geosciences

MDPI

Article

Comparison Study to the Use of Geophysical Methods at Archaeological Sites Observed by Various Remote Sensing Techniques in the Czech Republic

Roman Křivánek

Institute of Archaeology of the Czech Academy of Sciences, Prague, v.v.i., Department of Archaeology of Landscape and Archaeobiology, Letenská 4, 118 01 Prague 1, Czech Republic; krivanek@arup.cas.cz; Tel.: +420-2-5701-4033

Received: 4 August 2017; Accepted: 1 September 2017; Published: 7 September 2017

Abstract: A combination of geophysical methods could be very a useful and a practical way of verifying the origin and precise localisation of archaeological situations identified by different remote sensing techniques. The results of different methods (and scales) of monitoring these fully non-destructive methods provide distinct data and often complement each other. The presented examples of combinations of these methods/techniques in this study (aerial survey, LIDAR-ALS and surface magnetometer or resistivity survey) could provide information on some specifics and may also be limitations in surveying different archaeological terrains, types of archaeological situations and activities. The archaeological site in this contribution is considered to be a material of this study. In case of Neolithic ditch enclosure near Kolín were compared aerial prospection data, magnetometer survey and aerial photo-documentation of excavated site. In the case of hillforts near Levousy we compared LIDAR data with aerial photography and large-scale magnetometer survey. In the case of the medieval castle Liběhrad we compared LIDAR data with geoelectric resistivity measurement. In case of a burial mound cemetery we combined LIDAR data with magnetometer survey. In the case of the production area near Rynartice we combined LIDAR data with magnetometer and resistivity measurements and result of archaeological excavation. Fortunately for successful combination of geophysical and remote sensing results, their conditions and factors for efficient use in archaeology are not the same. On the other hand, the quality and state of many prehistoric, early medieval, medieval and also modern archaeological sites is rapidly changing over time and both groups of techniques represent important support for their comprehensive and precise documentation and protection.

Keywords: archaeological prospection; remote sensing; data integration; condition assessment

1. Introduction

Remote sensing techniques represent the quickest and fully non-destructive source of information on the scale of whole archaeological sites and/or particular segments of cultural (archaeological) landscapes. Their main advantages are new extensive identification of sites and quick and long-time possibility of passive/active collecting of various data. For archaeological heritage is also very important the progressive documentation and qualitative monitoring of condition changes (including various hazard risks) of different archaeological situation or landscapes. Aerial survey and later LIDAR have been for a few decades the most intensively applied RS methods with many published results [1–4]. Current increasing importance of wider RS techniques in archaeology confirms more about this issue oriented publications [5–11]. Results of RS data were also in some conferences compared with results of ground non-invasive prospection methods [12,13]. From the beginning of their application in archaeology geophysical methods in the sphere of archaeological prospection have had different goals, scale or accuracy based on the surface monitoring of changes in physical properties of subsurface layers [14,15]. From the point of view of the methodology of measurement (use of terrestrial sensors), geophysical methods are sometimes included in a broader group of various remote sensing techniques. However, from a practical point of view of surveyed responses of subsurface physical changes, geophysical prospection in archaeology can offer 2D (or also 3D) information about archaeological sites and especially about individual archaeological features, structures and layers [16,17]. Therefore from an archaeological point of view, the specific application of the geophysical method in archaeology is more often ranked among archaeological prospection methods, methods of non-destructive (or non-invasive) archaeology, methods of field archaeology or near-surface geophysical methods. All of these views are based on the use of geophysical methods in archaeology and are justified.

In the Czech Republic, various remote sensing techniques have been applied in archaeology up until now in varying intensities and scales of use. Aerial photography and LIDAR (respectively ALS —airborne laser scanning) have been the most intensively used results of RS by archaeologists for a longer period of time [18–23]. In recent years, some interdisciplinary projects and works have extended these data to include multispectral data and drone surveys results [24]. Comparison of potential of chosen satellite images (from satellite systems IKONOS, QuickBird and CORONA purchased through a Czech company ArcData to Dept. of Archaeology at the University of West Bohemia in Pilsen) with aerial archaeological survey photographs has been done in four selected regions [25]. The subsequent cooperation of archaeologists specialised in aerial archaeology and geophysicists working in archaeology also had a rather long tradition with many projects, outputs and compared results. The examples presented in this paper should demonstrate different ways of subsequent application of remote sensing techniques and surface geophysical methods, their interdependence and differences in use for archaeology.

2. Materials and Methods

As study material of this contribution, we use surface and subsurface relics of selected archaeological situations and sites. Five chosen examples compare results from different types of archaeological sites (enclosure, fortified area, medieval settlement, funeral and production area), but there are also examples from sites with other characteristic human activities (for example mining area, communication, military area or polyfunctional site).

As study methods, we use the complexity of applying various remote sensing techniques and geophysical methods and, above all, comparison of their results. Suitable methods for the geophysical survey of any archaeological situation are closely related to the current field conditions of measurement. For years, magnetometer surveys have been the main and most intensively applied geophysical method in Bohemian archaeology. Two types of magnetometers have been used over the past two decades. Since 1998, a gradient variant of the caesium vapour magnetometer Smartmag SM-4g (Scintrex Ltd., Concord, ON, Canada) was performed, with an approximate network of 1.0 × 0.25 m (Kolín, Rynartice), with some details in a 0.5 × 0.2 m density (Údraž). Since 2010, a five-channel Magneto-Arch magnetometer system with FMG-650B (Sensys GmbH, Bad Saarow, Germany) fluxgate gradiometers has been used with a data density of 0.5 × 0.2 m (Levousy) or 0.25 × 0.1 m. This is the most powerful method for the identification of various sunken features or burned situations on arable fields, meadows or pastures, but on a much smaller scale we can also use it also in some forested terrains. Magnetic susceptibility measurement in open archaeological situations (in situ) is also used in archaeological excavations. Geoelectric resistivity measurement as a second geophysical method also has a long tradition of use in Bohemian archaeology. Since the beginning of the 21st century, the RM-15 instrument (Geoscan Research, Bradford, UK) has been used for geoelectrical resistivity surveys primarily in a Wenner or Schlumberger configuration and a common data density of 1 × 1 m (Liběhrad), some details in 0.5 × 0.5 m (Rynartice). This method was applied in various agricultural and also forested terrains for the identification of various remains of features with an expected stone construction and their destructions. The results of these geophysical methods are presented in this paper. However, in some other specific cases we combine their results with other geophysical methods: electromagnetic or radar measurement (detection of stone structures or unfilled areas beneath pavements, tiles or floors) or thermometry (unfilled areas inside sacred architecture or buildings). Geophysical data were in paper compared with aerial photographs (from the archive of the Institute of Archaeology, CAS, Prague, v.v.i.) or Digital Terrain Model of the 5th generation (DMR 5G provided as fully public service from the Czech Office for Surveying, Mapping and Cadastre [26]. In this study, were used oblique aerial photographs of M. Gojda, but also in partial cases some orto-photographs from fully public web services (at present time five different years of public aerial photography are on public web server [27]). LIDAR-ALS data were also public and in case of filtered Digital Terrain Model of the 5th generation (DMR 5G) they represents image of the natural or man-modelled terrain with total mean error of the height 0.18 m in an open terrain or 0.3 m in a forested terrain (previous DMR 4G had total mean error 0.4 m in an open terrain and 1 m in a forested terrain which was insufficient for archaeological purposes).

3. Results

3.1. Ditch Enclosures

Neolithic roundels, Eneolithic interrupted ditch enclosures, Bronze Age oval ditch enclosures and La Tène quadrangular enclosures are common types of different ditch enclosures or enclosed systems found in the Czech landscape. Most of them have been identified on agricultural land thanks to characteristic crop marks from aerial photographs, and only a few of these enclosures can be distinguished in forested areas from LIDAR data. Long-term or deep ploughing of fields did not allow the preservation of sufficiently distinguished anthropogenic relief formations (low chance for identification in LIDAR). However, possibilities of aerial prospection are also highly variable depending on soil pedology and the geology of ploughed fields. For example, Neolithic roundels are very often localised on sloped (eroded) terrains with varying layer of loess. For aerial prospection, these conditions are not optimal for the identification of sunken features such as ditch enclosures, but are very suitable for successful geophysical (magnetometer) prospection [28]. In the case of the Neolithic roundel (1) near Kolín (Kolín district), preliminary magnetometer survey helped precisely before the start of the rescue archaeological excavation of the Kolín bypass road. Remains of the Neolithic roundel with a diameter of over 200 m were identified on three fields around the junction of present roads (Figure 1b). The results were locally disturbed by different electric power lines and also subsurface cable and metallic gas pipe lines (high magnetic violet-blue lines in Figure 1b). The roundel probably originally had four entrances, and subsequent archaeological excavations in the corridor of the bypass confirmed three circular ditches and a fourth unfinished ditch [29,30]. The Neolithic roundel was never identified on loess from aerial photographs (see Figure 1a), and the aerial documentation of uncovered parts of the enclosure was carried out during rescue excavations (see Figure 1c–e). Additional magnetic susceptibility measurements in situ on vertical profiles also documented changes in the fills of open ditches-more about fills in [31]. Another measurement of magnetic susceptibility observed the superposition of the end of the outer unfinished ditch of the roundel with a Neolithic long house (different phases of Neolithic settlement and activities at the site). Result of magnetometer survey in this case helped (without any previous successful RS data) to manage efficient rescue archaeological excavation of endangered parts of the one of the largest bohemian Neolithic roundels.

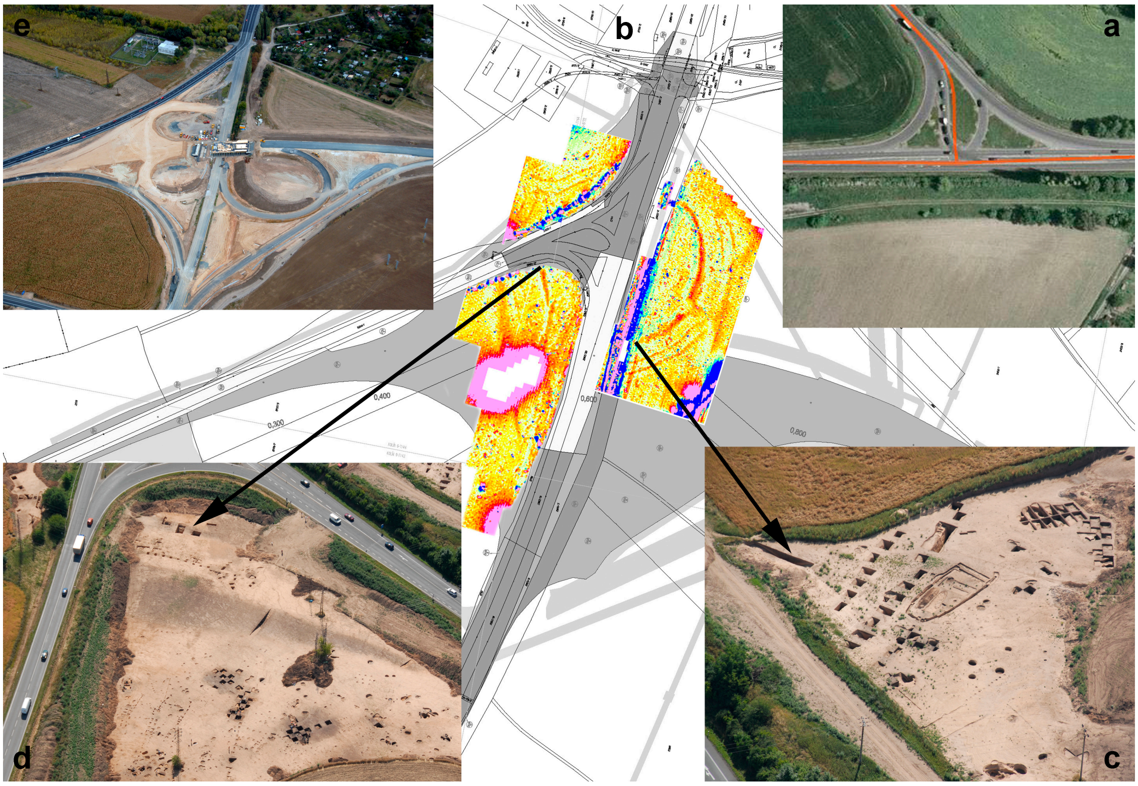

Figure 1. Kolín, district Kolín–Neolithic roundel. The combination of results of (**a**) aerial photography before excavation, (**b**) results of magnetometer survey in place of planned corridor of bypass road and (**c**–**e**) aerial photodocumentation of uncovered remains of enclosure and other settlement (source: archive of the Institute of Archaeology, CAS, Prague, v.v.i.–photo: M. Gojda, surveyed area: approx. 2.15 ha, geophysical survey: Křivánek 2008).

3.2. Fortified Settlement Areas

Prehistoric and early medieval hillforts were the most common types of fortified and often internally structured settlements in Bohemia (until the 13th century AD). Their positions in the landscape were targeted at strategic places, on promontories, hilltops, near important communications, rivers, sources of raw materials, etc. Aerial photography is very intensively used for the overall documentation of hillforts situated in agricultural areas, whereas LIDAR is often more helpful in forested areas. Preserved remains of fortification systems can be identified on the surface from identified linear elevations or depression, while some subsurface remains of destroyed fortifications can be observed from vegetation (linear crop marks) or soil changes. The application of geophysical prospection then offers much more detailed information about the real extent, structure, entrances, internal settlement and other activities at hillforts [32,33]. Magnetometer measurements are often focused on the verification of large-scale unexcavated areas of sites or on the verification of particular new situations from aerial photographs or field artefact collections. In some specific areas (such as gates, parts of ramparts, paths, places with an expected stone construction), these data then add particular geoelectric resistivity measurements. The final interpretation of geophysical data then depends on more regionally and/or locally specific limits (variability of geology, pedology, level of soil erosion or modern-recent disturbances of measurements, preservation of the original terrain, etc.), also including the often repeated use of the same site in different periods. In the case of the Late Bronze Age and early medieval hillfort near Levousy (Litoměřice district), a magnetometer survey of all accessible terrains of fields includes sunken or locally burned features with highly varied dating of these activities. LIDAR images of the fortified site show how the strategic claystone promontory above the Ohře River was chosen in different periods (Figure 2a). Archaeological excavation of inner ramparts by trenches confirmed the first settlement in the Neolithic and Eneolithic periods, while the first fortification of part of the site is expected in the Late Bronze Age; settlement continuation in the Iron Age has been confirmed. The Slavic hillfort (9th and 10th century AD) was enlarged to an area of over 12 ha of the fortified site [34]. However, the promontory also played an important military function during the Austro-Prussian War in the second half of the 19th century. Results of a magnetometer survey then include magnetic anomalies (sunken features) from various prehistoric periods, remains of the ploughed-out perimeter rampart, remains of internal divisions (baileys) of the early medieval hillfort, but also later lines of military polygons (the remains of two "reduta" fortifications) from the 19th century and also local magnetic disturbances from modern agricultural and orchard activities at the site (see Figure 2c). Military remains and different types of settlement were also confirmed by aerial photographs (straight lines in Figure 2b). Additional local resistivity survey confirmed the ploughed-out stone construction of destroyed parts of the perimeter rampart. Result of a large-scale magnetometer survey in this case could be (with results of aerial surveys) used as a new level of information for evidence and protection of immovable archaeological monument (hillfort with repeated prehistoric and early medieval settlement and modern military use).

3.3. Abandoned Medieval Sites

The Bohemian countryside today includes many ruins of abandoned medieval strongholds, villages and small castles. These settlement areas and places of lower regional nobility were later abandoned, destroyed, forgotten or deeply changed by the modern landscape and land-use changes. Their remains in agricultural areas are in a very poor condition and often without any possibility to identify regular shape and extent of origin medieval structures. The situation seems to be somewhat better in forested areas, where better surface and subsurface remains with stone components can be found. Details in LIDAR data is also used for the preliminary identification of these remains in often forested and not easily accessible areas (Figure 3a,b). Their precision is highly variable and is connected with the present state of the original terrain of sites, with qualitative changes in the landscape and also with recent timber harvesting and new afforestation. Systematic surface geodetic and archaeological documentation is then important for more precise evidence of these sites. Geophysical survey could also help in some cases of preserved clear situations and landscapes. This was also the case of the ruins of small Liběhrad Castle near Libčice nad Vltavou (Praha-západ district) abandoned in the 16th century; a medieval village known from written sources from the end of 10th century with later Zbraslav Monastery property during the 13th/14th century [35]. Modern landscape changes meant that geodetic-archaeological surface documentation and application of geophysical methods were very limited. The northern part of the original castle was partly destroyed by the construction of the railway, and the state of the remodelled and forested landscape within the electro-magnetic disturbances of the electrified railway line did not facilitate the efficient use of magnetic or electromagnetic methods. Newertheless, the results of a geoelectric resistivity survey of the accessible inner part of castle identified some subsurface remains of internal castle settlement structures (Figure 3c,d). High resistivity anomalies confirmed remains of the collapsed perimeter wall on the rampart and other stone destructions (blue areas in Figure 3d). Low resistivity anomalies indicated the possible destruction of another structured settlement (sunken features, platforms) inside (yellow areas in Figure 3d). A detailed geodetic survey of the surface combined with geophysical measurement showed an efficient way for the detailed documentation of evidence and the protection of a highly remodelled archaeological site. Result of limited resistivity survey (combined with LIDAR-ALS data new geodetic plan of site) contributed to more detailed non-destructive information about partly damaged medieval castle.

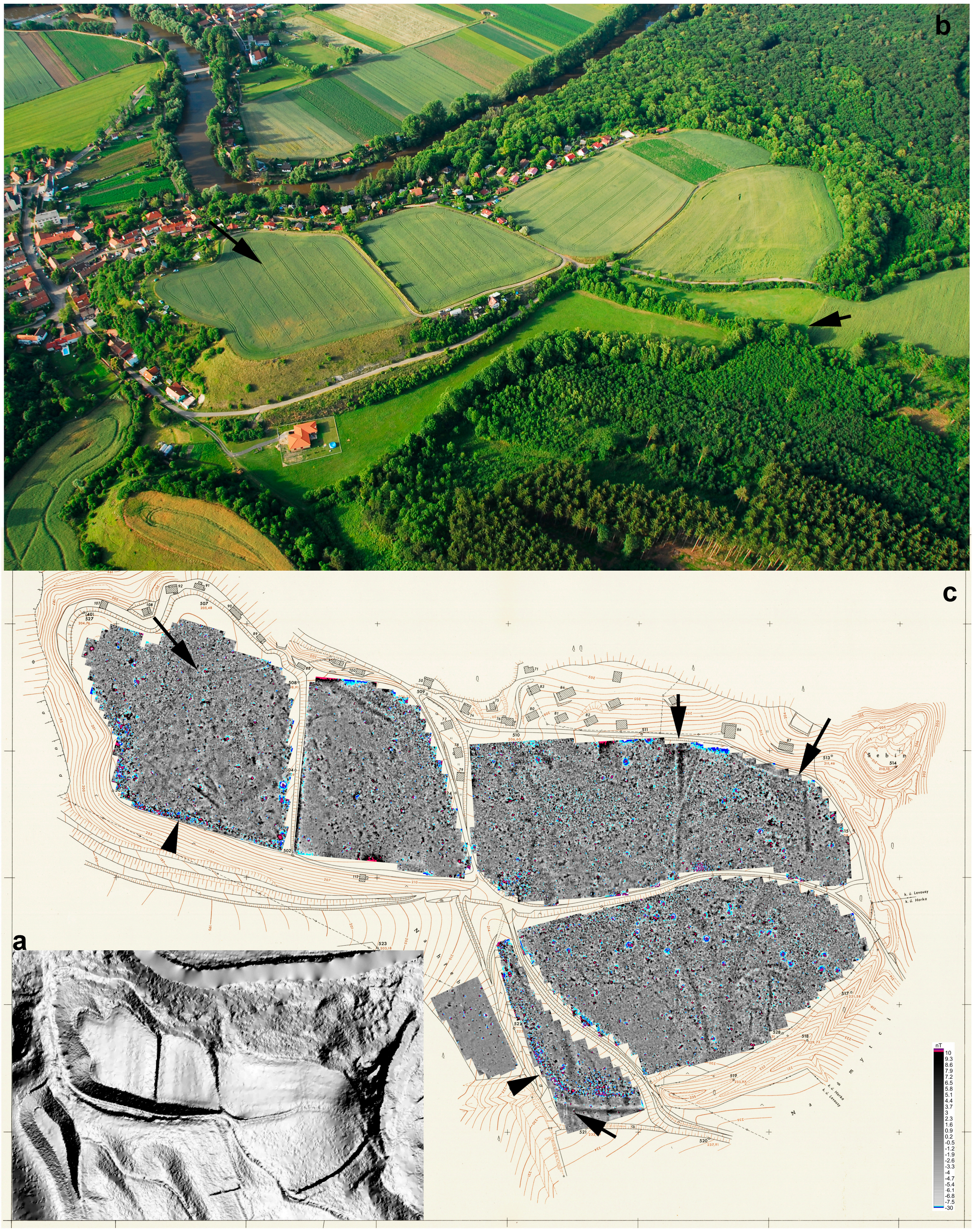

Figure 2. Levousy, district Litoměřice–prehistoric and early medieval hillfort. The combination of results of (**a**) LIDAR–DMR 5G in shaded relief (left bottom corner), (**b**) aerial photography and (**c**) large-scale magnetometer prospection of site including linear remains of ploughed out rampart (short triangular arrows), ditch fortifications and modern military activities (longer arrows) from 19th century (source: archive of the Institute of Archaeology, CAS, Prague, v.v.i.–photo: M. Gojda and www.geoportal.cuzk.cz-Copyright © ČÚZK, surveyed area: approx. 9.8 ha, geophysical survey: Křivánek 2015).

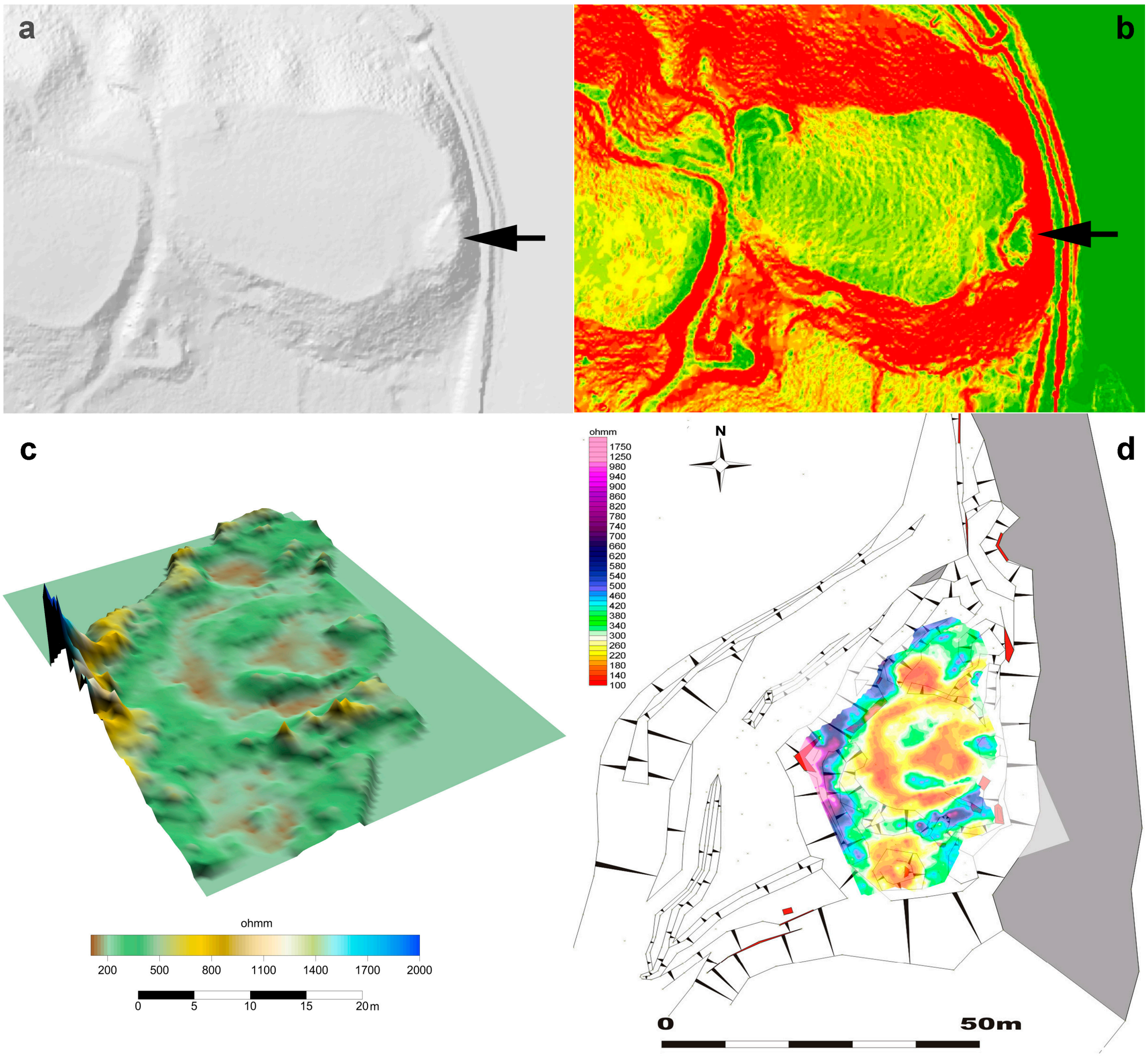

Figure 3. Libčice n. V., district Praha-západ–medieval Liběhrad Castle. The combination of results of (**a**) LIDAR–DMR 5G in shaded relief and (**b**) inclination of slopes (arrows points place of castle), (**c**) 3D-presentation of resistivity measurement results and (**d**) geodetic plan of remains of abandoned castle with resistivity data (source: [35] (Figures 15 and 22) and www.geoportal.cuzk.cz-Copyright © ČÚZK, surveyed area: approx. 1100 m^2, geophysical survey: Křivánek 2006–2007).

3.4. Funeral Sites

Prehistoric or early medieval burials and barrow cemeteries are a very typical type of archaeological sites, especially in forested parts of south and west Bohemia. Most of these remains with funeral activity have been looted, and some barrow cemeteries were also excavated by archaeologists very early (beginning in the 19th century), some on agricultural land were ploughed-out, and others in forests were damaged or remodelled by repeated afforestation. However, due to characteristic elevations, many of them were (or their remains) inside forests can still be safely distinguished by LIDAR data, and it is possible to separate groups of burial mounds, different shapes of burial cemeteries and/or the different sizes of individual burial mounds. As a second step, we can then apply more surface archaeological methods, including geophysical techniques. Magnetometer measurements are often combined with geoelectric resistivity measurements, but sometimes also with electromagnetic and even GPR measurement. The efficiency and choice of suitable geophysical methods in forested areas depends greatly on the type and material of burial mounds, the type of landscape, geology or the funeral activity. In the case of the Bronze Age barrow cemetery near Údraž (Písek district), a magnetometer survey was aimed at verifying potential outer flat graves and observing the state of the subsurface preservation of a chosen group of three funeral features (Figure 4b). The result confirmed the anticipated coincidence of three elevations, from LIDAR (Figure 4a) or surface geodetic documentation [36,37], with magnetic anomalies of barrows (the slightly magnetic layers of burial mounds) and a few another anomalies in the flat terrain, possible sunken feature outside of barrows [38–40] (red small areas out of barrows in Figure 4b). Results from the magnetometer most likely showed the not fully oval shape of burial mounds. The varied character of magnetic anomalies over individual barrows could indicate the different state of subsurface preservation of barrows and burials inside. In the case of two barrows, interruptions are visible inside features (probably remains of old excavations or illegal looting with a metal detector); in the case of the third barrow, it seems to be the central place without any disturbed or relocated material. Result of a partial magnetometer survey (together with LIDAR-ALS data and without successful aerial prospection-forest) helped to verify the state and extent of partially excavated prehistoric burial mound cemetery.

3.5. Production Areas

Abandoned medieval or modern archaeological sites with specific production activity (glass-works, charcoal pens, pitch-production) are typical for the more mountainous border regions around Bohemia. In the case of the Czech-Saxon Switzerland National Park in north Bohemia, the remains of more pitch-production centres were identified during field surveys in forested areas [41]. Due to the typical quite high waste heaps from this production, we could identify also some of these elevation details from LIDAR (Figure 5a). However, due to highly variable and rugged terrain with typical sandstone formations and valleys, identification is quite complicated and limited by the character of the local terrain. More suitable geophysical methods were used to distinguish between smaller production features such as pitch-furnaces and the scope of waste materials. The combination of detailed field surface survey with magnetometer prospection seemed to be best way to identifying the remains of abandoned medieval or Early Modern production sites in intensively forested regions. In the case of the medieval pitch-production centre near Rynartice (Děčín district), a magnetometer survey helped distinguish the most highly magnetic parts of the terrain (Figure 5b) between two elevations formed by massive layers of burned ashes (violet-blue high magnetic anomalies between magnetic red areas in Figure 5c). This result provided a better and much more efficient verification of the site by archaeological excavation [37,39]. Subsequent archaeological trenches [42] uncovered the remains of a furnace from the 14th/15th century for pitch distillation (Figure 5e,f). The original source of the highly magnetic anomaly was shown to be a combination of heavily burned clay materials and also partly the stone construction of the furnace with neovolcanic material [43]. The results of the excavation with the uncovered pitch-furnace were also supplemented with another geoelectric resistivity measurement combined with magnetic data (Figure 5d). A survey of the wider area confirmed the presence of more pitch-production activities—the wider extent of production near a water source with a partly preserved path. Result of combined magnetometer and resistivity survey in this case could (with result of archaeological excavation, partial result of LIDAR-ALS data and without possible results of aerial survey) illustrate efficient combination of methods in the study of similar forested and separate medieval/modern production areas.

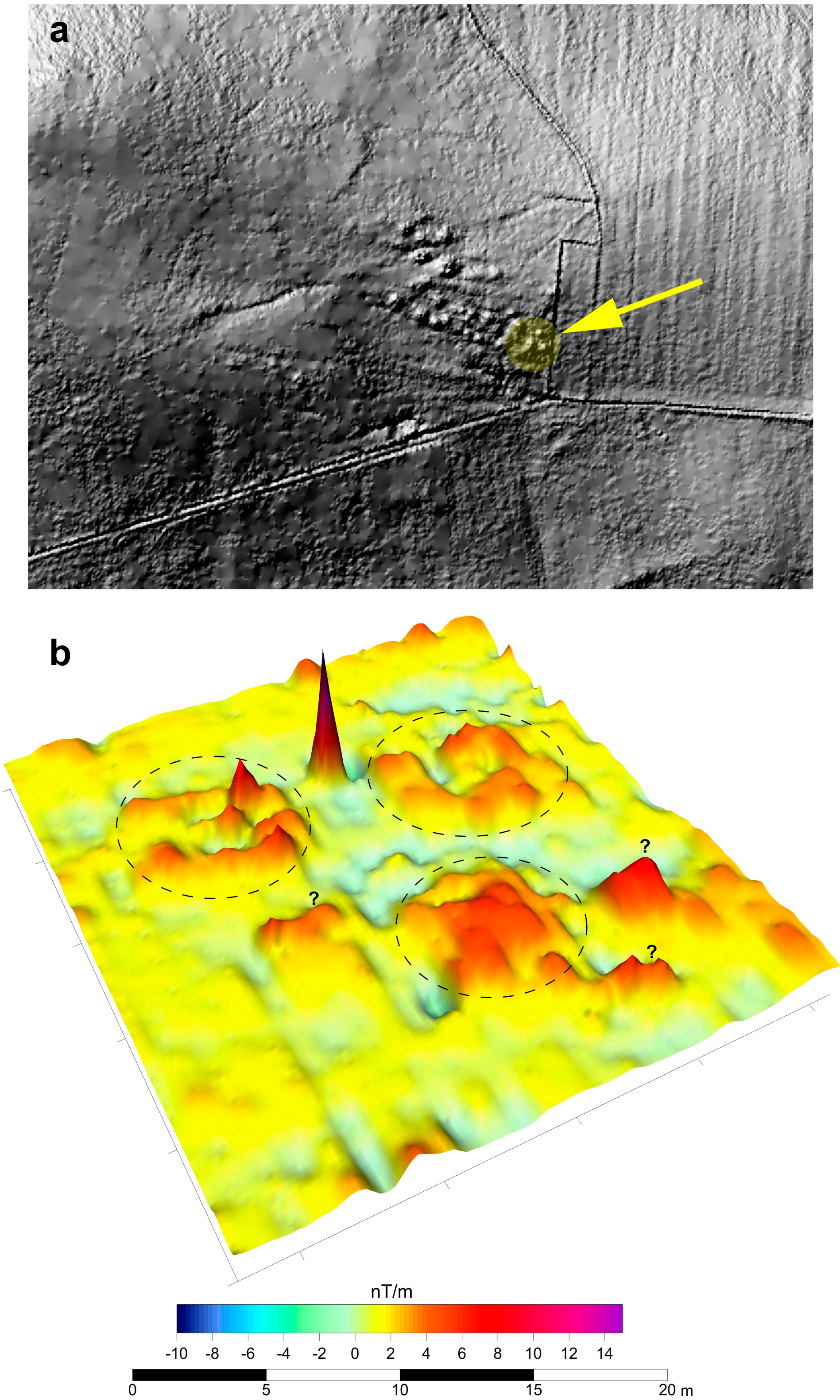

Figure 4. Údraž, district Písek–Bronze Age burial mound cemetery. The combination of (**a**) LIDAR–DMR 5G documentation of the whole site (yellow arrow points group of verified barrows) and (**b**) detail of 3D-presentation of magnetometer measurement result over three barrows (source: [38] (Figure 2) and www.geoportal.cuzk.cz-Copyright © ČÚZK, surveyed area: 575 m^2, geophysical survey: Křivánek 2006).

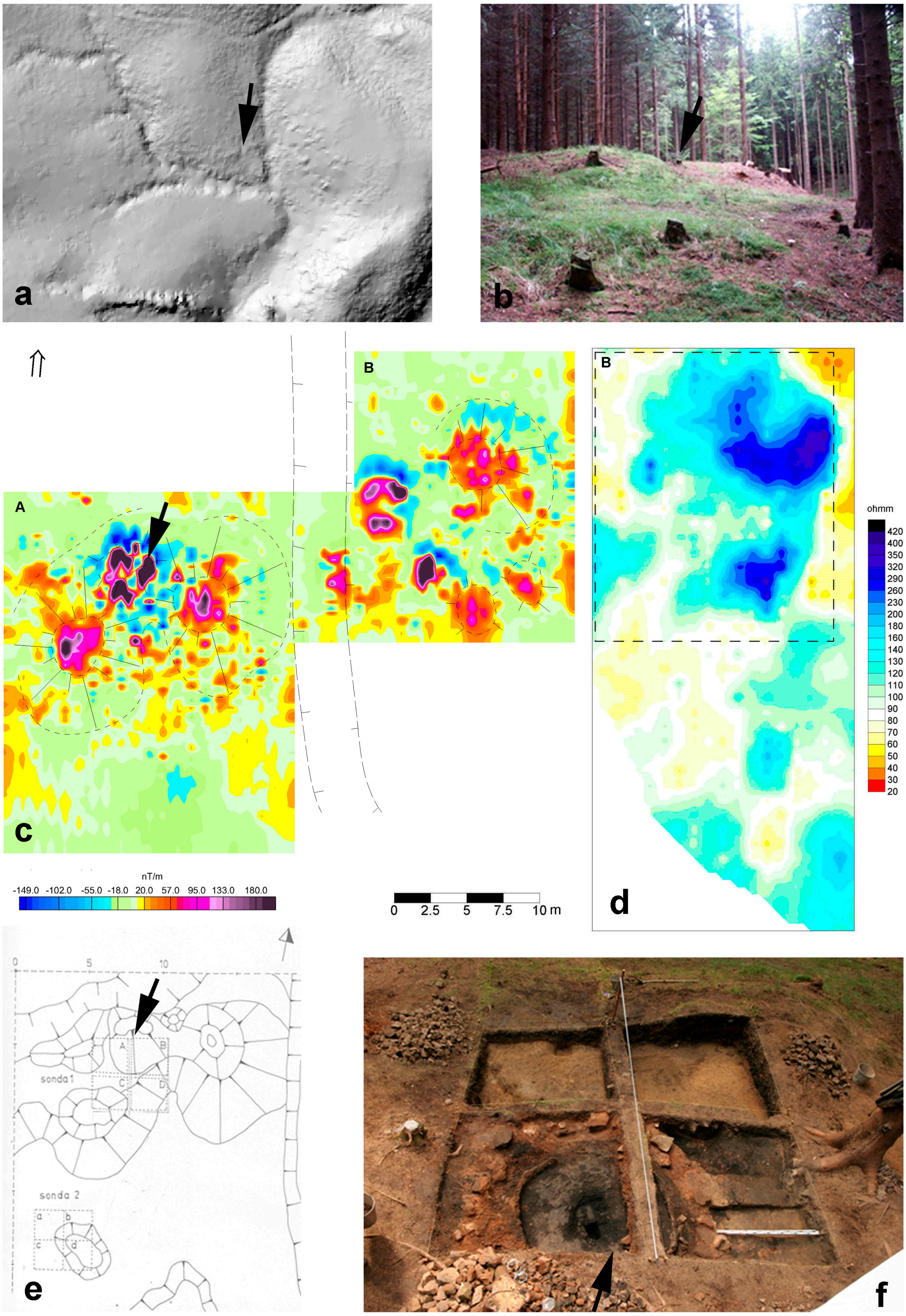

Figure 5. Rynartice, district Děčín–medieval pitch production area. The combination of results of (**a**) LIDAR–DMR 5G, (**b**) photodocumentation of site before excavation, (**c**) result of magnetometer survey of areas A and B, (**d**) results of resistivity surveys of area B, (**e**) plan with archaeological trenches and (**f**) final uncovered medieval pitch-furnace (arrow points place of pitch-furnace; source: [40,42] and www.geoportal.cuzk.cz-Copyright © ČÚZK, surveyed area: 0.15 + 0.1 ha, geophysical survey: Křivánek 2004–2005).

4. Discussion

In this paper, five examples from various types of archaeological sites document different possibilities of the chosen remote sensing techniques and applied geophysical methods. Their information is irreplaceable and their subsequent cooperation is very often necessary and leads to the more efficient study of archaeological sites. However, from the view of specific and different principles of collecting data we can see also some specific advantages and disadvantages of particular methods and techniques. The quality and level of results of remote sensing techniques is very often dependent on suitable time and the conditions of application of airborne or space-borne sensors. For example, quality of data from passive satellite systems is limited by the type of low (CORONA), high (LANDSAT) or very high (IKONOS) spatial resolution. Quality of active ALS-LIDAR is for example very connected with density of data collection but also with subsequent processing, classification, filtration or interpolation of origin data. Active aerial archaeology is then for example very dependent on actual conditions of monitored areas (existence of crop/soil/snow/shadow-marks) and height above the terrain. However, success of all of passive and active remote sensing methods is closely related to other field conditions like terrain surface variability or level of impact of land-use changes. Another very limiting factor of many RS techniques, except the LIDAR-ALS, is vegetation and mainly intensity of afforestation of terrain. A big advantage of all RS techniques is then the possibility of use of changing data in longer horizon of collecting data. These sets of repeated data could illustrate how fast and important are modern changes of archaeological sites and terrains. Their most efficient use is on the scale of whole archaeological sites or the cultural (archaeological) landscape, where we can observe surface changes of individual sites in time as spatial contexts of different archaeological sites and wider areas. Collected data from RS techniques play an important role in protection and recording of immovable archaeological heritage, but also in other archaeological disciplines (like for example regional history, settlement dynamics, networks or environmental archaeology). Disadvantages of successful application of geophysical method in archaeology are very often connected with the actual state of preservation of physically distinguishable archaeological situations beneath the soil. The results of geophysical measurements are always dependent on the state of the archaeological site and field conditions, the quantity and intensity of land-use changes, landscape changes, pedology and geology of studied area. In very variable conditions of archaeological sites we cannot always use the same geophysical methods for identification of similar remains of subsurface situations or activities. For example somewhere we can find clear results from aerial photographs with less readable results from magnetometer measurements (sand-gravel sediments and terraces), somewhere else we can see clear results from magnetometer surveys without clearly visible features from aerial prospection (loess or clay sediments). Regional and local pedological and geological conditions play a very important role in archaeo-geophysical prospection. Possibilities of geophysical prospection by various methods are then also very dependent on vegetation and/or local disturbances for different methods. Their most efficient use is on the scale of particular archaeological sites or their parts (only some newly extensively and intensively applied geophysical techniques offer monitoring of some parts of the archaeological landscape). The main advance of geophysical methods is in the possibility of identifying or distinguishing the subsurface remains of smaller individual features and archaeological situations. Various geophysical methods (in the field, but sometimes also in the laboratory) can be applied at different scales of new archaeo-geophysical information. Some geophysical measurements we can use before archaeological verification of the site, others during archaeological investigation and another also after finished particular destructive excavation of site. However, from the perspective of archaeological sites and landscape protection, we can see a very close interdependence between these methods. Neverthless, an effective combination of these methods cannot be done without the support of further information and data (e.g., from the fields of historical cartography, geography, geospatial data, geochemistry, etc.).

5. Conclusions

Valid for all non-destructive geophysical methods and remote sensing techniques is that agricultural activities such as the ploughing of fields, afforestation, mining or building activities play a very important role in the real preservation of surface and subsurface archaeological layers. Together with subsequent erosion or irreversible landscape changes they play also a very important role in the real preservation of surface and subsurface archaeological layers, preservation and possibilities for monitoring archaeological sites. From all of combined data it is clear that quality (and in some regions also quantity) and state of archaeological sites is rapidly, and somewhere also dramatically, changing over short time. Archaeology together within cultural heritage management will need more complex and precise documentation of endangered sites and landscapes.

Acknowledgments: All sources of funding of the study should be disclosed. Please clearly indicate grants that you have received in support of your research work. Research work has been supported mainly during research project of the Institute of Archaeology in Prague AV0Z80020508; some results were produced also during the project of Regional cooperation "Non-destructive geophysical surveys of significant and endangered archaeological sites in the Ústí Region, Czech Republic" R300021421 (CAS, Křivánek 2014–2016). Clearly state if you received funds for covering the costs to publish in open access.

Conflicts of Interest: The author declares no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

References

1. Rackowski, W. *Archeologia Lotnicza—Metoda Wobec Teorii (Aerial Archaeology—Method in the Face of Theory)*; Wydawnictwo Naukowe UAM: Warszawa, Poland, 2002; ISBN 83-232-1194-9. (In Polish)
2. Doneus, M. *Die Hinterlassene Landschaft—Prospektion und Interpretation in der Landschaftsarchäologie*; Mitteilungen der Prähistorischen Kommission der Österreichischen Akademie der Wissenschaften; Verlag der Österreichischen Akademie der Wissenschaften: Wien, Austria, 2013; ISBN 978-3-7001-7197-3. (In Germany)
3. Bewley, R.H.; Crutchley, C.A.; Shell, C.A. New light on an Ancient Landscape: Lidar Survey in the Stonehenge World Heritage Site. *Antiquity* **2005**, *79*, 636–647. [CrossRef]
4. Devereux, B.J. The Potential of Airborne Lidar for Detection of Archaeological Features under Woodland Canopies. *Antiquity* **2005**, *79*, 648–660.
5. *Remote Sensing in Archaeology: An Explicitly North American Perspective*; Johnson, J.K., Ed.; University of Alabama Press: Tuscaloosa, AL, USA, 2006; ISBN 978-0-8173-5343-8.
6. *Remote Sensing in Archaeology*; Wieseman, J.R., El-Baz, F., Eds.; Springer: New York, NY, USA, 2007; ISBN 978-038-7444-4536.
7. *Remote Sensing for Archaeology and Cultural Heritage Management*; Lasaponara, R., Masini, N., Eds.; Aracne: Rome, Italy, 2008; ISBN 978-88-548-2030-2.
8. Parcak, S.H. *Satellite Remote Sensing for Archaeology*; Routledge: London, UK, 2009; ISBN 978-0415448789.
9. *Remote Sensing for Archaeological Heritage Management*; EAC Occasional Paper No. 5; Cowley, D., Ed.; Archaeolingua: Budapest, Hungary, 2011; ISBN 978-963-9911-20-8.
10. Cower, D.C.; Harrower, M.J. *Mapping Archaeological Landscapes from Space*; Springer: New York, NY, USA, 2013; ISBN 978-1-4614-60732.
11. *Sensing the Past. Contribution from the ArcLand Conference on Remote Sensing for Archaeology*; Posluschny, A., Ed.; Habelt-Verlag for ArcLand: Bonn, Germany, 2015; ISBN 978-3774939640.
12. *Interpreting Archaeological Topography: Airborne Laser Scanning, 3D Data and Ground Observation*; Occasional Publication of AARG No. 5; Opitz, R.S., Cowley, D., Eds.; Oxbow Books: Oxford, UK, 2013; ISBN 978-1842175163.
13. *A Sense of the Past: Studies in Current Archaeological Applications of Remote Sensing and Non-invasive Prospection Methods*; Kamermans, H., Gojda, M., Eds.; BAR. International Series; Archaeopress: Oxford, UK, 2014; ISBN 978-1-4073-1216-3.
14. *Archäologische Prospektion: Luftbildarchäologie und Geophysik*; Becker, H., Ed.; Arbeitshefte des Bayerischen Landesamtes für Denkmalpflege; Bayerisches Landesamt für Denkmalpflege: München, Germany, 1996; ISBN 3-87490-541-1. (In Germany)

15. Gater, J.; Gaffney, C. *Revealing the Buried Past: Geophysics for Archaeologists*; Tempus Publishing: Stroud, UK, 2003; ISBN 978-0-7524-2556-6.
16. Witten, A.J. *Handbook of Geophysics and Archaeology*; Equinox Publishing: London-Oakville, UK, 2006; ISBN 1-904768-59-8.
17. *Mittelneolithische Kreisgrabenanlagen in Niederösterreich: Geophysikalisch-archäologische Prospektion-ein interdisziplinäres Forschungsprojekt. Mitteilungen der Prähistorischen Kommission der Österreichischen Akademie der Wissenschaften*; Neubauer, W., Melichar, P., Eds.; Verlag der Österreichischen Akademie der Wissenschaften: Wien, Austria, 2010; ISBN 978-3-7001-6684-9. (In Germany)
18. *Ancient Landscape, Settlement Dynamics and Non-Destructive Archeology—Czech Research Project 1997-2002*, 1st ed.; Gojda, M., Ed.; Academia: Praha, Czech Republic, 2004; ISBN 978-80-200-1215-X.
19. Gojda, M. *Archeologie a Dálkový Průzkum: Historie, Metody, Prameny (Archaeology and Remote Sensing: History, Methods, Data)*; Academia: Praha, Czech Republic, 2017; ISBN 978-80-200-2644-6. (In Czech)
20. Křivánek, R. 2.3. Geophysical Prospection. New Perspectives for Settlement Studies in Bohemia. In *Ancient Landscape, Settlement Dynamics and Non-Destructive Archeology—Czech Research Project 1997-2002*, 1st ed.; Gojda, M., Ed.; Academia: Prague, Czech Republic, 2004; pp. 39–71. ISBN 978-80-200-2644-6.
21. Křivánek, R. Geofyzikální měření při ověřování výsledků leteckých průzkumů v severozápadních Čechách. In *Archeologické Výzkumy v Severozápadních Čechách v Letech 2003–2007 (Sborník k životnímu jubileu Zdeňka Smrže)*; Ústav Archeologické Památkové Péče Severozápadních Čech v Mostě: Most, Czech Republic, 2008; pp. 385–397. ISBN 978-80-86531-05-2.
22. Gojda, M.; John, J. *Archeologie a Letecké Laserové Skenování Krajiny (Archaeology and Airborne Laser Scanning of the Landscape)*; Západočeská universita v Plzni: Plzeň, Czech Republic, 2013; ISBN 978-80-261-0194-9. (In Czech)
23. Křivánek, R.; Gojda, M. Půdní a Geologické Podmínky při Leteckém a Geofyzikálním Průzkumu–Soil and Geological Conditions in Aerial and Geophysical Surveys. *Živá Archeol. (re)Konstr. Exp. Archeol.* **2010**, *11*, 92–95. (In Czech) (extended variant of paper on http://www.zivaarcheologie.cz/CasopisZivaArcheologieCisla.html)
24. Chytráček, M.; Chvojka, O.; Egg, M.; John, J.; Kozáková, R.; Křivánek, R.; Kyselý, R.; Michálek, J.; Stránská, P. A Disturbed Late Hallstatt Period Princely Grave with a two-wheeled Chariot and Bronze Vessels in Sedlina Forest near Rovná in South Bohemia: A Preliminary Report. In *Archaeological Sites in Forests—Strategies for their Protection, Inhalte–Projekte–Dokumentationen, Sriftenreihe des Bayerisches Landesamt fur Denkmalpflege*; Volk Verlag: Munchen, Germany, 2017; pp. 83–90. ISBN 978-3-86222-226-1.
25. Gojda, M.; John, J. Dálkový Archeologický Průzkum Starého Sídelního Území Čech: Konfrontace Výsledků Letecké Prospekce a Analýzy Družicových Dat. *Archeol. Rozhl.* **2009**, *61*, 467–492. (In Czech)
26. Český Úřad Zeměměřický a Katastrální (ČÚZK) (Czech Office for Surveying, Mapping and Cadastre). Available online: www.geoportal.cuzk.cz (accessed on 9 August 2017).
27. Public Web Server with Base Maps and Current Air Maps–Copyright © 1996–2017 Seznam.cz, a.s. Available online: https//mapy.cz (accessed on 2 July 2017).
28. Křivánek, R. Geophysical Surveys of Abandoned Quadrangular Enclosures ("Viereckschanzen") from La Tène Period in Bohemia. *ISAP News (The newsletter of the International Society for Archaeological Prospection)*. Issue 36. August 2013, pp. 5–7. Available online: http://www.archprospection.org/isapnews/isapnews-36 (accessed on 1 August 2013).
29. Šumberová, R.; Malyková, D.; Vepřeková-Žegklitzová, J.; Pecinovská, M. Sídlení Aglomerace v Prostoru Dnešního Kolína. Záchranný Výzkum v Trase Obchvatu Města (Settlement Aglomerations in Today's Kolín Area, Central Bohemia. Rescue Excavations along the Town by-pass Road). *Archeol. Rozhl.* **2010**, *62*, 661–679. (In Czech)
30. *Cesta Napříč Časem a Krajinou: Katalog k Výstavě Nálezů ze Záchranného Archeologického Výzkumu v Trase Obchvatu Kolína 2008-2010*; Šumberová, R., Ed.; Archeologický ústav AV ČR: Praha, Czech Republic, 2012; ISBN 978-80-87365-52-6. (In Czech)
31. Lisá, L.; Bajer, A.; Válek, D.; Květina, P.; Šumberová, R. Micromorphological Evidence of Neolithic Rondel-like Ditch Infillings: Case Studies from Těšetice-Kyjovice and Kolín, Czech Republic. *Interdiscip. Archaeol. Nat. Sci. Archaeol.* **2010**, *4*, 135–146.
32. Křivánek, R. Changes of Structure and Extent of Early Medieval Strongholds in Central Bohemia from Geophysical Surveys of Sites. Archaeological prospection. In Proceedings of the 10th International Conference on Archaeological Prospection, Vienna, Austria, 29 May–2 June 2013; Neubauer, W., Trinks, I., Salisbury, R.B., Einwögerer, C.H., Eds.; Austrian Academy of Sciences Press: Wien, Austria, 2013; pp. 281–284.

33. Křivánek, R. Hillfort Investigations in the Czech Republic. In *Field Archaeology from Around the World. Ideas and Approaches. Springer Briefs in Archaeology*, 1st ed.; Carver, M., Gaydarska, B., Eds.; Springer International Publishing: Cham, Switzerland, 2015; pp. 157–161. ISBN 978-3-319-09818-0.
34. Zápotocký, M. Raně Středověké Sídelní Komory na Dolní Ohři. *Archeol. Rozhl.* **1992**, *44*, 185–215.
35. Hložek, J.; Křivánek, R. Komplexní Nedestruktivní Výzkum Hradu Liběhradu. *Castellologica Bohemika* **2009**, *11*, 297–312. (In Czech)
36. Krištuf, P.; Rytíř, L. Mohylová Pohřebiště na Okrese Písek. Metoda Zaměřování Mohylových Pohřebišť—Burial Mound Cemeteries in the Písek Region. Method of Visual Survey of the Burial Mound Cemeteries. In *Opomíjená Archeologie 2005-2006–Neglected Archaeology 2005–2006*; Krištuf, P., Šmejda, L., Eds.; University of west Bohemia: Plzeň, Czech Republic, 2007; pp. 133–140. ISBN 978-80-254-1062-2. (In Czech)
37. Chvojka, O.; Krištuf, P.; Rytíř, L. *Mohylová Pohřebiště na Okrese Písek: Barrow Cemeteries in the Písek District. Archeologické Výzkumy v Jižních Čechách. Supplementum*, 1st ed.; Jihočeské Museum: České Budějovice, Czech Republic, 2009; ISBN 978-80-87311-02-8. (In Czech)
38. Křivánek, R. Possibilities and Limitations of Surveys by Caesium Magnetometers in Forested Terrains of Archaeological Sites. In *Študijné Zvesti Archeologického Ústavu SAV 41–2007, Archaeological Prospection–Topics and Abstracts, Proceeding of the 7th International Conference on Archaeological Prospection, Nitra, Slovakia, 11–15 September 2007*; Kuzma, I., Ed.; Archeologický Ústav SAV: Nitra, Slowakia, 2007; pp. 202–204. ISBN 978-80-89315-00-0.
39. Křivánek, R. Využití Geofyzikálních Metod ARÚ Praha při Průzkumech Archeologických Lokalit v Jižních Čechách. *Archeol. Výzkumy Již. Čechách* **2007**, *20*, 435–451. (In Czech)
40. Křivánek, R. Příklady Využití Magnetometrických Metod při Průzkumech Zalesněných Archeologických Lokalit. *Služ. Archeol.* **2008**, *20*, 70–77. (In Czech)
41. Lissek, P. Povrchový Průzkum Dehtářských Pracovišť v Českém Švýcarsku. *Archeol. Tech.* **2005**, *16*, 72–78. (In Czech)
42. Lissek, P. *Archeologický Výzkum Areálu Dehtářského Pracoviště "Pod Purkarticemi" na k. ú. Rynartice, okr. Děčín v Roce 2005*; Investorská zpráva pro Správu Národního parku české Švýcarsko (Report for the Investor of Archaeological Excavation); Ústav archeologické památkové péče severozápadních Čech v Mostě: Most, Czech Republic, 2015.
43. Křivánek, R. Detailní Měření Magnetické Susceptibility v Odkrytých Archeologických Situacích (Detailed Measurement of Magnetic Susceptibility in an Open Archaeological Situation). *Archeol. Rozhl.* **2008**, *60*, 695–724. (In Czech)

© 2017 by the author. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).