



A Sense of the Past

Studies in current archaeological applications of
remote sensing and non-invasive prospection methods

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A Sense of the Past: Studies in current archaeological applications of remote sensing and non-invasive prospection methods

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Front cover illustration: DTM of a set of artillery forts (a later addition to the great fortified town of Terezín (north-west Bohemia, Czech Republic) which was constructed across the Labe river in the mid 19th century), a result of ALS (March 2011). The current state of the monument which has been partly levelled (forts 1 and 4) is well illustrated by this way. Also, a dense network of former trackways and linear earthworks of which some may have been connected with the fort system is apparent.

Back cover illustration: Vladař (western Bohemia, Czech Republic) DTM of extensively fortified Iron Age hillfort produced from airborne laser scanned data acquired in March 2010. The image displays perfectly the current state of the site and its individual components, such as the so-called acropolis situated in the highest part of the hillfort (coloured blue) and the fortification system of ramparts and ditches in the western and northern parts of the flat table hill.

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TESTING THE POTENTIAL OF AIRBORNE LiDAR SCANNING IN ARCHAEOLOGICAL LANDSCAPES OF BOHEMIA: STRATEGY, ACHIEVEMENTS AND COST-EFFECTIVENESS

Martin Gojda

Abstract: *This paper presents an overview of the recently acquired application of ALS in archaeology in the Czech Republic. The main focus is on a general description of the first ever project in Bohemia (western half of the Republic,) the principle aim of which was to test the potential of air-borne LiDAR in a Central European landscape (heavily affected by long-term farming, most typically by means of extensive and destructive application of tillage cultivation), both forested and open. Apart from the geographical units (14 test polygons measuring together 123 sq. kilometres, irregularly spread over the whole country), the paper also provides information on two special aspects connected with the project: on testing the accuracy of historical 18th – 19th century military maps compared to a few military defensive features still preserved in more or less ruined remains in the field, and on the comparison of cost effectiveness for getting a 3D model of a large prehistoric hillfort by means of a ground-based geodetic survey on the one hand and through ALS on the other.*

Keywords: *ALS - air-borne LiDAR - digital terrain model (DTM) - ground-based geodetic survey - historical military maps*

Introduction

Bohemia, situated in the very heart of Europe, is the principal and largest part of the historical Czech Kingdom and currently of the Czech Republic. Due to its geographical position, the country had been a crossroad of major central European – and many times pan-European – political and military events. At the same time its territory, surrounded on its perimeter by an almost continuous mountain range, is a rare example of a geomorphological unit in which various climatic and terrain environmental zones are present. The fertile lowlands of the country's core area in central Bohemia (the lower Labe/Elbe and Vltava/Moldau basins are around 180 metres above sea level (asl)) are surrounded by rising undulating low-hill regions. Beyond these are highlands which rise to a more-or-less continuous mountain range that surrounds the country like a ring on its borders, the highest peak of which is over 1600 metres asl. Thus enclosed, it represents a model country in terms of an effective investigation of diachronic (prehistoric, medieval, post-medieval, early modern) processes of settlement and landscape colonisation.

A large number of archaeological remains in many countries in the northern half of Europe have been damaged or destroyed by long-term cultivation. However, in central Europe, including Bohemia, many remains are preserved as earthworks which are now in woodlands. In the post-war period some of these may have been damaged by heavy tree-harvesters and tractors, and currently by activities of illegal metal detectors and looters (*Gojda 2011, 1450*). But these remains are generally better protected in woodland

than in open landscapes (cf. *Neustupný 2010*) where cultivation, on land up to 1000 metres asl, has been actively pursued in many places since medieval times.

Large-scale mapping of features in woodland is not easy and it can also be difficult to precisely geolocate their position. For these and many other reasons the arrival of airborne laser scanning (ALS) as part of the practice of archaeological detection and mapping offers a significant innovation. In the above context it is especially the potential of ALS to operate over woodland which radically may, and hopefully will, accelerate the process of systematic recording and relatively precise mapping of not only single features and sites but also complex archaeological landscapes in Bohemia.

Objectives

The development of LiDAR technology started soon after the invention of the laser in the late 1950s (see e.g. *Chang-Chang Wang 2011*), but its application in archaeology and past landscape studies was not introduced systematically until the first half of the 2000s. This application has progressed most dynamically in a few European countries, such as Austria (*Doneus - Briese 2011*), the UK (*Devereux et al. 2008; Crutchley – Crow 2010*), Ireland (*Shaw - Corns 2011*), France (*Georges-Leroy 2011*) and Germany (*Bofinger -Hesse 2011*). Apart from in Slovenia (*Rutar - Črešnar 2011*), archaeological applications of ALS are just beginning in some countries of the former Soviet bloc.

In the context of a methodological progress in

archaeological data-gathering and data-processing which resulted from positive political shifts in the early 1990s, a two-year project, *The potential of ALS for archaeological landscape survey in the Czech Republic*, has recently been completed (Gojda et al. 2011). Its aims and interim results are presented in this contribution and it is of importance at least in two aspects. Firstly, our use of ALS was a pioneering job in a small central European country in which the value of non-invasive methods of remote sensing for both theoretically-based research and heritage management has been recognised during the past two decades (e.g. Gojda 2004; Kuna et al. 2004). Secondly, at the time when the application for the Czech Science Foundation (CSF) was being prepared, only a very small area of Bohemia had been scanned by airborne LiDAR and was available only as shaded relief digital surface/terrain models in *.tiff/*.jpg formats. Consequently, it was necessary to ask the CSF for financial support to allow us to define areas that would be scanned exclusively for the project's purposes at a standard spatial resolution. Luckily, our project application was accepted at the first attempt and the necessary money allocated so that our planned strategy did not need to be changed and the principal aims of the project could be achieved.

In brief, the effort of the project team was focused on the assessment of the effectiveness and potential of the new remote sensing method in terms of heuristics (identification and evidence of archaeological earthwork heritage), interpretation of sites and features through additional activities (such as ground observation of a range of features recorded on the LiDAR images) and mapping. Also, we wanted to find out the degree of effectiveness of LiDAR application in archaeology, especially in terms of the quality of results with respect to final costs. Comparison with traditional ground-based survey (geodetical) methods producing a similar digital terrain model was carried out. The project's duration was two years (from 2010 to 2011) and was carried out by the academic staff of the Department of Archaeology, University of West Bohemia in Pilsen.

Strategy and areas selected

The selection of areas to be scanned was subject to several factors. It was intended to examine extensive areas (regions, geomorphological units, landscape transects), medium-sized areas (hillforts, postmedieval to early modern field fortification systems) and smaller areas (deserted medieval villages, barrow sites, etc.). Areas were also chosen because they were known to include an as extensive and varied representation as possible of both prehistoric and historic sites, monuments and features. Choices were weighed against the effort needed to acquire information that would enable a comparison of ALS results with conventional mapping and documentation.

As noted above, the main reason why Czech archaeology so far has not had the opportunity to use the ALS data was the very limited coverage of the Czech Republic by LiDAR

imagery, and the high cost of new LiDAR data acquisition. The present project may therefore be considered as a certain breakthrough into field archaeological survey, documentation and mapping of archaeological heritage scattered over the countryside, as it brings with it a vast potential for complex study of extensive landscape units.

The particular regions of interest to the project can be divided into two main groups:

1. Areas that have been scanned by means of ALS for the first time. Altogether 14 test polygons were selected, in which a wide range of features of various types are situated (Fig. 1).
2. Areas that had already been scanned in the past by means of ALS, but primarily for purposes other than archaeological. Those data can be used to extract the archaeological content of such areas. This includes the area of the Bohemian Switzerland National Park with its unique dynamic geo-relief landscape characteristics that had in the past, and has to date, great influence on the evolution of demographic aspects of this region, and the quality and quantity of traces of its past human settlement activities.

Collecting and evaluating the data

Six of the selected territorial units (polygons) were scanned in late March 2010 and the remaining eight in March 2011. Most are approximately 10 sq kilometres in extent. The former were scanned by the German company *Milan Geoservice GmbH* using the laser scanning device Riegl LMS-Q560 at flight level 600 m. Raw data collection was at a density of 4 points/m² and filtered to produce a digital terrain model (DTM) with a resolution of 1x1 m². The remaining eight polygons were scanned by the Czech company *Geodis Brno* using a Riegl LMS-Q680i LiDAR at flight level 900 m with raw data at a density of 2-3 points/m² and (in one case) 10 points/m². The raw data were delivered in *.las format, the filtered data (DSM, DTM) were both submitted in ASCII/*.asc format.

Existing data for the area of the Bohemian Switzerland National Park was scanned between 2004 and 2006 as part of the international project Interreg IIIA GeNeSis (Geoinformation Network for Crossborder National Parks Bohemian-Saxon Switzerland) under the auspices of the Institute of Remote Sensing of the Earth of the Dresden University for Technology.

In the first phase of assessment, output from the ALS carried out during 2010 and 2011 was subject to heuristic analysis by comparing it with documentation of recorded archaeological sites as well as with historic maps and plans. The subsequent, very important, step is the verification on the ground of individual features by means of a surface survey. For example, a barrow burial site Hádky/Javor and medieval moated site Javor (Fig. 2) was evaluated using both visual reconnaissance and control measurements of

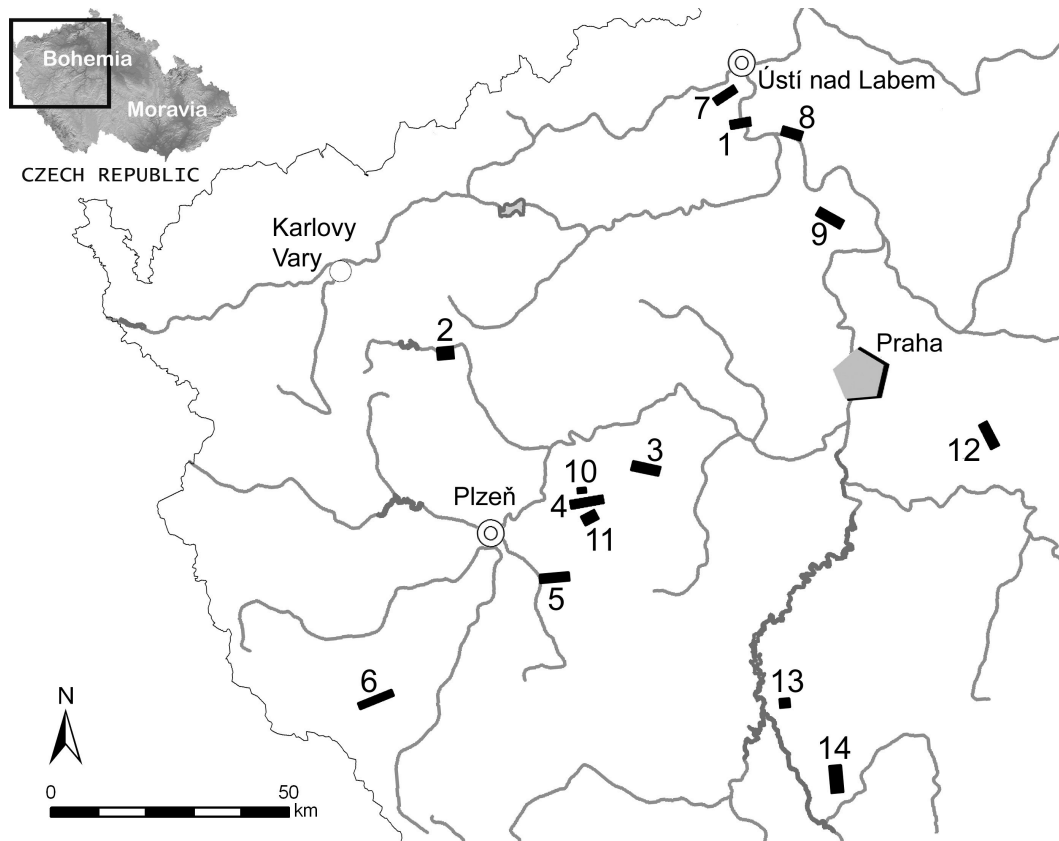


Fig. 1. Map of that part of Bohemia in which target LiDAR scanning was carried out in 2010 – 2011. The scanned areas are numbered 1 – 14 and their size and shape are marked by black rectangular polygons. All of them are rich in archaeological earthworks, and the majority of them are situated in woodland.

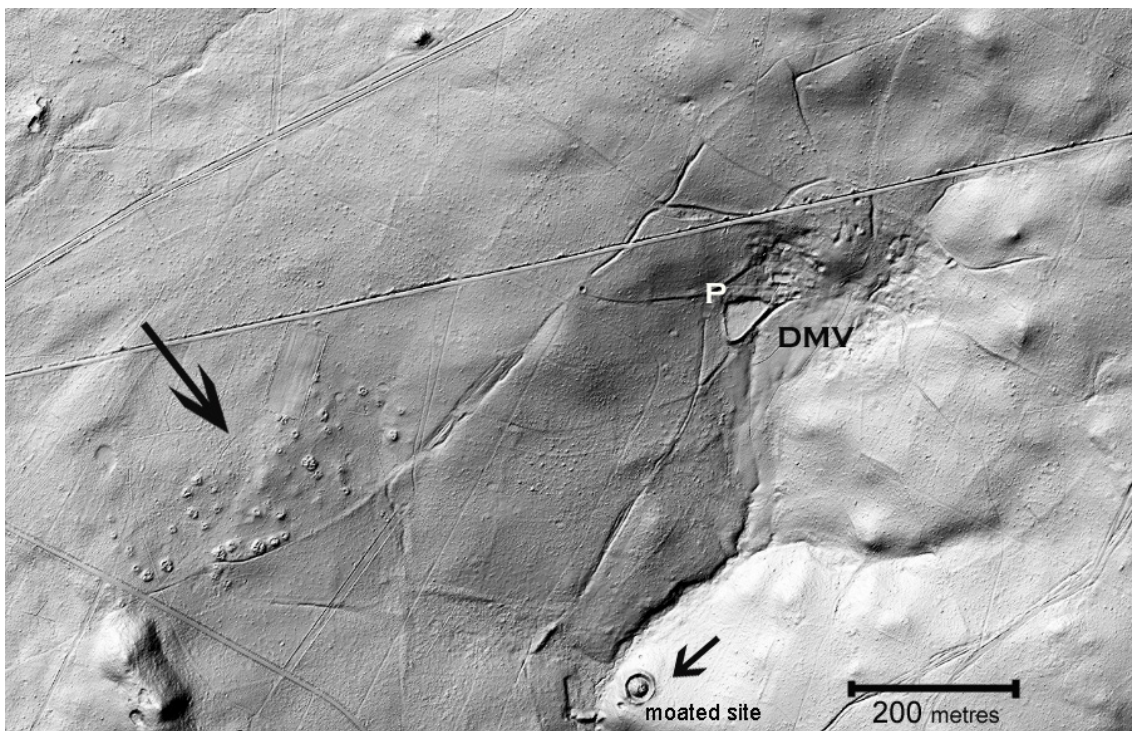


Fig. 2. An extremely well-preserved archaeological landscape, both prehistoric and historic, near Pilsen, western Bohemia with visible Bronze Age barrow cemetery (bottom left corner), deserted medieval village (DMV) including its field system attached around its perimeter and a pond (P), and a contemporary moated site of the medieval owner of the village. The whole area is covered by mixed forest. Shaded relief DTM, project polygon no. 5.

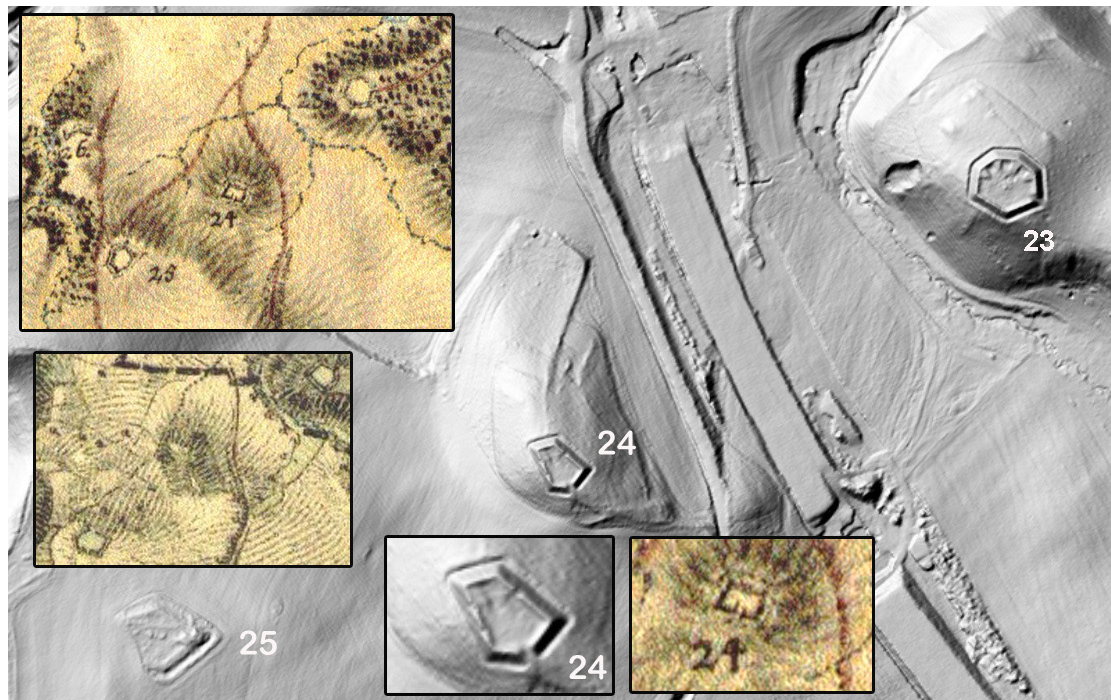


Fig. 3. Žim, northwest Bohemia (project polygon no. 7) showing part of a complex defensive system dating to the end of the 1770s. For a detailed description see text.

selected archaeological key points. Comparison of the terrestrial survey results with those achieved by ALS proved the sufficient precision of this innovative method. This raises the question whether, in future, ALS may effectively replace terrestrial survey, if suitable conditions of data recording can be met.

A similar verification technique was applied also in the area of the National Park Bohemian Switzerland during a two week terrain survey of the area. This focused mainly on the production areas of the region, detected by DTM (glassworks, tar workshops), and the settlement structures, in particular the Hely village deserted after 1945, where the ALS results enabled us to map and record both the built-up areas and the surroundings of the site.

Applying the LiDAR-derived digital terrain model to testing the accuracy of old maps: a case study

Airborne LiDAR data, with its accurate representation of the ground surface, can also be compared with the earliest modern military maps of medium to large scales that were produced by surveyors working in the field. In Bohemia, three sets of the so-called *Military Mapping* were produced between 1760 and 1870. In this case study, the first two sets were used to compare the accuracy of ground plans of military defensive features as illustrated on these maps with those documented by the ALS-derived DTM. These types of remains are spread in relatively large numbers over the Bohemian countryside: some in a more-or-less ruined form, and perhaps even more in a completely levelled/buried state.

For the purpose of this article an example of just one site is used from project polygon no. 7. This is a group of three well-preserved fortified artillery battlements near the small village of Žim, in northwest Bohemia. These form part of a complex defensive system constructed in the second half of the 18th century as a result of repeated offensive military campaigns by the Prussian army against the Habsburg Monarchy, of which the Czech Kingdom was then an integral part. Currently all of these are covered by trees and dense bushes. In the top left corner of Fig. 3 a section from the *First Military Mapping* (FMM) is shown in which a group of three fortlets can be clearly identified. The FMM was produced between 1763 and 1787 as an ‘à la vue’, rather than by means of proper triangulated measurements, and the maps were produced on a 1:28,000 scale. Interestingly, the ground plan of feature no. 23 corresponds almost precisely with the ground plan from the ALS-derived shaded relief DTM. Note the earth ramps around the structure’s perimeter on which guns were placed. Both ALS and the FMM show feature no. 25 to have a pentagonal plan, although each of them differs in the setting and length of individual sides. The greatest differences are apparent in the plans of fortlet no. 24. On the map it is depicted as a rectangular feature with an entrance gap near the centre of its southwest side, whereas the DTM indicates that in reality this fortlet has a pentagonal plan with the entrance placed at the convergence of two sides on its southeast side (see the more detailed view at the bottom centre of Fig. 3). It is not easy to interpret these differences, but they may reflect the results of the work of more than one group of licensed military surveyors, mapping the terrain, whose ability and/or professional responsibility was not the same.

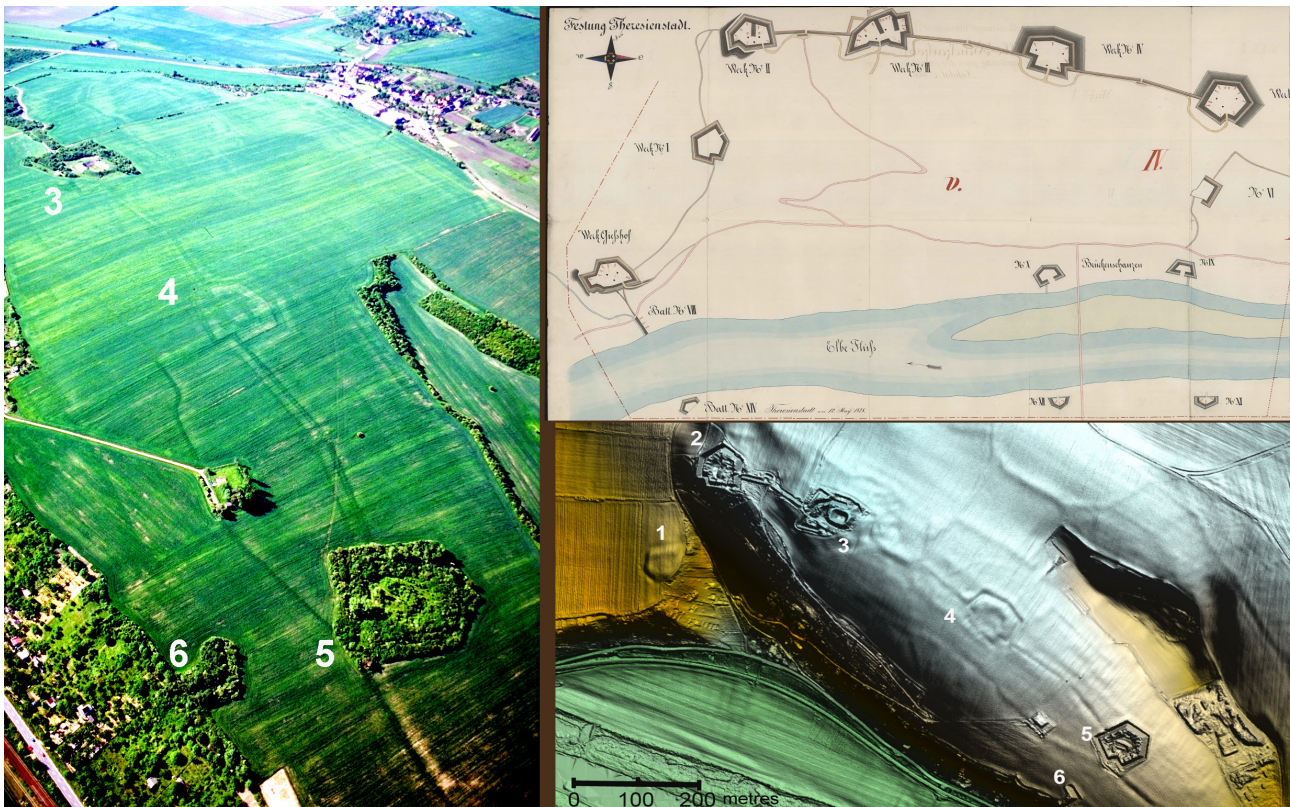


Fig. 4. Partly buried early modern (mid-19th century) fortification near the district town of Litoměřice, northern Bohemia. The site was almost completely preserved until the 1960s since when the forts no. 1, 4 and partly also 3, and the line of a rampart and ditch connecting individual forts have been levelled. Currently they are recordable through cropmarks (image to the left, excluding fort 1). Although the area has been regularly cultivated (ploughed annually) for some five decades, and its remains are almost invisible on the ground, the LiDAR 3D relief shaded DTM (bottom right) shows them clearly, as well as a network of many former roads and ditches. The evidence of the original plan (upper right) as compared with the relief-shaded DTM shows no visible differences either of the overall structure or in details; just one exception may be a sort of ditch/bank that seems to be located along the break in the slope to the SW which is visible on the DTM, but not on the map. The site lies in project polygon No. 8.

The smaller map on the left is a section of the *Second Military Mapping* which was produced between 1836 and 1852 and based on trigonometric measurements of the land surface. In comparison with the FMM no numbers denominating individual fortlets have been inserted in this map and, more significantly, feature no. 24 is not depicted at all. These differences can perhaps be explained by the fact that the defensive system was by then 50 - 60 years old and had lost its significance in the period between the end of 18th and middle of the 19th centuries when there were no wars and military campaigns. However, the complete absence on the map of a fortlet is hardly explicable other than as intentional omission for unknown reasons.

On the contrary, project polygon no. 8 includes a fortified line of artillery bases erected close to Terezín / Theresienstadt (one of two huge brick late 18th century forts and garrisons in Bohemia) in the 1860s, seven to eight decades after the military nodal point Terezín was constructed (Fig. 4). Here, the LiDAR-derived DTM shows practically no difference in the ground-plans of individual fortlets from as they are mapped on the original plan (Fig. 4, top right).

ALS or ground-based geodetic survey? Comparing the cost effectiveness of mapping a large prehistoric hillfort and its surroundings

Project polygon no. 1 includes Hrádek, one of the most impressive ancient Czech hillforts the defensive double ditch and rampart of which are completely covered by deciduous forest (Figs. 5 and 6). As a detailed ground-based (geodetical) survey of the hillfort and its surrounding area was carried out five years before the ALS survey, this provided us with a very good opportunity to compare the cost-effectiveness of both methods and to analyse how far mapping accuracy achieved by the two methods is conditioned by cost (dependent primarily on time and labour demand).

The geodetical ground-survey of the Hrádek hillfort including surrounding area was carried out as contract work by the private company *GeoNet Praha*. Mapping of the site was one of the objectives of the project "The Labe/Elbe Valley in Prehistory" carried out by the contracting authority – the Institute of Archaeology of the Czech

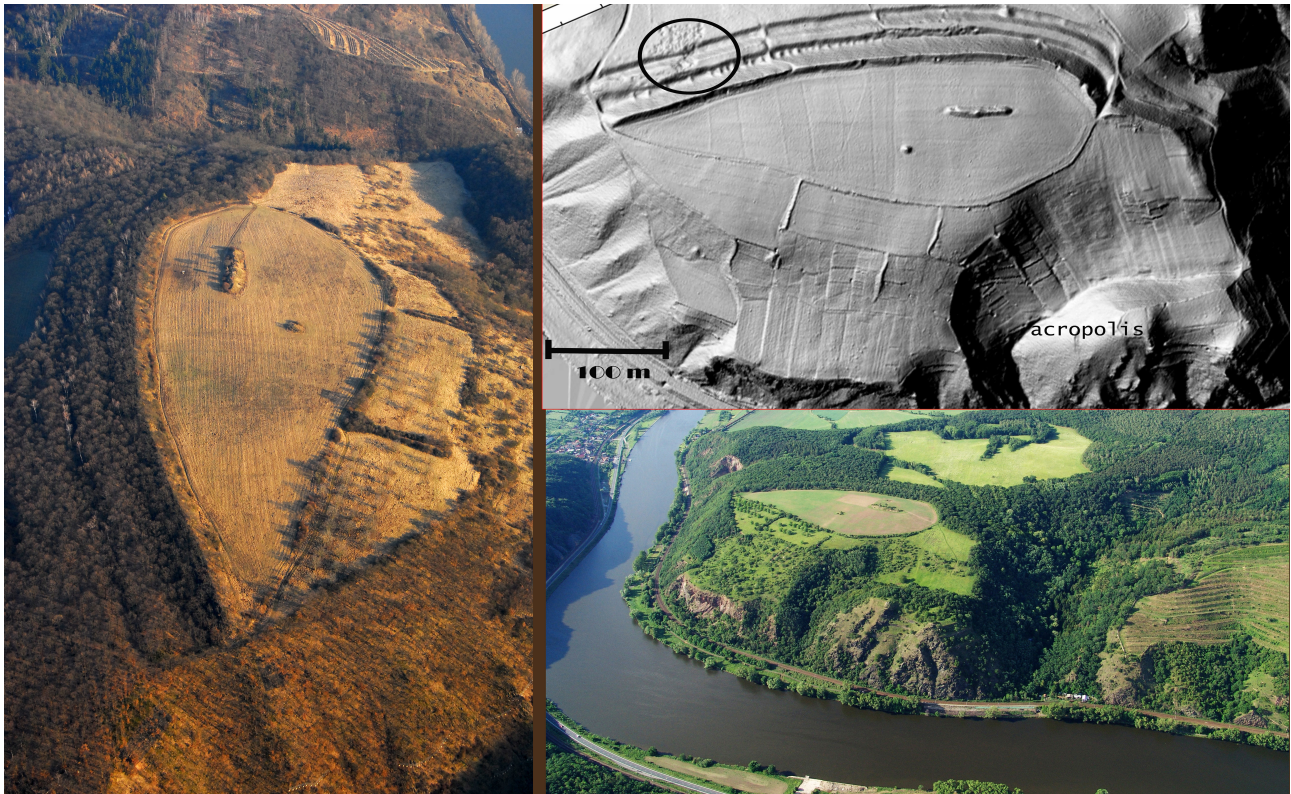


Fig. 5. Hrádek district Litoměřice, northern Bohemia (project polygon no. 1). Woodland canopy almost completely obscures the huge double ditch and rampart of one of the largest and most heavily defended hillforts in Bohemia (aerial images to the left and bottom right), while the LiDAR shaded relief DTM (top right) shows it properly including some details (number of small ramparts crossing the bottom of the inner ditch, and modern diggings at the top of the outer rampart marked here by a black circle).

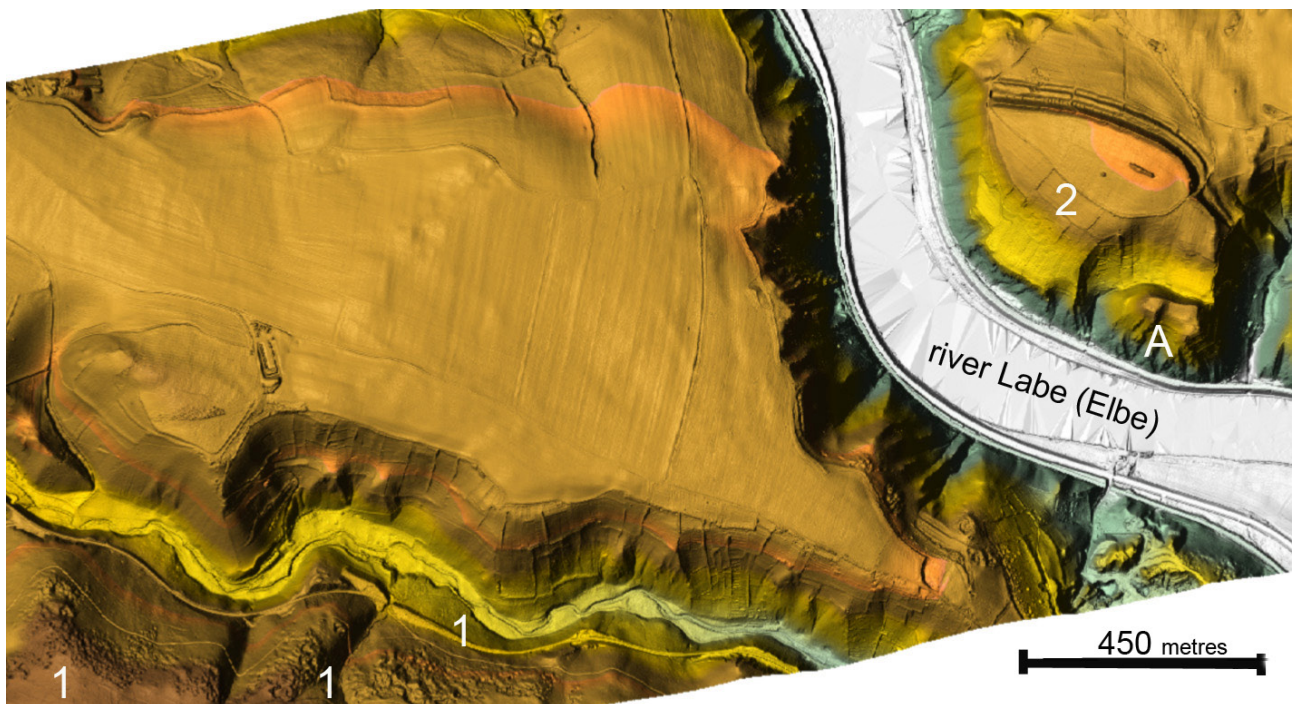


Fig. 6. 3D surface DTM of the prehistoric and early medieval hillfort Hrádek and its surroundings. 1: large area of a Late Iron Age stone extraction (material for the local production of Celtic rotary hand-mills which had been distributed over distant parts of Central Europe) located on the southern slopes of a valley whose bottom stream is a tributary to the Labe/Elbe river 2: the Hrádek hillfort, A: the so-called acropolis of the hillfort, probably its focal place.

Academy of Sciences in Prague. The following are principal data on the ground survey campaign and its cost:

1. A territory of 57.5 hectares was mapped in 3D (x, y, z axes) of which approximately a third (20 hectares) constitutes the hillfort itself. The territory has varied elevation differences and character including sloping terrain of most of the hillfort's area, natural local terrain elevation of the Three-Cross Hill, which is believed to have served as focal point in the site (the so-called *acropolis*) constituted by steep (in a part vertical) rocky slopes, and the Elbe valley bottom banks.
2. The whole area was mapped with a high-standard total station in the course of two months (not continuously, but depending on weather conditions) by a team of five to ten persons. These figures include data processing.
3. The final product of the ground geodetical survey of the selected territory is a plan on a 1:500 scale and a digital terrain model in which the accuracy of georeferenced points is within 5 centimetres in both plan (x, y) and altitude (z). The relatively low accuracy is due to the (unstable) terrain surface, which would otherwise have been higher.
4. The total cost of undertaking the ground-based mapping today can be guessed at only in general terms rather than as a definite figure. This is especially due to the fact that the sum total reflects various aspects influencing its value, such as actual (market) demand for geodetic works conditioned by the economic situation of society and of the potential customer, the number of currently existing geodetical companies, the season of the year in which the works (contracts) are required, etc. With respect to these determinants it is possible to express the current cost of ground-based detailed 3D mapping of the hillfort Hrádek and its surroundings as between € 5600 and 6000 (personal information P. Hulík, director of the *GeoNet Praha*).

Compared to this, the cost we had to pay for LiDAR-derived data (both raw and filtered) of the Hrádek territory can be expressed as an average cost of a square kilometre within the whole area scanned in 2010 (60 sq km), and this amounted to € 210. The LiDAR-derived DTM's absolute accuracy is 30 cm in plan and 10 cm in altitude. It should be stressed that the total cost of delivered data is also conditioned by the distance between the home air-base and polygons to be scanned and between individual polygons. For this reason it is important to properly design the polygons in terms of their ground plan and distance relative to each other (basically, the longer and narrower the better, as it means fewer parallel flights to fully scan a polygon, shorter flying time and – consequently – lower costs).

Concerning spatial resolution, it is obvious that although the absolute accuracy in x - y is much higher in the case of ground-based measurements, in the case of height accuracy the resulting difference between the two methods is much smaller. The importance of absolute spatial accuracy must be

considered in terms of the size of the mapped archaeological feature: the larger the mapped site, the (relatively) less important it is. In the case of a 20 hectare hillfort, such as the Hrádek, the accuracy difference in terms of a few tens of centimetres is not significant. If we compare – in this context – the price of a (traditional) ground-based survey with that for ALS we can see that the latter is considerably cheaper. Spatial (3D) mapping of a one hectare area of the hillfort by a team of surveyors using total station amounts to € 120. On the other hand, the LiDAR data scanned over the hillfort and surrounding landscape, which represents an area of four square kilometres, costs approximately € 840, i.e. € 210 per square km, or € 2.1 per hectare.

Apart from cost demands, another factor that significantly supports the effectiveness of 3D mapping by means of ALS is time. Scanning a site such as the Hrádek hillfort and its surroundings would take no more than two hours (including transit from the home airfield to the scanned polygon and back). Comparing this with a ground-based geodetical survey which took two months, the difference in timescale is more than obviously in favour of ALS. Also, LiDAR data processing, including filtration, is a matter of a few days rather than weeks.

To conclude: the possibility to compare the costs to produce an elevation plan (DTM) of an ancient hillfort by means of ground-based mapping and ALS showed the following results: although the absolute spatial accuracy is higher in the case of geodetical measurements, it is the lower cost and time consumption which distinctly indicates much lower demands and consequently higher effectiveness of ALS.

Conclusion

The project, as the first of its kind in the Czech Republic, demonstrated the potential of ALS and its effectiveness to identify and document archaeological heritage of various kinds, situated in a variety of landscape types. During the two-year project, ALS data from representative sample areas that included known prehistoric and medieval to post-medieval features and sites was collected and compared with existing records.

The huge potential of data derived from airborne laser scanning for the identification and recording of archaeological sites and features preserved in the form of earthworks has been recognised. A consequence of this is that it enables 3D mapping of whole archaeological landscapes. There is no doubt that in this respect ALS is changing current investigation, recording and complex documentation of isolated archaeological features on the one hand, and of archaeological monuments adjoining local architectural and urban heritage on the other. For instance, some kinds of earthworks of historical (medieval, post-medieval and early modern) origin, whose occurrence in some parts of the countryside is extremely high, can only be studied seriously (recorded and mapped) under current circumstances provided by airborne LiDAR potential in

terms of speed and accuracy of data gathering. This is, for example, the case with remains of charcoal production platforms (usually preserved as ruined lower bases of charcoal piles, circular in plan) of which groups ranging from ten to many hundreds are spread over woodlands situated most typically in hilly landscapes and highlands. Due to their high number, very little attention has been paid to their systematic study, because mapping them – which obviously is the first step in any effort to analyse their spatial distribution, the relation to environmental conditions and to contemporary settlements and road networks – by any kind of ground-based survey would take a lot of time. In Bohemia there are a large number of territories with plenty of charcoal piles more or less well conserved, datable to the period of 15th – 20th centuries. A systematic investigation of these extremely important production areas, neglected until recently, can now be easily launched.

Also, a DTM derived from ALS data is often used for monitoring the state of preservation of archaeological earthworks (either simple, such as medieval moated sites whose standing constructions have been completely destroyed, or combined with architectural remains, such as ruined castles) and as such this usage of processed LiDAR data has its significance in heritage management and protection.

It seems pointless to give exact numbers of new archaeological components identified in the Bohemian ALS data as it is difficult to interpret seriously large areas full of surface depressions and elevations without further ground-based field survey and investigation. It is primarily this way which can bring us properly to closer understanding of the origin (man-made or natural), function and age of each of them. Raw LiDAR data acquired from territorial units, whose area totals 123 sq. kilometres, at a relatively high spatial resolution constitutes a valuable basis for modern recording and 3D documentation of georeferenced traces of past human settlement activities in Bohemia. During the project's course, the information potential of this dataset was utilised just in a limited way. Its further evaluation is currently under way and our results will be published soon in a special volume and in archaeological journals.

The project also aimed at a critical evaluation of the effectiveness and potential of applications of ALS in archaeology and in particular in situations where a number of aspects influencing the final dataset must be taken into account (scanning parameters, raw data processing techniques, software and hardware requirements that are necessary to manage these large amounts of data, complementarity of applied analytical methods, landscape type of investigated area). These are included in current work on the project's results and their evaluation is a part of studies published recently (Gojda – John *et al.* 2013).

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