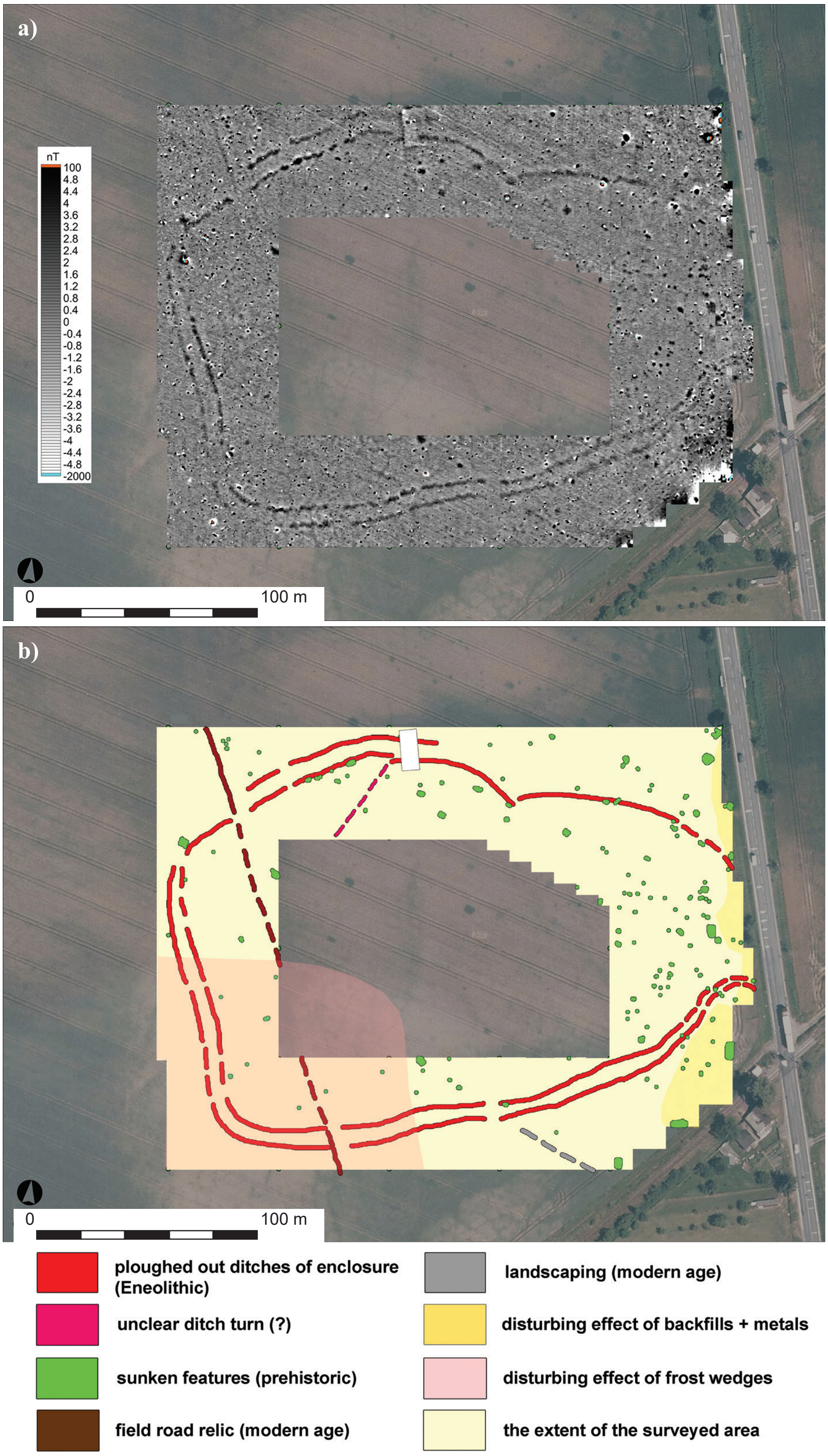
Example of a question arising from results but extending beyond non-destructive prospection: Which anomalies actually belong to the Neolithic site?

3.1.2 Všechlapy (Nymburk district) – Eneolithic ditched enclosure

Main survey objective: Spatial delimitation of the shape and scope of the Eneolithic ditched enclosure newly verified by archaeological test pits.
Surveyed area: c. 3.9 ha.
Geology: Mesozoic marlstone with local limestone.
Pedology: chernozem modal (CEm).

We frequently encounter the difficulties of safely distinguishing prehistoric archaeological situations from modern changes in intensive agricultural land use in fertile lowland areas. One of the most recent examples is the result of a magnetometer survey of the Eneolithic ditched enclosure near Všechlapy in the Nymburk region. Additional research aimed at defining the ground plan of a double irregular-ditched enclosure was carried out in direct connection with the archaeological excavation of the site with a test trench as part of the ongoing project at the Department of Archaeology of the University of West Bohemian in Pilsen (Krištuf *et al.*, 2019). The investigation from 2018 confirmed two ditches of a non-identical shape dating to the Middle Eneolithic. The large area magnetometer survey was finished only after the completion of the archaeological excavation trench at the site (Figure 3a). The survey of the whole shape of the enclosure for the archaeologists was aimed at verifying the idea of an irregular and probably unfinished double-ditch enclosure.

Figure 3. Všechlapy, Nymburk district. The result of the magnetometer survey over the area of the Eneolithic ditched enclosure (a) and an interpretative diagram of the likely origin of the strongest magnetic anomalies (b).



But particular areas along the enclosure were ploughed to a varying extent and influenced the quality of the measured data. The inner area was not verified due to deeper ploughing.

Interpretation: The result of the magnetometer measurement clearly reflects the current state of preservation of the ditches in the subsoil that is appreciably and unevenly affected by soil erosion. According to archaeological excavation and field artefact collections, the Eneolithic ditched enclosure of a truly-less-typical shape (with magnetic anomalies between +2 and +6 nT) is the oldest archaeological situation in the magnetogram (red in Figure 3b). The double-ditched enclosure was probably not fully completed, as only one ditch arc is visible in the north-eastern section. In the following sections, both ditches are obviously in different positions of the enclosure at unequal distances and are not parallel along the entire perimeter (according to the first results from the test trench, the two ditches do not even have the same structure). A relatively large number of mostly irregularly distributed interruptions in the ditches can be identified around the entire perimeter, in some places in both, in others only in one of them. Irregular to isometric anomalies (magnetic anomalies between +3 and +8 nT) were also confirmed in the inner and outer part of the monitored segment of the field, which, in agreement with surface surveys and finds from the area, can document settlement features from later prehistoric periods (green in Figure 3b). Whether these were settlement features from a later period after the disappearance of the ditch, or also some sunken situation existing at the time of the enclosure's use, cannot be established on the basis of a single non-destructive prospecting method. We know from old maps (maps of the stable cadastre from the middle of the 19th century) that in the modern past of the area there was also a different division of the terrain, layout of the fields, parcels and field paths, which were only completely ploughed up in recent decades (low, narrow, linear and interrupted anomalies between +1 and +2 nT; brown and grey in Figure 3b). Locally, therefore, we can also attribute several interruptions of the ditch enclosure to modern changes in the terrain. The most striking rectangular interruption of the ditches in the north is the result of another fill of the aforementioned archaeological test pits from 2018 (negative magnetic anomalies over test pit filling between –1 and –3 nT). The modern-to-recent consequences of agricultural activities have led, and continue to lead, to uneven soil erosion, and recent local landslides and terrain modifications (railways, roads) have also made it difficult to safely distinguish the entire ground plan and entrances to the prehistoric enclosure (many small bipolar anomalies +/– 4–15 nT; yellow in Figure 3b).

Main result: The atypical shape of the double-ditched enclosure, multiple interruptions and signs of further settlement are identified on the accessible area. However, the state of individual situations is partly fragmented, mainly due to highly-intensive agricultural activity.

Example of a question arising from results but extending beyond non-destructive prospection: Which interruption of the ditched enclosure came from the Eneolithic period?

3.1.3 Levousy (Litoměřice district) – grounds of hillfort with multi-phased use

Main survey objective: Verification of the spatial variability of settlement, internal division and condition of the site with multicultural and multifunctional use.
Surveyed area: c. 9.8 ha.
Geology: Mesozoic calcareous marlstone and claystone, southern edge of area with clayey limestones.
Pedology: chernozem carbonated (CEc).

We also encounter the repeated use of landscapes of various scope, character and purpose on the grounds of different fortified sites; such changes in the cultural landscape are apparent, for example, from geophysical surveys of the Levousy fortified settlement. Although the dominant promontory on the edge of the significantly elevated terrace has undergone significant changes in modern history and some parts of the fortified site have not been preserved (modification of the terrain by gardens and local stone mining), relics of various activities beneath the cultivated ground have not been completely erased. However, assigning the many magnetic anomalies from the magnetometer survey to one of the numerous cultural periods and uses of the site is difficult and limited in terms of the possibilities (Zápotocký, 1992). For example, many oval sunken features (for example, pits), from different prehistoric, mediaeval and modern periods have a similar sandy soil fill at the site (and very similar magnetic anomalies between +2 and +8 nT). Archaeological excavations in test pits across the inner transverse rampart of the fortified settlement (Váňa, 1973) show that the strategic position above the southern course of the Ohře River was inhabited in the Neolithic, the Eneolithic, and in various periods of the Bronze Age and Iron Age. The first fortification of the highland settlement at the site is dated to the Late Bronze Age, whereas the expansion and further division of the fortified area of the early mediaeval hillfort occurred during the course of the 9th and 10th centuries (Křivánek, 2019c). However, the actual differentiation of the true origin of the positive linear magnetic anomalies is also complicated by other military uses of the location in the modern period (Figure 4a).

Interpretation: The results of the magnetometer survey can only be used to roughly (and tentatively) classify several smaller groups and lines of sunken settlement pits into the earliest broad period of unspecified agricultural prehistory (green in Figure 4b). Their irregular distribution, sometimes consistent with the vegetation marks from aerial photographs, can only suggest the fragmented preservation of the ploughed-up evidence of a prehistoric settlement. The relics of the oldest fortifications of the hillfort from the Late Bronze Age cannot be reliably distinguished in the results. However, it is possible in the results to trace several lines of possible fortifications or the division of the internally-structured hillfort, with a probable dating of the relics of the fortifications to the Early Middle Ages (blue and red in Figure 4b). Naturally, in some cases, a dating to later periods of agricultural prehistory cannot be ruled out, but this can no longer be resolved by the non-destructive prospecting method. From the magnetometer measurements in the western to south-western part of the fortified site, we identified fully ploughed-up relics of the originally early-mediaeval perimeter rampart (blue in Figure 4b). The remnants of the ploughed-up rampart had an earth-stone structure or also a front stone face with, among other things, neo-volcanic rock from the Bohemian Central Mountains (for example, basalts or phonolites; many small bipolar and high magnetic anomalies +/–10–40 nT).

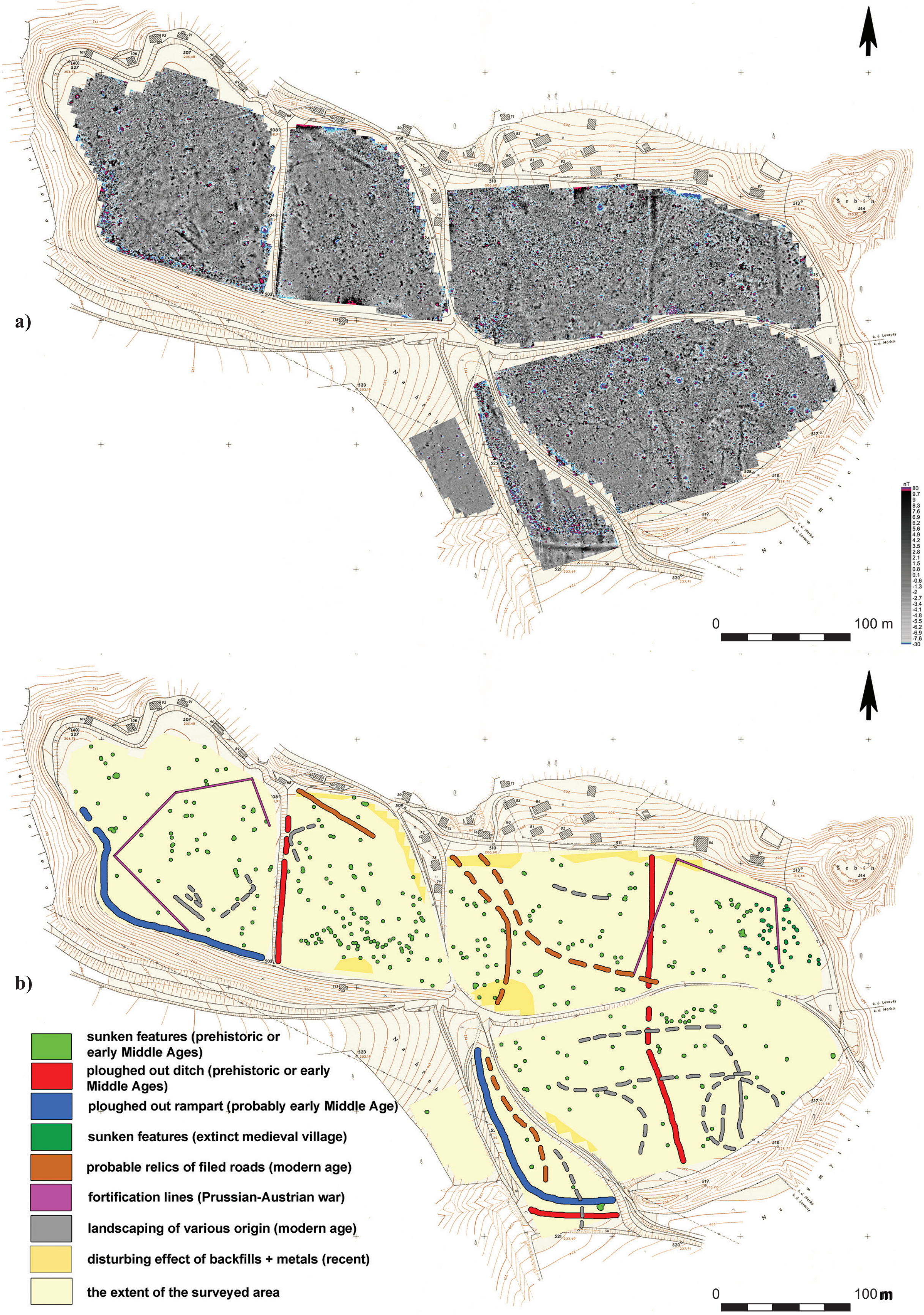


Figure 4. Levousy, Litoměřice district. The result of the magnetometer survey over the area of the prehistoric and early mediaeval fortified settlement (a), an interpretative diagram of the likely origin of the strongest magnetic anomalies (b) and second alternative interpretative diagram from the same data (c).

c)

Figure 4. Levousy, Litoměřice district. The result of the magnetometer survey over the area of the prehistoric and early mediaeval fortified settlement (a), an interpretative diagram of the likely origin of the strongest magnetic anomalies (b) and second alternative interpretative diagram from the same data (c). (*Continuation*)

The original above-ground rampart along the edge of the promontory was confirmed at the southern perimeter of the acropolis and also by a combination of magnetometer and resistivity measurements at the south-western edge of the southern bailey, where the further continuation of the rampart to the east is still preserved in the forest. Another division of the hillfort by a ditch was distinguished in the eastern bailey (linear magnetic anomalies between +3 and +6 nT; red in Figure 4b). Here, and in the southern bailey, we can locally observe groups of small, oval, magnetic anomalies indicating sunken settlement features (magnetic anomalies between +3 and +8 nT). However, over most of the inner area of the fortified site, it is difficult to distinguish between the traces of probable settlement activities dating to agricultural prehistory, the Early Middle Ages and also later periods. In the Middle Ages, Šebín Castle was built in the rugged wooded terrain east of the fortified area (Křivánek, 2015a). A concentrated sunken situation at the easternmost tip of the eastern bailey of the hillfort (with numerous finds of mediaeval pottery) may indicate relics of a smaller mediaeval settlement in the western extramural area of the castle (dark green in Figure 4b). Nevertheless, the terrain of the fortified settlement was also changed and modified in later periods. The areas of the acropolis and the eastern foregrounds were used as a fortified firing position during the Austro-Prussian War in the second half of the 19th century, and the situation has also been repeatedly documented by aerial survey. Several straight and angled narrow lines of abandoned firing positions and possible relics of redoubts can also be traced on the magnetogram (purple in Figure 4b). In the eastern bailey of the fortified settlement, the course of such polygonal lines in superposition disrupts the wider ditch dividing the area to the east of the fortified settlement into two extramural areas. Further complications in the possibility of interpretation of the final result of the magnetometer measurement are related to even more recent changes in the later agricultural use of the areas (grey in Figure 4b). According to a comparison with old maps, the broad and magnetically-inhomogeneous linear anomaly beneath the terrace (a relic of the original rampart) east of the acropolis represents a manifestation of subsoil remains of a ploughed-out sunken field path (brown in Figure 4b), which apparently had a course similar to the ditch originally in front of the rampart; although it cannot be distinguished today, the ditch was confirmed in an early archaeological excavation (Váňa, 1973). Recent local magnetic disturbances are also recorded above the northern to north-western edge of the promontory (yellow in Figure 4b), where fenced gardens were established on the slopes of the terraces.

In the example of this multi-cultural site, we can demonstrate the ambiguity of the limited interpretation of magnetometer survey data. We can also assume, for example, that modern archaeological situations and activities will be best preserved subsurface and that activities and relics of situations from the early Middle Ages or prehistory will be preserved only in places undisturbed by modern activities. Further, a number of magnetic anomalies from the site can be interpreted in another alternative way. We can identify fortified firing positions from the Austro-Prussian War on the magnetogram in all straight lines and possible relics of redoubts (violet in Figure 4c). In the case of magnetic isometric anomalies within military fortifications, we can also assume a connection with modern military activity (dark purple in Figure 4c). Apart from military fortifications, it is already possible to assume for isometric anomalies any (prehistoric, early mediaeval, mediaeval or modern) sunken features (green in Figure 4c). The significant wider line anomalies within and especially around the perimeter of the site can already be interpreted in the same way (blue and red in Figure 4c). Other irregular linear anomalies can also be interpreted in general as relics of mediaeval or modern agricultural land use (brown in Figure 4c).

Main result: The ploughed-up relics of various activities, including the remains of fortifications, divisions, various settlements, possible paths and also military fortifications, were distinguished over nearly the entire area. However, the state of individual situations is mostly fragmented, with the low possibility of dating the origin of sunken features without excavation. From non-destructive results, we could make some relative preliminary dating (older/younger) in the case of some linear superpositions, or in the case of some linear pit arrangements with analogies in sunken features in the region.

Example of a question arising from results but extending beyond non-destructive prospection: How many times was the site actually fortified?

3.1.4 Mnetěš (Litoměřice district) – pseudo-locality

Main survey objective: Verification of the origin of linear vegetation marks from aerial images.
Surveyed area: c. 0.75 ha.
Geology: Mesozoic marlstone and Quaternary fluvial alluvial sediments.
Pedology: chernozem carbonated (CEc).

Complications with the interpretation of measured geophysical results due to changes in land use are also encountered on land with much lower settlement activity and use. One example is the result of verification of the assumed semi-rectangular ditched enclosure on the basis of the positive result of aerial images in the cadastral area of Mnetěš. In the last decade of the 20th century, a broken line resembling a ditched enclosure was distinguished by vegetation marks. Several similar broken-line ditch enclosures come from the broader Mt. Říp region, so the issue of the origin of the ditched enclosure presumed from aerial photographs was resolved using non-destructive methods. However, thanks to the later construction of the motorway, part of the field verified by magnetometer survey was demarcated by a section of the motorway and by a small regulated water source, *i.e.*, the "Věšín Gully" (Figure 5a). Surface collections conducted in cooperation with archaeologists from the Institute of Classical Archaeology in the Faculty of Arts at Charles University in Prague (Kút *et al.*, 2014) produced only individual fragments of pottery from agricultural prehistory and the modern period. Prehistoric settlements and burial grounds are also known in the vicinity of the D8 motorway, Straškov and Mnetěš, from earlier aerial and geophysical prospection in the southern Mt. Říp micro-region.

Interpretation: Although nothing from the results of the magnetometer measurement confirmed the presence of the semi-rectangular ditched enclosure, many magnetic anomalies were identified in the studied area (Figure 5a). However, their origin is entirely different (Křivánek, 2012). The earliest irregular polygonal anomalies can be explained as changes in the distribution of soil of a natural origin – frost wedging (brown in Figure 5b). Frost wedges are caused by the natural cracking of freezing shallow gravel-sand subsoil. These cracks gradually widen due to climate change and are filled with more humus and magnetic topsoil. In the magnetometer prospecting results, they then appear as irregular polygonal positive magnetic anomalies of similar amplitudes as, for example, ditch fills (between +3 and +8 nT). Polygonal magnetic anomalies from frost wedging are common on various gravel-sand terraces of the Mt. Říp region and have also been geophysically identified at archaeological sites in the past (*e.g.* Hašek and Pavelčík, 2000; Křivánek, 2004, Figure 2.26; Tengler, 2016). Only a few isolated isometric (oval or semi-oval) anomalies can be regarded as possible later, most probably prehistoric, signs of low-intensity settlement (green in Figure 5b). However, most of the verified areas are dominated by a network of narrow linear magnetic anomalies (varying between +/– 5–25 nT), which are clearly of recent origin and connected with the local amelioration system (cyan in Figure 5b). These are from digging related to soil improvement (under nationally-coordinated widespread "field drainage" programmes), probably with preserved subsurface ceramic (magnetic) pipes (*e.g.* Štér, 1958; Piperková, 2002; Vašků, 2011).

Main result: The origin of linear vegetation marks from older aerial photographs was very probably related to recent major land improvement activities. Although we cannot fully rule out the existence of a ditch in general (no magnetic anomaly was detected indicating a ditch), the existence of a broken ditch is not probable even with regard to the present location in the lowland waterlogged terrain around the regulated stream.

Example of a question arising from results but extending beyond non-destructive prospection: Can we detect ditched enclosures in intensively reclaimed terrain? Perhaps in some cases we can, in others we cannot. Everything depends on many geological, pedological, agricultural, landscape remodelling and other factors.

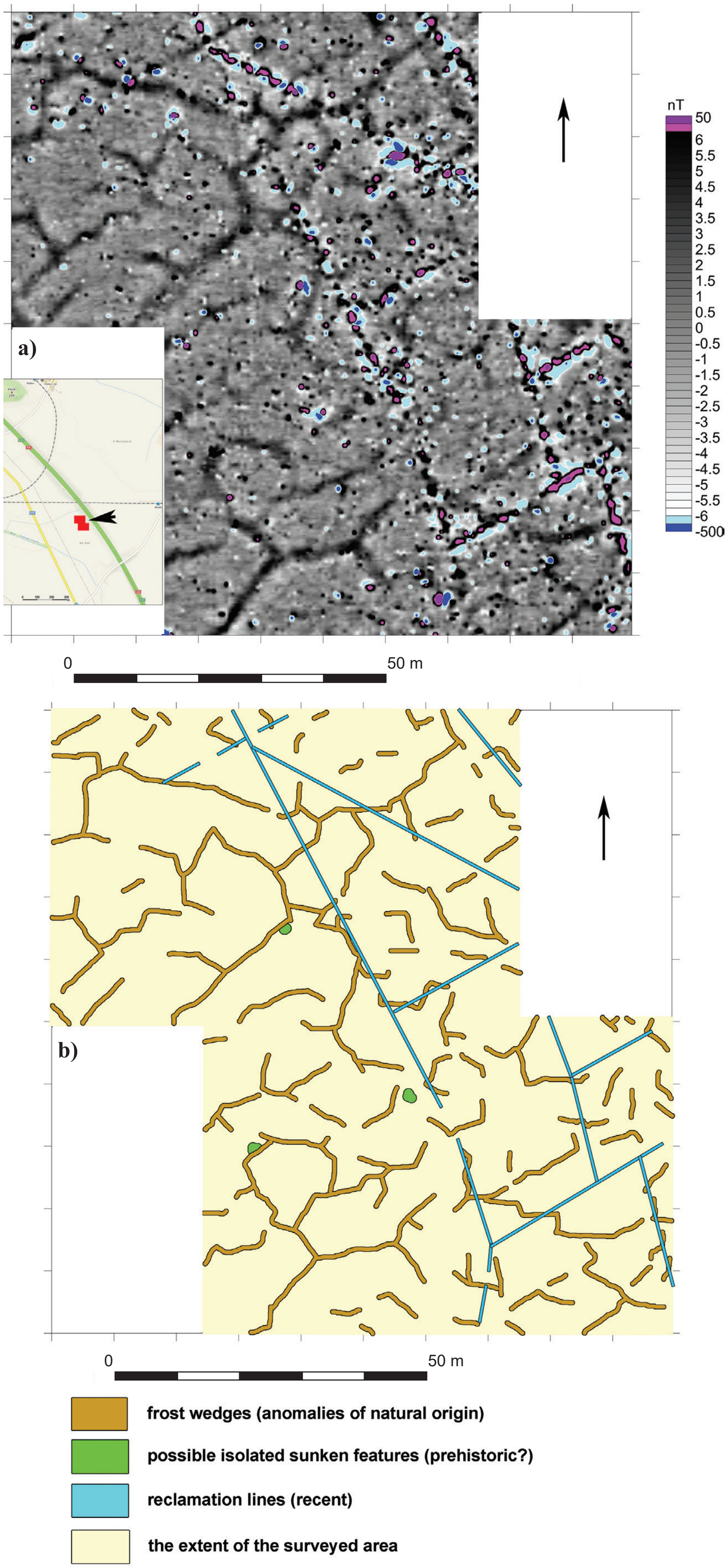


Figure 5. Mnetěš, Litoměřice district. The result of a magnetometer survey over the area of the presumed semi-rectangular ditched enclosure with the survey area on the map marked (a) and an interpretive diagram of the likely origin of the strongest magnetic anomalies (b).

3.2 Resistivity measurement

Employed apparatus: RM-15, Geoscan Reseach (UK), Wenner electrode array A0.5M0.5N0.5B (at Švihov also A1M1N1B), measurement density: 1×1 m.

3.2.1 Švihov (Klatovy district) – Švihov Castle annex
Main survey objective: Verification of potential defunct buildings in the castle's annex.
Surveyed area: c. 0.38 ha.
Geology: Quaternary fluvial and alluvial sediments.
Pedology: fluvial soil (FLg).

Transformations of the original terrain, which are manifested in the results of archaeo-geophysical surveys in a highly disruptive manner, are also encountered at fortified mediaeval castles. The results of geoelectric resistivity measurements on the grassy area of the fortified annex of Švihov Castle contain a number of relics of mediaeval, modern or recent situations that are difficult to distinguish. The resistivity survey of the castle annex was brought about by the interest of archaeologists (*e.g.* Durdík, 1995) in connection with new excavation results obtained by the Plzeň branch of the National Heritage Institute (e. g., Foster, 2009). The area was studied at two depth ranges (up to 0.5 and up to 1 m).

Interpretation: Despite the relatively short period the castle was used, we can, after consultation with an archaeologist, distinguish several different origins and probable dates of the occurrence of various resistivity anomalies (Figure 6a). The oldest manifestations of relics of archaeological situations of defunct buildings in the northwest annex corresponding to the period of use of the central castle are thought to be linear and right-angled anomalies of increased resistivity (apparent resistivity between 250 and 650 ohmm) conspicuously concentrated on the elevated terrain in front of the bridge to the inner castle (blue in Figure 6b). Relicts of the foundations of what appears to have been a square tower were identified (remarkably similar to the ground plan of the square tower in the central castle), with a possible continuation of the defunct buildings or paved paths towards the entrance gate to the annex. Resistivity measurements with a greater depth range confirmed the deeper placement of stone settings, while also locally confirming the nearby bedrock – local slate outcrop in the middle of river sediment layers (apparent resistivity between 200 and 350 ohmm; purple in Figure 6b). A circular high-resistivity anomaly (between 240 and 350 ohmm) at the southern edge of a barn, apparently a relic of an unknown fortification, possibly comes from a similar mediaeval period (according to T. Durdík, it could have been the stone rubble of a circular stone tower). Anomalies of a higher resistivity manifested only in a fragmented manner along the buildings of today's built-up annex (possible signs of the original foundations of the bastions in the outer fortifications) are apparently related to the subsequent period of development of the fortified castle annex. The wider foundation of the entrance gate to the annex was confirmed by a similarly fragmented anomaly. However, it was not possible to distinguish the defunct mediaeval buildings (if there actually were any) in the central part of the annex, which is now open and covered with grass. The interpretation of the data here was heavily influenced by the anomalies of low resistivity (varying between 20 and 80 ohmm) of recent origin caused in various periods of the modern use of the castle. One such period was the beginning of the second half of the 20th century, when the castle grounds were used by a collective farm with a pigsty on the site of the filled castle ditch in the annex. The foundations of several wooden buildings (aptly termed parasitic building, in the case of castles, as used by archaeologist T. Durdík) that were later demolished were reflected in the results by several angled bands of the lowest resistivity (yellow in Figure 6b). Multiple linear anomalies of low-resistivity with several diversions to annex buildings are of an even more recent dating. These lines were caused by new water mains accompanied by linear trenches with a clearly different conductive backfill (cyan and green in Figure 6b). Recent interventions in the terrain of the castle annex from the perspective of archaeological situations deeply affected the possibility of interpretation of the geophysical survey.

Main result: Defunct buildings were verified in several places in the castle annex. However, the state of the subsurface situations of the entire annex was fundamentally disrupted by several other recent activities and drastic interventions in the terrain.

Example of a question arising from results but extending beyond non-destructive prospection: How many different periods are recorded in the history of the subsoil of the castle's annex?

3.2.2 Klášterní Skalice (Kolín district) – grounds of a former monastery
Main survey objective: Verification of the presumed relics of the defunct buildings of the accessible remnant of the former monastery.
Surveyed area: c. 0.13 ha.
Geology: Quaternary eolic sediments and loess soil, in the vicinity sources of Proterozoic mica-schist.
Pedology: chernozem modal (CEm).

The grounds of defunct monasteries also represent a very specific group of various sacred buildings as well as other activities, the collective preservation of which to the present day can be considered exceptional. Their state of surface preservation was influenced by many fundamental circumstances, from their location, the length of time the specific order was in operation, social changes, military conflicts, up to ongoing changes in settled areas, the development of new aristocratic residences and socio-political and ownership-user changes of similar buildings in the second half of the 20th century. In the built-up areas of municipalities, the state of preservation of the remains of above-ground (though often only subsurface) sacred architecture was most significantly influenced by the local use of defunct areas (agricultural cooperatives, farms, warehouses, *etc.*) and the activities in these areas

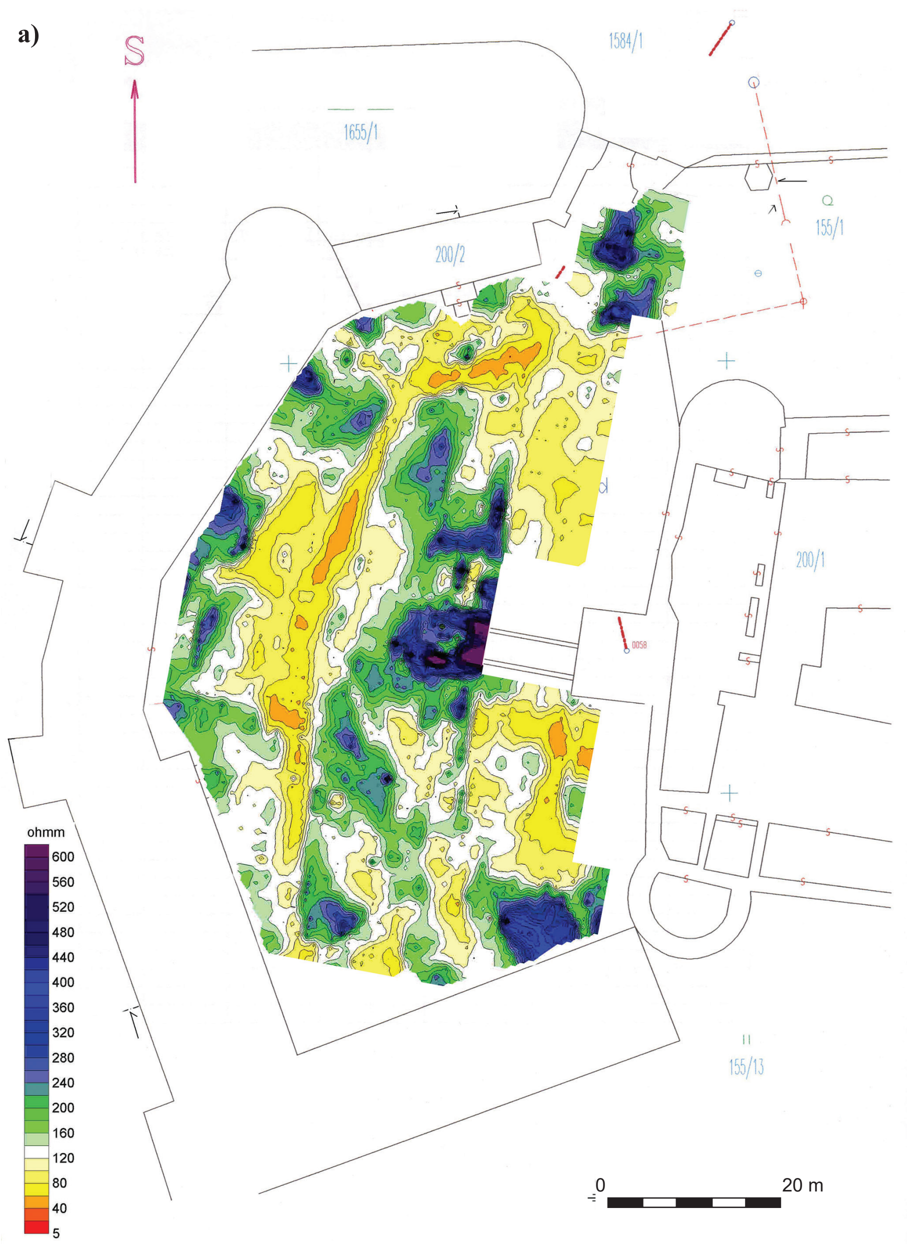


Figure 6. Švihov, Klatovy district. The result of the geoelectric resistivity survey of the annex of Švihov Castle (a) and the interpretive scheme of the likely origin of the strongest resistivity anomalies (b).

(reconstruction, ground levelling, backfilling, the removal of ruins, *etc.*). Most modern changes to the original terrain listed above also apply to the area of the defunct monastery in Klášterní Skalice. This monastery was located on a large area directly in today's urban area, but the land of the defunct monastery spread over a number of plots is privately used in a variety of ways and is currently inaccessible. An example of the result of a separate resistivity survey comes from a grassy and publicly accessible area with the only surviving pillar from the transept of the original monastery church near the north corner of the château. The rest of the perimeter walls of the church ruins were still preserved in the terrain at the beginning of the 19th century (see the drawing by the painter Pařízek from 1807 in Figure 7a), but in 1840 the above-ground relics were already definitively removed (Vlček *et al.*, 1997, pp.300–302; Kroupa and Žižka, 1990). Despite the obvious repeated terrain modifications, the results suggest that some parts, even below the surface, may hide the last indications of the buildings from the defunct monastery.

Interpretation: The scope of resistivity measurements with a shallow depth range was uncontrollably limited by the extent of the accessible area delimited from the east by the perimeter wall and from the west by the terrace break and the modified access road to the château. The approximately trapezoidal-shaped area is dominated by two highly distinct groups of resistivity anomalies: anomalies of high resistivity closer to the perimeter wall and the château and an area of low resistivity further north (Figure 7a). Thanks to a possible comparison with several older plans of the partially preserved monastery and also period paintings, we can assume that the sources of these resistance anomalies may (tentatively without archaeological verification) be related to the subsurface rubble of monastery buildings. In the case of linear and partially-angled high resistivity anomalies

Figure 6. Švihov, Klatovy district. The result of the geoelectric resistivity survey of the annex of Švihov Castle (a) and the interpretive scheme of the likely origin of the strongest resistivity anomalies (b). (*Continuation*)

(between 150 and 250 ohmm) closer to the château, and also the perimeter wall continuing to the east, it is possible to assume manifestations of subsurface stone rubble (perhaps even relics of masonry in places) of probably several possible stone foundations of monastery buildings (blue and green in Figure 7b). With regard to the conspicuously-identical orientation with a broad low-resistivity anomaly, we can also not rule out a complex of several related buildings that no longer have remains above the surface. Some anomalies are also almost parallel to the measurement profiles, but because of the strict adherence to the same electrode orientation across all profiles, we do not think that the data would be affected by the measurement method. A comparison with the preserved image from 1807 contributed to the most probable interpretation of the striking rectangular and large-scale anomaly of low resistivity (between 30 and 60 ohmm; see Figure 7a). The painting showed that the ruins of the large monastery church were still standing on the studied area at the beginning of the 19th century. The area of low resistivity (c. 35 m long and c. 18 m wide) may indicate the location and orientation of the original monastery church (light green in Figure 7b). The fact that high resistivity values

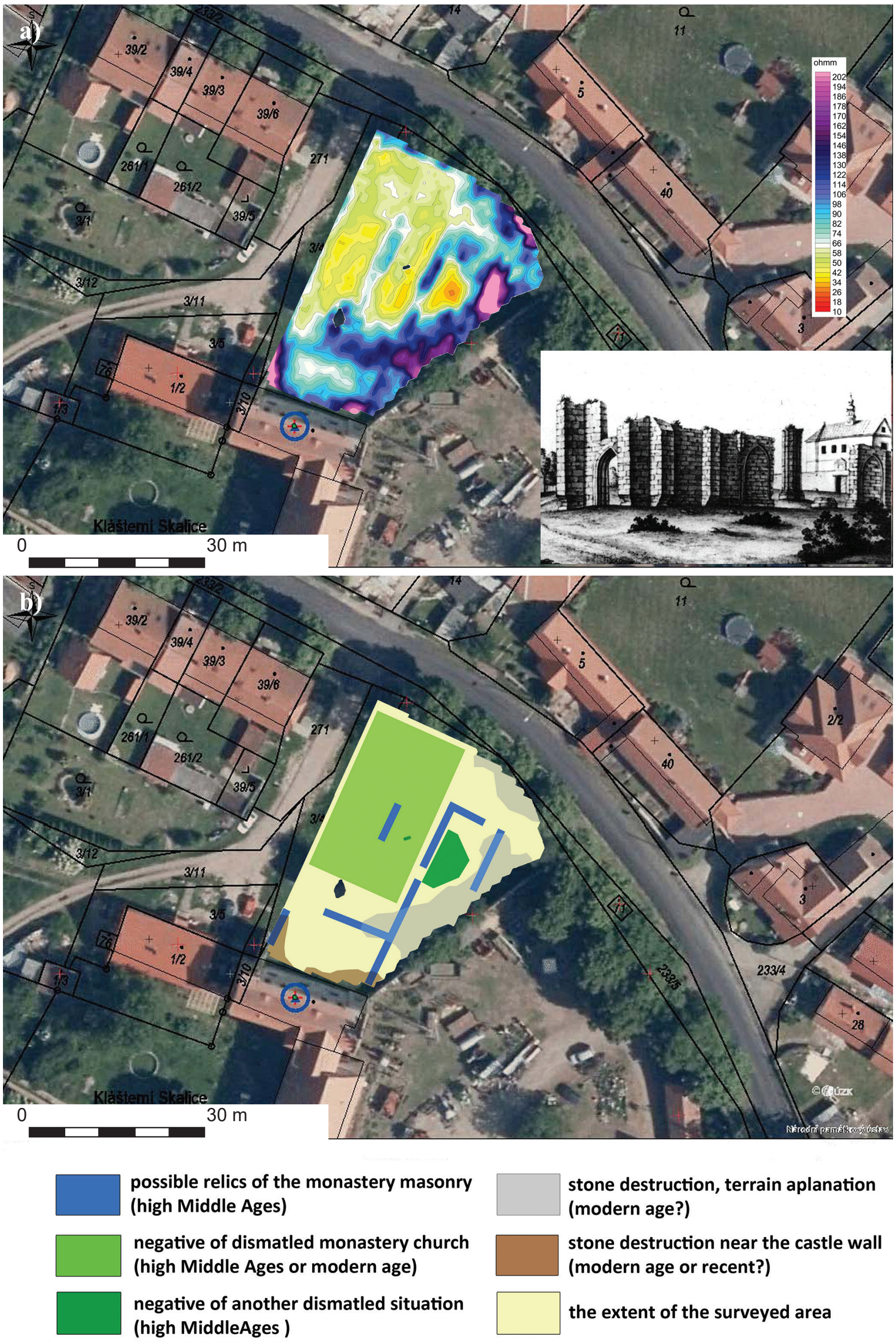


Figure 7. Klášterní Skalice, Kolín district. The result of a geoelectric resistivity survey of the area on the grounds of the defunct monastery with an additional copy of the painting by the painter Pařízek from 1807 (a), an interpretive diagram of the likely origin of the strongest resistivity anomalies (b) and second alternative interpretative diagram from the same data (c).

(stone foundation, floor or masonry) were not confirmed at a shallow depth below the surface seems to indicate the absence of stone material (at least to a depth of 0.4–0.5 m; a deeper situation would have to be verified, for example, by radar) and the predominance of more conductive, *i.e.*, earth or clay, fills. The church, including the foundations, could have been dismantled by the locals for building stone, after which the area was filled and levelled. To the east of this large low resistivity anomaly, another anomaly of low resistivity (between 20 and 60 ohmm) of smaller dimensions was identified, delimited on all sides by indications of high resistivity linear anomalies (dark green and blue in Figure 7b). Again, we cannot rule out clay fill after the removal of other stone materials or another area intentionally modified in this manner without buildings (such as a garth, a courtyard, *etc.*). Although in general the high resistivity lines are consistent with the orientation of the adjacent buildings on the old plans of the ruin of the monastery near the château, more detailed information on this open space is missing. However, a more precise demarcation of the rectangular relics of the defunct monastery buildings in the results was also locally complicated by the occurrence of more pronounced and irregular surface and subsurface accumulations of material with high resistivity (with apparent resistivity between 150 and 250 ohmm). Although the presence of subsequently spread stone material from the time of the monastery cannot

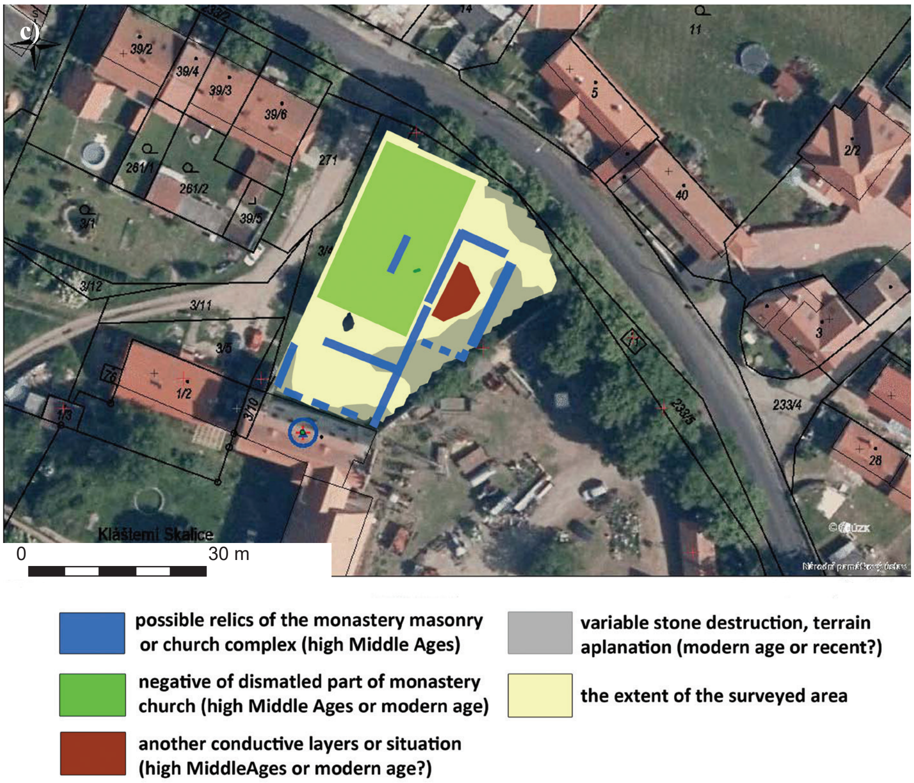


Figure 7. Klášterní Skalice, Kolín district. The result of a geoelectric resistivity survey of the area on the grounds of the defunct monastery with an additional copy of the painting by the painter Pařízek from 1807 (a), an interpretive diagram of the likely origin of the strongest resistivity anomalies (b) and second alternative interpretative diagram from the same data (c). (*Continuation*)

be ruled out, in some surface finds of modern bricks it is also possible to infer the local contamination of the measurement area by modern stone rubble and backfill. In particular, these are more frequent along the perimeter wall of the cooperative's warehouse, and others are apparent closest to the perimeter wall of the château with the accumulations of old roof tiles (grey and brown in Figure 7b). The full size of the monastery was not even verified on the interior areas of the château grounds. And yet, all of these areas are either less suitable or inaccessible for future geophysical survey.

On the example of this abandoned site, we can also illustrate the clear ambiguity of data interpretation from this spatially-limited resistivity survey. The extent and amount of terrain modification due to the abandoned and destroyed monastery in the modern age is unknown. We can also assume that from geophysical surveys of such a terrain we can only get very limited information. We can do only a simplified interpretation where it is possible to separate some places of different areas of the monastery church complex. The large-scale apparent resistivity anomaly may indicate only a northern part of the original monastery church without stone foundations (light green in Figure 7c). High resistivity linear anomalies in the southern and eastern part of the surveyed area may indicate some continuation of the monastery church complex with subsurface preservation of stone foundation remains (blue in Figure 7c). The origin of another anomaly of low resistivity of smaller dimensions could also be unclear and indicate some more conductive layers from the time of the monastery church or many later terrain modifications (brown in Figure 7c). In the area along the perimeter wall of the cooperative's warehouse and château we cannot separate anomalies of modern stone rubble and backfill from removed stone destructions of the monastery (grey in Figure 7c).

Main result: On the accessible segment of the area, the continuation of the monastery and probably also the place of the monastery church were confirmed; the monastery complex could continue towards the east and west. However, the state of preservation of situations below the surface is fragmented due to terrain modifications.

Example of a question arising from results but extending beyond non-destructive prospection: What happened to the rest of the foundations of the monastery buildings?

3.3 Radar measurements

Employed apparatus: RAMAC-X-3M, Geoscience Mala (Sweden), density measurement: 0.3×0.05 m for V. Kozmálovce, 0.5×0.05 m for O. Lúka

3.3.1 Veľké Kozmálovce, (Levice district) – All Saints Church

Main survey objective: Identification of the defunct Romanesque church beneath the later Baroque church.
Surveyed area: c. 196 m^2.
Geology: Quaternary fluvial soil sediments.
Pedology: luvisoil (L1).

We also encounter regular mediaeval and modern changes in the cultural landscape in less populated rural environments. In addition to broad changes in the manner and extent of use of agricultural land, the structure and intensity of built-up areas also changes. In many cases, the defunct buildings of the lower nobility (*e.g.* fortresses, small

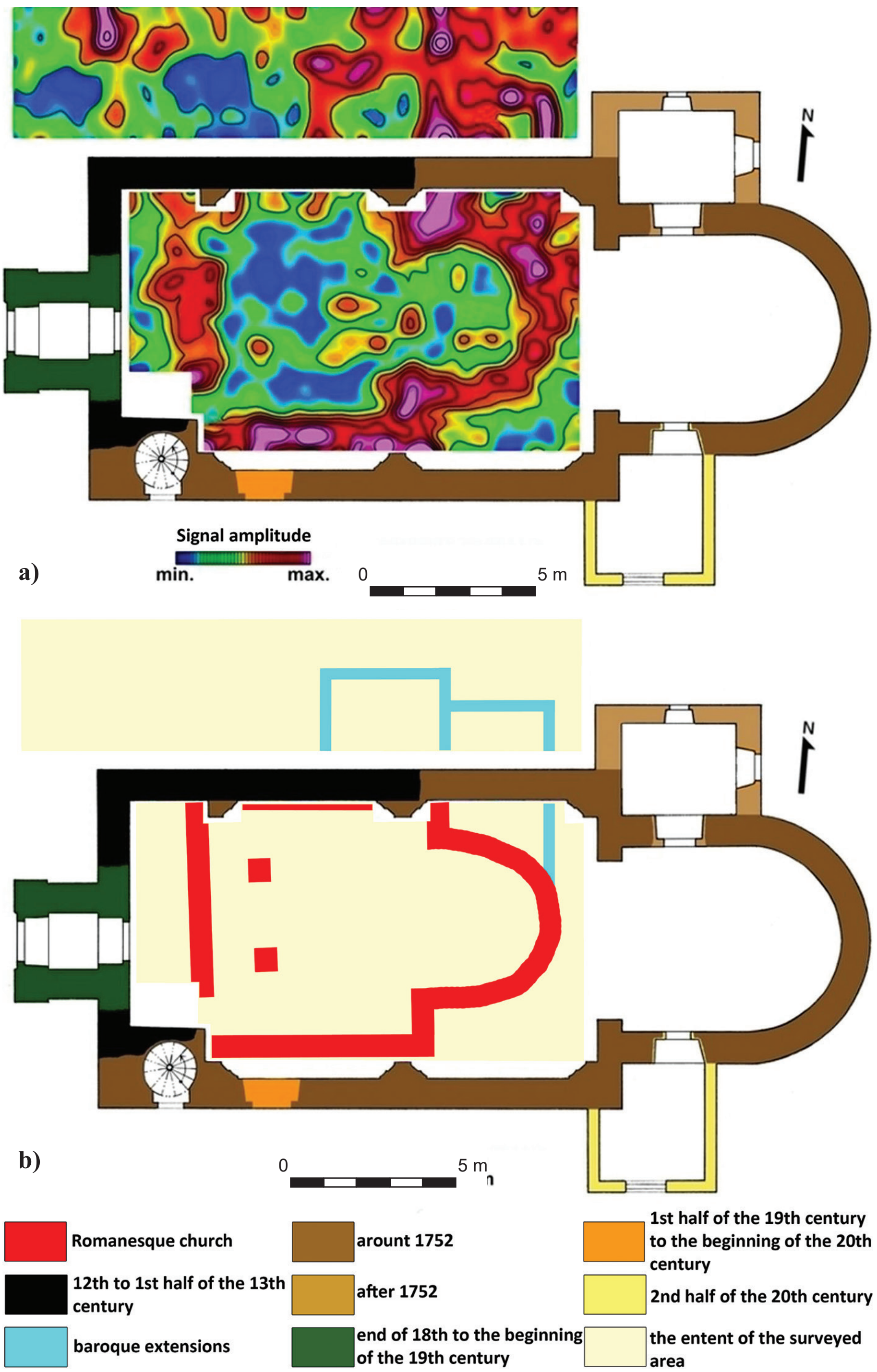


Figure 8. Veľké Kozmálovce, Levice district. Examples of the results of the radar survey of two areas in the form of depth sections (100–120 cm) on the area of the defunct All Saints Church (a – source: Tirpák, 2018, fig. 716) and an interpretive diagram of the likely origin of the most significant reflections (b – source: Tirpák, 2018, fig. 717, modified).

castles or other farmsteads) give way to such construction activities, while elsewhere these are abandoned and become gradually disappearing structures of sacral architecture (*e.g.* churches, chapels and even cemeteries). We then encounter fragmented relics of the above-ground parts of the defunct buildings incorporated into new reconstructions, less often as part of new buildings. In such cases, the possibilities of non-destructive geophysical surveys are already considerably spatially limited in terms of past construction activities. With the low prospects for survey methods, geophysical measurements are no longer common in such conditions, and sometimes not even regularly published (among other things, this also confirms the absence of similar geophysical results in the central archive of the Institute of Archaeology in Prague). A clear exception is the results of geophysical measurements in the interiors or on the grounds of churches (*e.g.* Hašek and Unger, 2010; Hašek *et al.*, 2013a; 2013b; Tirpák, 2013; 2016; 2018; 2019). These can be performed using several possible geophysical methods and also by methods based on the subject of verification or subject of anticipated identification. With numerous irremovable items in the inventory of commonly-used churches, the survey of floors in the interior of churches is usually spatially limited. To verify earlier subsurface stone and masonry situations and rubble, electromagnetic measurements or profile radar measurements are usually used above the loose paving strips. Microgravimetry (Mrlina, 2001; Pašteka *et al.*, 2013; 2020) and thermometry (Moscicki, 1987; Khesin and Eppelbaum, 1994; Mrlina *et al.*, 2005; Křivánek, 2013b), for example, are also used to detect unfilled spaces. Relatively better conditions for surveys exist inside churches, where it is possible to carry out full-area measurements on the church tiles without the high risk of disruptive manifestations of inventory or utility lines. From the detailed results of radar measurements processed into the form of time or depth sections, we can then observe the subsurface changes of defunct situations in the 2D (= one depth section) or 3D (sequence of many depth sections processed in 3D-software visualisation) display of results. The effectiveness of three-dimensional results of radar measurements and their interpretation can be further supported by written sources describing the historical changes at church sites. This is also the case, for example, with the defunct mediaeval All Saints Church in the village of Veľké Kozmálovce. Written sources indicate that the Roman Catholic All Saints Church was founded in the village in the first half of the 14th century, but due to its poor condition, a new Baroque church of the same name was built in 1752 (Tirpák, 2018, pp.390–398).

Interpretation: Based on the example of the individual result of a detailed radar measurement on two surfaces (interior and northern exterior of the church) processed into the same depth sections with a depth interval of 100–120 cm, we can positively confirm the perimeter foundations of the original All Saints Church beneath the paving (red in Figure 8a). The strip of distinct reflections under the main nave of the standing church is delimited by an older single-nave Romanesque church oriented in the same direction with a semi-circular apse featuring external dimensions of c. 8.4×6.9 m and indications of the foundations of the columns of the mediaeval empora (red squares in Figure 8b). However, in the presented separate result, later building modifications were also distinguished in the vicinity of the original church, when a rectangular Baroque sacristy was added north of the church between 1674 and 1714, followed by an ossuary to the west (Tirpák, 2018, p.397; cyan in Figure 8b). The later history of the transformation of the sacral place is then based on written sources and historical-building research, when in 1752 a new All Saints Church was built on the site of the defunct church (brown in Figure 8b). A tower was added to the west side of the new Baroque church at the turn of 19th century, and other external extensions were added to the nave of the church between the second half of the 18th century and the second half of the 20th century (dark green and yellow Figure 8b). The results of radar measurements with the 3D-display of data (Tirpák, 2018, pp.390–398) made it possible to confirm the multiphase development of the sacral site from the Romanesque church, through Baroque extensions, subsequent abandonment, the construction of a new Baroque church and other modern extensions.

Main result: The precise identification of the defunct Romanesque All Saints Church beneath the new Baroque church, including several extensions were verified. The state of the subsurface foundations is fragmented due to repeated newer reconstructions and terrain modifications.

Example of a question arising from results but extending beyond non-destructive prospection: What is left of the foundations of the earlier church?

3.3.2 Ostrá Lúka, (Zvolen district) – defunct Church of the Epiphany

Main survey objective: Verification of the presence and confirmation of the foundations of a church with no surface remnants.
Surveyed area: circa 560 m^2.
Geology: Tertiary basaltic volcanic.
Pedology: black soil (G1).

However, the changes in the cultural landscape and remnants of sacral architecture in the rural environment also contain numerous and (for monument protection) alarming examples in which small sacral buildings have completely disappeared and are documented in regional memory only by old maps, roads, place names or official records and property inventories. In contrast to the previous example of geophysical survey of gradually changed but still above-ground sacral architecture, the following example concerns a church that has completely disappeared from the face of the Earth. Compared to standing buildings, perhaps a bit paradoxically, we can expect greater prospects for geophysical surveys (by certain methods) in the cases of some buildings no longer present on the surface and where there are not so many above-ground situations disrupting the survey. The possibilities of methods and interpretation of the measured situation are naturally more promising under conditions of open and subsequently undeveloped (or even covered with low vegetation) areas, knowing the circumstances of building abandonment, at least a partial history of terrain modifications and also with the availability of written sources on earlier defunct buildings. The areas of completely defunct sacral buildings in the rural environment can be verified by several geophysical methods and various procedures, for the most part depending on the current state of the terrain of defunct sites and the survey objectives. Easier methods may include a survey of ploughed-up agricultural areas (or wooded terrain only with higher vegetation) by a combination of, for example, magnetometer (brick foundations or rubble) and resistivity measurements (stone foundations, rubble), which can also be supplemented with, for example, electrical resistivity tomography (ERT) profiles. Other methods of electromagnetic or radar survey are suitable under conditions of difficult broken and uneven terrain (rubble or stone layers near the surface). With the real possibility of areal and detailed radar measurement, the possibility of 3D-display, and some evaluation and presentation of measured data, is a great advantage, as in vertical view it can also capture multiple transformations of

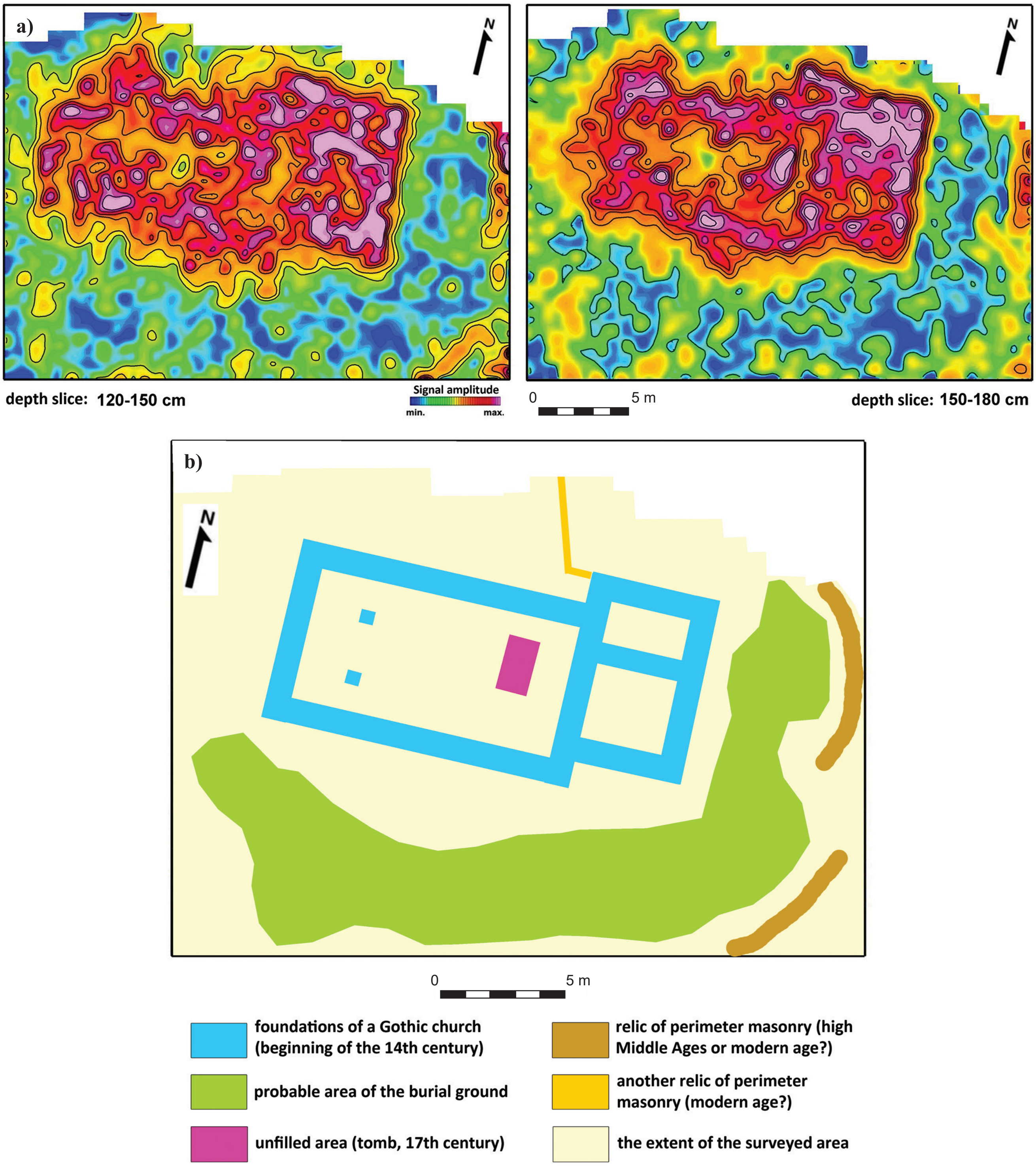


Figure 9. Ostrá Lúka, Zvolen district. Examples of radar survey results in the form of two depth sections in the area of the defunct Church of the Epiphany (a – source: Tirpák, 2018, Figures 526 and 527) and an interpretive diagram of the likely origin of the most significant reflections (b – source: Tirpák, 2018, Figure 528, modified).

an area with a defunct sacred building. One such example is the result of radar measurements in the area of the defunct mediaeval Church of the Epiphany near the village of Stará Lúka. According to written sources, the village Gothic Church of the Epiphany was mentioned at the beginning of the 14th century; it was probably abandoned by the 17th century, but the ruins of the church were still recorded at the site in 1905 (Tirpák, 2018, pp.291–295). During the 20th century, the construction rubble was levelled and the area was no longer used even for burials and was abandoned.

Interpretation: An example of a combination of two particular results of a detailed radar measurement on the presumed broader area of the defunct Church of the Epiphany processed into two depth sections with depth intervals of 120–150 cm and 150–180 cm that can be used to locate fragmented remains of the ground plan of a sacral building (Figure 9a). From the fragmented presence of high amplitude reflections, it seems that the state of subsurface preservation of the church's foundations is most likely fragmented, the scattered stone surface rubble decreases with the depth of the observed sections, and the probable ground plan of the building takes a clearer shape. The band of discontinuously concentrated reflections at greater depths is delimited by a defunct Gothic single-nave church measuring c. 16.5×6.5 m, with a probable rectangular apse measuring circa 5×5 m (cyan in Figure 9b). In the north-eastern part, outside the perimeter of the church, the rectangular extension of the sacristy was further confirmed. Remains of the foundations of the supporting pillars were probably also detected in the western part of the nave, and in the eastern part of the main nave, the site of the defunct crypt was probably identified by distinct reflections (purple in Figure 9b). Written sources show that a member of an aristocratic family, Melchior Ostrolucký, was buried in the crypt in 1612, only to be moved to another Protestant church in the village at a later date (Tirpák, 2018, p.295). Outside the delimited single-nave church, other relics of linear reflections of the foundations of the perimeter walls defining the extent of the cemetery around the church were also distinguished (brown and yellow in Figure 9b). The extent of probably the most intensively-used area for burial may also be indicated by larger areas in the southern to eastern vicinity of the church, with a pronounced absence of reflections on radar profiles and depth sections (green in Figure 9b) and the probable presence of clay layers without a significant share of stones. Despite a significant change in the surface of the platform and thick rubble layers, thanks to the application of radar measurements with a sufficient depth range, the deeper parts of the original completely defunct Church of the Epiphany were delineated, including several partial building details and the subdivision of the internal area.

Main result: Confirmation of the relics of the foundations of the defunct Church of the Epiphany beneath extensive stone rubble was made. The state of the deeper subsurface foundation is probably fragmented.

Example of a question arising from results but extending beyond non-destructive prospection: What can be read from the thick stone rubble below the surface?

4. Conclusion

Different subsurface features can be identified by using a wider range of different geophysical methods as well as selected survey methodologies. Similar geophysical methods, measurement principles and sometimes also other apparatus are used today in shallow subsurface geophysical surveys for geological purposes, in archaeo-geophysical prospecting, and sometimes also in monitoring changes in the environment or for the needs of construction geology or the search for minerals. In the current cultural landscape, one which is repeatedly modified, the measured data usually reflect the projection of several different circumstances and changes in the environment of different scope and origin. The goal and methodology of geophysical prospecting is then, to a great extent, determined by what we would like to identify, what we would like to distinguish in the measured data, and also by how best one can interpret the measured situations.

The presented set of examples, of the application of various geophysical methods in the different conditions of sites, is clearly not fully consistent in terms of the different approaches and archaeological benefits. However, from the point of view of the main goal of this article, practical examples of the limited possibilities of archaeological interpretation of geophysical measurements in the conditions of an altered cultural landscape, it can be considered representative. We find a common denominator in all the above results and in the limitations of our own interpretation. Changes in the cultural landscape carried out in modern historical times after the end of the studied archaeological activities at a site have a major impact on the possibilities for the site's survey and evaluation. These cannot be underestimated or overlooked, especially when we often do not even know what was happening in the cultural landscape. To study the history of land use, we need a wider range of methods (such as the study of old and specialised maps, geomorphology, physical geography, pedology, Quaternary geology and other such scientific fields and laboratory methods). The supplemented examples of questions after the main summary of individual results also have a common denominator. In addition to new findings, new results of geophysical measurements also raise new questions. It is of critical importance to admit that the mere expansion of a non-destructive survey is no longer sufficient to further address these issues; we must have a broader scope of archaeological methods and study the interrelationships in our landscape.

The primary goal of the geophysical survey in archaeology (archaeo-geophysical prospecting) is to search for and distinguish archaeological situations. However, there are more situations and sources of various anomalies in the resulting measured data. Although the aim of the evaluation of the measured data is archaeological interpretation, this must be preceded by geophysical interpretation, of which one aspect of interest is the differentiation of sources and the changes of possible non-archaeological origin. Depending on the complexity of the measured environment, there are often multiple alternatives to the possible archaeo-geophysical interpretation of the data. To help in narrowing down the most probable archaeological interpretations it can be of great assistance to provide information on the archaeological situations at the site from either excavation or other investigation methods. However, our illustrative examples of results draw attention here to the rather common fact that the interpretation of the measured data is always ambiguous and cannot be resolved only by focussing on the archaeological interpretation. That we cannot clearly distinguish the archaeological origin of some anomalies from the changes of other anthropogenic and natural origins in a complex environment should not be taken as a shortcoming of the application of geophysical methods in archaeology. Although archaeologists may not welcome this or that variant of ambiguous archaeological (and perhaps other) interpretation of the measured data, the one proposed can often be considered as being the correct one under the given conditions of a complex or transformed environment. It would be a greater shortcoming if, given the inhomogeneous conditions of measurement and the legibility of the data having been affected in various ways, we were to try to present only a single archaeological interpretation of the measured anomalies. Because we know that the natural environment modified by various (including anthropogenic) processes is not just modified by human but also by geomorphological, pedological or geological processes, we cannot expect and interpret only the traces of archaeological situations within the archaeo-geophysical data.

Acknowledgements

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