

Multi-Method Archaeological Prospection and Integrated Interpretation. Investigation of the Kreuttal Area in Austria

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Abstract

Since its foundation in 2010, the Vienna-based Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro) has been investigating the Kreuttal, an area located 25 km north of Vienna, as one of several case studies. Different methods have been tested and developed for efficient archaeological prospection. The methods applied include geophysical prospection, airborne and terrestrial laser scanning, aerial photography, soil sampling, fieldwalking and targeted archaeological excavations. A special focus was placed on the development and application of motorised magnetic prospection. Over the past years, considerable parts of the landscape have been surveyed and investigated through fieldwalking, so that recent changes could be documented. This case study highlights how the acquired datasets provide valuable information on various parameters of fundamental archaeological interest. Soil erosion and accumulation have transformed the landscape significantly, affecting the detection and identification of archaeological remains. By comparing all collected datasets, it is possible to analyse the various physical parameters such as topography, soil characteristics and humidity based on an integrative approach to data interpretation.

Keywords

Motorised magnetometry, landscape archaeology, multi-methodological datasets, integrated interpretation, spatio-temporal analysis, GIS-based archaeological information system (G-AIS)

Zusammenfassung – *Multimethodische archäologische Prospektion und integrierte Interpretation. Untersuchungen zur Genese der archäologischen Landschaft im Kreuttal, Niederösterreich*

Seit seiner Gründung im Jahr 2010 führte das Ludwig Boltzmann Institut für Archäologische Prospektion und Virtuelle Archäologie

(LBI ArchPro) multidisziplinäre Untersuchungen im Kreuttal durch. Diese Region 25 km nördlich von Wien war eine der zahlreichen internationalen Fallstudien. Dank seiner Nähe zum Institutssitz in Wien bot es eine effiziente Möglichkeit, Methoden der archäologischen Prospektion zu testen und weiterzuentwickeln. Der angewandte Methodenkanon umfasste dabei luftgestütztes und terrestrisches Laserscanning, Luftbildarchäologie, Bodenbeprobungen, Feldbegehungen, einzelne gezielte archäologische Ausgrabungen und vor allem die geophysikalische Prospektion, hier speziell die Entwicklung motorisierter Systeme. So konnten bis zum Ende der Laufzeit des LBI ArchPro 2024 weite Teile der archäologischen Landschaft dokumentiert und rezente Veränderungen bei Feldbegehungen erfasst werden. Diese Fallstudie veranschaulicht, wie multimethodologische Datensätze grundlegend den archäologischen Interpretationskontext erweitern können. Erosion und Akkumulation haben das Erscheinungsbild der Landschaft nachhaltig geprägt und bestimmen so die Erkennbarkeit archäologisch relevanter Strukturen. Eine Kombination verschiedener Datensätze erlaubt es, gezielt verschiedene physikalische Parameter zu untersuchen, einzelne Erkenntnisse integrativ miteinander zu verknüpfen und so ein vollständigeres Bild der räumlich-zeitlichen Veränderung der archäologischen Landschaft zu erzielen.

Schlüsselbegriffe

Motorisierte Magnetometrie, Landschaftsarchäologie, multi-methodologische Datensätze, integrierte Interpretation, räumlich-zeitliche Analyse, GIS-basiertes archäologisches Informationssystem (G-AIS)

1. Introduction

To understand the development of archaeological landscapes over time, investigations must integrate information derived on multiple scales with a range of resolutions.¹ Spatially limited archaeological excavations accompanied by analyses of artefacts, biofacts and ecofacts can provide deep and detailed insights, but only in relation to rather small areas. They only allow for a highly focused and therefore biased examination and subsequent interpretation of an archaeological site, often ignoring the context of the surrounding archaeological landscape. Landscape archaeology aims to investigate the cultural and natural development across large areas and long periods of time. It focuses on the interactions of human societies with their surrounding environment.² For this purpose, the past landscape is examined using various methods based on different scientific disciplines. Once environmental settings have been derived or reconstructed, archaeological theories regarding past societies, their evolution and their impact and dependence on the environment can be studied. Recent methodological developments in the integrated interpretation of multidisciplinary data acquired across large areas can provide archaeological and ecological contexts for spatio-temporal analyses at the landscape level.³

By investigating the archaeological landscape using a top-down approach, from the largest extent to smaller regions and subsequently the site level and the archaeological feature, detailed phenomena can be observed and analysed. In the investigation of the major structural elements of a landscape, archaeological prospection methods can reveal patterns of human activity, palaeoenvironmental settings and their topographic context.⁴ Such methods all respond differently to environmental conditions and comprise inherent characteristics concerning the mapped physical parameters, sample spacing, measurement sensitivity and speed. The most effective application of any of these methods requires a well-defined research question based on a preliminary analysis of the prevalent physical properties (e.g. geological and pedological background, soil conditions, vegetation, topography) to guarantee a certain quality and reproducibility of the data acquired and subsequently deduced results. An integrated interpretational approach may

permit the extraction of valuable information, even when evidence of buried archaeology is not visible in all datasets.⁵

Among the methods considered for archaeological prospection are aerial photography, airborne laser scanning (ALS) and near-surface geophysical prospection. For over a century, aerial photography has been the primary and most accepted source for the investigation of archaeological landscapes.⁶ This method permits the efficient coverage of large areas, which has resulted in the discovery and mapping of numerous archaeological sites or phenomena around the world. However, the detection capability of aerial surveys is dependent on seasonal changes, weather conditions, vegetation, and geological and pedological settings. In recent decades, airborne laser scanning has been introduced as a promising archaeological prospection technique, mapping the topography in detail. ALS can be used efficiently for the generation of digital surface models (DSM), and also of digital terrain models (DTM) after task-related classification and subsequent filtering of ground points from the data.⁷ Therefore, ALS has been an important source for the detection of topographically distinguishable archaeological features, even in forested areas.⁸

Ground-based near-surface geophysical prospection methods have been successfully applied in archaeology for the last sixty years. Magnetic prospection, ground-penetrating radar (GPR), magnetic susceptibility measurements, earth resistance (ERT) and electromagnetic induction measurements have all been adapted for archaeological purposes. The accurate positioning of geophysical prospection data is essential for the proper alignment and mapping of the collected data, which may depict buried archaeological features, referred to as ‘anomalies’, in the prospection data.⁹ Traditionally, to conduct a ground-based prospection survey, a grid had to be established and the survey equipment was operated manually along defined survey lines or measurement transects. The potential for dense sample spacing and spatial coverage was rather limited in the early days, but improved steadily. For the application of geophysical prospection at the level of landscapes, it became obvious that motorising multi-sensor arrays and the use of automatic positioning systems were required.¹⁰

1 ASTON 1985. – ZIMMERMANN et al. 2004. – MEIER 2009. – NAKOINZ et al. 2020. – SCHÖRNER 2022.

2 GRAMSCH 1996. – DARVILL 2001. – JOHNSON 2007. – DAVID, THOMAS 2008.

3 GOSDEN et al. 2021. – DONEUS, DONEUS, COWLEY 2022.

4 SCOLLAR et al. 1990. – DONEUS 2013a.

5 WILKINSON 2003. – CAMPANA 2018. – DONEUS et al. 2018.

6 BRADFORD 1957. – BOWEN, BUTLER 1960. – WILSON 2000.

7 DONEUS, MANDLBURGER, DONEUS 2020. – ŠTULAR, LOZIĆ 2020. – LOZIĆ, ŠTULAR 2021.

8 CHASE et al. 2011.

9 NEUBAUER 2001. – ASPINALL, GAFFNEY, SCHMIDT 2009.

10 GAFFNEY et al. 2012. – SCHMIDT, LINFORD, LINFORD 2015. – COZZOLINO et al. 2018.

Today, landscape archaeology can rely on various highly efficient mechanised archaeological prospection techniques, enabling coverage of many square kilometres, rather than square metres or hectares, in a manageable time.¹¹ Within an integrated interpretation approach, the results of the acquired datasets can be combined with other archaeological information based on traditional sources such as excavations or historical maps. Using large-scale prospecting data, targeted excavations can be conducted to answer a specific research question formulated through the multidisciplinary analysis of archaeological prospecting data.

The objective of this report is to examine the potential insights that multi-layered prospection can offer and to what extent these insights could inform the strategy of planning archaeological excavations. In the following, we present the case study area, the Kreuttal, and describe the methods used for data collection, with particular emphasis on the development of motorised magnetic prospection devices. The results chapter then presents the contribution of the individual methods to the overall interpretation and concludes with a discussion.

1.1. Archaeological Prospection on a Landscape Scale: The Kreuttal Case Study

The Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology was founded in 2010 to develop and apply the latest methodology and technology for archaeological prospection. In collaboration with its European partner organisations – universities, museums, national heritage boards, research institutions, regional governmental organisations and small and medium enterprises – the institute conducted several archaeological prospection case studies throughout Europe. Every case study represents a specific archaeological and environmental setting for the development and testing of methodologies and technologies advanced by the institute. Therefore, throughout the past years, a multi-method dataset was created, comprising results from remote sensing (aerial archaeology, airborne laser scanning, imaging spectroscopy), near-surface geophysical prospection (magnetometry, GPR and magnetic susceptibility surveys), geoarchaeological sampling and fieldwalking. In collaboration with the Vienna Institute for Archaeological Sciences (VIAS) and the Institute of Prehistoric and Historical Archaeology of the University of Vienna, several archaeological excavations within the study area were conducted, based on the non-invasively obtained

archaeological prospection results. All of the gathered data was subsequently integrated to achieve a complete archaeological interpretation of the prehistoric landscape.

Since 2011, the LBI ArchPro has been investigating the archaeological landscape of the Kreuttal region, located about 30 km northwest of Vienna. A ridge of hills oriented in a north-south direction forms a natural barrier to the Marchfeld plain in the east and marks the border to the Korneuburg bay in the west. This ridge is intersected by a valley – the so-called ‘Kreuttal’ – connecting the bay of Korneuburg with the eastern plains. Due to the periglacial deposition of fertile loess soil and its topography, the area has always been ideally suited for agriculture. From the top of the ridge, on a clear day, one can see the Hungarian plains and the Carpathian Mountains to the east, and the Alps to the south. The area hosts several large prehistoric settlements, some of which had been fortified, as well as ritual monuments dating from the Neolithic to modern times. This fact also reflects the strategic importance of the area due to its geographical location from prehistory to the end of World War II. Thanks to its proximity to the LBI ArchPro headquarters, various archaeological prospection techniques could easily be tested there.

2. Methodology

2.1. General Aspects

For the non-invasive investigation of archaeological landscapes, a set of well-defined methods is applied to solve specific research questions. These questions could concern either research into further methodological development and technological advancement or archaeological research. Since the results generated will always depend on the methodology chosen, a clear definition of the purposes and limits of every method or technique applied has to be the basis of an integrated interpretational approach. Results and data provided by each method have to be compared within a reproducible framework. The development and design of such an integrative methodological and theoretical environment is a scientific challenge. This task includes the definition of the type and structure of a corresponding database, the appropriate visualisation of the data and integrative analysis and interpretation thereof.

The methods used for the archaeological prospection in the Kreuttal case study will be described briefly below. They include non- or minimally invasive methods (mainly the aforementioned prospection techniques) as well as invasive methods (systematic fieldwalking, soil sampling and archaeological excavations). The methodological development of motorised geophysical prospection (primarily magnetic prospection), which was also correlated with the

¹¹ DONEUS, DONEUS, ETTINER-STARČIĆ 2017. – BANASZEK, COWLEY, MIDDLETON 2018. – GOSDEN et al. 2021.

analysis of soil characteristics, was the primary interest and is described in detail.

2.2. Design of a GIS-Based Archaeological Information System (G-AIS)

Archaeological research must always deal with both legacy datasets and recently recorded data. The challenge here is to ensure the comparability of these datasets. Older datasets often need to be adapted to be used within a new methodological framework. In this context, the reliability of legacy data and their comparability with recent data and results have to be carefully considered. All archaeological data have in common that in principle they can be correlated with a corresponding geographic position and a time interval. Therefore, any archaeological information system (AIS) has to be capable of dealing with both spatial and temporal information. This requirement necessitates the introduction of a 4D AIS, as also proposed and described by Berdien De Roo et al.,¹² in contrast to common 3D Geographical Information Systems. A typical standard procedure for the interpretation of archaeological prospection data would start with spatial data segmentation, a process that can be partly automated. As a second step, data classification of the generated segments is implemented by making use of additional archaeological information. Finally, the generated archaeological entities are correlated with time intervals, ideally resulting in interpretation regarding their function and spatial as well as temporal extension.

We want to stress that important archaeological information can already be derived through the simple comparison of different datasets (e.g. aerial imagery and geophysical prospection). In this respect, the application of an integrated interpretation approach is self-evident. As archaeology traditionally draws on analogies (and the above-mentioned comparison is just one), the comparison of prospection datasets to reveal patterns and analogies fits perfectly into this archaeological method of operation. Nevertheless, most arguments are based on a qualitative analysis of the data rather than a quantitative analysis such as is possible using a 3D or 4D AIS. The design of such an AIS should guarantee the reproducibility and comparability of the presented results in a quantitative manner.

For this purpose, a GIS-based archaeological information system (G-AIS) was designed to deal with archaeological prospection data and the integrated spatial interpretation thereof. This G-AIS consists of a GIS core, permitting the control and analysis of spatial relations, and a dedicated

geodatabase, which includes raster datasets and feature classes (point, line and polygon). For the integrated interpretation of archaeological prospection data, a standardised workflow was developed, starting with the segmentation and classification of the observed archaeological evidence at four levels: features, structures, distinct areas and seamless areas.¹³

The basic level is the single archaeological feature (e.g. remains of pits, postholes, walls, etc.) followed by structures (e.g. house). While data segmentation on the first level can be partially semi-automated in the case of magnetic prospection data, all other steps have to be carried out manually. The next two levels (distinct areas and seamless areas) represent more of an abstract functionality of the defined entities. For example, a farmstead is a distinct area consisting of features and structures. Its spatial extension is related to the functionality of this area; its boundaries can also be interpreted based on other datasets.

The comparison and integrated interpretation of multiple datasets are made possible by the G-AIS. For the creation of a suitable raster geodatabase, and as a support for the visualisation of geophysical prospection data and their semi-automated interpretation, software tools were developed to be used as extensions of ArcGIS.¹⁴

Within the Kreuttal case study, all existing data, including geophysical survey data, aerial imagery, airborne laser scanning and airborne imaging spectroscopy data, geological maps, historical maps and field survey data, were collected, digitised (if necessary) and archived. The resulting data archive is the main repository for the raster geodatabase that is regularly supplemented with newly collected data.

Data visualisation, integrated interpretation and analysis of all the data are realised within the G-AIS. The spatial database concept of ArcGIS was used for the integrated interpretation of the multiple data sources, utilising its various possibilities for data visualisation. For instance, for the landscape analysis of the topographical information, which is mainly based on ALS data, various visualisations are generated according to different parameters and algorithms that have been developed and successfully applied in recent years. Whereas the processing and visualisation of DTMs according to slope and aspect have been widely applied for the last two decades,¹⁵ principle component analysis of

¹² DE ROO et al. 2014.

¹³ KASTOWSKY-PRIGLINGER 2013.

¹⁴ PREGESBAUER, TRINKS, NEUBAUER 2013. – TORREJÓN VALDELOMAR et al. 2016. – ArcGIS was chosen as the main GIS software to be used by the LBI ArchPro.

¹⁵ BENNETT et al. 2012.



Fig. 1. The fortification of the 'Türkenschanze'. Low sun and snow cover reveal topographical details (LBI ArchPro, M. Kucera).

shaded relief models,¹⁶ local relief modelling¹⁷ and positive and negative openness¹⁸ provided new improved ways to visualise the data. The mathematical functionality of GIS regarding spatial analysis and network analysis is crucial for the interpretation of the data at the level of archaeological landscapes. Least cost path analysis allows for the investigation of probable and observed road and pathway systems.¹⁹ In combination with historical maps, it becomes possible to detect previously unknown archaeological sites and to derive the functional segmentation of the archaeological or historical landscape.

2.3. On-Site Visits

Right from the start of the project in 2011, the case study team has spent a lot of time walking the case study area to visit archaeological structures and to get a feel for the topographical and spatial relations. This fieldwalking has been done during geophysical survey campaigns, whenever spare

time was available, and has been on a more qualitative basis. Although spatial analysis can be carried out remotely on a computer, a more accurate understanding of an archaeological landscape to prove or falsify hypotheses can only be gained by experiencing the local topography and the features therein during fieldwalking (Fig. 1). Additionally, the processes which transformed evidence of human activity may still be observable within the landscape. In this sense, the landscape can be regarded as a laboratory on a 1:1 scale. For instance, after a severe thunderstorm in May 2012, one of the main roads was flooded and a large amount of eroded loess soil was deposited on the road. The material originated from a gentle slope uphill. This process illustrated how large masses may be relocated during a single weather event. The deposit, formed within a couple of minutes, was up to 30 cm thick and covered an area of approximately 1,000 m², including parts of the aforementioned road. In another place, reeds were observed within a cornfield, indicating a swampy zone, suggesting the presence of a small pond. When the field was visited during a drier period, this marshy zone was no longer observable. Observations like these can be very helpful for the archaeological interpretation of landscapes.

Another important aspect of field visits is that one is exposed to the weather. In combination with

¹⁶ DEVEREUX, AMABLE, CROW 2008.

¹⁷ HESSE 2010.

¹⁸ DONEUS 2013b.

¹⁹ DONEUS 2013a. – GUSTAS, SUPERNANT 2017.

micro-topographical changes that may reveal favourable places for human occupation and activity, this aspect constitutes another important source of information by describing micro-climatic regions. The preference for a specific location is multifaceted and depends on various factors including geographical, social, infrastructure, and ritual aspects. Nevertheless, the first arguments can be derived from geographical description and analysis of the landscape. A Linear Pottery settlement discovered near the modern village of Hornsburg perfectly illustrates this geographical aspect. The settlement is situated on a shoulder of a slope facing southeast, within a small basin at the end of a valley oriented southwards. The settlement was protected from westerly winds, and since it was located at some distance from the valley bottom, the settled areas avoided the swampy zones. Whereas one Middle Neolithic circular ditch enclosure (*Kreisgrabenanlage* – KGA) with two ditches and two entrance gateways is located more or less within the settlement area, another one, consisting of three ditches and two entrance gateways, is located on the top of the opposite ridge of the basin. The latter is today completely exposed to the wind but must have formed a landmark visible from many other places in the wider area, if potential vegetation is neglected. The second KGA lacks evidence of any larger nearby settlement structures.

2.4. Systematic Fieldwalking

From 2012 to 2015, several pedestrian surveys (see also Fig. 3) were conducted in collaboration with the University of Vienna, covering a total area of 75 hectares, including testing a new data collection technique.²⁰ In general, these surveys should provide the necessary temporal information based on collected material and artefacts. Most of the area was covered by means of line walking surveys using 5 to 15-m cross-line spacing. Based on the geophysical dataset, specific areas have been additionally investigated by means of raster fieldwalking surveys and individual artefact locations through GNSS (global navigation satellite system) measurements. This research was driven by the question of whether or not a correlation can be observed between the distribution of surface artefacts and the mapped magnetic anomalies. Of special interest was the spreading of presumed activity zones due to the effects of erosion and ploughing, as well as the presence of archaeological material on the surface. The absence of anthropogenic finds on top of or adjacent to observed magnetic anomalies may indicate their non-anthropogenic origin or their state of

preservation. This argumentation can also be based on the analysis of the local topography.

2.5. Aerial Archaeology

Since the second half of the 20th century, the Austrian Air Force has repeatedly undertaken photographic aerial surveys. From the late 1970s, the Kreuttal area was recorded from the air several times, thereby documenting recent changes in the landscape. Aerial photographs taken by the Royal Air Force (RAF) in 1943 are also available. Some of these pictures were used to generate historical digital terrain models (hDTM) by applying image-based modelling (IBM) techniques.²¹ Besides the targeted photographic recording of the area for military purposes, several flight missions were undertaken by the Aerial Archive of the Department of Prehistoric and Historical Archaeology of the University of Vienna. Over the course of the project, known archaeological sites were recorded under different environmental and climatic conditions, and several new, so far unknown structures of archaeological interest were discovered.

Aerial archaeology has lately seen major developments regarding the application of various photographic sensors and filters, as well as automated positioning and orientation equipment (GNSS receivers and inertial measurement units). Recently formulated standardised workflows were suggested for optimised data capturing, data processing and archiving.²² An automated workflow for fast and accurate image rectification and geolocation of aerial photographs was developed.²³

The use of different sensors and the possibilities provided by IBM approaches have widened the range of applications of aerial archaeology. The dataset available for the Kreuttal case study enables analysis of the landscape regarding different forms of land use and infrastructural changes (e.g. regarding the shift of field borders, the erection of power lines, different agricultural field uses, etc.). DTMs and hDTMs generated with different sets of aerial photographs using IBM allow the investigation of topographic changes that have occurred over the past 70 years.

2.6. Topographic Surveys

Digital terrain models based on ALS data were provided by the federal state of Lower Austria. ALS-based topographic data is perfectly suited to detecting archaeological and palaeoenvironmental features based on their expression in

²¹ SEVÁRA 2016.

²² VERHOEVEN, SEVÁRA 2016.

²³ VERHOEVEN et al. 2012. – DONEUS et al. 2016.

²⁰ COOLEN et al. 2013.

today's (micro-) relief, even if this impact is very small. The fact that minute features in the relief can even be detected by processing ALS data acquired over vegetated areas has revolutionised our knowledge about archaeological remains preserved in woodlands.²⁴ A wide range of archaeological and palaeoenvironmental features can be discerned using various visualisation techniques (e.g. using colour scales based on slope, the local-relief model, positive and negative openness, or multiple hill-shade techniques). Abundant information on remains of ramparts, mounds, ditches, field systems, terraces, platforms, ruined walls, stone quarries, extraction pits, military hideouts, bomb craters, as well as complete systems of paths and hollow ways, which become more or less visible within the ALS-based DTM data after digital removal of the vegetation, can be generated. During the fieldwalking campaigns in the Kreuttal region, such structures were visited and further examined on the ground. Although the 0.5-m resolution of the ALS-based DTM is sufficient for archaeological prospection, higher-resolution datasets were desirable for the detailed interpretation of specific locations. In such cases, terrestrial laser scanning (TLS) was applied to generate even more detailed DTMs. Amongst other features, the southern entrance gate of the enormous Iron Age fortified hillfort 'Türkenschanze' (approximately 85 hectares of enclosed space) in Kreuttal was scanned using TLS.

2.7. Geophysical Prospection

For the cost- and time-efficient geophysical prospection of archaeological landscapes, motorisation of the survey devices, accompanied by precise automated geospatial positioning based on GNSS technology, has been necessary. The survey systems employed are required to be durable, weatherproof and easily transportable. Their physical properties and geometric setup must enable the acquisition of data of a quality comparable to that of conventional, manually operated systems. The geophysical sensors have to be moved as smoothly as possible over the survey areas, and measurement and vehicle speed have to be optimised with regard to the sensor sampling rate. Devices designed for magnetic prospection must, as far as possible, be void of magnetically disturbing components (i.e. metal parts or electrically conducting components), without decreasing the mechanical stability of the system. As an entirely non-magnetic motorised prospection system is not feasible, the development and application of data post-processing and filtering techniques that mitigate the disturbances in the data caused by the survey system were critical. A well-designed geometry

of the sensor arrays and carriers has been established, and straightforward maintenance and practical fieldwork routines have been elaborated. Given the fact that the case study area is close to the headquarters of the LBI ArchPro, most of the systems that have been developed and continuously improved here were tested in the Kreuttal area. Besides the testing of the physical setup of the systems, general survey logistics and routines were developed. As a result of the experience gained in the Kreuttal case study, clear personal responsibilities, maintenance procedures and survey routines²⁵ were derived. It was also here that many of the institute's staff and interns were trained in the operation of the geophysical survey systems for the first time.

Due to the specific geological and pedological settings in the case study area, which is characterised by an accumulation of loess, large variations in density within the near-surface soil layers were not to be expected. Therefore, the focus was on magnetic prospection. Ground penetrating radar (GPR) surveys were only carried out at a smaller scale, namely in areas where erosion was expected to have taken place and where the absorbing loess cover has been removed prior to human activity. The average size of the agricultural fields in the investigation area is about three to five hectares, with a topography suited to motorised surveys. First surveys were carried out in the northern part of the case study area, around the villages of Hornsburg and Kreuzstetten.

During the first fieldwork campaigns in 2011, motorised fluxgate magnetometer systems were tested and modified. At this time, these systems had been in operation, with minor changes made to their configuration (regarding the geometry and type of data loggers), since the first surveys were carried out by the LBI ArchPro in Stonehenge, Sweden and Norway in the summer and autumn of 2010.

In general, a motorised system for magnetic archaeological prospection consists of a non-magnetic cart towed by an all-terrain vehicle (ATV, Fig. 2). Initially two slightly different designs of these carts were tested, one with a single drawbar of 6 m in length, and the other with a triangular drawbar arrangement. To increase transportability and stability, the single drawbar cart was favoured and equipped with a telescopic drawbar. This shortened the length of the system during transport to 3 m and allowed for fast deployment of the cart in the field. Most construction parts of the

²⁴ DONEUS 2013a.

²⁵ Survey routines include logistical issues (transport, storage and maintenance of equipment, survey planning, data acquisition workflow) resulting in best practice routines to enable comparability of datasets and time- and cost-efficient fieldwork.



Fig. 2. Motorised magnetic prospecting. The ten Foerster FEREX CON650 gradiometer probes are mounted on the cart, which is towed by an ATV. The wheels are independently suspended (LBI ArchPro, M. Kucera).

magnetometer sensor cart are made from fibreglass and glued or connected using plastic screws.

The cart supports up to ten fluxgate gradiometer sensors at a distance of approximately 6 m from the ATV and is designed to absorb vibrations and bumps through four wheels with independent suspension. The cart's suspension is effected by means of elastic ropes. The tension of these ropes can be adjusted depending on the roughness of the surface of the survey area. The wheels are mounted with glass ball bearings, which proved to endure speeds of approximately 50 km/h. The sensors are placed on a frame of fibreglass poles with a rectangular or u-shaped cross-section. This frame is approximately 175 cm by 100 cm in size, providing space for eight sensors with a cross-line distance of 25 cm. The size of the frame was adapted in width for transport in a closed, roadworthy trailer. Two additional gradiometer sensors could be mounted on extractable side extensions on either side of the cart. Due to the observed higher noise levels of these two sensors caused by the increased vibrations, it was decided that a gradiometer array consisting of only eight fluxgate-type sensors instead of ten should be used, eliminating one sensor on either side.

Foerster FEREX CON650 gradiometer probes were used as magnetometer sensors, measuring the vertical component of a 65-cm gradient of the earth's magnetic field with a sensitivity of 0.2 nanoteslas (nT). To protect the sensors from the effects of the weather and to facilitate cleaning of the system after fieldwork, the gradiometer probes are placed in sealed plastic tubes. Furthermore, repeated monitoring of the physical measurement properties of the gradiometer probes is crucial for quality control and maintenance. For the accurate global positioning of the measured

data, a real-time kinematic global navigation satellite system (RTK-GNSS) rover (Javad Triumph or Sigma) is placed on the drawbar 2 m from the sensors. As a base for the RTK-GNSS system, a second Javad Triumph receiver is used. The base was placed on official triangulated survey points maintained by the Federal Office of Metrology and Surveying (BEV – Bundesamt für Eich- und Vermessungswesen).

Next to the RTK-GNSS rover, an analogue-digital converter (10-channel EasternAtlas) is placed in a protective casing. All data is recorded on a ruggedised field computer (Panasonic Toughbook) mounted in front of the driver on the ATV. Initially, regular ruggedised laptop mounts were used and fixed with two M8 screws onto the front rack of the ATV. After two years of operation, these screws broke on one of the systems. This demonstrates the amount of force induced by vibrations during off-road operation, and the wear and tear experienced by the rigid connections. Now, the laptops are placed inside Peli cases padded with soft foam.

The specifically developed magnetic data acquisition and navigation software LoggerVis 2.0, developed by the LBI ArchPro,²⁶ combines the data strings of the GNSS unit and the magnetic data. It allows for recording and storing of data and metadata (e.g. weather and ground conditions, operator names, etc.), specification of the system used (e.g. the cross line distance of sensors resulting in the overall coverage width, sensor type and basic geometry of the cart) and controlling the on-screen real-time visualisation of the system for navigation. Using the LoggerVis navigation screen,

²⁶ SANDICI et al. 2013.

the operator can navigate the system efficiently across the field and optimise the coverage. This feature is particularly useful on fields where the tracks of the cart and the ATV are not or are barely visible, such as harvested cornfields. For enhanced orientation and survey planning, an aerial image can be displayed in the background of the navigation screen, showing the surveyed areas and possible gaps in the data acquisition.

Most important for the quality of the collected data is the feature of the LoggerVis data acquisition software that provides quality control of the basic functionality and the physical characteristics of each fluxgate probe. Diagrams showing the actual noise level of each gradiometer can be visualised to detect malfunctions, and a simple red/green colour-coding system alerts the operator if any sensor or the GNSS position data stream shows abnormalities or insufficient precision. Once all system checks have been performed and all metadata have been stored, the measurement can be started. The data is recorded along survey lines. A recorded survey line can be of any length permitted by the data storage capacity of the system, for instance covering an entire field, without having to be a straight line. During the measurement, the quality of the positioning data is displayed. Usually, the recording of the data is stopped manually, for example when errors occur or when another sector of the survey area is to be measured. After interrupting data acquisition on the current line, the operator can choose whether the collected data is good, should be kept, or can be deleted. If errors occur, standardised procedures help the operator to solve these problems in the field. Typical errors encountered include bad or no GNSS signal, and no data being recorded by one or more magnetometer sensors. In most cases, a faulty cable connection can be identified as the cause of such errors, due to the constant vibration and mechanical strains on the survey system. The online data visualisation provided by the LoggerVis software in the form of a greyscale image is a very helpful tool for checking the basic data quality during data acquisition and ensuring that every important feature visible in the data has been mapped as completely as possible. In any case, the survey results should be checked carefully several times per day to ensure sufficient data quality and complete coverage. For this purpose, an initial simple data processing can be performed easily in the field using the default settings of the data processing software ApMag. This magnetic data processing and imaging software has been developed for manually operated magnetometer systems by LBI ArchPro's partner ZAMG (Zentralanstalt für Meteorologie und Geodynamik) and extended through the cooperation to permit the processing of magnetic prospection data acquired with

motorised survey systems. ApMag has been almost constantly adapted and optimised by its creator and developer Alois Hinterleitner through the implementation of new filters to reduce the influence of the ATV on the probes, enhanced data positioning and direction-dependent filtering.²⁷ It has been observed that the influence of the motorised tow vehicle on the data varies between different ATVs, which is of importance when considering renting or acquiring new ATVs. Additionally, the characteristics of each sensor can and have been analysed to determine the individual noise levels and possibly problematic sensor behaviour.

With the described magnetometer system setup, it is possible to collect data at an approximate speed of 15 to 25 km/h, with a cross-line sampling resolution of 25 cm, and a speed-dependent in-line sample spacing of 5 to 10 cm. Although the system can collect data at even higher rates, the mentioned speed limits should not be exceeded in order to guarantee sufficient data quality and the longevity of the entire system. Depending on the surface condition (roughness), size and shape of the survey areas, which tend to be rather small and more complex in shape in the Kreuttal area, average daily coverage of eight to ten hectares can be expected per system. The progress of the survey and fieldwork depends on the strategy employed to cover a specific field and the skills and experience of the system operator. In order to cause minimum damage to the field and possible crops, turning of the system should be carried out along the bordering field tracks. For best data quality, the direction of measurements should be oriented in the direction of ploughing or harrowing. In 2013, three of the described motorised multi-channel magnetometer systems operated simultaneously in the Kreuttal area.

In parallel to surveys with the fluxgate-type magnetometer systems, a motorised caesium magnetometer system was developed and tested in the Kreuttal case study area. The basic construction of the sensor cart is the same as with the fluxgate magnetometers. Eight optically pumped total field caesium magnetometers (Scintrex CS3) can be mounted on the sensor carrier. This cart was adapted to allow various arrangements of gradiometers at three height levels above the ground surface. The first level consists of five sensors, each mounted 44 cm apart at a minimum distance of 35 cm from the ground. The offset to the second level (two sensors spaced 124 cm apart horizontally) and the third level (one centred sensor) could be arranged between 50 cm and 120 cm, and 200 cm, respectively, above ground level. Currently, tests are being undertaken to

²⁷ HINTERLEITNER, NEUBAUER, TRINKS 2013.

improve the physical characteristics of the array to satisfy specific demands. Depending on the size, depth and physical properties of the expected archaeological features, as well as the surrounding material, the gradiometer settings can be adapted.

The heavy electrical units and counters of the caesium sensors are mounted on the tow bar of the cart. Similarly to the fluxgate magnetometer system, four-channel analogue-to-digital converters connected in series are placed on the back rack of the ATV in a protective housing. To supply the necessary power, the generator of the ATV was modified to provide 24V output, and additional batteries were added. Providing a measurement resolution in the range of picotesla, the caesium magnetometer system is about 200 times more sensitive than the fluxgate gradiometer system.

Besides the magnetic surveys, various smaller manually conducted prospection surveys were carried out in forested areas, applying both GPR and two different magnetic prospection carts equipped with three FEREX CON650 gradiometer probes and six Scintrex CS3 optically pumped total field caesium magnetometers, respectively. The latter caesium magnetometer system had already been used ten years earlier for the prospection of other sites in the area.²⁸ The data positioning in the case of the manually operated systems was realised in the traditional way, using survey lines placed on the ground in regular grids. In a recent development, these carts have been modified to permit the integration of RTK-GNSS systems for automated data positioning.

2.8. Soil Sampling and Excavations

For an improved understanding of the detected magnetic anomalies, archaeological excavations and soil sampling surveys were conducted at the sites of Ochsenberg (an Early Bronze Age hillfort) and Hornsburg (a Linear Pottery settlement and two *Kreisgrabenanlagen*: Hornsburg 1 and Hornsburg 2). Soil samples were collected from 71 points at 10-m intervals on four transects running north to south along the hillside west of the KGA Hornsburg 2. Sampling was conducted using a hand-operated Oakfield soil corer with a sampling tube of 24 cm in length and 2 cm in diameter. The Oakfield soil corer eliminates the mixing of soil horizons and is thus useful for both stratigraphic characterisation and the collection of samples for further analysis. Sediments were described in the field based on Munsell soil colour charts, soil texture, boundaries between layers,

and inclusions. Soil samples were tested for available phosphate (Pav) using a ring chromatography test or a spot test based on the method developed by Heinrich Gundlach²⁹ and modified by Robert C. Eidt³⁰ and Victor M. Bjelajac et al.³¹ This method integrates well with surface collection and geophysical surveys.³² It has proven particularly useful in determining the horizontal and vertical limits of sites and the general location of activities that result in organic inputs.³³ For 21 samples, pH measurements were carried out using an Oakton Acorn 6 pH meter and a soil-to-water ratio of 1:1.

At the site of KGA Hornsburg 1, an archaeological excavation was undertaken in 2013 and 2014, in collaboration with VIAS and the Department of Prehistoric and Historical Archaeology of the University of Vienna. From the analysis of the geophysical prospection data, a good state of preservation of the monument was expected. It was decided to locate the excavation trench on top of the western entrance gateway of the KGA, including both ends of all three circular ditches. Before the mechanical removal of the topsoil (plough layer and B horizon), soil samples were taken.

The area was also surveyed using a manually operated array of six caesium magnetometers (Scintrex CS3) in a one-to-one gradiometer setup before and after removal of the topsoil. Together with the data from a magnetic susceptibility survey conducted with a Bartington MS3 kappameter, the latter survey already revealed archaeological evidence for structures inside the gateway. These structures turned out to be postholes, pits and the remains of a smaller palisade, or possibly visual obstacles in the line of sight for anybody approaching the monument. Their presence indicates the good state of preservation of the monument. Additionally, the surfaces of the first deposits to be removed from the inner ditch were documented with magnetometry using the magnetoscanner and magnetic susceptibility measurements.³⁴

3. Results

3.1. General Aspects

Each archaeological method of investigation only allows specific propositions to be made in relation to its general theoretical framework (according to the scientific discipline

28 NEUBAUER 2001. – MELICHAR, NEUBAUER 2010.

29 GUNDLACH 1961.

30 EIDT 1973.

31 BJELAJAC, LUBY, RAY 1996.

32 SALISBURY, BERTÓK, BÁCSMEGI 2013.

33 HOLLIDAY, GARTNER 2007. – SALISBURY 2016. – SALISBURY 2020.

34 KAINZ 2016.

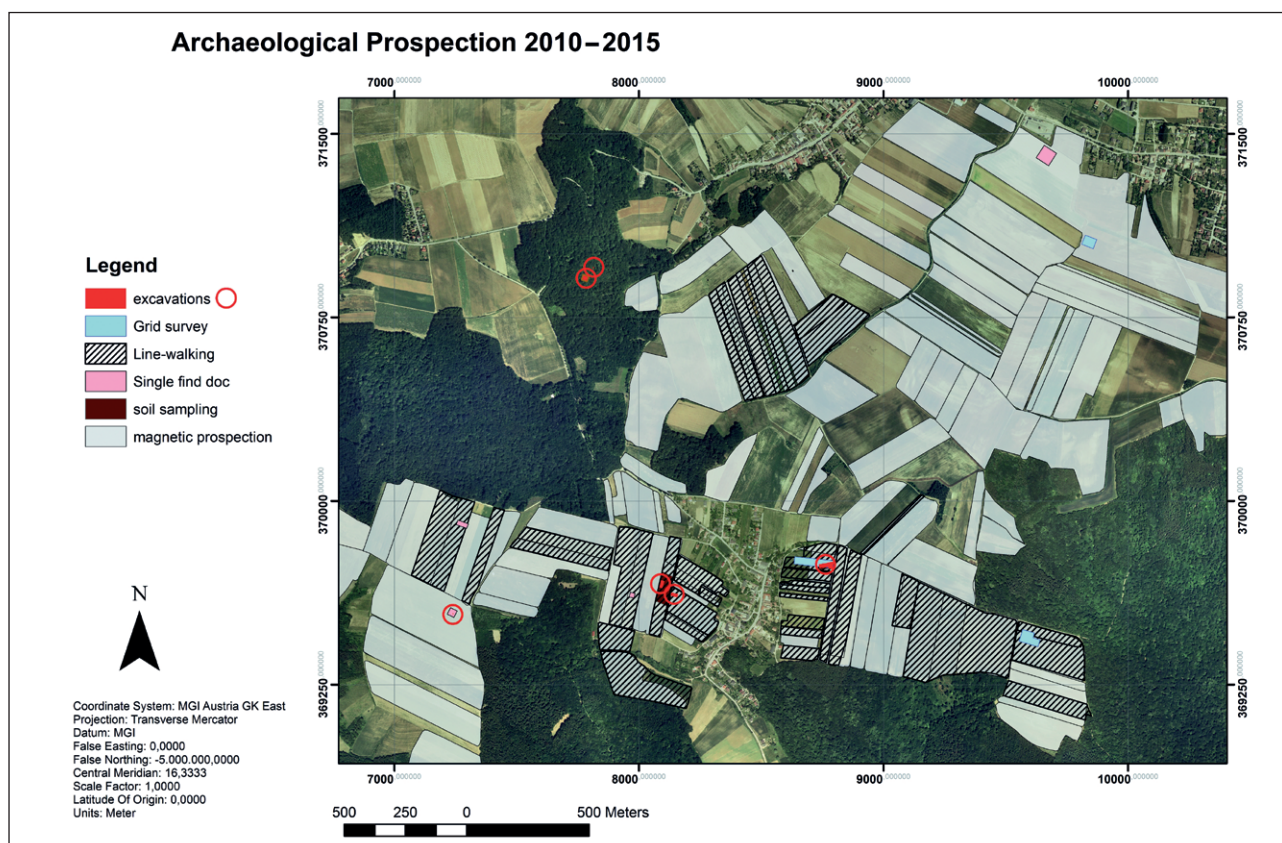


Fig. 3. Total coverage of archaeological prospection in the Kreuttal area. Surveyed areas are indicated (LBI ArchPro, M. Kucera).

to which it belongs) and the inherent accuracy and precision of the techniques used.³⁵ Only well-defined investigation methods can guarantee the reproducibility and comparability of the generated results. To limit bias in data interpretation, each dataset acquired through a specific method must be analysed individually. While an entirely consistent treatment of the different datasets can never be fully expected, an attempt should nevertheless be made to distinguish clearly between the different methods in the initial data processing and analysis phase. Once specific results are established, they can be compared and merged for a closer integrated interpretation. Datasets being used for the present study are displayed geographically in Figure 3.

3.2. Remote Sensing

Aerial photographs are the most important source for thematic mapping of recent changes that occurred in the landscape of the Kreuttal case study area. Although landscapes seem to be static as we travel through them, aerial photography collected at different times can reveal land-use

dynamics. In the 1980s, most of the field systems dating back to mediaeval times were rearranged to facilitate industrial farming. Within a few years, old roads and hollow ways were relocated and the original ones disappeared. Thus, the first task in this study was to record the rather recently vanished features, including tracks and paths, field boundaries and the course of power lines marked by their poles. This record of modern features is crucial for a correct interpretation of the prospection datasets. For example, a power line which has already been removed but with the foundations of the pillars left in place is causing significant magnetic anomalies within the Middle Neolithic settlement area of Hornsburg 2 (Fig. 4). While more recent features may have already disappeared, evidence of them can still be found in the archaeological survey data, allowing the corresponding features to be placed in chronological order.

The comparison between archaeological interpretations of aerial photographs from the 1980s and more recent ones indicates a decline in the number of observable archaeological features due to ongoing or increasing erosion at exposed sites. This hypothesis was supported by magnetic prospection, while the absence of some features on

³⁵ KUCERA, LÖCKER 2007.



Fig. 4. Aerial picture of an electric powerline, which had been removed but is still visible in the magnetic dataset.

two different aerial photographs could also be explained by the variability of environmental and climatic conditions. The observed disappearance of archaeological features motivated a general focus on the effects of accumulation and erosion processes in the available datasets. A general overview of the average erosion rates is provided by the Austrian Ministry for Agriculture, Forestry, Regions and Water Management (BML). For a more detailed analysis, hDTMs based on IBM of aerial photographs from earlier flight missions were compared with recent DTMs gained from ALS. So far, the research has focused on the description and analysis of the accuracy and comparability of the generated hDTMs, depending on the photographic material provided and post-processing workflow.³⁶ The first results of the comparison of hDTMs and recent DTMs indicate significant changes in the local topography over surprisingly short time frames. Without the knowledge of these recent topographical changes in the landscape, the

collected prospection data might easily be misinterpreted. A more detailed study has been presented by Christopher Sevara,³⁷ and the approach has been applied in other environments, such as Sicily.³⁸

The analysis of the available ALS data revealed various features and structures of archaeological interest, in particular in the forested areas. While the ‘Türkenschanze’ site has been known since the 19th century to have been a fortified hillfort covering some 85 hectares of area,³⁹ it has been possible to detect more detailed internal structures – such as terraces, pathways, field systems, and at least two construction phases of the bank – in the ALS data. The application of the analytical visualisation techniques mentioned above dramatically enhances our ability to detect these faint features. In relation to heavy combat that occurred at the site of Ochsenberg during the final stages of World War II, traces

³⁶ SEVARA 2016.

³⁷ SEVARA 2015.

³⁸ SEVARA et al. 2020.

³⁹ SCHAD’N 1953.

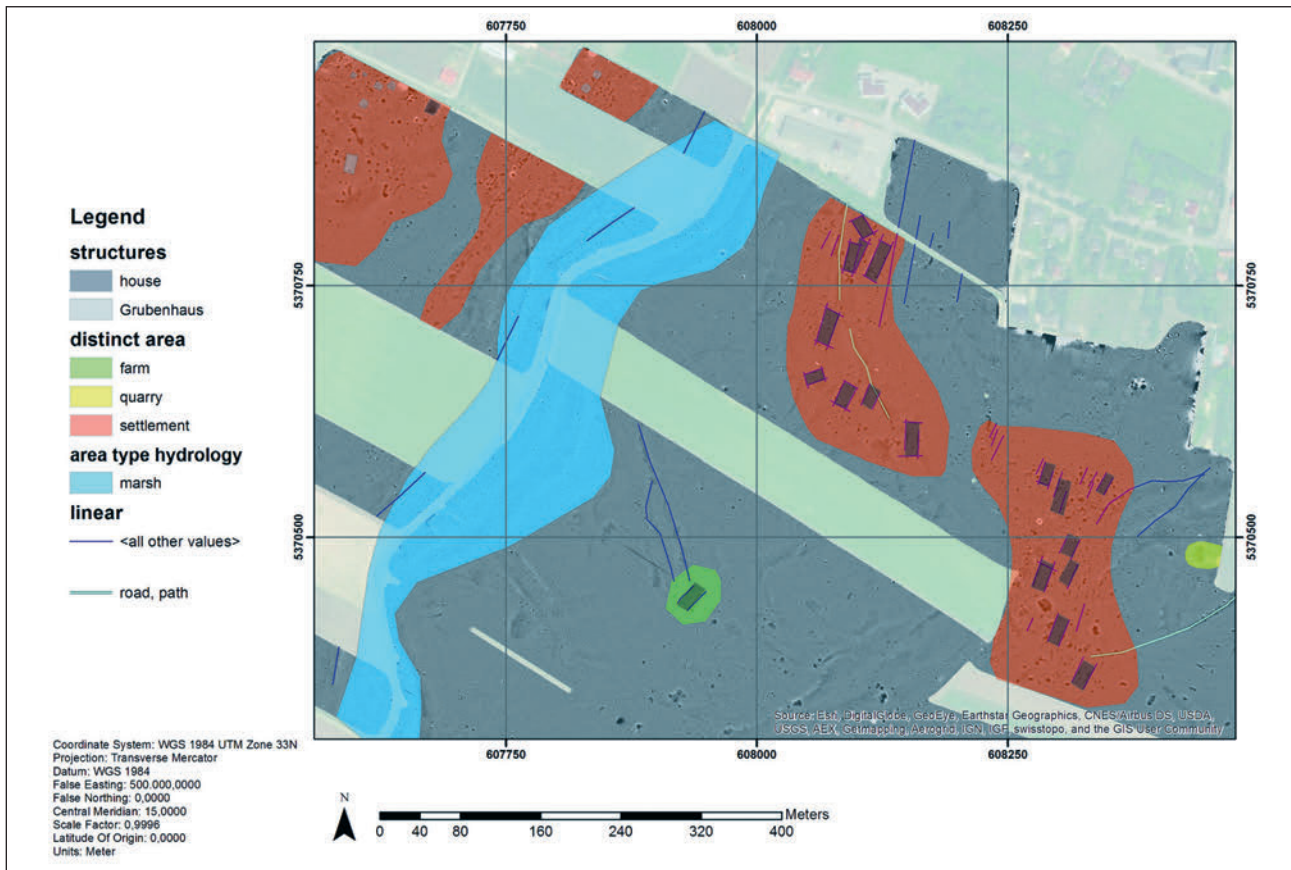


Fig. 5. Interpretative mapping of distinct areas south of Kreuzstetten indicating the location of a presumably Linear Pottery Culture (LBK) settlement (LBI ArchPro, M. Kucera).

of military activity in the form of emplacements for grenade launchers and tanks, foxholes and bomb craters could be detected all over that area.

3.3. Fieldwalking

The fieldwalking surveys, carried out between 2012 and 2015, revealed artefacts dating from the Neolithic to modern times. Most artefacts collected could be dated to the late Middle Ages and modern times. At the presumed Middle Neolithic sites, a typical variety of artefacts was documented, which can be connected to the settlement activities (painted pottery, a part of a stone axe, grinding plates and flints). Of special interest were areas that indicated a lower intensity of possible human activity according to the magnetic dataset. At nearly all of these areas, detailed raster and individual find location surveys suggest an archaeological relevance of the observed features.⁴⁰

⁴⁰ COOLEN 2018.

3.4. Geophysical Prospection

From 2011 to 2015, six major geophysical prospection campaigns were carried out, each lasting at least two weeks, using up to three motorised magnetometers. This magnetometry fieldwork resulted in a total coverage of 3.5 km² with mapped areas in the northern parts of the Kreuttal case study area, specifically around the village of Hornsburg and south of the village of Kreuzstetten. The magnetic prospection data collected revealed a multitude of archaeological features. Besides the known KGA monuments Hornsburg 1 and Hornsburg 2, various accumulations of anomalies observed in the data indicate settlement areas of the size of small villages and individual farmsteads. A key aspect has been the discovery of several Linear Pottery houses (Figs. 5–6, 9) and two presumably Iron Age settlements south of Kreuzstetten. The manually operated magnetic surveys carried out at Ochsenberg and ‘Türkenschanze’ revealed settlement activities in the centre of each respective site.

Although the density of observed archaeological features varies significantly across the entire study area, areas that are completely void of features of archaeological

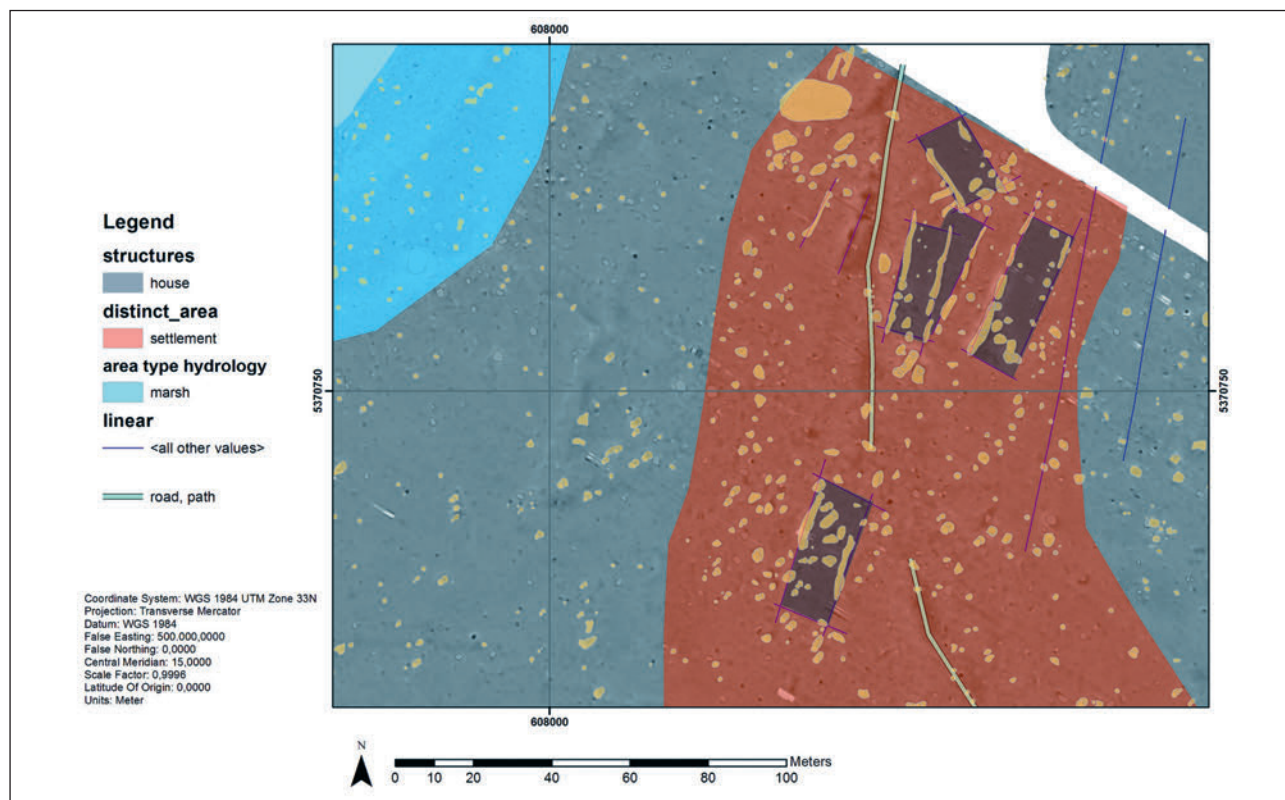


Fig. 6. Detail of the LBK settlement with mapped magnetic anomalies (LBI ArchPro, M. Kucera).

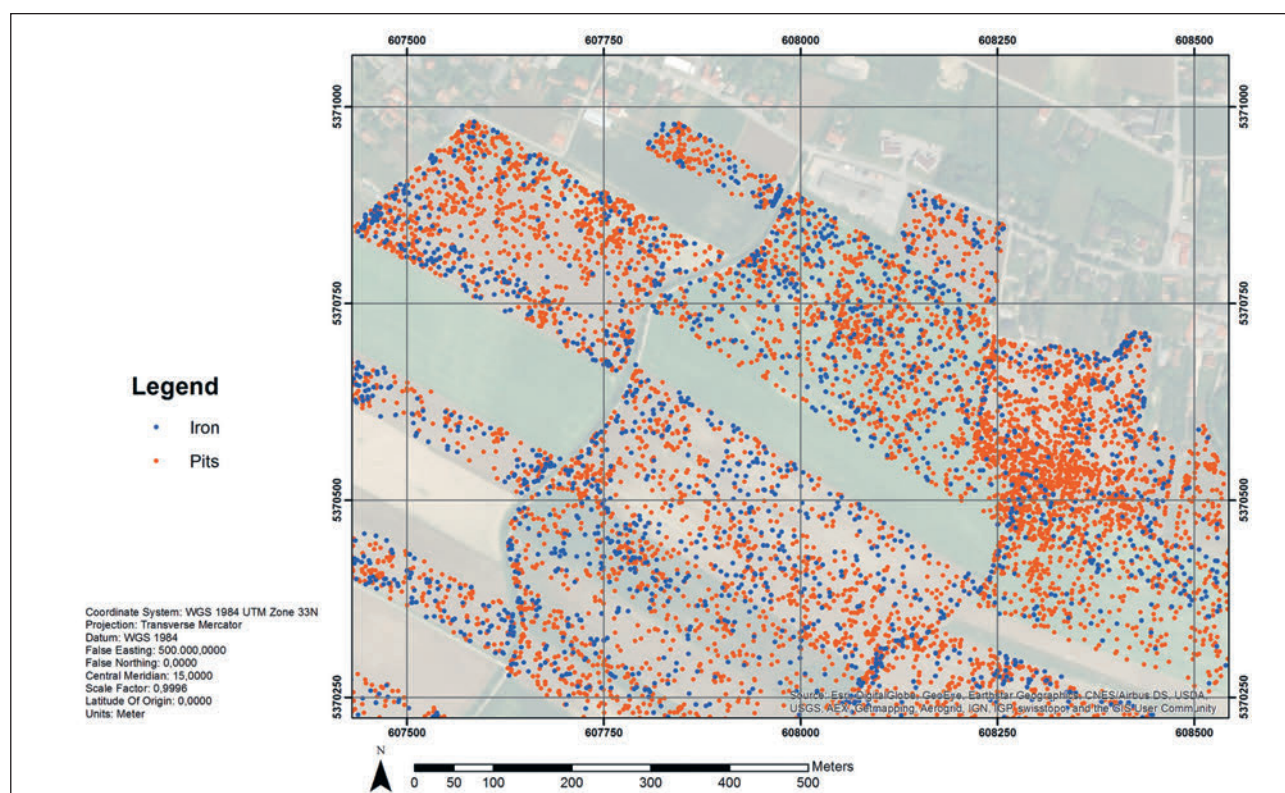


Fig. 7. Distribution of magnetic anomalies caused by iron objects and archaeological features (pits). The location of iron often indicates old pathways (LBI ArchPro, M. Kucera).

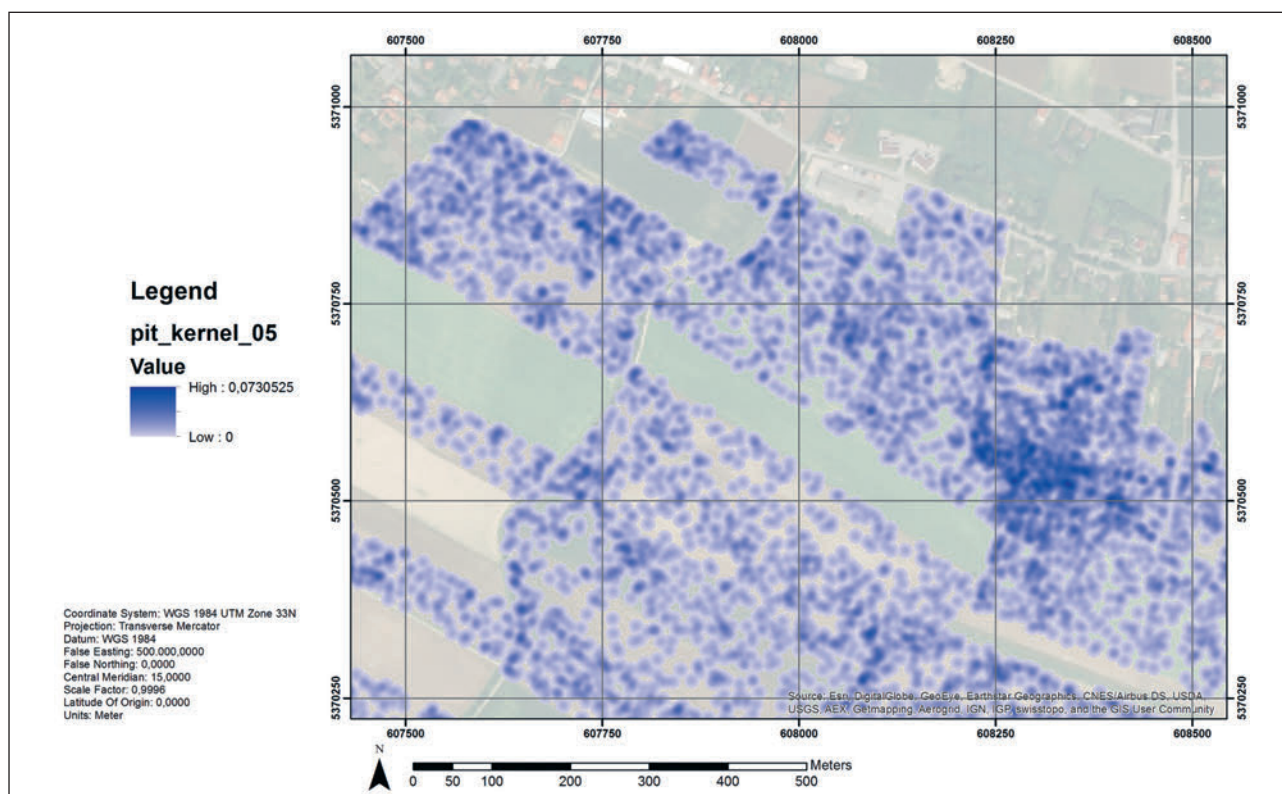


Fig. 8. Point density calculated from the distribution of archaeological features (pits). Settlement areas and activity zones are represented (LBI ArchPro, M. Kucera).

interest are rare (Figs. 7–8). Even in areas where archaeological evidence is not to be expected, individual features and buried structures of presumably anthropogenic origin indicate past human activity. These features can only be interpreted through an integrated interpretation approach. Two such structures should be mentioned by way of example here: at a pass on top of the ridge to the west of Hornsburg, an arrangement consisting of four pits of the same size (2-m diameter) was detected in the magnetic prospection data. These pits were arranged in the shape of the letter T. A further, linear pit alignment was observed to the east of Hornsburg, stretching over a small plateau from southwest to northeast. These examples illustrate the effectiveness of magnetic prospection data in not only mapping the expected settlement areas but also providing information on archaeological remains across the landscape, including the perceived emptiness between known archaeological sites.

From a technical perspective, both the logistics and the operation of the motorised prospection systems could have been optimised. Investigations of the observed measurement-induced noise within the data led to a series of system and sensor tests, which resulted in a reduction in

the number of probes mounted on the cart from ten to eight sensors. While a lot of time was spent testing, adjusting and operating the systems during the initial surveys, set-up procedures became more effective over time. The fieldwork workflows for system mobilisation and operation were described in the form of best practice guides, which proved valuable even for experienced staff. While initially the expectations and predictions regarding the daily coverage rate could hardly be met, the daily output now exceeds eight to ten hectares per system in the field. A standardised workflow including maintenance, transport, setup, operation and backup of the collected data was formulated and established.

3.5. Soil Sampling and Excavation

The upper soil layer at Hornsburg 2 and the Linear Pottery Culture (LBK) settlement consisted of dark, yellowish-brown (10YR 4/4) clayey silt with few or no inclusions, low organic content and an average pH of 7.97 ± 0.07 ($n = 20$), representing a weakly alkaline soil. An abrupt boundary separated this modern plough zone from the underlying, light olive-brown (2.5Y 5/4) silty loess. Results of coring and sediment characterisation at Hornsburg 2

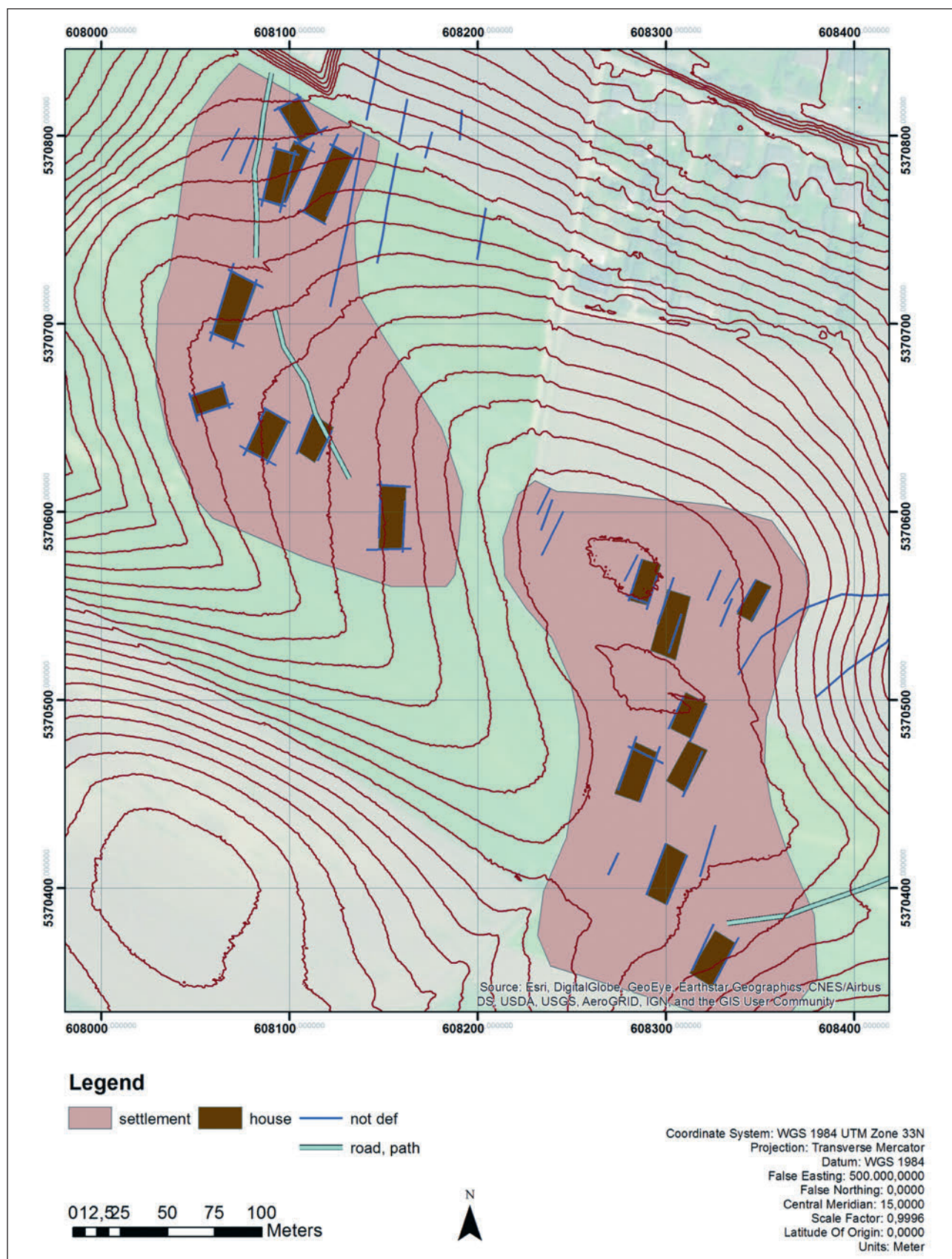


Fig. 9. The location of the settlement also respects the local topography (LBI ArchPro, M. Kucera).

and the settlement indicate that erosion has removed the original topsoil as well as an unknown quantity of the upper subsoil.

Despite the erosion, the results of the available soil phosphate (Pav) analysis (Fig. 10) reveal remnant patterns of anthropogenically enriched phosphate in the sampled parts of the site. Phosphorus and certain other chemical elements, as well as pH, magnetic susceptibility and organic content, are typically enhanced by human activities. These include, for example, slaughtering, cooking and other food preparation, fertilisation, the use of fire and disposal of waste such as animal and human faeces. Phosphorus, in the form of phosphates, remains fixed in the soil and is not easily removed through day-to-day processes of ploughing or natural chemical processes. Available or labile phosphates in soils are enriched primarily through the deposition of organic matter, especially bones, blood and manure. Therefore, high levels of phosphorus correlate strongly with human activity.⁴¹ Elevated Pav values were interpreted as an indicator of patterned, intensive deposition of organic matter, most likely associated with human habitation and/or activities associated with the KGA. The results correlate perfectly with the results of the 2015 excavation at Hornsburg. The excavation revealed archaeological features (pits, ovens, postholes) which were heavily affected by modern agriculture and disturbed by a vineyard dating to modern times (presumably abandoned in the 19th century and therefore unknown to the locals). The recorded artefacts indicate a rich and exceptional variety of pottery, micro-flints and even anthropomorphic figurines rarely found in typical settlements from this period. A correlation with the nearby entrance of the KGA (excavated in 2009 and only 50 m away) could be assumed. In parallel, excavation of a single feature (pit) detected by magnetic prospection proved the archaeological relevance of the observed anomaly. The pit could be interpreted as a cooking pit – based on the presence of fire-exposed stones, charcoal, and the colouring of the surrounding soil – which explains the clear visibility of the corresponding anomaly in the magnetic prospecting data.

Targeted excavations based on the archaeological prospection results were carried out at Ochsenberg in 2011 and 2012. Through these invasive investigations, the monument could be dated to the Early Bronze Age. Several pits, which had already been observed in the geophysical prospection data, were uncovered and demonstrated the potential of the applied methods in forested areas.

The excavations at the KGA Hornsburg 1 (2013–2014) proved the exceptionally well-preserved state of this Middle Neolithic monument. Massive V-shaped ditches still preserved down to a depth of 4.5 m had been carefully maintained throughout their existence. This observation is indicated by several documented ditch-cleaning and maintenance phases. The temporal synchronisation of the observed phases within every ditch is currently under investigation, based on the typology of the collected artefacts, radiocarbon dating, and the sequencing of the refill processes. For a detailed analysis of the material aspects of the refill processes, various methods, including portable X-ray fluorescence (XRF), magnetic susceptibility measurements,⁴² geomorphological sampling and multispectral imagery (RGB, IR, UV) combined with IBM, have been applied. The latter image data have already been analysed with regard to a possible semi-automated procedure for the classification of layers with different physical properties. This work, carried out within the framework of a diploma thesis, encourages further investigations regarding automated feature extraction based on multispectral imagery.⁴³

3.6. Summary

So far, the overall Kreuttal dataset consists of magnetic survey data covering some 3.5 km²; complete coverage with aerial imagery from different acquisition years; a topographic model gained by ALS; imaging spectroscopy data; historical maps; fieldwalking, soil-sampling and excavation data, just to mention the most important components for the ongoing research. All these data are available within a repository to be uploaded into the G-AIS. After carefully analysing the results of every method applied, an integrated interpretation approach is crucial for gaining a closer understanding of the archaeological information content and context of these data (Fig. 11). Within the physical and theoretical framework of the G-AIS, the reproducible comparison of different results and datasets is realised, and an integrated interpretation approach attempted.

4. Discussion

The integrated interpretation of such a multi-layered detailed dataset is a demanding long-lasting process. Some of the observations made during the interpretation process are challenging and require further reflection and analysis.

Spatial analysis tools provided by the geographical information system have to be combined with concepts for

41 PARNELL, TERRY, SHEETS 2002. – HOLLIDAY, GARTNER 2007.

42 KAINZ 2016.

43 SCHWEIGHOFFER 2015.

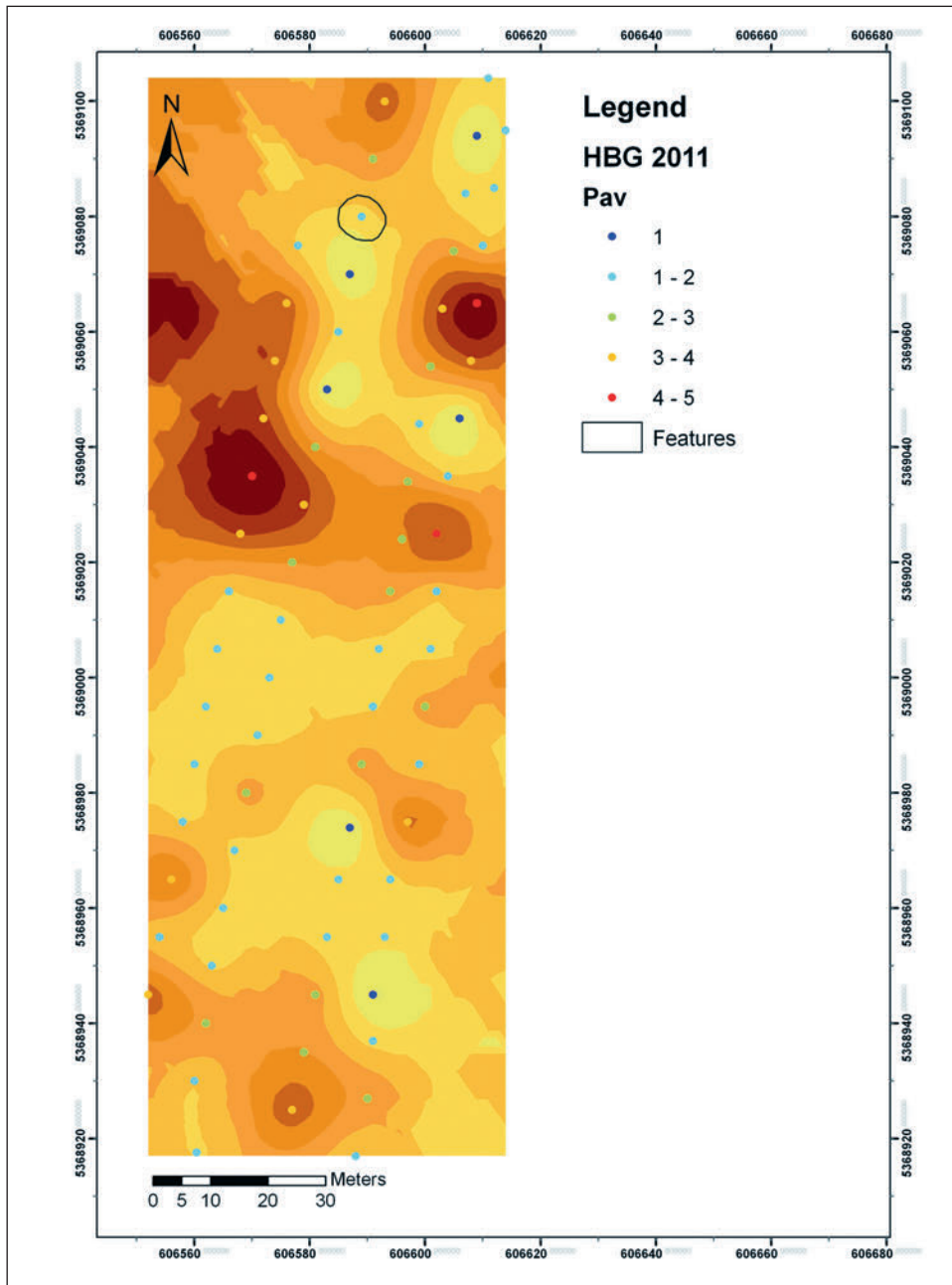


Fig. 10. Distribution of Pav values based on soil phosphate analysis (R. B. Salisbury).

the investigation of temporal relations in the data and of the observed archaeological phenomena. Whereas in some datasets only a relative spatial superposition of archaeological features can be observed, other datasets provide precise information about the stratigraphic relationships of these features. For example, aerial imagery can reveal that features are superimposed but not the respective sequence. GPR data allows volumetric analysis of the documented features and enables the derivation of a stratigraphic sequence for some of these features.

The spatial superposition of individual features or structures is often difficult to interpret, but it can mostly be addressed when examining larger areas. Nevertheless, as soon as spatial superposition is detected or presumed within the dataset, no matter at which level, important archaeological information is provided and needs to be documented. Although a complete stratigraphic sequence of a given archaeological landscape could never be derived, at least some archaeological entities could be spatially ordered. For instance, the spatial superposition of pathways, earthworks

and erosion channels at the 'Türkenschanze' site, as observed within the ALS data, was studied in detail during on-site visits. The first interpretational arguments for the temporal development of this site are based on these observations. Again, the integrated analysis and interpretation approach is crucial for gaining new knowledge on spatial relations.

Whenever archaeological evidence is observable in only one dataset, this dataset must be critically analysed. By combining the datasets derived through magnetic prospection with topographical data and data gathered through fieldwalking, the lack of archaeological evidence in one or two of these datasets can become understandable. At a settlement in the Kreuttal area, which could be dated through fieldwalking to the Neolithic period, the distribution of artefacts seems to be relatively constant, whereas the magnetic data indicates an absence of features in specific areas. By analysing the topography gained through ALS, the absence of anomalies is shown to correspond with zones of possibly higher soil accumulation rates. These rates could be estimated by the change in the pitch of the slope where the settlement is located. By interpreting the results of these three data sources (ALS, magnetic prospection and fieldwalking) the contradiction of a constant distribution of artefacts related to human settlement activity and the local absence of archaeological evidence in the magnetic data could be discussed. Within a subsequent analysis, a DTM based on ALS data will be compared to an hDTM derived from aerial imagery dating to the 1980s. The comparison with low-resolution data on recent average erosion rates already indicates significant changes that have occurred on the surface within the last decades.⁴⁴

When comparing recent aerial imagery with pictures from the early 1980s, massive landscape changes become apparent. During the land consolidation in the 1980s, the legal structure and property borders of large regions in Lower Austria were restructured, which led to the disappearance of old paths, trackways and field boundaries. These structures are still visible as soil and vegetation marks in some of the collected datasets. Where and when these features become observable in a specific dataset depends on the type of feature, the local soil and geological setting, and seasonal changes. An old trackway may be visible within aerial photographs, while it may be invisible in the magnetic prospection data. It may only be visible in the magnetic prospection data when magnetically enriched material, such as rubble from a building, including pieces of bricks and roof tiles,

for example, was deposited along the way to compact the path. At another site, the underlying bedrock became visible within the magnetic data in the form of meandering parallel anomalous bands. When compared against old aerial photographs, some of these bands (and only these specific bands) are more likely to have been caused by old field borders that are still visible in the topographic data.

A major advantage of the archaeological prospection of entire archaeological landscapes is the ability to explore the space between sites or zones of increased human activity and other features presenting archaeological evidence. An example is the recently detected pit alignment within the magnetic prospection data mentioned above (Fig. 12). It is located on a small plateau running southwest to northeast. The pits are approximately 2 m in diameter and spaced at distances of multiples of 30 m. Although the appearance of this pit alignment is reminiscent of the placement of poles of electric power lines, no evidence of a recent intervention could be found within the other datasets. The alignment passes by a possible prehistoric settlement area, indicated by large arrangements of pits. The pit alignment ends at the centre of a very faint circular structure of about 80 m in diameter. This structure is visible within the ALS data and requires further investigation to determine its origin and possibly function. During a fieldwalking survey, no archaeological evidence has been found that could be linked to either the pit alignment or the settlement. From analysing the topography, only minor erosion could be expected to have happened here, which may explain the absence of artefacts. In this case, the only way to clarify the situation would be a targeted sampling survey or a targeted excavation.

Within a similar setting, a T-shaped arrangement of four pits of approximately two metres in diameter has been detected through magnetic prospection. Again, these pits are located on a plateau of a ridge on a faint topographic saddle. No corresponding evidence of human activity could be found within the other datasets, including from fieldwalking. A targeted excavation of one of the pits proved the presence of an accumulated soil cover, sealing the archaeological evidence. After removing the topsoil, the pit only showed up in the magnetic susceptibility data. It would have been missed entirely if only traditional excavation techniques had been applied.

The aforementioned points also demonstrate the considerable potential of the multi-layered data recorded over a vast area in this project. It is a fallacy to assume that landscapes are devoid of human influence; the imprint of human activity is ubiquitous. An archaeology that relies on individual prospecting methods or describes itself as an exclusively excavating 'science of the spade' will be unable to

44 SEVARA 2015.

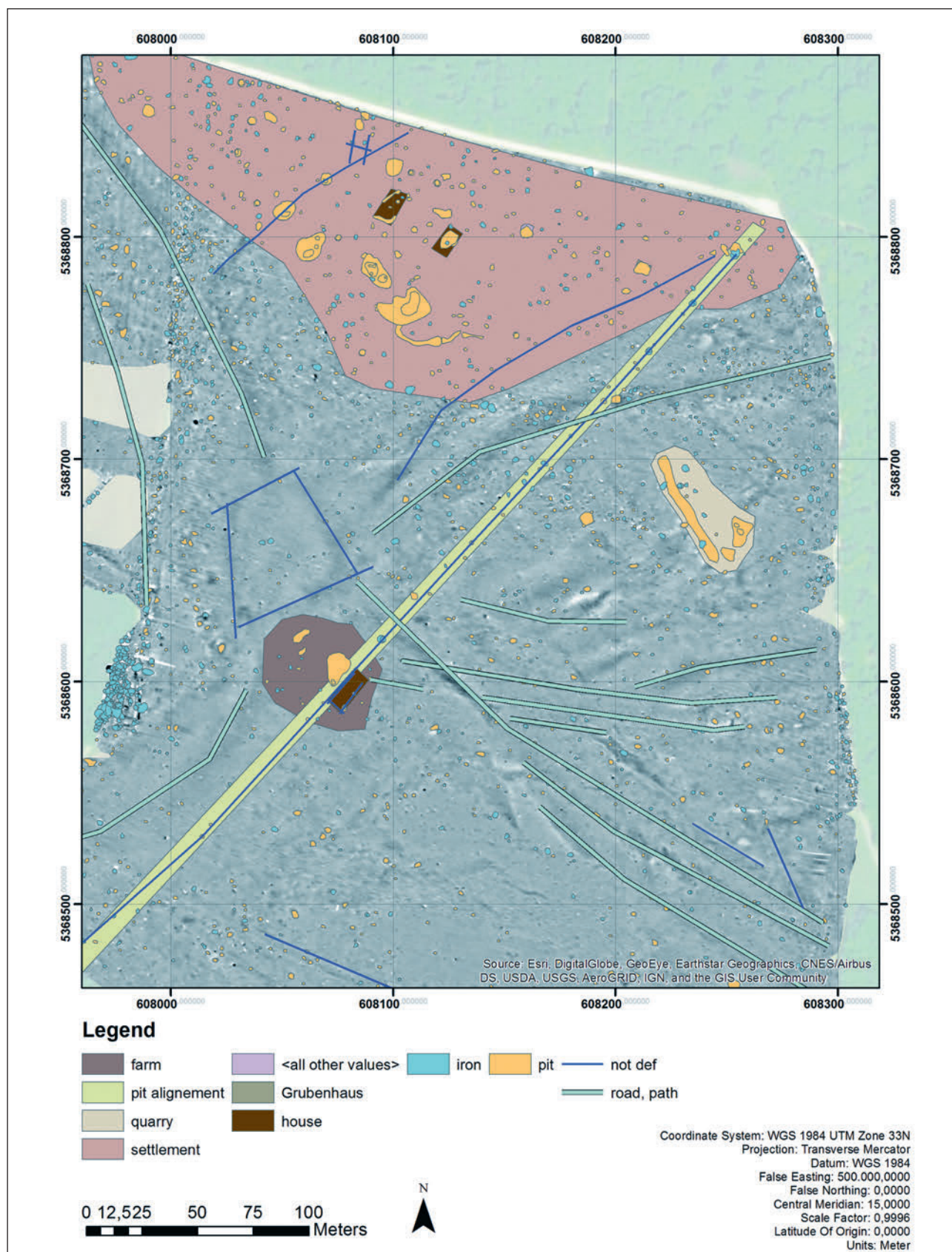


Fig. 11. Interpretative mapping of magnetic anomalies. A settlement area, a pit alignment and path systems were detected by magnetic prospection (LBI ArchPro, M. Kucera).

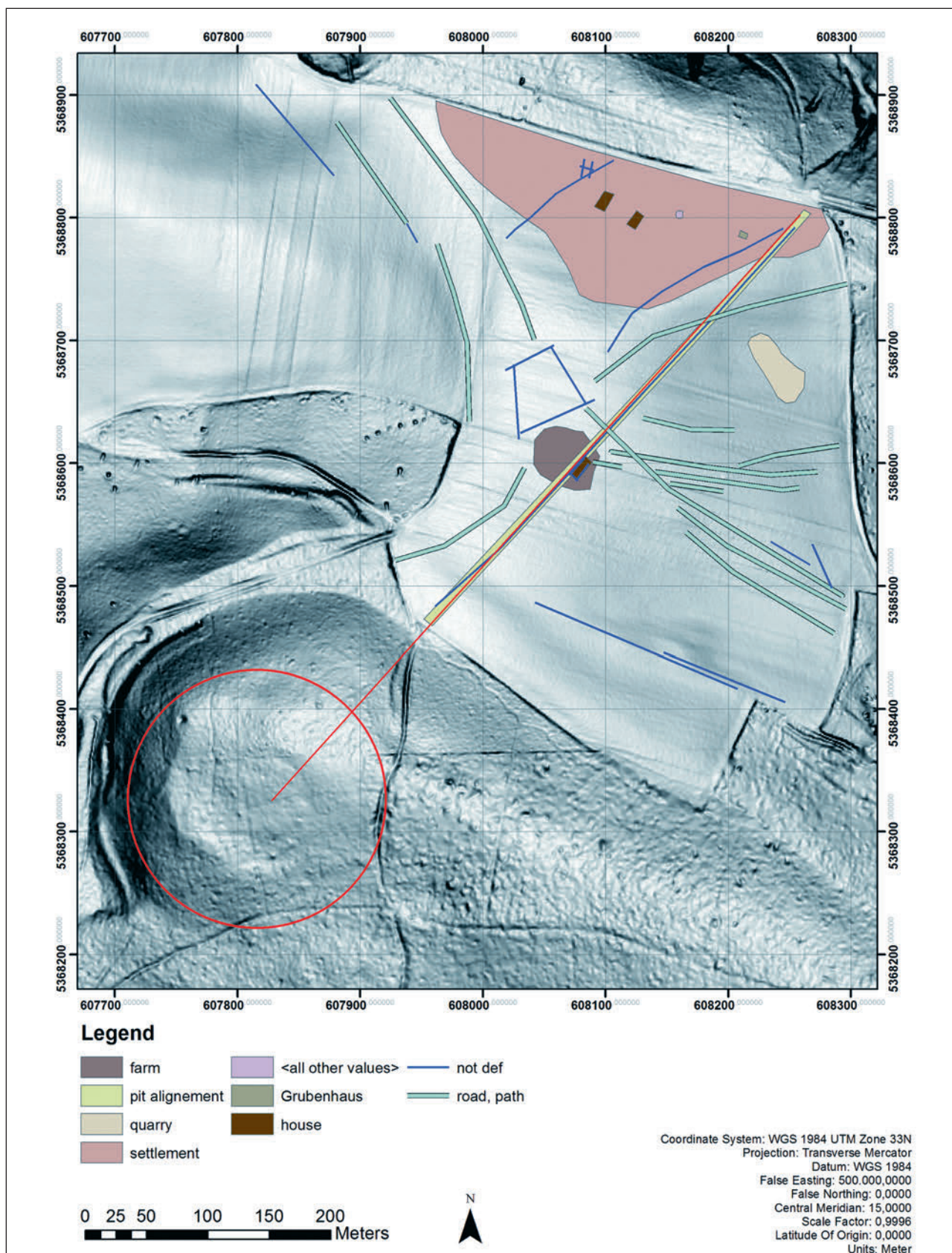


Fig. 12. The pit alignment is oriented towards a circular structure (inside the circle) (LBI ArchPro, M. Kucera).

capture this potential. In light of the considerable number of human remains documented through various prospection techniques in areas designated as ‘offsite’ or ‘non-site’, our findings prompt a reassessment of the archaeological process in landscape archaeology. In order to gain a more comprehensive understanding of archaeological landscapes, it would be more appropriate to focus on investigating landscape features such as individual pits or ditches rather than concentrating on excavations at specific sites. Thus, excavations can be used not only to reveal archaeological content of interest but also to evaluate and optimise the interpretations of the non-destructive surveys. This approach would allow for a more holistic interpretation of the landscape.

5. Conclusions

To understand and interpret the spatio-temporal development of archaeological landscapes, an integrated multi-method approach is crucial. When archaeological information based on different datasets had to be analysed and interpreted, a GIS-based AIS proved to be the right tool to ensure the reproducibility of the hypotheses derived. A standardised archaeological interpretation process, comprising data segmentation, data classification and the analysis of spatial and temporal superpositions of entities is crucial for the comparability and traceability of the interpretations that are generated. Each method or technique has to be well-defined in terms of its abilities, limitations, accuracy, precision and validity for addressing or answering a specific research question. One has to be aware that the outcome of archaeological investigations in particular depends mainly on the research question posed and the set of methods chosen to answer it. In this sense, a single methodological approach may be critical.

The combination of different methods enables further specific and comprehensive conclusions to be drawn from the observed evidence. The integration of datasets gained by archaeological prospection at the landscape scale and smaller surveys or invasive archaeological excavations guarantees an increase of possible knowledge according to a well-defined canon of methods. By displaying and understanding archaeological landscapes at a large scale, the context of the observed details can emerge and become comprehensible. Concerning responsibility for the preservation of cultural heritage, invasive methods such as archaeological excavations can be planned based on prospection data as targeted keyhole interventions that address specific and well-defined research questions.

Although a traditional archaeological excavation appears to be comparably absolute in terms of representing a physical reality, it reveals only what we are trained to find

depending on our experience, prior knowledge, and methods. The absence of evidence in one or more datasets does not prove either its non-existence or its existence. On the contrary, negative evidence allows a critical discussion of the methods applied in this specific context to find an explanation for the lack of evidence, since the lack of evidence is not evidence of lack,⁴⁵ a fact well understood in exploration geophysics.

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⁴⁵ HUBER 2016.

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