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The Application of Non-Destructive Geophysical Measurements for Mapping and Surveying the Hillforts in the Czech Republic

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The Czech landscape and its archaeological resources include the most varied types of prehistoric or early medieval hillforts. These fortified sites are found across a variety of different locations and possess different functions and dimensions (very often in units of hectares, unlike the later medieval strongholds, characterized by the dimensions of tenths of hectares of fortified areas). Due to this large area, the hillforts were verified using mainly small-scale archaeological investigations. Many other hillforts are also known to exist without any archaeological trenching, research or exact dating. A combination of various remote sensing techniques and non-destructive methods seems to be, in the last two decades, a fast and low-priced way to acquire new spatial information about these fortified sites. Geophysical measurements of hillforts and different methods were under all circumstances limited by various field conditions and the performance of used equipment. But some of the geophysical methods now offer new surveys of large areas of hillforts or nearly complete fortified sites. Seven chosen examples of various geophysical methods and techniques in this paper should illustrate the different possibilities of modern prospection and non-destructive mapping of hillforts. Their results could be used in archaeology, heritage care of intangible archaeological monuments or on different occasions for particular kinds of conservation, new protection or systematic study of hillforts.

Keywords: geophysical survey, hillfort, non-destructive archaeology, fortification, Czech Republic, archaeological prospection, settlement.

Nedestrukcinių geofizinių metodų taikymas tyrinėjant Čekijos Respublikos piliakalnius

Čekijos kraštovaizdyje ir archeologijoje aptinkama skirtingų tipų priešistorinių ir ankstyvųjų viduramžių piliakalnių. Šių įtvirtintų vietų lokalizacija, funkcija ir dydžiai labai skirtingi (nuo kelių hektarų iki dešimčių hektarų įtvirtintų viduramžių tvirtovių teritorijų). Dėl šios priežasties didžiuosiuose piliakalniuose buvo atlikti tik nedidelės apimties archeologiniai tyrinėjimai. Daugelyje kitų piliakalnių archeologiniai tyrimai iš viso nebuvo vykdyti, tikslesnis tų piliakalnių datavimas nežinomas. Panašu, kad įvairių nuotolinių technologijų ir nedestrukcinių metodų derinimas per pastaruosius du dešimtmečius tapo greitu ir pigiu būdu gauti norimą erdvinę informaciją apie šias įtvirtintas vietoves. Geofiziniai piliakalnių tyrimai ir skirtingi metodai buvo labai ribojami laiko dėl skirtingų lauko sąlygų ir įrangos techninių galimybių. Tačiau šiuolaikiniai geofizinių tyrimų metodai leidžia ištirti dideles piliakalnių teritorijas arba net ištisas įtvirtintas vietoves. Pasirinkti septyni skirtingų geofizinių metodų ir technikų taikymo pavyzdžiai šiame straipsnyje iliustruoja skirtingas šiuolaikinių žvalgymų bei piliakalnių nedestrukcinių tyrimų galimybes. Šių tyrimų rezultatai gali būti naudojami archeologijos moksle, nekilnojamojo kultūros paveldo apsaugos ir išsaugojimo srityse, tolesnėse detaliose piliakalnių studijose.

Reikšminiai žodžiai: geofiziniai žvalgymai, piliakalnis, nedestrukciniai archeologiniai tyrimai, įtvirtinimai, Čekijos Respublika, archeologiniai žvalgymai, gyvenvietė.

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Introduction

Hillforts in the archaeology of the Czech Republic represent very specific types of archaeological sites, which are very often situated at strategic places in the landscape and surrounded by typical fortifications. The dating of hillforts varies between the Neolithic/Eneolithic and the end of the early medieval period. The function (role) of these hillforts could be very variable and relates to many aspects concerning the type of settlement pattern (or other activities), the communication system, the location in the terrain, the type of landscape, the period and length of use of the site etc. Hillforts are also very variable in the dimensions (scale and internal structuring) of the fortified area, from tenths of hectares to more than 100 ha (for general information, see the following encyclopaedias: Lutovský, 2001; Čtverák et al., 2003; Čižmář, 2004). The location of the hillforts in strategic, dominant or specific places is very often connected with the variability of the Czech landscape (elevated hillforts in lowlands or flood plain areas, hillforts on plateaus, promontories or terraces of the mainly flat landscape, hilltop hillforts or fortified complexes in upland areas etc.). The archaeological investigation of these large and complicated fortified sites frequently requires multiple archaeological excavations, fully systematic field and post-processing work, financial and personal security and a great deal of working time and energy. In the present conditions of archaeology, the research of hillforts does not offer detailed information about more than just smaller areas at some chosen sites (the dating and study of the structure of fortifications, gates etc.). Other hillforts lack these detailed archaeological data. Many more hillforts are also without any archaeological excavation, detailed documentation or plans. Non-destructive methods and some remote sensing techniques (e.g., aerial prospection, LIDAR, geochemical and geophysical surveys) could bring, in a much shorter time and with much lower financial costs, new spatial information about hillforts.

In the case of the geophysical measurements at hillforts, the first geophysical resistivity profile measurement was carried out across the rampart of the early medieval Old Kouřim hillfort very early, in 1950 (Šolle, 1969; 1977, p. 95). The first magnetometer measurement in Czechoslovakia and the first geophysical survey of a chosen part of a Czech oppidum was carried out by R. Linington in 1968 at the Závist oppidum (Linington, 1969; 1970). Other areas of different hillforts were surveyed during the 1970s. For example, geophysical measurements were carried out at the Hallstatt hillfort of Minice or at the La Téne oppidum of Třísov (*Šilhová* and Pavlík, 1973). The first systematic geophysical surveys at the early medieval Budeč hillfort started in 1976 with resistivity (Bárta, 1978, p. 105–107) and continued with large-scale magnetometer measurements (Bárta et al., 1979, p. 15–19; Marek et al., 1979; Marek, 1983, p. 85–89; Pleslová-Štiková et al., 1989, p. 30–31). In the case of Moravia, one of the first geophysical measurements of hillforts was carried out in 1979 at the Pohansko early medieval hillfort (Dostál et al., 1981, p. 55–57; Hašek et al., 1983, p. 144–146), followed by other areas in the 1980s (Hašek, 1999, p. 66–68). In the case of Slovakia, at the end of the 1970s, the fortification of the early medieval Pobedim hillfort was surveyed (Ludikovský et al., 1978). The other smaller areas of the Závist oppidum were surveyed using geophysical methods in 1979 (Majer, 1980) and later during the systematic archaeological investigations at the site. During the 1980s, various geophysical methods were applied at other situations inside hillforts. For example, an infra-thermometry with a resistivity survey was carried out in 1981 inside the Basilica of St. Peter and Paul at the early medieval Vyšehrad hillfort in Prague (Nechvátal and Hrdlička, 1983, pp. 123–128). In 1986, part of the outer area of the prehistoric and early medieval Rubín hillfort was also surveyed using a resistivity measurement (Bárta and Majer, 1997). A large resistivity survey was carried out at the early medieval Prague-Vinoř hillfort in 1987–1988 (Bárta et al., 1989, p. 44–48). During the 1990s, some geophysical surveys were also connected with regional archaeological research, projects and new available results of aerial archaeology. In the case of Moravia, the result of magnetometer measurements at the prehistoric Kokory hillfort in 1995 could be a good example (Hašek, 1999, p. 62–64).

The Study of Hillforts in Projects

From the end of the 20th century, prehistoric or early medieval hillforts were surveyed using geophysical methods not only for the needs of archaeological excavations but also during various archaeological projects. This was possible thanks to new project investments in geophysical equipment and important software. Many fortified sites and hillforts identified by aerial prospection were verified using geophysical methods in the project "The Prehistoric Settlement Pattern of Bohemia – the Potential of Non-Destructive Methods in Archaeology" (Grant Agency of the Academy of Sciences of the Czech Republic: 404/97/K024 – Gojda et al., 1997–2002; Křivánek, 2004a; 2004b). New possibilities for the prospection of hillforts for the needs of archaeological heritage and protection were shown on the basis of the results of the project "The Identification of Destroyed Fortifications and the Internal Structure of Settlement of Hillforts" (Grant Agency of the Ministry of Culture of the Czech Republic: PK99P04OPP007 – Křivánek, 1999–2000; Křivánek, 2000; 2001; 2002; 2003a). Geophysical measurements were also implemented in the archaeological project "The Přemyslid Hillfort at Stará Boleslav – Its Role and Status in the Early Přemyslid State" (Grant Agency of the Academy of Sciences of the Czech Republic: 404/99/1060 – Boháčová et al., 1999–2001; Křivánek, 2003b). Another archaeo-geophysical project, "Geophysical Surveys in Archaeologically Unexcavated Areas of Czech Oppida," focussed on the prospection of important La Téne hillforts-oppida in Bohemia (Grant Agency of the Academy of Sciences of the Czech Republic: A8002301 – Křivánek et al., 2003–2007; Křivánek, 2005; 2011; Křivánek et al., 2013). A complex of more non-destructive methods was used in the project "The Inner Bailey of the Libice Stronghold – Possibilities of Non-Destructive Archaeology and Modern Technology in the Process of the Study of Archaeological Sources" (Grant Agency of the Academy of Sciences of the Czech Republic: KJB800020803 – Mařík et al., 2008–2010; Křivánek and Mařík, 2009; Mařík and Křivánek, 2012). Some hillforts were also geophysically surveyed during the last decade in the internal institutional subproject "Enclosed Areas in the Prehistoric and Early Medieval Period" (research project of the Institute of Archaeology in Prague – AV0Z80020508; Křivánek, 2012; 2013; 2015a). Since the beginning of this decade, international (CZ-PL) cooperation was also pursued in the project "Stratigraphy of the Selected Strongholds of the State of Přemyslids and Piasts in Light of Comparative Non-Invasive Investigations" (IA CAS Prague – IAE PAN Poznan – MPP Dziekanowice: Kara-Křivánek et al., since 2010; Křivánek and Tabaka, 2014). Hillforts were also observed using geophysical methods during the project "Non-Destructive Geophysical Research of Important and Endangered Archaeological Sites in the Ústí Region" (Project of the Regional cooperation between CAS and regional institutions: R300021421 – Křivánek et al., 2014–2016; Křivánek, 2015b). Of course, over the last two decades, some geophysical measurements of hillfort areas were outside of any projects and were carried out for the needs of different archaeological institutions and in connection with planned landscape changes of fortified sites (Křivánek, 1999; 2008; 2010).

Methods of Geophysical Surveys

Many older geophysical measurements of hillforts were limited by the performance of equipment and the applied methods. Often, only particular areas were chosen for surveys, with measurements focused on the verification of fortification systems, the location of gates, paths and the identification of features related to specific activities. Changes in the efficiency of new geophysical equipment in the last two decades also altered the possibilities of applying non-destructive geophysical methods for the survey of large areas of hillforts and to a more detailed density of measured data. Thanks to these circumstances, we were able to formulate new goals for geophysical surveys of hillforts, such as comprehensive monitoring of the settlement's internal structure as well as the divisions and extents of fortified sites. In the case of surveys of hillforts in the Czech Republic, magnetometer and geoelectrical resistivity surveys have long been the two main geophysical methods. Magnetometers seemed to be the most powerful geophysical method for surveys of large arable fields, pastures, meadows, but also less dense

forested areas without lower unpassable vegetation. Different types of magnetometers have been used over the last three decades. The Smartmag SM-4g caesium vapor magnetometer (Scintrex, Canada) was used intensively in 1998–2010 (common density of data approx. 1 × 0.25 m). The five-channel Magneto-Arch magnetometer (gradiometer) system with fluxgate sensors FMG-650B (Sensys, Germany) has been used since 2010 (parallel five-profile measurements with data density 0.5 × 0.2 m, chosen details in density 0.25 × 0.1 m). Geoelectric resistivity measurements seemed to be a very useful geophysical method in Czech archaeology for the survey of hillfort areas with an expected stony component, constructions or fortifications in open agricultural or forested terrain. These areas have been surveyed using the RM-15 instrument (Geoscan Research, UK) since 2000 (Wenner configuration with four separate electrodes A0.5M0.5N0.5B or A1M1N1B, data density 1 × 1 m, details in density 0.5 × 0.5 m). Only in some specific areas of hillforts was the potential of other geophysical methods, like electromagnetic conductivity or GPR measurements, also tested. These surveys were conducted using the DIKO EM-38b (Geonics, Canada) and GPR Cobra-WIFI II (Radarteam, Sweden). Geophysical surveys from more hillforts confirmed that the subsequent combination of magnetometer and resistivity measurements seemed very efficient and important, especially in specific inner or outer areas of the fortified sites – gates, roads, ramparts, specific settlements, places of trade or special production activity (Křivánek, 2013a; 2015a; Křivánek and Tabaka, 2014). During some archaeological investigations of hillfort areas, additional magnetic susceptibility measurements were then used in detailed scale *in situ* in horizontal or vertical open archaeological situations. KT-5c (Geofyzika Brno, CZ) or SM-20 (GF-instruments, CZ) kappameters were used for these measurements.

Examples of Results

Seven examples of the application of different geophysical methods were chosen for this paper. The examples of these results illustrate the wide potential of geophysical techniques in surveying and monitoring various prehistoric or early medieval hillforts.

1. Zlončice, Mělník District, probable prehistoric hillfort. The site is situated on a wider elevated promontory, above the right bank of the Vltava River. Settlement or ditch fortifications had never been identified from any aerial photographs, and the site was discovered only from surface artefact collections by a regional amateur archaeologist (probably polycultural prehistoric site but mainly Neolithic finds). A rather complicated system of more ditch fortifications had been confirmed only due to an intensive magnetometer prospection in 2010 (Fig. 1a; see also Křivánek, 2013b, Fig. 2, 3 and 5; Křivánek, 2015a, p. 158, Fig. 27.1). Additional geophysical resistivity surveys across the middle ditch fortification system provided no indications or relics of any rampart or stony construction. The inner ditch fortification system consists of three parallel bows of ditches with very similar interruptions situation near the SW edge of the promontory (Fig. 1b). The central part of the fortified area is deeply ploughed and includes remains of another narrow ditch or groove with an east-west orientation. The middle ditch fortification system consists of two ditches, and an interrupted area seems to be in the middle of the promontory. For these inner areas of the very probable hillfort, intensive settlement activity is very typical (many oval magnetic anomalies from probable sunken features – pits). In the middle part of fortified area, we can also identify magnetic anomalies with diameters of 3–4 m, where we can expect larger sunken features (possible houses, groups of pit alignments or other sunken depressions). The outer ditch fortification system consists of one single ditch with some remains of another ditch in superposition. This outer area of the hillfort was not as intensively settled, and a part of it was damaged by a trench built for a metal water pipeline and by a field path. Unfortunately, no archaeological investigation has been conducted at the site to date, and the preliminary prehistoric dating of the probable hillfort can be confirmed only after an archaeological investigation of the site. An example of a large-scale magnetometer survey of a new unexcavated hillfort showed how data from a non-destructive method could be used for a more precise separation of the whole site (the fortified area consists of 12 to 13 ha) and the future recording and protection of an immovable archaeological monument.

Fig. 1a. Zlončice, Mělník District. The magnetometer survey result of the system of ditch fortifications on the base map (source: www.kontaminace.cenia.cz; surveyed area: approx. 9.5 ha; survey: *Křivánek 2008–2010*).

1a pav. *Zlončice, Mělník rajonas. Magnetometrinių žvalgymų rezultatai – gynybinė griovių sistema. Pagrindas – topografinis planas (šaltinis: www.kontaminace.cenia.cz; žvalgyta teritorija: apie 9,5 ha; žvalgymai: Křivánek 2008–2010)*

Fig. 1b. Zlončice, Mělník District. An interpretation of the ditch fortifications (red), probable interruptions-entrances (V?) and the edge of promontory (violet) on the base map (source: www.kontaminace.cenia.cz; surveyed area: approx. 9.5 ha; survey: *Křivánek 2008–2010*).

1b pav. *Zlončice, Mělník rajonas. Gynybinės griovių sistemos interpretacija (raudona spalva), spėjami tarpai – įėjimai (V?) ir iškyšulio ribos (violetinė spalva). Pagrindas – topografinis planas (šaltinis: www.kontaminace.cenia.cz; žvalgyta teritorija: apie 9,5 ha; žvalgymai: Křivánek 2008–2010)*

2. Vesec near Sobotka, Jičín District, probably Late Bronze Age (and/or Hallstatt) and early medieval hillfort Poráň. The prehistoric and early medieval hillfort is situated on a dominant narrow promontory above the sandstone cliffs of a protected valley inside the *Český Ráj* Protected Landscape Area. The prehistoric hillfort was fortified with a massive rampart with an outer ditch (fortified area approx. 2 ha). The whole hillfort and this fortification have been verified by an archaeological trench only once at the end of the 19th century and the beginning of the 20th century (Píč, 1909, p. 380; Profantová and Waldhauser, 2007). New results of aerial prospection in this area showed two ditches and (together with LIDAR) the ditch fortification remains of the new unknown outer ditch fortification (Fig. 2a). A geophysical measurement of the Poráň hillfort was carried out in 2014 and 2016 with a subsequent combination of the magnetometer measurements of ploughed fields and meadows, particular resistivity measurements inside the forested front of the promontory, and additional radar profiles across the main fortification system. The overall results of magnetometer measurements finally covered the whole acropolis and outer bailey of the hillfort after new protection changes of the area and the reduction of the original private fenced orchards. The magnetometer results have unfortunately confirmed that the main fortification was ploughed out, with only the narrow magnetic lines from ditches visible (Fig. 2b). Two wide ditches from former aerial photographs have been identified by us only as one narrow line of an inner ditch and a strip of scattered magnetic anomalies in the outer ditch. Many scattered small and often dipole magnetic anomalies inside of the promontory also confirmed the ploughed-out rampart and intensive settlement of the whole acropolis (prehistoric hillfort). In the original construction of the rampart, neovolcanic stones were used. Deeper destruction of the original rampart was evident in the results of resistivity and radar measurements. The magnetometer results

Fig. 2. Vesec near Sobotka, Jičín District. A comparison of data from aerial photography (a) and the results of magnetometer measurements (b) of the area of the Poráň hillfort (source of aerial photo: archive of the Institute of Archaeology, CAS, Prague, v.v.i.; surveyed area: approx. 4.8 ha; survey: *Křivánek, 2014 and 2016*).

2 pav. *Vesec prie Sobotka, Jičín rajonas. Poráň piliakalnio teritorija, aeronuotrauka (a) ir magnetometrinių žvalgymų rezultatai (b) (aeronuotraukos šaltinis: Archeologijos instituto archyvas, CAS, Praha, v.v.i.; žvalgyta apie 4,8 ha teritorija, žvalgymų šaltinis: Křivánek, 2014 and 2016)*

also showed the separation of the outer and much less densely settled bailey fortified by a single ditch (the probable area of the early medieval hillfort was 4 ha). The source of the most of dipole magnetic anomalies in the outer part of the hillfort is connected with modern landscape changes (removed orchard fences and paths). Additional resistivity surveys in the forested front of the hillfort identified the probable remains of an unexpected

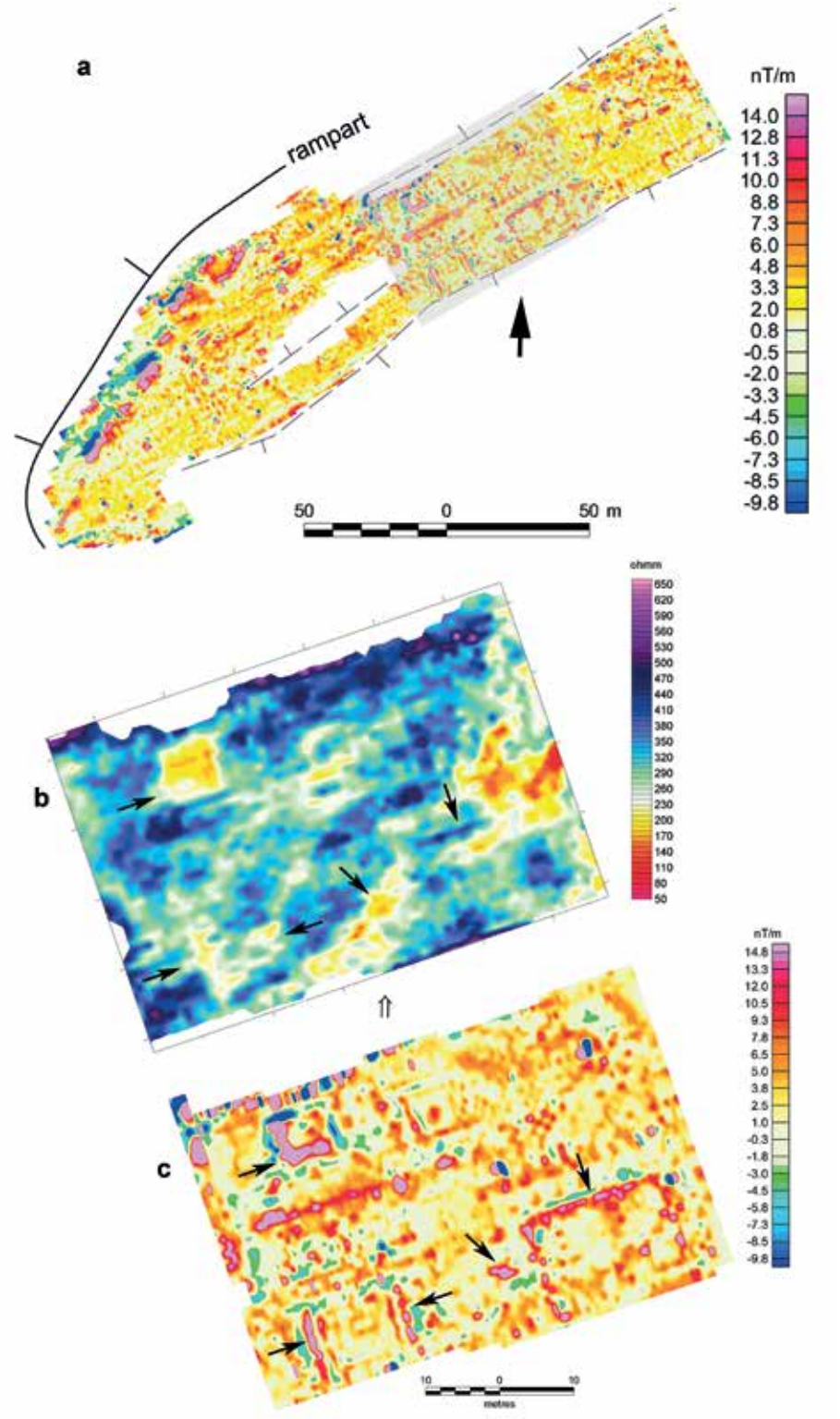

Fig. 3. Oppidum Stradonice, Beroun District. The result of a magnetometer survey of the northern acropolis (a) with a particular comparison of geoelectrical resistivity (b) and magnetometer (c) results (surveyed area: magnetometer: 1.35 ha, resistivity: 0.3 ha; survey: *Křivánek 2006 and 2010*).

3 pav. *Opidumas Stradonice, Beroun rajonas. Šiaurinio akropolio magnetometrinių žvalgymų rezultatai (a) ir dalies teritorijos elektrinės varžos (b) ir magnetometrinių (c) tyrimų rezultatai (žvalgyta teritorija: magnetometras – 1,35 ha, elektrinė varža – 0,3 ha; žvalgymai: Křivánek 2006 and 2010)*

perimeter rampart (high resistivity from probable stone accumulations along the edge of sandstone promontory). The example of the combination of non-destructive results from the Poráň hillfort described an efficient method of prospection even in conditions of more modern land use changes at the site.

3. Stradonice, Beroun District, La Téne oppidum. Different areas of a very large Celtic oppidum were investigated using non-destructive geophysical methods during an archaeo-geophysical project focussed on the surveys of unexcavated parts of Czech oppida (overall results were published in Křivánek et al., 2013). One specific result of the magnetometer survey of the northern acropolis also brought interesting information about the possible subsurface remains of the structured settlement of the dominant area (Fig. 3a). Of course, the results of prospection were influenced by different changes in land use (today a meadow, but previously a long-term ploughed field). The magnetometer survey of the observed area of the acropolis identified the subsurface remains of rectangular or subrectangular structures (probable the subsurface remains of buildings) and a possible system of paths oriented in two main directions – SW-NE and SE-NW (Fig. 3b). The preservation of remains of a probable rectangular structure of this area after the initial buildings seems to be quite unique, because the other large central areas of the oppida are agricultural fields with intensive ploughing. The subsequent additional geoelectrical resistivity measurement of the most interesting part of the acropolis then confirmed some remains of stone walls or local stone rubble (Fig. 3c). A comparison of some linear, highly magnetic and high resistivity anomalies then showed the locally different states of preservation of various features and the deep impact of previous deep and long-time ploughing of the area. The detection of stone destructions and lines on the acropolis together with magnetic structures probably confirms the connection with the original abandoned above-ground buildings, roads and perhaps also other sunken features. In the NW part of observed area, by using both of the geophysical methods, we cannot rule out an approximately square sunken feature (such as a water tank or other remains of a deeper, sunken square structure). The whole area of the northern acropolis is lacking a modern archaeological investigation. An example of the combination of different geophysical techniques in this specific area of the oppidum could initiate better future protection and an eventual systematic archaeological study of the important areas.

4. Libice nad Cidlinou, Nymburk District, early medieval hillfort. The Libice hillfort represents a different type of large important fortified site situated on low terraces above the flood plain area of the Cidlina River. The central part of this hillfort (inner bailey or acropolis) was never settled after the end of function of site, while the second part (outer bailey) was settled since the medieval period and is situated under the settlement of today's small town. Geophysical surveys conducted in 2008–2010 and 2014 were concentrated in the agricultural fields of the inner bailey of the hillfort. The results of large-scale magnetometer measurements have clearly shown that the nearly complete inner bailey was intensively inhabited, and many various sunken features remain (Fig. 4a). The structure of these sunken features was not probably the same in the northern and southern part of the inner bailey. More structured groups of magnetic anomalies, together with local dipole anomalies, are visible in the southern part of the inner bailey (in terms of the presence of a younger early medieval settlement and slags from field artefact collections). Magnetometer results with high magnetic remains of linear anomalies revealed some less-expected information concerning the presence of a gateway (interruptions) in the western, SW or southern perimeter fortification, the very locally variable presence of the burned perimeter fortification remains, the division or structure of inner areas within indications of possible paths inside the hillfort (Mařík and Křivánek, 2012, p. 67–70). But the same results also confirmed the variable quality of the subsurface preservation of features and the major impact of long-time ploughing of the entire site. Additional resistivity measurements of the surroundings of a formerly uncovered church and palace also confirmed some modern landscape changes in the area of the remodelled perimeter rampart. Geophysical data from the Libice hillfort were also subsequently used for comparison with other applied surface survey methods, like field artefact collection (ceramics, slags, and stones, for example, Fig. 4b) or metal detector surveys. Concentrations of stones along the perimeter of hillfort also confirm a heavily ploughed out rampart fortification with original stone walls or a construction. Some parts of

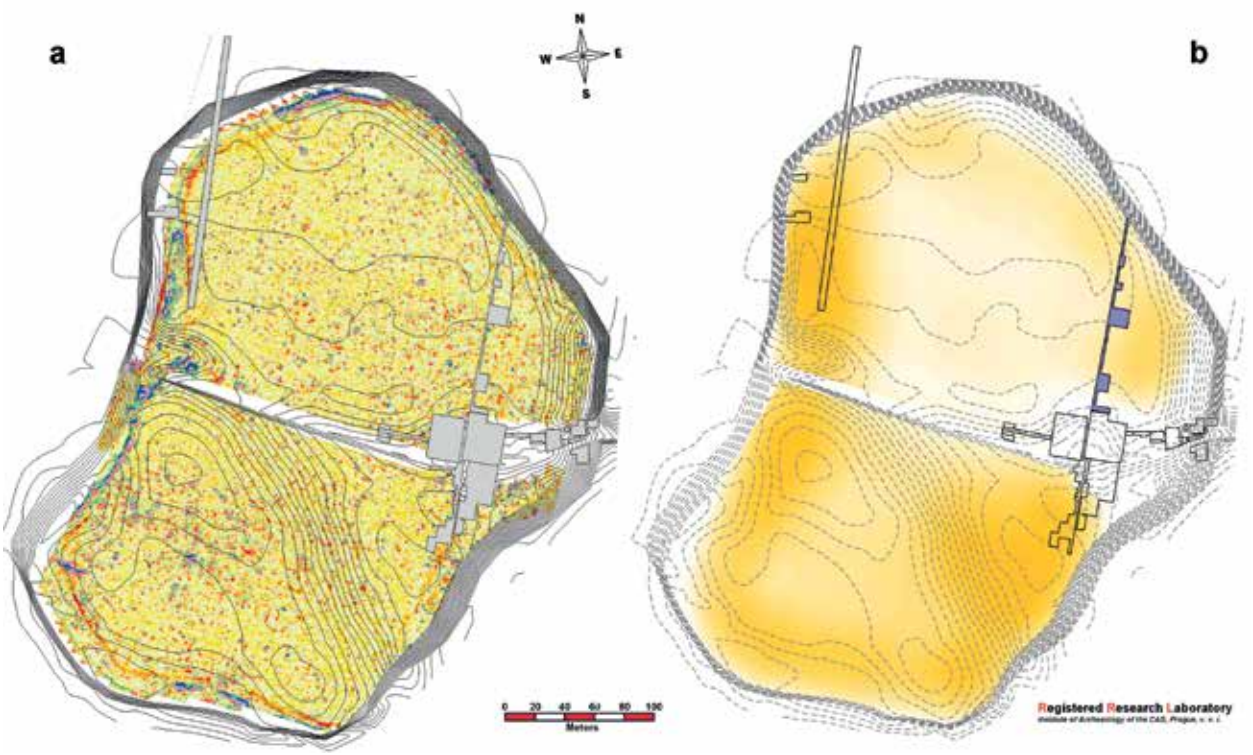

Fig. 4. Libice n. C., Nymburk District, early medieval hillfort. A comparison of the magnetometer prospection (a) of inner bailey and the distribution of clay stones (b) from a ploughed-out rampart fortification (source: Mařík, 2008–2009; surveyed area: 10.5 ha; survey: *Křivánek 2008–2009*).

4 pav. *Libice nad Cidlinou, Nymburk rajonas, ankstyvųjų viduramžių piliakalnis. Vidinės piliakalnio dalies magnetometriniai tyrimai (a) ir molio bei akmenų iš nuarto gynybinio pylimo paplitimas (b) (šaltinis: Mařík, 2008–2009; žvalgyta teritorija – 10,5 ha; žvalgymai: Křivánek, 2008–2009)*

the inner bailey are also planned for future repeated and more detailed magnetometer or magnetic susceptibility measurements, together with local archaeological verification. An example of the geophysical results represents how non-destructive data could be incorporated into an archaeological project focused on studying the terrain of hillforts endangered by ploughing and illegal metal detector users.

5. Vraný, Kladno District, early medieval hillfort (preliminary dated between the 10th and 12th centuries AD). The central part of the hillfort is located on a forested sandstone terrace promontory named the "Žižkaperk" above the northern bank of the Vranský Stream. The site has not been verified using any archaeological excavation (only a test pit by Knor at the end of the 1950s). The forested fortification with a rampart and outer ditch enclosed an area of about 2.5 ha. The continuation of settlement activity and a possible outer fortification here were indicated by the positive results of previous field artefact collections (Křivánek, 2012, fig. 5) and new aerial photographs on public websites. These accessible outer areas of the fields and meadow were then chosen for magnetometer prospection. Results of the magnetometer measurements finally confirmed two different and previously unknown outer ditch fortifications of the hillfort (Fig. 5). The inner ditch seems to have an interruption (entrance) in the southern part of linear anomaly, the outer ditch being interrupted in northern part near the edge of the promontory. Detected along with these two single ditch fortifications were sub-surface remains of probable sunken and burned features. Identified settlement activity in the outer areas of the hillfort corresponds to the identified extent of early medieval ceramic sherds and a slag from previous field artefact collections. Outer ditches are not visible today on the surface of the ploughed fields, and settlement remains here are also endangered by continuous ploughing on the locally shallow depth of sandstone bedrock. The results from the outer part

Fig. 5. Vraný, Kladno District. A combination of the results of a magnetometer prospection with the segment of an aerial photograph of an early medieval hillfort. (source: www.kontaminace.cenia.cz; surveyed area: approx. 3.1 ha; survey: *Křivánek, 2012*).

5 pav. *Vraný, Kladno rajonas. Ankstyvųjų viduramžių piliakalnio magnetometrinių žvalgymų rezultatų ir aeronuotraukos sugretinimas (šaltinis: www.kontaminace.cenia.cz; žvalgyta teritorija – apie 3,1 ha; žvalgymai: Křivánek, 2012)*

of the site (field) are also influenced by variable sloped soil erosion. The combination of geophysical and surface artefact collection results altered previous archaeological ideas regarding the scope of the fortified site. The early medieval hillfort had three different parts: an acropolis and two fortified outer baileys with a total fortified area of 5–6 ha (Křivánek, 2012, p. 158–159). The example of these results represents a simple and quite common application of the geophysical method for the verification of other non-destructive results and the revision of the structure and original extent of a hillfort only partly preserved in the present landscape.

6. Vlastislav, Litoměřice District, early medieval hillfort (9th–10th century AD). The archaeological site is situated on elevated and sloped terrain above the eastern bank of the Modla Stream. Geophysical measurements of the early medieval Vlastislav stronghold were carried out in 2016 during a regional project focussed on investigating important archaeological sites in NW Bohemia. The hillfort and its fortification system were verified by previous archaeological excavations in the 1950s (Váňa, 1954; 1968). Since the time of the archaeological investigation, the whole area of the hillfort has been used as ploughed fields and is today cultivated by private farmers. The internal rampart and ditch fortifications were ploughed out into terrain waves covered with stone destruction visible from the air as bright soil marks (Fig. 6a), The results of a magnetometer survey confirmed the very poor state of the sub-surface preservation of all archaeological situations and the deep and extensive soil erosion of all steep-sloped terrains inside the hillfort (Fig. 6b). The last remains of the original burned internal ramparts were identified only in more flat and less ploughed areas next to the terraces. The outer ditches of these fortification systems were detected only due to the filling of depressions with ploughed magnetic material from destroyed ramparts (burned clay stones). Additional geoelectric resistivity measurements of a segment of one

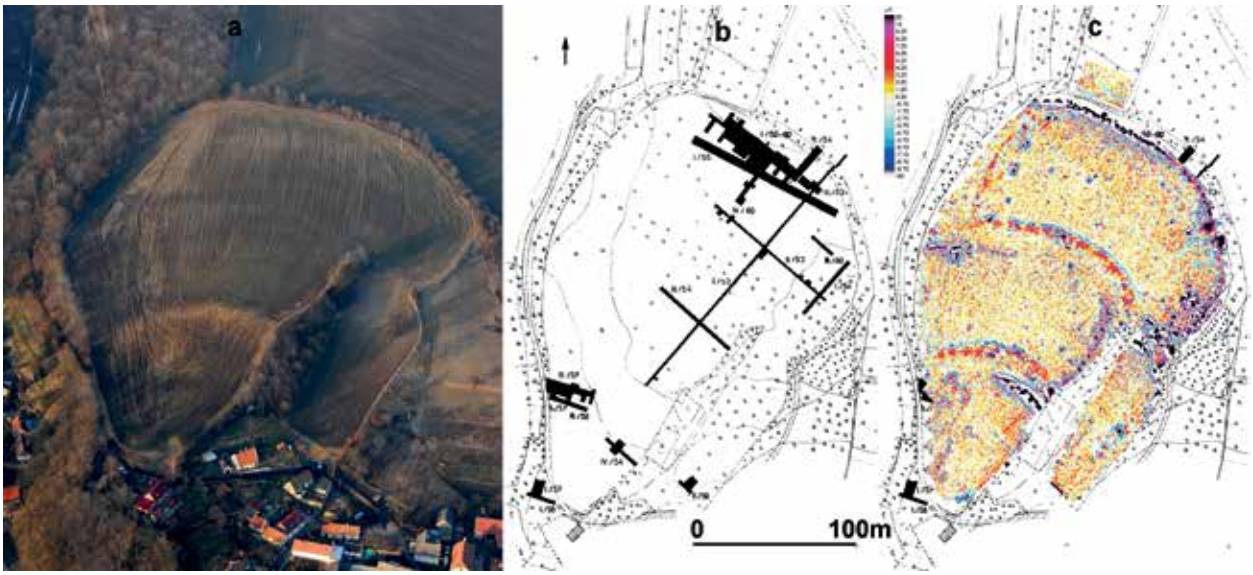

Fig 6. Vlastislav, Litoměřice District. A combination of an aerial photograph (a), a plan of an old archaeological investigation (b) and the results of a magnetometer measurement (c) of an early medieval stronghold (source: aerial photo: archive of the Institute of Archaeology, CAS, Prague – Gojda; archaeological plan of previous investigations: 1953–56 and 1957–60 – Váňa, 1968, Fig. 7; surveyed area: approx. 3.2 ha; geophysical survey: *Křivánek 2016*).

6 pav. *Vlastislav, Litoměřice rajonas. Ankstyvųjų viduramžių tvirtovės aeronuotraukos (a), anksčiau atliktų archeologinių tyrimų (b) ir magnetometrinių tyrimų rezultatų (c) sugretinimas (šaltiniai: aeronuotraukos: Archeologijos instituto archyvas, CAS, Praha – Gojda; anksčiau atliktų archeologinių tyrimų planas: 1953–1956 ir 1957–1960 – Váňa, 1968, Fig. 7; žvalgyta teritorija – apie 3,2 ha; geofiziniai žvalgymai: Křivánek 2016)*

inner rampart and outer ditch also confirmed the completely ploughed-out original stone walls inside of the rampart (without any higher resistivity linear anomalies). According to the results of the old archaeological excavations with uncovered areas of a settlement with various sunken features, the result of the magnetometer survey did not detect many magnetic anomalies that could indicate a preserved concentration of a hillfort settlement. In some places, next to terraces or filled roads, only magnetic modern and recent dumps or remodelling of the landscape (including remodelling of the origin ramparts or gates) were identified. From the results of archaeological excavations in the 1950s, we know about a quite intensive settlement inside of the hillfort. But the majority of shallow (and perhaps medium-deep) sunken features were ploughed out. The results of the non-destructive geophysical survey of the hillfort could be an important example for the protection of unmovable archaeological monuments, where very serious risks of the loss of archaeological situations in areas of uncontrolled agricultural activity really exist. The attached example of results could document how the geophysical method, applied after a particular investigation, might change information about the present state of the preservation of features in conditions of deeply eroded soil and subsoil layers.

7. *Klecany, Prague-east District, early medieval hillfort*. Various geophysical methods (magnetometer and resistivity measurements) were applied during different stages of the survey of some particular and accessible parts of the early medieval hillfort (for the case of an excavated EM cemetery inside of the hillfort, see Profantová, 2010). Other techniques (detailed magnetometer measurements of the closest vicinity of the graveyard, magnetic susceptibility measurements using a kappameter *in situ* in open archaeological situations) were then also used during archaeological excavations (Fig. 7a). According to all previous examples of large-scale geophysical results, the example chosen here represents a different and less common use of a detailed geophysical measurement in an open archaeological situation. An archaeological excavation of the perimeter rampart fortification by trenches (Profantová, 2013) provided an additional vertical magnetic susceptibility documentation

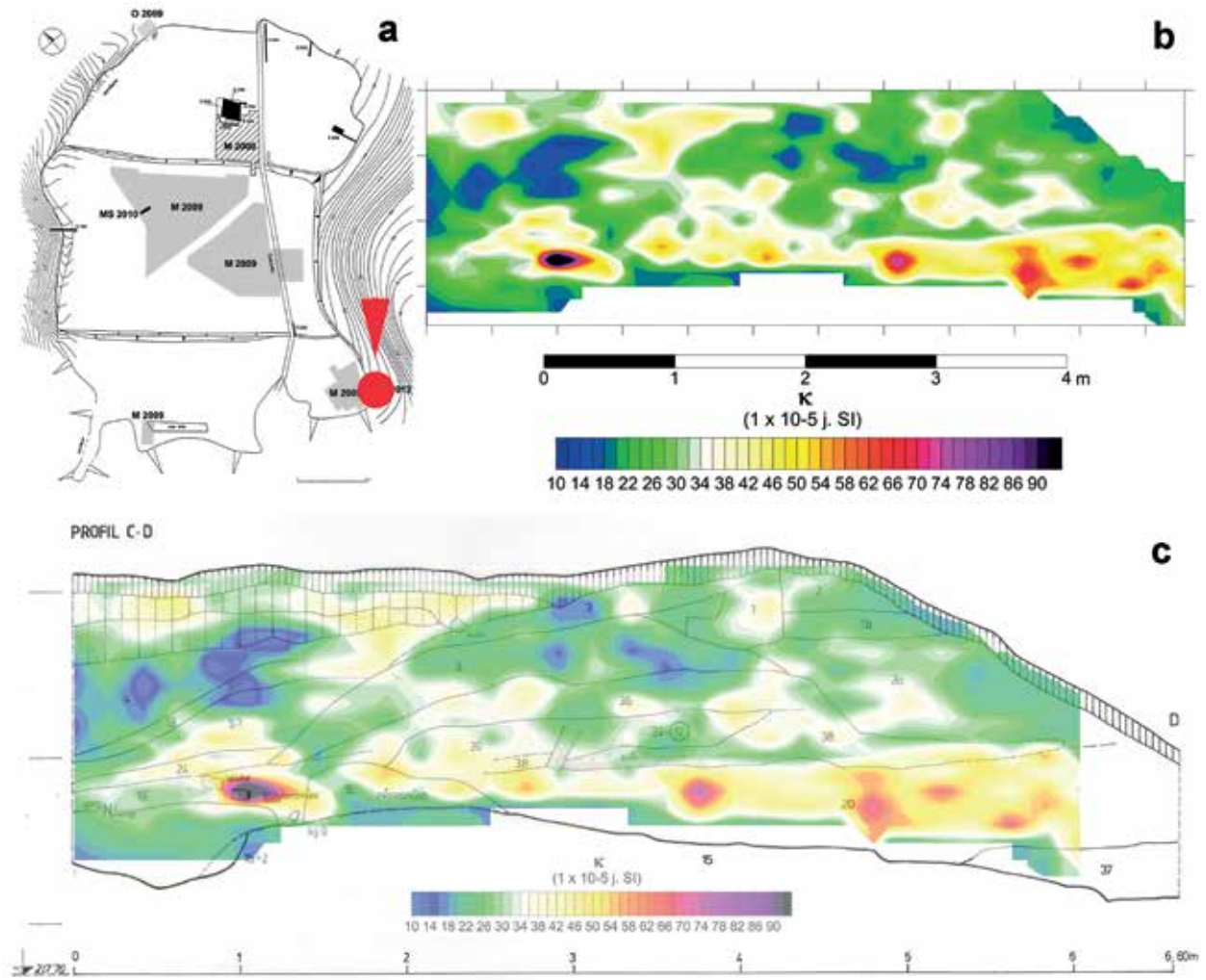

Fig. 7. Klecany, Prague-east District. The plan of a hillfort with areas of excavation (black) and geophysical measurements (grey; a), the result of a magnetic susceptibility measurement in situ (b), in combination with an archaeological profile documentation (c), a separation of layers of a probable prehistoric settlement with magnetic anomalies beneath the early medieval perimeter rampart destruction (source: Profantová, 2011; surveyed area: approx. 8 m^2; survey: *Křivánek 2011*).

7 pav. *Klecany, rytų Prahos rajonas. Piliakalnio planas su pažymėtomis archeologinių (juoda spalva) ir magnetometrinių (pilka spalva) tyrimų vietomis (a), magnetinio jautrumo matavimo rezultatais* in situ *(b), suderintas su archeologinio profilio brėžiniu (c), matyti priešistorinės gyvenvietės sluoksnių su magnetinėmis anomalijomis (d), buvusiomis po suardytu ankstyvųjų viduramžių pylimu, magnetograma (šaltinis: Profantová, 2011; žvalgyta teritorija – apie 8 m^2; žvalgymai: Křivánek 2011)*

of the rampart remains *in situ*. The results of the kappameter measurements of profiles across the fortification showed the different magnetic properties of the distinct layers of rampart destruction (Fig. 7b). Unfortunately, in the upper part of the soil-stone destruction of an early medieval rampart, magnetic susceptibility was quite low and homogenous. Only deeper situations seemed to have different higher magnetic susceptibility (soils). A combination of archaeological documentation with magnetic susceptibility results (Fig. 7c) then helped confirm and separate the source of the most magnetic layers beneath the rampart construction. These magnetic layers very probably represent the original prehistoric layers of the original terrain (prehistoric settlement of the promontory with ceramic sherds) before the later construction of the early medieval rampart fortification. An example of small-scale kappameter measurements during the archaeological excavation of the hillfort fortification described a different use of the specific geophysical method during the destructive investigations of hillforts.

Conclusion

Geophysical surveys with a different scale and intensity of measurements were performed at several dozen hillforts. This is still a smaller fraction of all known and registered hillforts in the Czech landscape (an estimate of the number of known hillforts is between 700 and 800, without calculated medieval or later strongholds). Still, the experience of intensive archaeo-geophysical surveys of hillforts allows us to formulate some basic general conclusions that seem to be valid for more than just individual fortified sites.

The application of different non-destructive geophysical methods at various hillforts can offer both a quantitative and qualitative view of the subsurface state of archaeological situations.

A large-scale magnetometer survey, together with particular resistivity measurements, seems to be (in Czech archaeology) the best combination for surveys of many hillforts.

The scale of spatial information of geophysical results can provide a great deal of new information for archaeology, the efficient planning of other (non-destructive or destructive) archaeological methods, the protection or change of land use for endangered archaeological heritage.

The use of geophysical results from hillforts (including their interpretation) increases in combination with data from other non-destructive methods and remote sensing techniques (aerial survey, LIDAR, surface artefact collections, metal detector survey, study of old maps or geochemistry) or also with destructive archaeology.

Geophysical surveys of archaeological heritage monuments, such as hillforts, could describe the real state of subsurface situations of the sites and may in some cases prevent the loss of subsurface situations on ploughed or newly afforested terrains.

On the other hand, these non-destructive geophysical methods do not have the same possibilities. Significant and specific limitations also exist for these methods.

We can observe and separate archaeological situations only in the case of preserved subsurface (subsoil) features *in situ* and in the conditions of different physical properties of features, surrounding areas and bedrock.

However, the geophysical surveys of fortifications using some methods and techniques may have potential even at sites previously surveyed as part of local archaeological investigations (Křivánek, 2015c).

The possibilities of geophysical measurements and the verification of hillforts in areas of modern settlements and industrial zones are much more limited by various outer factors and disturbances. In any case, any geophysical surveys on areas with irreversible and deep landscape changes are too late.

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Nedestrukcinių geofizinių metodų taikymas tyrinėjant Čekijos Respublikos piliakalnius

Roman Křivánek

Santrauka

Šiandieninės archeologinių tyrimų metodikos ir nekilnojamojo kultūros paveldo objektų apsaugos reglamentai nesudaro sąlygų platesniems piliakalnių tyrimams. Archeologiniai tyrimai gali būti orientuoti tik į mažesnes ir (arba) specifines piliakalnių teritorijas (pavyzdžiui, įtvirtinimus, vartus, laidojimo vietas, gamybinės veiklos centrus ir kt.). Archeologiniai kasinėjimai ir vėlesni gautų duomenų tyrimo ir radinių tvarkymo darbai yra riboti didelių finansinių, laiko ir darbo sąnaudų. Nedestrukciniai archeologinių tyrimų metodai kartu su kai kuriais nuotolinio žvalgymo metodais (pavyzdžiui, aeronuotrauka, LiDAR, geofiziniai, geocheminiai tyrimai ar paviršiniai žvalgymai) gali per trumpesnį laiką pateikti naujos erdvinės informacijos apie skirtingas piliakalnių vietas. Įvairių nedestrukcinių tyrimų duomenų derinimas su skirtingais geofiziniais tyrimais gali būti veiksmingas būdas, vykdant nežinomų ir netyrinėtų piliakalnių teritorijų stebėseną. Čekijoje skirtingi geo-

fiziniai metodai ir technologijos tyrinėjant ir žvalgant piliakalnius yra taikomi beveik 70 metų. Geofiziniai metodai iš pradžių buvo taikomi tik archeologinių kasinėjimų metu. Tačiau per pastaruosius du dešimtmečius šie nedestrukciniai metodai buvo taikomi daugelyje platesnių archeologinio paveldo tyrimų projektų.

Šiam straipsniui buvo atrinkti septyni tyrimų, atliktų piliakalniuose geofiziniais metodais ir technikomis, pavyzdžiai. Pasirinkti atvejai rodo skirtingas šiuolaikines objektų žvalgymo, dokumentacijos ar kartografavimo galimybes tiriant skirtingus piliakalnius. Pirmasis priešistorinio įtvirtinto objekto netoli Zlončice Vidurio Bohemijoje pavyzdys iliustruoja, kaip nauji nedestrukcinių magnetometrinių žvalgymų rezultatai parodo suartoje archeologinėje vietovėje buvusias gynybines griovių sistemas. Antrasis priešistorinio ir ankstyvųjų viduramžių piliakalnio Porán prie Voseco Rytų Bohemijos pavyzdys atskleidžia geofizinių metodų svarbą tikrinant, kokia yra žinomo archeologijos paminklo kultūrinių sluoksnių išlikimo būklė. Trečiasis pavyzdys iš La Tène opidumo Stradonice Vidurio Bohemijoje rodo, kaip geofizinių metodų derinys gali išskirti gyvenviečių liekanas, esančias po žeme, ir inicijuoti geresnę archeologiškai svarbios dalies apsaugą ateityje. Ketvirtasis ankstyvųjų viduramžių piliakalnio Libice pavyzdys Vidurio Bohemijoje reprezentuoja galimybę kombinuoti skirtingus nedestrukcinio pobūdžio tyrimų erdvinius duomenis, tiriant jau sunaikinto fortifikacinio įrenginio pobūdį arba piliakalnyje buvusios gyvenvietės struktūrą. Penktasis ankstyvųjų viduramžių piliakalnio tyrimų pavyzdys netoli Vranio rodo skirtingų nedestrukcinių metodų derinį, identifikuojant visą mažiau žinomą vietovę. Šeštasis pavyzdys iš ankstyvųjų viduramžių piliakalnio Vlastislav Šiaurės Bohemijoje iliustruoja, kaip geofizinis tyrimo metodas, taikomas atlikus archeologinius tyrimus, gali pakeisti kokybinę informaciją apie esamą kultūrinių sluoksnių būklę. Septintasis pavyzdys iš ankstyvųjų viduramžių piliakalnio netoli Klečanos, į šiaurę nuo Prahos, parodo skirtingas ir specifines magnetinio jautrumo matavimų galimybes ir jų pritaikymą atliekant archeologinius kasinėjimus įtvirtintoje vietovės teritorijoje.

Ilgametė Čekijos piliakalnių intensyvių geofizinių tyrimų patirtis leidžia mums suformuluoti keletą svarbiausių išvadų, kurios, atrodo, tinka ne tik pavienėms įtvirtintoms vietovėms. Įvairių nedestrukcinių geofizinių metodų taikymas skirtinguose piliakalniuose gali suteikti naują tiek kiekybinį, tiek kokybinį požiūrį į archeologinių vietovių kultūrinių sluoksnių būklę. Manoma, kad Čekijos archeologijoje didelio masto magnetometriniai žvalgymai kartu su daliniais elektrinės varžos matavimais yra geriausias daugelio piliakalnių tyrimų derinys. Atliekant geofizinius tyrimus gauta gausi erdvinė informacija gali suteikti daug naujų žinių, veiksmingai planuojant kitus (nedestrukcinius ar destrukcinius) archeologinius tyrimus, bandant apsaugoti nykstantį archeologinį paveldą. Piliakalnių geofizinių tyrimų rezultatų (taip pat jų interpretacijų) taikymo galimybės padidėja duomenis derinant su kitais nestandartiniais tyrimo metodais ir nuotolinio žvalgymo technologijomis (aeronuotrauka, LiDAR, paviršiniai žvalgymai, tyrimai metalo detektoriais, senųjų žemėlapių analizė arba geocheminiai tyrimai) arba ir su destrukcine archeologija. Geofiziniai archeologijos paveldo paminklų, taip pat piliakalnių tyrimai gali nusakyti po žemės paviršiumi esančio paveldo būklę ir kai kuriais atvejais apsaugoti šį paveldą nuo sunaikinimo teritorijose, naudojamose žemės ūkio reikmėms. Tačiau, kita vertus, šių nedestrukcinių geofizinių metodų galimybės ne visur yra vienodos. Šiems metodams taip pat būdingi nemaži specifiniai trūkumai. Archeologinius objektus galime pastebėti ir identifikuoti tik tada, kai yra *in situ* išlikusios įgilintos struktūros ir tik kai tos struktūros pasižymi skirtingomis savybėmis nei jų aplinka bei įžemis. Vis dėlto geofiziniai žvalgymai piliakalniuose, taikant tam tikrus metodus ir strategijas, gali būti perspektyvūs net tais atvejais, kai tos pačios vietovės jau buvo žvalgytos anksčiau tradiciniais metodais. Piliakalnių geofizinių tyrimų galimybės šiandieninių gyvenviečių ir pramoninių zonų teritorijose taip pat yra ribotos dėl įvairių išorinių veiksnių ir trukdžių. Didelio masto ir gilius suardymus patyrusiose vietovėse geofiziniai žvalgymai laukiamų rezultatų neduotų.