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Editorial

For the second time in its history, *Archaeologia Polona* dedicates an entire volume to archaeological prospection, understood as a growing range of non-invasive methods for recording archaeological structures. As in volume 41 issued in 2003, there is foremost a large set of articles documenting the application of geophysical methods in the investigation of archaeological sites. There are also articles on the GIS methods, processing and visualization, technical aspects. Recent years have witnessed a rapid development of ground-scanning technology (LiDAR), also represented in the volume. A novel element are articles from the field of the history of archaeological geophysics.

The volume accompanies the 11th International Conference on Archaeological Prospection, organized on 15–19 September 2015 in Warsaw by the journal's publisher, the Institute of Archaeology and Ethnology of the Polish Academy of Sciences (together with the Polish Centre of Mediterranean Archaeology of the University of Warsaw and the Scientific Association of Polish Archaeologists). For the past decade or so, the organizers of successive conferences have adopted the principle of publishing not the commonly accepted abstracts, limited to a few sentences, but rather brief articles including illustrations and references that give in effect a representative review of what is going on in the field, both in scientific institutes and in commercial companies around the world.

The strong representation of archaeological feedback in the volume is the effect of there being a full-day session devoted to the topic at the conference. Nine invited guest lecturers representing different centers from France, Germany, the Netherlands, Austria, Italy and Poland make up this session, the idea of which is to evaluate the effectiveness of prospection methods from the point of view of those commissioning the research, that is, the archaeologists. The objective is to popularize prospection methods among archaeologists in Poland.

The first part of the volume contains articles by Polish authors, discussing relevant research carried out in Poland (articles on research of Neolithic, Early Bronze Age and Medieval sites) and in Egypt where Polish geophysics contributed significantly to research over the past 30 years (article by Zych and Herbich on the Hellenistic/Roman harbour in Berenike). This part is rounded off with an article giving a historical overview of the development of the magnetic methods from its first application in 1958 to the late 1990s. It is only right after half a century since its inception to look up the beginnings of the field and the factors that contributed to its development. Not the least, it is practically the last moment to talk to the founders of the discipline, the authors of those first implementations of the method in the field.

The volume is also a way of paying homage to two extraordinary men, Alain Tabbagh and Helmut Becker, whose contribution to the development of archaeological geophysics has been momentous. Prof. Alain Tabbagh, a student of Albert Hesse (whose founding role in the field was acknowledged in *Archaeologia Polona* vol. 41), has dedicated a lifetime to research on the development and applications of the electromagnetic method. A lecturer at the University of Pierre et Marie Curie in Paris, he has educated a generation of researchers whose work has placed French geophysics at the top of the field. Their articles are found in this volume. As for Dr. Helmut Becker, his varied contribution to the field includes pioneering work on digital recording of measurement data, implementation of cesium magnetometry, the uses of mobile multi-sensor magnetic systems, visualization and interpretation of results and the integration of geophysical research with aerial photography, the latter in association between his laboratory in Munich and Otto Brasch. The achievements of both researchers have been presented in brief articles opening the volume.

Dedicating this volume of a journal with "Polona" in its title to these two scientists is validated also by their links with Poland. Both Alain Tabbagh and Helmut Becker have carried out research in Poland, working in cooperation with researchers from the Institute of Archaeology and Ethnology of the Polish Academy of Sciences and the Institute of Archaeology of the University of Warsaw. They have shared their immense experience as well as their equipment, which was not available by any means in Poland in those early years. Alain Tabbagh supported Polish research on early metallurgy of iron, whereas Helmut Becker provided the apparatus necessary to carry out Polish geophysical projects in Egypt in the 1990s. Our gratitude for this and much more is boundless.

Tomasz Herbich

Alain Tabbagh

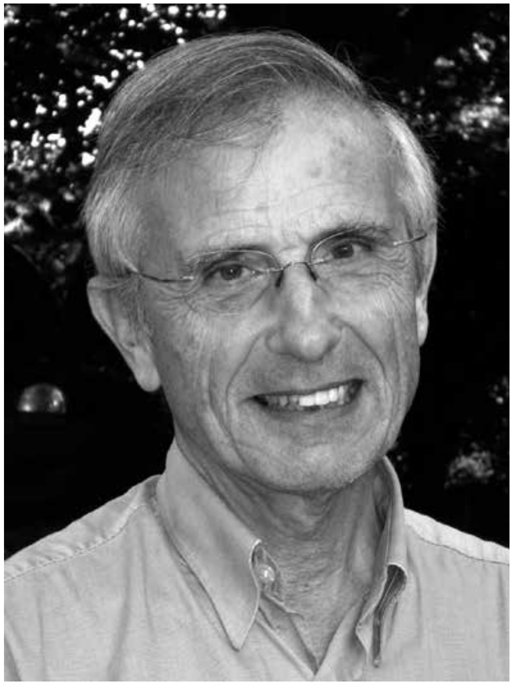

Photo: C. Tabbagh

Alain Tabbagh is one of the most eminent French geophysicists of the past 40 years. It is difficult to give an exhaustive overview of such a rich career, in which so many new avenues of research were initiated, that had barely been scratched before.

Having completed a PhD on the use of electromagnetic methods in archaeology under the direction of Albert Hesse in 1971, Alain Tabbagh became Assistant Lecturer at the University of Pierre et Marie Curie (UPMC) in 1972. He spent his entire career thereafter at the UPMC: Assistant Lecturer 1972–1978, Lecturer 1978–1984, Assistant Professor 1984–1988, Professor of applied geophysics 1988–2012, Professor Emeritus since 2012.

His research in geophysics concerns different applications, such as hydrology, soil science, civil engineering and archaeology. In the latter domain, he is one of the most eminent figures of French archaeometry. He is one of the founding members of the GMPCA in 1976 (Group for Physical and Chemical Methods in Archaeology, renamed Group for Interdisciplinary Methods Contributing to Archaeology in 1987) and presided over it from 1991 to 1995. He headed from 1988 to 1989 the Geophysical Research Center at Garchy, which was one of the pioneer institutions in Europe for the application of geophysical methods in archaeology. He was also Director of the Sisyphe laboratory (renamed METIS in 2014) from 2001 to 2008. Alain Tabbagh is also member of several international societies: European Association of Geoscientists and Engineers (EAGE), Society of Economic Geologists (SEG), International Society for Archaeological Prospection (ISAP, honorary member since 2014), American Geophysical Union (AGU), International Union of Soil Sciences (IUSS), Institute of Electrical and Electronics Engineers (IEEE), and associated editor of various international journals.

As professor at the UPMC, he was Study Director of the engineering section in geophysics and geotechnics from 1992 to 2005, and Director of the postgraduate programme 'Sciences de l'Univers, Environnement, Ecologie' from 2004 to 2011. He supervised 40 PhD theses, including several in applied geophysics in archaeology, among them theses by Michel Dabas, Christophe Benech, Julien Thiesson and François-Xavier Simon. He has published more than 130 articles, demonstrating a broad range of research in the application of geophysics in archaeology.

With his extensive experience in both theoretical and experimental approaches, Alain Tabbagh initiated important developments in the EMI domain. For small-sized dipole-dipole instruments using the slingram configuration, he was the first to make the measurement of magnetic susceptibility possible by using the in-phase response and built the first stabilized EMI device for archaeology (SH3) as well as a large series of different instruments of similar type enabling simultaneous measurement of apparent magnetic susceptibility and apparent electric conductivity. He proposed also a 3D-modelling technique based on the moment method, taking into account contrasts both in conductivity and magnetic susceptibility, and calculated the theoretical response for the different coil orientations to estimate the most pertinent configuration for the best depth of investigation. He developed also new TDEM devices to measure the magnetic viscosity of archaeological structures. All these technical and theoretical innovations were decisive for a more extensive use of EMI methods in archaeology and not just in environmental studies. The measurement and characterization of different kinds of magnetization helped considerably with the interpretation of magnetic properties of soils and their relationship with human occupation. Experiments with these instruments in the field (including the EM15 by Geonics) improved the interpretation of the physical nature of responses (anomalies) produced on survey maps by specific archaeological targets. Alain Tabbagh participated or directed many successful field surveys, including such prominent projects like the search for Bronze Age deposits in Marchezieux, delimitation of ancient metallurgic workshops as revealed by direct measurement of the magnetic susceptibility of slag deposits and the exploration of pavements of diverse churches and other buildings.

He initiated the development of electrostatic devices with the use of non-galvanic arrays, particularly useful in urban contexts and less limited than with the GPR in the case of conductive soils. He developed systems for different depths and with different array configurations and established the 1D- and 3D interpretation of the data. Such systems are particularly powerful in urban context and represent a good alternative to GPR devices when the penetration depth is limited by too conductive environments. Electrostatic systems have been used successfully for the study of the ancient topography of modern cities, like Tours in France and Alexandria in Egypt, and also for investigation inside historic buildings, like cathedrals.

As an alternative to traditional aerial archaeology, Alain Tabbagh developed new devices to measure the variations of surface temperature of the soils by using airborne and satellite infrared remote sensing as a thermal geophysical exploration method. Variation of soil temperature had already been used in aerial survey for the detection of archaeological structures like ditches, particularly when the snow is melting, which limited such investigations to a very short period during the year. By using a radiometer to measure radiation transmitted by ground soil, he carried out very impressive thermal surveys over wide areas, detecting Neolithic ring ditches and ancient land divisions. The use of the method was very limited due to the complexity of data processing and interpretation, but Alain Tabbagh computed the 3D numerical model, evaluated the thermal inertia contrasts and established the heat exchange conditions at the soil' surface favourable for surveying.

He also pursued a collaboration initiated by Albert Hesse during the 1980s with Polish colleagues Tomasz Herbich and Krzysztof Misiewicz. He participated in the publication of EM surveys with the SH3 on the sites of Słonowice and Milanówek and came back to Poland with Julien Thiesson in 2004 for the study of the pottery workshops in Stołpie.

His lifetime of work had impact on applied geophysics far beyond the specific context of archaeology that is summarised here in brief. However, it is for archaeological prospection that he invested his energy and enthusiasm and the many ways of research that he initiated are still being pursued by a younger generation of geophysicists. It is indeed a great gift to young students who are starting on their PhD to give them visionary and innovative subjects of research to help them find a place for themselves in the scientific community.

Christophe Benech and Albert Hesse

Helmut Becker

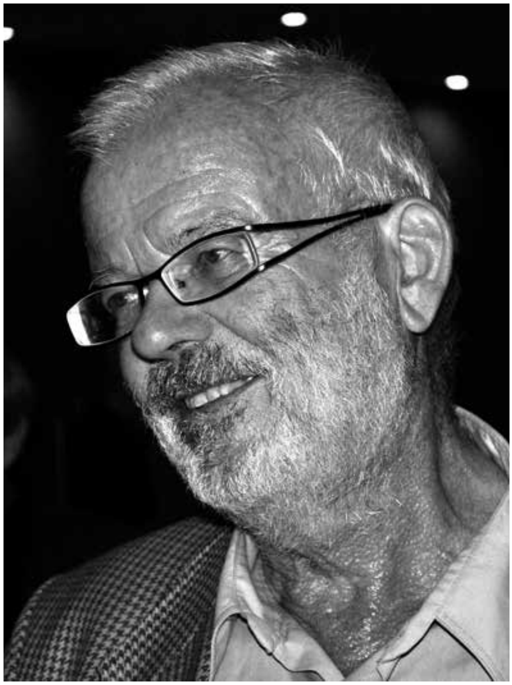

Photo: T. Herbich

Helmut Becker is one of the eminent German scientists specializing in archaeological geophysics in the past 40 years. An overview of his work in Bavaria as well as in the Near and Far East, Egypt, Eurasia and China, which was presented in the Arbeitshefte des Bayerischen Landesamtes für Denkmalpflege (BLfD - Bavarian State Department for Monumets and Sites) in 1999 and 2001, revealing the great range and diversity of his work on archaeological sites of the Old World.

His geophysics diploma and his doctoral thesis under the direction of Heiner Soffel at the Institute for General and Applied Geophysics of the Ludwig-Maximilians-University Munich, as well as his first scientific work from 1971–1973, dealt with paleomagnetism in Iran and the verification of seafloor spreading in Iceland. But since the very beginning of his career Helmut Becker also studied archaeology and was involved in a multitude of archaeological research projects in Turkey, Greece and Iraq, where he undertook topographical measurements, archaeomagnetic studies and, last but not least, in 1976, his first magnetometer surveys in Turkey and in Greece.

Within the frame of the Volkswagen Stiftung research project in 1977–1982, he came together with Irwing Scollar (Bonn), Emile Thellier, Albert Hesse, Alain Tabbagh (Garchy) and Martin Aitken (Oxford) to establish a new research field of Archaeo-Prospection and Archaeomagnetism at the Geophysical Observatory Fürstenfeldbruck and the Geophysical Institute in Munich. These successful and promising survey and research projects helped him to convince the director of the archaeological section of the Bavarian State Department for Monuments and Sites, Dr. Rainer Christlein, to establish the Archäologische Prospektion und Luftbildarchäologie section at the Bavarian State Department. This was the first time in Germany that a geophysicist was employed in an archaeological institute for archaeological geophysics. Helmut Becker directed this department from the start.

In 1982 Helmut Becker set up a cesium magnetometer system (Varian 101) with an automatic digital data recording system. Further development yielded in 1985 a wheel-deployed magnetometer prospecting system that allowed large areas to be measured in a comparatively short time. In the laboratory of the Bavarian State Department, Helmut Becker installed and developed a highly effective and powerful computer system for digital image processing of the geophysical data, rectification of oblique air photos and combined data interpretation. Together with aerial archaeologist Otto Braasch and from 1986 with Jörg Fassbinder, Helmut Becker accomplished very successful work at the Bavarian Department, not only with the discovery of previously unknown archaeological sites in Bavaria through aerial prospection and complementary magnetometer prospection, but also with a detailed and sophisticated interpretation and mapping of these sites. It was in his department that integrated prospection with a combination and data fusion of these complementary prospecting results and methods began.

Further development of the magnetometer system at the Bavarian State Department for Monuments and Sites ("From Nano- to Picotesla") was stimulated by the discovery of the lower city of Troy and the Bronze Age fortification of Troy VI. The result was the most sensitive magnetometer system for archaeological prospection in the 1990s. Subsequently the cesium magnetometer system was enlarged to a duo-and quad-sensor system respectively. The handheld caesium duo-sensor system (Scintrex Smartmag SM4G-Special and Geometrics G-858G) is still among the most sensitive and effective prospecting systems with respect to large areas in difficult terrain; large-scale measurements in Qantir in 1996–2003 are a good example.

Helmut Becker's idea for a geophysical prospecting section within an archaeological State Department was developed from the very beginning of his work. the objective was to survey different categories of archaeological monuments and to compare survey results for the development of further archaeological research questions. His idea to ascribe Neolithic ring ditch monuments to an archaeoastronomical context was one of the major results of such a prospecting approach.

Following this idea, we now have from Bavaria geophysical survey results and interpretation of all the known Neolithic ring ditch monuments from more than 15 large early Neolithic settlements, nearly 40 enclosures from the Hallstatt period, 35 Iron Age square enclosures, as well as survey results of nearly all accessible Roman *castella* in the Bavarian part of the limes, more than 30 Roman villas and about 15 early medieval castles, many of these sites previously completely unknown.

In 2005 Helmut Becker retired from the Bavarian State Department and started a new career with his private company "Becker Archaeological Prospection". He is still active in geophysical prospection and walking hundreds of kilometres with a magnetometer, from Portugal and Spain in the west to Cornesti (Romania) in the east and places like Turkmenistan and Uzbekistan in the Far East.

Jörg W.E. Fassbinder

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Magnetic prospecting in archaeological research: a historical outline[1]

Tomasz Herbich[a]

The article presents an overview of the history of the magnetic method in archaeological research, from its first use in 1958 in England through the 1990s. Brief presentations of the history of research using this method have already appeared in general works dedicated to archaeological geophysics, but merely as introductory chapters, which have focused on initial stages of the application of particular methods (chiefly magnetic and electrical resistivity) and highlighted achievements in the field in Western Europe, primarily the UK. In the present text, the author has also included the history of the use of the magnetic method in other parts of Europe (Central and Eastern Europe) and on other continents. He analyzes technological changes in the instruments used for research, from the proton magnetometer and magnetic balance to the increasingly advanced fluxgate and optically pumped magnetometers. He also examines the changes in measurement technology and data processing that have occurred and the factors shaping the development of the method.

KEY-WORDS: history of archaeological geophysics, magnetic method, magnetic balance, proton magnetometer, fluxgate magnetometer, optically pumped magnetometer

1. INTRODUCTORY REMARKS

Outlining a history of early archaeological geophysics is burdened by a lack of sources, the few existing studies being limited to the applications of the method in Great Britain (e.g. Aitken 1986; Clark 1990: 11-27) and Poland (Misiewicz 2002; Herbich 2011). Short reports have been published on the history of archaeological geophysics in Austria (Doneus *et al.* 2001: 15-17) and the Czech Republic (Hašek 1999: 1-2). Early issues of *Archaeometry* contained brief references to the first applications of the magnetic method to archaeological research in France, Germany and Italy, the United States of America and Poland (e.g. Hesse 1962; Scollar 1961b; Lerici 1961; Johnston 1961; Dąbrowski 1963). Mentions of historical

[1] The article covers the history of archaeological applications of the magnetic method until the end of the 1990s, because it was prepared in 2011-12 for publication in a volume dedicated to the history of archaeology in the 20th century. The volume has not been published yet, hence the author has chosen to present it in this volume devoted to non-invasive methods of archaeological prospection, without making any significant changes in the text. The author believes this will ensure better circulation of the publication among researchers interested in archaeological geophysics.

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importance can also be found in general studies, like Tony Clark's "Seeing beneath the Soil", and the collective publication edited by Irwin Scollar (Scollar *et al.* 1990: 513-515) as well as that of Chris Gaffney and John Gater (2003: 13-24), which are concentrated however on activities in Great Britain much less attention paying to research of this kind in other countries.

Fig. 1. Robert du Mesnil du Buisson. Courtesy Charles Henri Burgelin

To give an historical overview of the application of the magnetic method in archaeological research one thus has to peruse the early publications, a task made more arduous by the frequently limited distribution of local publications (and the language barrier in some cases!). The present author has taken up the challenge, knowing full well that he has surely missed a number of publications which would have benefited this presentation by contributing important, but not widely known facts. Recent archival studies by Albert Hesse and Bruce Bevan exemplify this best. Looking through old documents and publications, Hesse found that the first archaeologist to take note of the potential of geophysics in archaeological prospection, the magnetic method included, was the Frenchman Robert du Mesnil du Buisson (Fig. 1). This scholar, famous foremost for his discoveries in Syria, also wrote a textbook on excavation methods (1934), in which he listed, almost prophetically it would seem, the kinds of objects that could be located with the aid of geophysical methods, successively gravimetric, magnetic, electrical and seismic, while making the reservation that

> "it is too early to say how these methods will provide help for archaeology"
> (du Mesnil du Buisson 1934: 105; translation: Hesse 2000: 46).

Hesse believes that du Mesnil du Buisson owed his understanding of geophysics as a supplementary method in geological studies to his close neighbour, Conrad Schlumberger, creator of the geoelectrical method (their family estates in Normandy were only 43 km apart, see Tabbagh 2015: 132-136 and Hulin *et al.* 2015: 141-143), and to articles on geophysical methods which he cited in his textbook. However, since none of these articles or Schlumberger's works ever referred to archaeology, du Mesnil du Buisson must have come up with the idea of applying geophysical prospection methods in archaeology all by himself (Hesse 2000: 46-48).

In turn, Bruce Bevan ascertained that the first practical application of the geophysical method (electrical resistivity) in archaeological research had taken place in the United States in 1938 (Bevan 2000). Prior to Bevan's findings, it was the Englishman Richard Atkinson who was believed to have used the method for the first time in research carried out at Dorchester in 1946 (e.g. Aitken 1961a: 3; Clark 1990: 11-14). The first application of the magnetic method occurred much later, in 1957 or 1958 (depending on the position of the author, see below). The present article focuses on research until the early 1990s. Covering the intense development of geophysics after the beginning of the 1990s would have blown this article way out of size. There is also obvious bias in the presentation as much attention is devoted to the pioneering investigations in Great Britain and to the less well known developments in Poland and Czechoslovakia.

2. THE FIRST APPLICATION OF THE MAGNETIC METHOD: MAGNETIC BALANCE AND PROTON MAGNETOMETER

Archaeologists first took note of the magnetic method as a means of dating a certain category of finds. From the end of the 19th century iron oxides in the clay were known to take on a new permanent orientation as the clay cooled down, the direction corresponding to that of the Earth's magnetic field (Folgheraiter 1896, as quoted by Scollar *et al.* 1990: 513). This phenomenon, called thermoremanent magnetization, proved extremely useful in dating pottery kilns, a common feature at many archaeological sites, but until the late 1950s it was not applied as an archaeological prospection method for the non-invasive registering of archaeological features invisible on the surface.[2]

2.1. Magnetic prospection in Great Britain

The beginnings of the application of the magnetic method as a way of recording features invisible at the ground surface have been noted diligently in the topic literature. Interestingly, there are two versions depending on which project is considered as being first. The more common version is based on Martin Aitken's (Fig. 2) information published in 1958 in a number of places (Aitken 1958a; 1958b; Aitken *et al.* 1958) and repeated by him almost twenty years later (Aitken 1986). This version has been adopted in a number of textbooks on archaeological geophysics (e.g. Clark 1990: 16-17; Gaffney and Gater 2003: 16-17). According to it, on 13 February 1957 the Canadian physicist John Belshé (Fig. 3) gave a lecture at the London Society of Antiquaries about pioneering research carried out in Cambridge on dating with the magnetic method. In the discussion that followed the engineer and archaeologist Graham Webster asked about the potential for a magnetometer to locate features of baked clay, like kilns, for example. Belshé had no reservations about

[2] Du Mesnil du Buisson had already noted in the late 1940s the disturbing effect of archaeological features made of fired clay while testing his metal detectors in the field (Laming 1952: 72)

Fig. 2. Martin Aitken (left) and Helmut Becker during the "Pioneering Archaeological Prospection" conference organized by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology, Laa an der Thaya (Austria), October 2011. Photo T. Herbich

Fig. 3. Michael Tite, Janine Hesse, Albert Hesse and John Belshé (from left to right) during the "Pioneering Archaeological Prospection" conference organized by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology, Laa an der Thaya (Austria), October 2011. Photo T.Herbich

the efficiency of the method for such applications, especially as he had observed in his own work a meaningful disturbance of the magnetic field caused by features of this kind (Belshé 1956). Webster's question had a practical dimension: as an archaeologist he was investigating ground under an extension of the A1 trunk road next to the Roman site of Durobrivae at Water Newton near Peterborough in Northamptonshire. Surface finds indicated the presence of furnaces in this region. Webster approached the geology faculty of Birmingham University and Martin Aitken from the freshly established Research Laboratory for Archaeology and the History of Art at Oxford University. Aitken and his lab director Edward Hall jumped at the opportunity for a quick verification of magnetic prospection results (roadworks were set to begin in eight weeks) and began constructing a proton magnetometer, the principles of which had been developed just a few years earlier

(Packard and Varian 1954) and which had just been adapted for fieldwork (Waters and Francis 1958). The first measurements were taken in the field in March 1958. The instrument constructed in Oxford had 1 γ sensitivity and a measurement time of 5 sec. Plans for concurrent measurements with a conventional Askania torsion balance, to be carried out by Tony Rees from Birmingham University, were dropped owing to the time needed for each measurement – about five minutes. Five hectares were surveyed in the course of 10 days, but with little success beyond finding a water-pipe and modern iron objects. Then an anomaly strong enough to correspond to a furnace was discovered in an area adjoining a fragment of a furnace uncovered by the roadbuilders, supporting expectations of more structures of the kind being found in the neighbourhood. In the centre the value of the anomaly reached 100 γ; the area with values exceeding 50 γ was 2.5 m in diameter and disturbances falling in the range 25-50 γ were recorded in a radius of 4 m from the centre of the anomaly. A test pit was excavated immediately, uncovering a section of the top of a furnace at a depth of 1 m (Aitken 1958b: 24-25; 1986; Aitken *et al.* 1958).

Irwin Scollar (Scollar *et al.* 1990: 513-514) was of a different opinion, granting precedence to J. Belshé, whose contact with archaeology occurred not only during the research on dating, but also when observing changes (with a fluxgate magnetometer) of magnetic susceptibility on an experimental forge built in 1957 by chemists and archaeologists from the British Museum. Reporting his interview with Belshé, Scollar wrote:

> "… in September 1957, using a grid of 1.5 m, a series of measurements were made with the Askania instrument in the neighbourhood of Kirkstall Abbey near Leeds and three anomalies were detected which were thought to come from a forge. This can properly be thought of as the first application of magnetic prospecting in archaeology"
>
> (Scollar *et al.* 1990: 514).

Scollar's opinion, different from Aitken's, was echoed in the textbook of Aspinall, Gaffney and Schmidt (2008: 46), who presented Belshé's research as the first in the field of magnetic prospection, but considered the contribution of Aitken and his Research Laboratory for Archaeology and History of Art at Oxford University as a turning point.

The survey at Water Newton, besides discovering a furnace, produced results of much further-reaching consequence by demonstrating not only that the baked clay, but also the soil inside pits and ditches could impact on magnetic field intensity changes (Aitken *et al.* 1958; Aitken 1958b). Soil magnetic properties are not as strong as those of baked clay, but with the use of appropriately sensitive instruments it is possible to distinguish archaeological features containing such soils. The increased magnetization of topsoil had been observed already by E. Le Borgne (1955), but it was Aitken's idea to apply this knowledge practically in archaeology. The results of research at Water Newton also constituted persuasive proof of the magnetic method's effectiveness in recording features concealed under the surface. Archaeological structures were not found anywhere in the 20 test pits excavated in different places under the planned road; in one case the anomaly was caused by geological features, in another by a horseshoe. The survey also supplied interesting data on the limitations of the method. Ferrous objects not visible on the surface, in quantities exceeding the researchers' expectations, were found to cause considerable magnetic disturbances (mine detectors were used to eliminate them), as did ferrous elements of fences and the uneven ground surface at the site (Aitken 1958b: 25).

Martin Aitken's work proved to be of prime importance for the application of the magnetic method in archaeological research. In the 12 months following the work at Water Newton, Aitken carried out measurements at 10 sites, six from the Roman Period, two from the Iron Age and one each from the Bronze Age and early Middle Ages (Aitken 1959a). The results demonstrated the range of features detectable with the magnetic method. At an Early Iron Age fortified settlement at Madmarstone (1st century BC - 1st century AD), the smallest of the four mapped pits was 0.7 m in diameter and 0.4 m deep (Aitken 1959a: 32). The larger pits were up to 1.5 m deep. They were filled with potsherds, hut remnants and organic remains (Fowler 1959: 38). At a Roman site at Cox Green a ditch, first noticed in aerial photos, was traced and tested, revealing a width of 2.5 m and a depth of up to 0.7 m; the excavation also showed that the ditch was covered with a 0.25 m thick layer of ploughed soil (Aitken 1959a: 33), which also filled the ditch. The other ditch observed in the aerial photo failed to be mapped by the magnetic method; it turned out that the fill in this case did not differ substantially from the ground in which the ditch had been dug. At Little Houghton, also a Roman site, it was noted that a big contrast between the fill and surrounding matrix permitted even small features, like a ditch 0.45 m wide and 0.35 m deep, to be discerned (Aitken 1959a: 33). The method proved useless at only one site where there was a dense forest and numerous ferrous objects in the ground that were invisible on the surface. Further investigations at Water Newton were carried out on an approximately 3 m grid (the assumption being that no place on the site would be more than 1.5 m away from a measurement point). Six areas of anomalous values, from 6 m to 12 m in diameter, were distinguished in effect. These areas were surveyed in a denser grid in order to determine with precision to 0.6 m the location of maximum values of anomalies and to trace their shape. The last stage in the process of interpretation was to establish the nature of the anomalies and to select spots for testing by archaeological means. All the anomalies reflected archaeological features, but not necessarily of the kind that was expected in each given place. And so anomalies interpreted as furnaces turned out to be pits and what was believed to be a pit tested as part of a ditch. Even so, three furnaces of Roman date were discovered, as well as remains of a forge, a pit filled with slag and the edge of a paved area (Aitken 1959a: 34-35).

Aitken's results to date were published in *Archaeometry*, a periodical of the Research Laboratory for Archaeology and the History of Art in Oxford established in 1958. This had an immediate impact on popularizing the method, as did publication in professional periodicals with a large readership, like *Antiquity* (Aitken 1959b), and popular ones, like the *Illustrated London News* (Aitken 1958a). The latter article reached Poland, giving rise to a description of the magnetic method by Zbigniew Bukowski (1960). Aitken's publication, in 1961, of the general principles of geophysical methods in archaeology, including the magnetic one, summing up the results of the first practical applications of the method in the field, also received a wide response (Aitken 1961a; Polish review: Dąbrowski 1964).

Interest in the magnetic method among archaeologists can be expressed by the number of sites on which measurements were carried out: by 1961 the Research Laboratory had surveyed 50 sites, gathering experience which led to conclusions of a general character regarding the efficiency of the method in investigating particular types of sites in different geological conditions (Aitken 1961b). Considering the time required to take measurements, and the laborious data processing procedures of the time (manual plotting of isolines), Aitken believed the method to be more effective in indicating the general location of specific features than in mapping archaeological sites in detail (Aitken 1961b: 84).

The availability of proton instruments and their low price and simple construction were also conducive to the spread of the method in archaeological applications. Of the two commercial versions of the instrument developed by Littlemore Scientific Engineering Company (in Littlemore near Oxford) in cooperation with the Research Laboratory for Archaeology and the History of Art in Oxford, the one called Maxbleep proved to be more popular; a prototype was ready in 1960 (Aitken 1960). The instrument was furnished with two sensors configured vertically as in a gradiometer, spaced 1 m apart, the lower one running approximately 25 cm above the ground surface. The measurement reading was transmitted as sounds of an appropriate number depending on the extent of the disturbance: twice for anomalies with values of 8 γ and three, four, five and six times respectively for 17, 25, 33 and 42 γ. The cable between the sensors and the electronics of the instrument was sufficiently long to avoid disturbance from the metal parts of the apparatus (Clark 1990: 19). It was also constructed to compensate for the effect of diurnal changes of magnetic field intensity and local disturbances caused, for example, by passing train. The instrument was tested on three sites in Britain: a Roman industrial site at Hartshill and two fortified settlements of the Iron Age at Croft Ambrey and Burrough (Aitken 1960: 40). Hartshill produced 24 anomalies, of which half were tested archaeologically. Nine anomalies turned out to correspond to furnaces. At Burrough anomalies in the range from 20 to 100 γ corresponded to storage pits. In his conclusions based on field experience of the application of the magnetic method on archaeological sites, Aitken spoke out in favor of using the gradiometer for quick mapping of disturbances over large areas, followed by detailed survey with a magnetometer measuring the total value of magnetic field intensity (Aitken 1960: 40).

2.2 Magnetic prospection in other Western European countries: Italy, Germany and France

Within a few years of Aitken's first application of the magnetic method it had become a point of interest in centres which had already tested electrical resistivity as a method for prospection. These were the Fondazione Lerici in Milan, Rheinisches Landesmuseum in Bonn and the Centre de Recherches Géophysiques CNRS at Garchy (initially: Centre d'Etudes Géophysiques).

The Foundation, which was established in 1947 by Carlo Maurilio Lerici (Fig. 4) at the Milan University of Technology, set itself the objective of using geophysical methods in search of mineral resources. In 1955 the Foundation ventured into the field of archaeology, gaining international renown thanks to spectacular results on Etrusacn tombs using the electrical resistivity method (Lerici 1958). In 1961 Lerici and a team from the Applied Sciences Centre for Archaeology (MASCA) of the Museum of the University of Pennsylvania conducted a two-month long survey of four sites in Italy: three Etruscan ones (necropolises in Tarquinia and Cerveteri, and a town in Veii) and the Greek colony of Sybaris. The survey aimed at comparing the effectiveness of the electrical resistivity method as used by Italians with the magnetic method which had not been used before in Italy (Lerici 1961; 1962). Measurements were taken with an Elsec proton magnetometer produced by Littlemore Scientific Engineering. Italian researchers were astounded by the effectiveness of the magnetic method: out of 11 anomalies recorded during the prospection in a test area 25 m by 50 m in the cemetery at Tarquinia, only one did not correspond to a rockcut burial chamber; the same area tested by the electrical resistivity method revealed only seven anomalies which could have corresponded to graves (Lerici 1961: 79). The magnetic method also proved useful in locating burial chambers cut in tuff at the necropolis in Cerveteri (Lerici 1961: 80-82). At Sybaris measurements confirmed the existence of a wall several hundred meters long under a layer of alluvium at least 2 m thick, recorded previously by the electrical resistivity method. The blocks of the wall were cut from limestone which in itself has no magnetic properties, but the surrounding accumulations contained soil with a large content of volcanic material of high magnetic suscep-

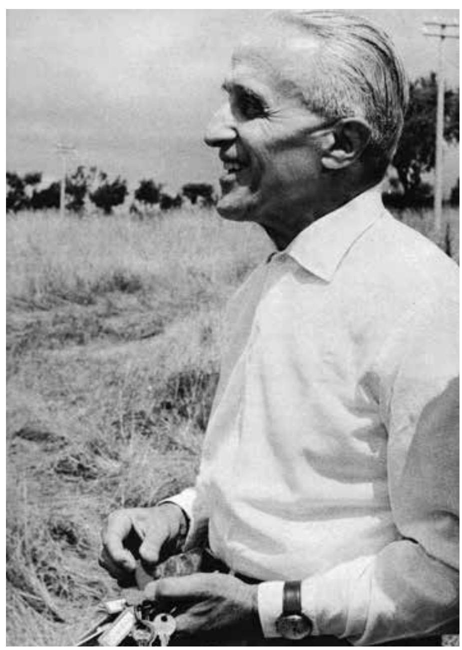

Fig. 4. Carlo Maurilio Lerici. After Lerici (1965)

Fig. 5. Richard E. Linington with an Elsec proton magnetometer. After Lerici (1965)

tibility; consequently, the wall was registered as a reverse anomaly compared to the surroundings (Lerici 1962: 6). The Sezione Prospezioni Archeologiche (archaeological prospecting unit) established by the Foundation in Rome was charged with carrying out research on archaeological sites. In 1961, following joint research with an American team, the unit was furnished with proton magnetometers developed in Oxford. Richard Linington, who came to Italy as a member of the Pennsylvania University team, became a key person at the Foundation, fostering widespread use of the method (Fig. 5). The Foundation not only conducted the field surveys, but also participated actively in popularizing geophysics in this new role. From 1963 it organized annual archaeological prospection methodology courses (including geophysics) and in 1966 it established the journal *Prospezioni Archeologiche*, dedicated in equal measure to presenting fieldwork results and theoretical aspects of research like modeling, data processing and visualization of results. The first volume represented the proceedings of a conference organized by the Foundation in Rome in 1965. Magnetic method-related subjects were taken up by R.E. Linington (1966a), I. Scollar (1966), J. Alldred and M. Aitken (1966a; 1966b), L. Langan (1966). There were three archaeologists among the 14 participants at this conference, most of them natural scientists; one of them was the Polish archaeologist Krzysztof Dąbrowski (more about him in the next section). The missionary character of its programme led the Foundation to conduct geophysical prospection in countries where archaeological interest was strong but the financial support for such methods was not as forthcoming as in Great Britain or Italy. Linington did magnetic research in Poland (Dąbrowski and Linington 1967) and in Czechoslovakia (Linington 1969b), in close cooperation with local archaeologists whose task was to choose as broad a spectrum of sites as possible in order to test the effectiveness of the method on different archaeological features from different periods.

The unit in Bonn, directed by Irwin Scollar, used proton magnetometers of their own design, LMB Mark, featuring a resolution constituting 1/50000 part of magnetic field intensity, which in northern Europe gives a resolution close to 1 γ (Scollar 1961a; 1963) (Fig. 6). Measurements were taken in the differential mode, that is, the

Fig. 6. Irwin Scollar taking test measurements in a park in Bonn with the first ever digital differential proton magnetometer, which he and his technician, Merken, custom-built to his design in the Rheinisches Landesmuseum in Bonn in 1960. Archive of the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology

reading being the difference between a sensor moving along measuring lines and a sensor mounted in a fixed position. Scollar worked mainly in the Rhineland where the abundance of sites created an excellent testing ground. The nature and geology of the sites determined the determined the choice of method, conditions being much better for the magnetic method as compared to the electrical resistivity method. Sites located from the air and based on an analysis of aerial photos were selected for further research (Scollar 1961b). First to be surveyed were Roman camps encompassing systems of ditches, fragments of which could be traced on the surface thanks to cropmarks. Since the object of the survey was to follow the earth fill of these ditches, the centre at Bonn focused on the magnetic properties of soils (Scollar 1965: 32-40; 1966: 43-45). I. Scollar worked on improving the instrument, introducing a new model in the mid 1960s (Scollar 1965: 54-89; 1966: 47-50) and another one at the beginning of the 1970s (Scollar and Lander 1972-73). Proton instruments of German make were also tested in Italy, in difficult conditions on sites covered with soils of high magnetic susceptibility. The results were sufficiently good for the instruments to start being used regularly by the Fondazione Lerici team beginning in 1967 (Scollar 1986: 86). I. Scollar also con-

Fig. 7. Albert Hesse taking magnetic measurements in Mirgissa, Nubia. Measurements were taken at each knot on a grid made of string, measuring 10 x 10 m with knots every 1 m. Archive of A. Hesse

tributed significantly to computer data processing procedures and graphic presentation of results, being the first to apply a computer to process measurement data, the first to filter data to make the results more readable, and the first to use dot density maps for presenting the results, where increased numbers of graphic symbols (initially hand-drawn dots) corresponded to increased values on a surface corresponding to one measurement. Further work, already in the 1970s, led to the introduction of the most commonly used greyscale display of magnetometer data (first implemented in his laboratory in 1976; Scollar *et al.* 1986). Scollar also used automatic recording of measurements on paper tape (Scollar 1966: 45-46; Scollar and Krückeberg 1966). He discussed his early experience with the magnetic method and the construction of a proton instrument in a comprehensive publication (Scollar 1965).

In France the first documented application of geophysics came in 1960, in the Centre de Recherches Géophysiques at Garchy, a unit formed in 1957 as part of the Centre National de la Recherche Scientifique and initially directed by Louis Cagniard.[3]

[3] The earliest prospection using the magnetic method in France was carried out by E. Thellier from the Institut de Physique du Globe in Paris. However, the results of measurements (done by R. Scheib from the same institute), which were aimed at registering pottery kilns, were never published (Hesse, personal communication)

The link with archaeologists was provided by contacts with the Centre de Recherches Préhistoriques de la Faculté des Lettres in Paris, directed by André Leroi-Gourhan. Albert Hesse (Fig. 3) was responsible for archaeological prospection at Garchy (he was joined by Allain Tabbagh in 1969); he used the electrical resistivity method from the very beginning and introduced the magnetic method in 1962 after gaining access to a proton magnetometer (Hesse 1962; Hesse, personal communication). In the first of two published instances of measurements with the magnetic method, at the Palaeolithic cave site of Arcy-sur-Cure (Hesse 1966: 98-99), it was unsuccessful, but it did prove useful in locating pits containing coffins at an early medieval cemetery site in Garchy (Hesse 1966: 139-140). A good example of the effectiveness of the method was the tracing of a ditch circle at the Neolithic site of Moneteau (Yonne) (Hesse 1966: 118-123). Outside France, of particular significance was Albert Hesse's survey of a Middle Kingdom fortress located in Mirgissa, Nubia, carried out between 1965 and 1967 in a region to be submerged by the waters of the high dam in Aswan which was then under construction (Hesse 1970) (Fig. 7). During the research, which helped to trace the inner layout of the fortress, the magnetic properties of Nile silt, ancient Egypt's key building material, were observed. Research at Mirgissa constituted the first application of the magnetic method on an archaeological site in the valley of the Nile.[4]

2.3. Magnetic prospection in Poland

It took 14 years from Atkinson's electrical resistivity survey in Dorchester for the first application of this method in Poland, which took place at an early medieval stronghold in Kalisz (Dąbrowski and Stopiński 1961), but only three years for the magnetic method counting from Aitken's first measurements. In Poland, the magnetic method was initially limited to using a magnetic balance (Herbich 2011). The magnetic method was applied on an iron-smelting site from the Roman Period (2nd-4th century AD) in the Holy Cross Mountains. The team was an interdisciplinary unit of metallurgists and geophysicists from the Kraków AGH University of Science and Technology: Kazimierz Radwan, Jerzy Kowalczuk (Fig. 8), Tadeusz Stopka, and archaeologist Kazimierz Bielenin from the Archaeological Museum in Kraków (Fig. 9). Having first studied the magnetic susceptibility of slag, the team moved to the site of Nowa Słupia on 19 April 1961 (Fig. 10). The method proved highly effective in locating slag leftovers from iron-smelting furnaces, the results tested immediately in the field by excavations (Kowalczuk and Stopka 1962; Bielenin *et al.* 1963). In the first phase of the research, between 1961 and 1964, 23 sites were surveyed (Bielenin 1992: 46). Geophysical prospection ebbed in intensity in the second half of the 1960s, the last measurements, still using a magnetic balance, being carried out in 1968 (Bielenin 1970). Interestingly, in 1961 the geophysicists from Kraków had no knowledge of any earlier experiments with magnetometry

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[4] For Albert Hesse and his work, see Tabbagh and Herbich 2003.

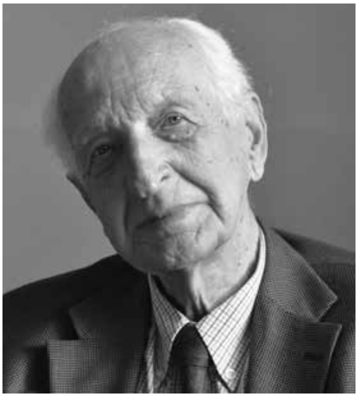

Fig. 8. Jerzy Kowalczuk, October 2011. Photo T. Herbich

Fig. 9. Kazimierz Bielenin in the late 1980s. Archive of the Archaeological Museum in Kraków

Fig. 10. Jerzy Kowalczuk and Tadeusz Stopka preparing to survey with magnetic balances, Nowa Słupia, April 1961. Archive of the Museum of History of the AGH University of Science and Technology in Kraków

Fig. 11. Krzysztof Dąbrowski (in front) during an aerial survey of sites in the region of Kalisz, early 1960s. Archive of T. Baranowski

Fig. 12. Wojciech Stopiński at the 1st National Conference for Archaeological Geophysics in Warsaw, June 9, 2010, giving a lecture to commemorate the 50th anniversary of his geophysical survey of the Zawodzie hillfort in Kalisz, the first Polish archeological-geophysical research. Photo R. Ryndziewicz

in archaeology and were convinced as to the pioneer character of their undertaking in Nowa Słupia (Kowalczuk and Stopka 1961; 1962, Herbich 2011).

Also in 1961 a team put together by Krzysztof Dąbrowski (Fig. 11) from the Institute of the History of Material Culture (now the Institute of Archaeology and Ethnology) of the Polish Academy of Sciences in Warsaw commenced testing the magnetic method in prospection on all kinds of sites from open settlements through fortified strongholds to cemeteries (Dąbrowski 1963). The first measurements were carried out by Wojciech Stopiński (Fig. 12) from the Geophysics Department of the Polish Academy of Sciences in the summer of 1961, using a magnetic balance, at a cremation burial ground from the period of Roman influences in Wesółki (Dąbrowski and Stopiński 1962). Results were verified immediately by excavations and the method proved useful in locating iron grave goods; the metal finds from individual burials weighed between 0.25 kg and 2.05 kg. More importantly, however, the method proved capable of also locating graves with nothing but clay vessels in their furnishing; this was verified once the humus surface layer was stripped in a test trench. That pits containing fill composed of dark soil, stones and fragmented pottery could be mapped suggested that the magnetic method could be applied for surveying open settlements (Dąbrowski and Stopiński 1962: 612-613). Promising results led to the establishment of an interdisciplinary unit for geophysical research including an archaeologist (K. Dąbrowski), a geophysicist (W. Stopiński) and a geologist (E. Stupnicka).

A Polish version of the proton magnetometer was designed in 1965 by Jerzy Jankowski with a team from the Geophysics Department of the Polish Academy of Sciences. The instrument was used for the first time to test iron-smelting sites in Słupia Nowa; tests were continued by J. Jankowski in 1966 at a multi-cultural site in Dębnica in the Wrocław district. The prospection at Nowa Słupia on sites 6 and 7 recorded areas of furnaces (Bielenin 1967; 1992: 46-48). In Dębnica the prospection traced the spatial extent of the settlement and located several concentrations of features: buildings, pottery kilns and metallurgical furnaces (Kaletyn 1968: 283).

In 1965 K. Dąbrowski invited Richard E. Linington to experiment jointly with a proton magnetometer on different kinds of sites typical of Polish territories (Dąbrowski and Linington 1967). K. Dąbrowski had been introduced to the effectiveness of these instruments two years earlier, in 1963, when he participated in the Lerici Foundation's project to investigate a Villanova Culture cemetery in Tarquinia (Linington and Dąbrowski 1964). The method was tested on a number of sites in the Kalisz region: an early medieval stronghold in Jarantów, a cremation burial ground from the late La Téne period in Zagórzyn and an open settlement from the late La Téne and Early Roman Period in Piwonice. Measurements were carried out with an apparatus of the Elsec type and verified archaeologically in 1966 (Dąbrowski and Linington 1967; Linington and Dąbrowski 1968). The results of the survey did not produce a unanimously positive opinion on the method's effectiveness in surveying prehistoric sites in the specific conditions of Poland (Herbich 2011). As said already, the intensity of magnetic prospection ebbed in the later part of the 1960s. Practically, only the geophysicists from Kraków continued to survey iron-smelting sites in the Holy Cross Mountains. Once K. Dąbrowski lost interest in archaeological geophysics, the Warsaw team was dissolved.

2.4. Magnetic prospection in the USA

In the United States magnetic prospection was applied in archaeological research for the first time in 1961. Working for a project directed by Glenn A. Black from the Indiana Historical Society, Richard Johnston from the Angel Mounds Archaeological Research Station used an Elsec instrument to conduct a survey of a native Indian village at Angel Mounds, which represented the Middle Mississippi Culture roughly corresponding to the European Middle Ages (Johnston 1961). The site contained remains of huts and a system of fortifications made up of a wall and palisade, partly observable on the ground. Testing of places where fortifications could be expected produced anomalous values and it proved possible to trace sections of the system where the walls were divided into two parallel structures. Measurements also revealed anomalies corresponding to pits in place of huts (Johnston 1961: 72). The first season of surveying ended with 58,000 measurements being taken on site, tracing some features, like the fortifications, over a distance of approximately 500 m. More measurements were taken in the same year at another native Indian village located at Wetherill Mesa in the Mesa Verde National Park in Colorado. The Angel Mounds success opened the way for the magnetic method to become a regularly used research tool at Indiana University; in 1971 the university established an independent unit, the Glenn A. Black Laboratory for Archaeology, one of the specialties of which is geophysical research.

The Applied Science Centre for Archaeology (MASCA) at the Museum of the University of Pennsylvania contributed significantly to the introduction of the method, although the first and main testing ground, at least in the early phase, was not in America but the Greek colony of Sybaris in southern Italy (Brown 1963). This research, in association with the Lerici Foundation, was mentioned earlier in reference to the Foundation. The Museum conducted intensive archaeological research on a number of continents during the first eight years of its activities; among the 34 magnetic surveys conducted by Elisabeth Ralph's team there were sites in Greece, Italy, Turkey, Ireland and Central America. Only half of the investigated sites were situated in the United States and Canada (Ralph 1969: 15-17).

2.5. Magnetic prospection in the USSR

The first trials with magnetic prospection in the Soviet Union were carried out in 1962 by a team from the Laboratory of Technologies Applied to Archaeology, Institute of Archaeology, which was part of the Leningrad branch of the USSR Academy of Sciences (now Saint-Petersburg Institute of the History of Material Culture, Russian Academy of Sciences). The survey covered the Neolithic site of Vyun in the Leningrad region. The proton instruments that were used had a resolution of 10 γ and were applied in differential mode. Measurements were taken along lines 100 m long at intervals of 5 m, reduced to 1.5 m in anomalous spots, tracing the spread of cultural layers in the horizontal plane. This gave an idea of the extent of the site. Explorations demonstrated that anomalous readings corresponded mainly to stones from hearths. It was also noted that rocks outside the cultural layers did not have magnetic properties; an experiment by the laboratory head Sergey Rudenko with heating rocks led to understanding the phenomenon and moreover pointed out the magnetic properties of pottery (Frantov and Pinkevich 1966: 136). In effect S. Rudenko established in the lab a separate unit to deal with applied geophysical methods. In 1963 this unit surveyed the medieval hillfort site near Isyaslav (Khmielnitsk province, Ukraine). The survey used a one-meter grid and revealed mainly iron-smelting sites (Frantov and Pinkevich 1966: 140-141). The Leningrad researchers' field experience and the belief in the usefulness of geophysical methods in archaeological research resulted in a 200-page textbook on archaeological geophysics being published as early as 1966 (Frantov and Pinkevich 1966).

3. INTRODUCING OTHER TYPES OF MAGNETOMETERS: FLUXGATE AND OPTICALLY PUMPED

Like the proton magnetometer, the fluxgate magnetometer was introduced by the Research Laboratory for Archaeology and History of Art in Oxford. It was tested together with other types of magnetometers by Michael Tite (Fig. 3) on an Iron Age hillfort at Rainsborough Camp near Oxford, in June 1961. First, the inside of the hillfort, close to 3 ha in area, was surveyed with a proton magnetometer, recording about 90 anomalies of an amplitude from 25 to 50 γ and diameter from 1.25 to 2.50 m. Excavations verified that the anomalies corresponded to features like pits, gullies and hearths. Further the testing was carried out in two small areas, 15 m by 15 m and 7.5 m by 7.5 m, where number of anomalies registered was than in other parts of the site; the objective was to compare the effectiveness of a proton magnetometer measuring the total value of field intensity, a proton gradiometer measuring the vertical gradient (resolution approx. 2 γ) and a fluxgate magnetometer (resolution 1 γ), also in gradiometer mode measuring the vertical gradient (Tite 1961). The magnetic images produced by each of the instruments were similar, but the intensity of the anomalies varied: three out of five structures measured with the proton magnetometer demonstrated values twice as high as those produced by a fluxgate magnetometer. However, the tests left no doubt as to the superiority of the latter instrument compared to other devices as far as measuring time was concerned: it was short enough to make it unnecessary to stop at each measurement point. Gradiometers were also shown to be less influenced by external disturbance. Taking into account the lower resolution of the proton gradiometer, the tests demonstrated the usefulness of the fluxgate instrument.

Fig. 13. Tony Clark with a Plessey fluxgate gradiometer, 1970s. Archive of The English Heritage

These strengths led the Research Laboratory in Oxford to develop a fluxgate instrument for wider application in archaeological research. This task was accomplished by John Alldred (1964). Proper operation of the instrument demanded, among other things, that the tube with the sensors be carried vertically during measurements. The sensors in J. Alldred's

Fig. 14. Elizabeth Ralph, leading researcher at MASCA. Archive of the University of Pennsylvania Museum of Archaeology and Anthropology

instrument were 1.20 m apart and the combined length of the tube was 2 m. Moving the instrument up and down the measuring line required two people. The cable connecting the magnetometer to the electronics was 70 m long. Resolution of the instrument when inactive was 1 γ, whilst tilting from the vertical during movement, if the tilt did not exceed 15 degrees, caused a drop in sensitivity to 3 γ. The fluxgates had to be parallel to one another to within 0.003 degrees, which necessitated manual regulation. Three large survey projects (a combined area of 10 ha) carried out with the fluxgate gradiometer over two seasons indicated that work was two to three times quicker than with the proton magnetometer. Assuming a distance of 1.50 m between measurement lines, a team of four (two carrying the magnetometer, one at the measuring device and the fourth laying out the lines) could survey 1 ha in three hours (Alldred and Aitken 1966a: 53-54).

An improved version of the fluxgate gradiometer was developed by the Plessey Company in 1968. Now the instrument could be carried by one person (Philpot 1972-73) (Fig. 13). The instrument was ideally suited to the needs of the unit doing most of the geophysical surveying in Great Britain at the time, the Ancient Monuments Laboratory established in 1967 by the Ministry of Public Buldings & Works. The unit at first employed only one person, Tony Clark (Clark 1975: 297; 1990: 20, 23-24). The instrument signal and its physical position on the survey grid were plotted as stepped graphical traces on paper by a chart recorder, allowing the immediate analysis of the results, presented as multiple trace plots; then the values read from the curves were used to draw maps of isolines (Clark and Haddon-Reece 1972-1973). The system was in use for 15 years until it was replaced by digital recording on a portable microcomputer. Trace plots were still used to read results in the field, but the computer stored the data on tape for subsequent processing (Clark 1986: 1405-1412). All structures of elongated shape such as ditches and walls (as long as these were not parallel to the measurement line) were visualized particularly well on trace plots. Data processing could eliminate anomalies of high amplitude generated by modern ferrous metal objects on or near the surface. The first application of the new version of the instrument in archaeological prospection took place on a site with two Romano-British pottery kilns in Lingwood (Philpot 1972-1973: 104, Clark and Haddon-Reece 1972-1973: 107). Large areas could be surveyed in a short period of time with this apparatus. For example, the survey of a Roman villa complex at Wharram le Street, Humberside, over an area of 5.5 ha and with 1-m spacing between measurement lines took only four days. The largest survey covered 18 ha. Operating on areas of such size allowed the mapping of many sites of considerable size, such as the above mentioned Roman villa at Wharram le Street and the complex of circular ditches of Bronze Age barrows at Radley in Oxfordshire (Clark 1986: 1407, 1409-1410).

The optically pumped instrument was introduced into archaeological prospection by researchers from MASCA (Fig. 14). Conditions which they encountered in Sybaris demanded a much more sensitive instrument than the proton magnetometer used in 1961 and 1962. Excavations had demonstrated that the ruins of the 6th century BC Greek town were located at a depth of from 4 m to 6 m, covered with layers of alluvial clay. The proton magnetometer had been proven to be effective in searching for archaeological structures down to a depth of 3 m, which in this particular case recorded only the Roman-age remains. An American company, Varian Associates, came through with a proposal for an optically pumped magnetometer with sensitivity a hundred times greater than that of a proton magnetometer (0.01 γ). The instrument that was used had rubidium sensors (Ralph 1964; Breiner 1965). Following tests carried out in May 1964 at Fort Lennox in Canada, the instrument was used in Sybaris in October of the same year. A differential configuration with one fixed sensor and one being moved along measuring lines proved to be the most effective. Readings were plotted as curves and anomalous values were also indicated by an emitted sound signal. Measurements were four times faster than with the proton magnetometer (Ralph 1964: 23-25). The manufacturer sent representatives to supervise the fieldwork and in effect undertook to construct an instrument that would take into account the special requirements of archaeological surveying. The readout provided values with a resolution of only 0.1 γ, but the instrument in differential configuration was not too heavy for one person to manage (Langan 1966: 64-65). Almost ten years of magnetic prospection at Sybaris failed to produce a town plan; however, it did approximately identify the areas of occupation in antiquity – which in the case of ruins scattered over 100 km^2 is no mean feat. This research was important in that it created an excellent testing ground for new types of magnetic instruments (Ralph 1969). The effectiveness of the optically pumped instruments was demonstrated persuasively for archaeologists by the Sybaris team's research on another site, the ancient town of Elis on the Peloponnesus, founded in the 5th century BC. A survey carried out in 1967 with a caesium magnetometer recorded rows of houses and walls. The conditions were exceptionally suitable: ruins could be found within a metre of the ground surface and reused terracotta rooftiles (material of a high magnetic susceptibility) were commonly used as building material in the walls. For the first time it became possible to map an entire ancient Greek town based on the magnetic measurements (Ralph 1969: 21).

4. APPLICATIONS OF THE MAGNETIC METHOD FROM THE END OF THE 1960s THROUGH THE 1980s: GRADUAL DEVELOPMENT

Reviewing publications on the applications of geophysics in archaeology one has the impression of a certain stagnation in the 1970s, which followed in the wake of the exciting pioneering days when instruments were being tested and the effectiveness of geophysical methods, including the magnetic one, established. This impression is due to a number of factors, not the least being the absence of a periodical devoted to the issues of archeological geophysics. The number of publications concerning geophysics published in *Archaeometry* clearly dropped over the years: in the first seven volumes (1958-1964) archaeological geophysics were the subject of 28% publications, 90% of which concerned the magnetic method. In issues 8, 10 and 11 there was only one article on geophysics (devoted to the magnetic method). Volume 9 was an exception from this clear trend as 33% of the issue was devoted to geophysics, but only one of the seven articles dealt with the magnetic method. The shift in interests observed in the periodical reflected the changing interests of the team of the Research Laboratory in Oxford, which began to concentrate on dating methods and physico-chemical analyses of finds, searching for innovative solutions in these fields.

The main forum for publishing archaeological geophysics was at this time the annual journal *Prospezioni Archeologiche*, which appeared for nine successive years in 1966-1974. The next and last, tenth volume was published twelve years later, in 1986, dedicated to the memory of the journal's founder, C.M. Lerici, who died in 1981, and his co-editor, R.E. Linington, who died in 1984. It should be noted that in that early period *Archaeometry* was focused specifically on publications concerning the magnetic method, while *Prospezioni Archeologiche* was open from the beginning to all kinds of geophysical methods.

The contents of these two periodicals identifies centres of research and development of the magnetic method: work on the proton and fluxgate magnetometers was carried out foremost in Great Britain (Aitken 1959c; 1960; Tite 1961; Mudie 1962; Hall 1962; Alldred 1964; Alldred and Aitken 1966a; Harknett 1969) and in Germany (Scollar 1961b; 1970a; 1986), while the optically pumped instrument was developed in the United States (Ralph 1964; Langan 1966); studies in Germany focused on applying computers to processing the measurement data and presenting the results (Scollar and Krückeberg 1966; Scollar 1968; 1969; 1970b), while in Italy the principal objective was data modeling and processing (Linington 1964; 1966b; 1968; 1969a; 1970).

The contents of the periodicals also demonstrates where, besides Great Britain, Italy, Germany and the United States, local research centers invested in the magnetic method. One should mention here France (Hesse 1962; 1967), Poland (Dąbrowski 1963; Dąbrowski and Linington 1967; Iciek *et al.* 1974a) and Czechoslovakia (Linington 1969b).

Changes in the organization and financing of science impacted the development of the magnetic method, as also did new legislation on protection of the archaeological heritage. Great Britain was again a leader, the processes observed there being copied to a greater or lesser degree in other countries in the coming decades. The Ancient Monuments Laboratory based in London, was focused primarily on practical applications of the method and improvements to instruments in use. An increasing emphasis on 'rescue archaeology', on a larger scale than before, is exemplified by the gas industry's infrastructure programme of pipeline develoment. British Gas, which spearheaded this effort, hired an archaeologist and a geophysicist to conduct extensive ground surveying, mainly using the magnetic method (Gaffney and Gater 2003: 20). In 1971, a unit charged with training in prospection methods was established at the University of Bradford. This unit, directed by Arnold Aspinall (Fig. 15) and focused mainly on supplementary training for archaeologists, taught the practical side of the application of the magnetic and electrical resistivity methods, as part of graduate and postgraduate courses in scientific methods in archaeology. Archaeological geophysics also became part of the curriculum at some universities with archaeology departments, for example Richard Atkinson (Fig. 16) lectured on the subject at the University of Cardiff in the early 1970s. A new updated textbook by M.J. Aitken (1974) also served the purposes of education, as did his contribution to a collective work on science in archaeology with chapters on archaeological geophysics including the magnetic method (Aitken 1975). In 1984 Bradford Roger Walker founded Geoscan Research, a company specializing in the production of instruments for geophysical surveying, fluxgate gradiometers in particular, as well as instruments for electrical resistivity research (Gaffney and Gater 2003: 56-60, 62-64).

Fig. 15. Arnold Aspinall, creator of the Bradford school of Archaeological Sciences and co-editor of *Archaeological Prospection* journal, 1990s. Archive of Armin Schmidt

Fig. 16. Richard Atkinson. Archive of Irvin Scollar

Fig. 17. Kath Walker of Geoscan Research with a prototype of a FM36 fluxgate gradiometer, 1986. Archive of Geoscan Research

Instruments made by this company monopolized the British market, being used by research institutions as much as by commercial companies (Fig. 17).

It was these four elements that established the magnetic method as an important research tool: firstly, routine and experimental prospection (especially by the Ancient Monuments Laboratory); secondly, the need to survey in advance of development (for example by British Gas); thirdly, training specialists; and fourthly, production of specialized instruments. Added to this was a new trend in archaeology: concentrating on reconstruction of the landscape and environment, covering cultural and geographical regions rather than individual sites (Gaffney and Gater 2003: 20-21). This kind of research encouraged the application of tools, such as the magnetic method, that could map archaeological features over large areas.

In the two decades between the end of the 1960s and the 1980s, changes also occurred as far as the leading centres of archaeological geophysics were concerned. In Italy, after the death of its founder the Lerici Foundation limited its participation in archaeological research. The Istituto delle Technologie Applicate ai Beni Culturali in Monetlibretti near Rome with a geophysics section was created within the framework of the state Consiglio Nazionale delle Ricerche. Unlike the Lerici Foundation, this section was interested chiefly in testing and implementing new measurement techniques and instruments with less emphasis on broad-scale practical application of new methods. The results of research on a settlement and cemetery from the 8th century BC at Acqua Acetosa on the Via Laurentina near Rome provides a good example of this approach (Brizzolari *et al.* 1991). Another example is Suasa, an important Roman-age site (Bruzzi *et al.* 1991). The magnetic method was one of at least three geophysical methods applied in this research. Proton magnetometers were used at Acqua Acetosa and fluxgate instruments at Suasa. At Acqua Acetosa all applied methods (electrical resistivity and seismic as well as magnetic) recorded the same features, but traced their extent differently (Brizzolari *et al.* 1991: 144-145); in the case of the prospection at Suasa, building remains were best imaged on the electrical resistivity map, but the magnetic method

Fig. 18. Helmut Becker using a Varian V101 caesium magnetometer in gradiometer mode. Survey in Aiterhofen, Lower Bavaria, in 1979. Archive of Jörg Fassbinder

did reflect the extent of the occupied area; the least distinct results were produced by the electromagnetic method (Bruzzi, dall'Aglio and de Maria 1991: 170-174).

In Germany, Irwin Scollar of the laboratory at the Rheinisches Landesmuseum reduced his participation in fieldwork in favour of work on processing data as digital images (Scollar *et al.* 1986; 1990), whereas the Bavarian State Department of Monuments and Sites in Munich gained prominence with the establishment in 1982 of a unit directed by Helmut Becker (Figs 2 and 18) (Becker 2015: 119-123; Jörg W.E. Fassbinder joined the unit in 1986). In Germany, this unit, which chiefly used magnetic prospection, operated not only in Bavaria, but was also very active in Turkey, southern Europe and the Near East. It specialized in combining magnetic prospection with aerial photography, taking advantage of I. Scollar's experimental work with data processing (Becker 1984; 1985; 1990a). The unit quickly abandoned proton magnetometers in favour of caesium instruments with 0.1 nT resolution[5], either as gradiometers (for areas with high magnetic disturbance near power lines, electrical trains etc.) or differential measurements (in areas without disturbances). The salvage character of the work and need for site protection in the face of threats from development and erosional processes, induced the Munich unit to place sensitivity and speed at the top of its list of priorities, meaning covering large areas in the shortest possible time with high measurement density. One way to achieve this goal was to automate the measurement recording. H. Becker first tested recording measurements on tape using proton magnetometers (Becker 1979) and the first data logger (registering data from a caesium magnetometer) connected to a portable computer Epson HX20 was in 1984 (Becker 1985), improved by J.W.E. Fassbinder in 1985-1986. This was also an important step towards the so-called "time mode sampling" which gave much higher resolution (with 10 samples per second meaning about 12 cm at normal walking speed). Another way of

[5] 1 nT (equal to 1 γ) as a unit of intensity of the Earth's magnetic field had been introduced in the 1960s, but was not commonly used in archaeological publications before the late 1980s.

achieving the goal was to expedite the moving of the instruments by mounting them on specially constructed carts. This system allowed for coverage of an area of 1-1.5 ha, with a sampling grid of 0.5 m (that is, recording 40,000 to 60,000 measurements) in two days by just two people: one person moving the mounted sensors and the other controlling the magnetometer readout and the data log. Portable computers facilitated data processing in the field (Becker 1990a: 30-32).

Inspired by the results produced by the highly sensitive caesium instrument, allowing detection of single postholes, the Bavarian team focused on researching the magnetic properties of soils. This led to the discovery of the presence of magnetic bacteria in the topsoil (Fassbinder *et al.* 1990; Fassbinder and Stanjek 1993; Fassbinder 1994; Stanjek *et al.* 1994) providing a giant step toward more informed interpretation of magnetic results, explaining for the first time anomalies produced by features of organic origin, not transformed by high temperatures caused by fire, as observed previously by E. Le Borgne (1960).

H. Becker's team's most interesting results included mapping of different kinds of sites from the Neolithic, like ditch circles (for example, at Schmiedorf and Kothingeichendorf, Becker 1987a and 1988), enclosures (Becker 1990b) and remains of long houses (at Baldingen, Becker 1987b), and in the Roman Period reconstructing the layout of the camp at Markbreit (research in 1986-1991 covered close to 25 ha of the site, Becker *et al.* 1992). Belief in the usefulness of magnetic results was enhanced by the manner of presentation introduced by the Munich group, showing the results as monochrome maps with 256 levels of greytone, giving an extremely readable presentation of the results and easy identification of anomalies – much better than the dot-density maps and contour line maps. The software used by the unit was geared to a graphic identification of archaeological features (ordinarily the effect of combined analyses of magnetic maps and aerial images produced by associate Otto Brasch), giving in effect a site map that archaeologists could read.

Fig. 19. Wolfgang Neubauer surveying a Germanic settlement in Drösing (Lower Austria) using a Geonics proton magnetometer, summer 1985. Archive of the Vienna Institute for Archaeological Science,University of Vienna, Photo A. Stuppner

A geographic information system (ARGIS) using digital cartography and with links to aerial archaeological databases and an inventory of all known archaeological sites in Bavaria was developed in Munich in 1991. Site plans kept in the ARGIS system were derived from rectified and collated aerial photos combined with geophysical survey maps. This served the purposes of archaeological monument protection services perfectly (Becker 1992).

In Austria, development of magnetic method applications in archaeology took a similar course as in Germany. Proton magnetometers were quickly rejected in favour of optically pumped instruments. Surveying with proton magnetometers was conducted in the 1970s and 1980s by the Institute for Geophysics of the Montanistic University of Leoben (Walach 1993). From 1985 Wolfgang Neubauer and Georg Walach worked on sites in Lower Austria. In spite of low resolution (1 nT), long measurement time (5 seconds) and a relatively coarse sampling interval (1 m), their results were promising for Neolithic ditch circles at Kammeg and Rosenburg, and at the Germanic settlement in Drösing (Neubauer 1990) (Fig. 19). In the late 1970s, Peter Melichar of the Department of Geophysics, Central Institute for Meteorology and Geodynamics in Vienna, adapted surveying with caesium magnetometers specifically to archaeological research within the framework of the "Neue Wege der Ur- and Frühgesichtsforschung" programme directed by the prehistorian Herwig Friesinger. A gradiometer version of the instrument was used and measurements were recorded automatically; a built-in printer permitted the raw data to be visualized right after the measurement. Cooperation between P. Melichar and W. Neubauer at the initiative of the latter gave a new stimulus in the late 1980s. Among successful surveys one should mention research on the Neolithic ditch circles at Strögen (Neubauer *et al.* 1995) and at Hornsburg (Melichar and Neubauer 1993).

In France the Centre des Recherches Géophysiques (part of the Centre National de la Recherche Scientifique) at Garchy did not lose its leading role, but concentrated on developing the electromagnetic method (Tabbagh 1986) and on quick electrical resistivity surveys (Dabas *et al.* 1990), whilst applying the magnetic method only sporadically in supplementary mode. Intensive work was also carried out on creating software for presenting results in the form of digital imagery. The first version of such software, prepared by Jeanne Tabbagh, was implemented in the early 1980s.

Polish researchers returned to magnetic prospection in the early 1970s when a team of geophysicists, archaeologists and historians headed by archaeologist Jacek Przeniosło (Fig. 20) operated in the area of Carthage in Tunisia (Iciek *et al.* 1974a). The team also used the electrical resistivity and gravimetric methods. The volume published on this research (Iciek *et al.* 1974b) was the first comprehensive presentation in book form of a site investigation that began with a geophysical survey (itself preceded by a careful review of historical and archaeological sources) and then followed up with excavation to verify and supplement the geophysical results. The analysis focused on reconstructing the topography of the town and contributing new information on its known history. The success of this research prompted the Institute of Archaeology and Ethnology of the Polish Academy of Sciences to establish a unit charged specifically with geophysical research; until 1990 it was headed by archaeologist J. Przeniosło. Proton magnetometers of Polish make were in use by the unit (successive models PMP4, PMP5), but the magnetic method was used rather sporadically, mainly due to the different specializations of the associated consultants from the State Enterprise for Geophysical Investigations in Warsaw: the geophysicist Aleksander Jagodziński, who specialized in the electrical resistivity method and the electronics engineers Janusz Konopacki (Fig. 20) and Leon Mucha, specialists in constructing electrical resistivity measuring devices (Misiewicz 2002: 113-114).

The most important magnetic research of the 1970s in Poland was conducted by geophysicists from the Kraków AGH University of Science and Technology who worked on a number of sites within a newly discovered ancient iron-smelting complex in the Masovia region. Surveying identified the extent of the areas where slag was present (Jarzyna *et al.* 1975, Woyda 1977). In 1981-82 the author surveyed a Palaeolithic haematite mine in Rydno (Holy Cross Mountains region), tracing the distribution of outcrops of the haematite-producing layer corresponding to the potential extent of extraction activities (Herbich 1984). In the middle of the 1980s the author started to work in Egypt; the magnetic method was applied without much success in a survey of the Coptic monastery at Naqlun (Godlewski *et al.* 1990), but it led to the discovery of the funerary chapel of an unknown vizier of the 6th Dynasty from the Old Kingdom in Saqqara (Myśliwiec and Herbich 1995; Herbich 2003: 16-18).

Research using the magnetic method in Czechoslovakia was initiated by Richard Linington from the Lerici Foundation in 1967. Together with researchers from the Archaeological Institute of the Czechoslovakian Academy of Sciences in Prague, he made a reconnaissance and selected a number of sites for magnetic surveying, the criteria being to cover as wide a chronological and typological range as possible. Surveying was undertaken in 1968 at four sites: a Funnel Beaker Culture settlement at Makotřasy, a large Celtic *oppidum* at Závist, a deserted medieval village at Svídná and a 5th-7th century AD settlement at Březno (Linington 1969b). Measurements were taken with a differential proton magnetometer developed in Bonn (Scollar 1965; 1986) and covered a combined area of 8 ha. On the first two of these sites, the survey proved to be of great value in that it solved important archaeological problems without the need for excavation. In Makotřasy, a ditch was traced around the site for a combined distance of about 500 m, allowing the squared shape of the settlement to be reconstructed (300 m to

Fig. 20. Jacek Przeniosło (right), head of the geophysical laboratory of the Institute of Archaeology and Ethnology, Polish Academy of Sciences, between 1972 and 1990 and Janusz Konopacki, head of a unit producing geophysical instruments at the State Geophysical Research Enterprise between 1980 and 1990. In 2011. Photo T. Herbich

the side); and at Závist a defensive ditch with an entrance was located (Linington 1969b: 133; 137). The invasion of Czechoslovakia in 1968 by troops from the Warsaw Pact interfered with further prospecting by Linington. His survey initiated extensive application of the method throughout Czechoslovakia in the next two decades, but the results did not filter into Western literature in any way. The Czech element of the work was carried out within the framework of cooperation between the Archaeological Institute of Czechoslovak Academy of Sciences, Prague, the Department of Applied Geophysics at the Faculty of Natural Sciences, Charles University and the state enterprise Geofyzika, Brno and Prague. In Moravia and Slovakia the units responsible were the Archaeological Institute of the Czechoslovak Academy of Sciences in Brno, the Geofyzika Brno enterprise, the High School of Mining in Ostrava, the Archaeological Institute of the Slovak Academy of Sciences in Nitra and the Department of Applied Geophysics at the Faculty of Natural Sciences, Komenský University in Bratislava. Four nationwide conferences on *Geophysics and archaeology* were organized between 1973 and 1982, all crowned by published proceedings (for references, see Pleslová-Štiková 1983: 14). The first independent attempts were made using a magnetic balance during tests carried out by Vilém Bárta at Makotřasy in 1968 and at Sázava-Černé Budy in 1969 (Bárta 1973). Proton magnetometers were used for magnetic prospection from the beginning of the 1970s, taking extensive measurements at the Great Moravian site Sady and starting a programme of regular investigations of metallurgical sites in the Boskovice area (Hašek 1999: 3). In 1976, an Interdisciplinary Improvement Team was established to prepare a comprehensive programme of research in Bohemia and Moravia. František Marek from the Department of Applied Geophysics at the Faculty of Natural Sciences of Charles University in Prague turned out to be a key figure in archaeological geophysics; important research was carried out by, among others, Jan Tirpák from the Archaeological Institute of the Slovak Academy of Sciences in Nitra and Vojtěch Gajdoš from the Department of Applied Geophysics in Bratislava, representing institutions with a base in Slovakia. The main task was to study all opportunities for the application of geophysical methods in archaeology and their practical use in field prospection. The number of surveys carried out by the year 1995 is the best proof of the team's activity: in Moravia alone 161 sites were investigated, the combined area being of 250 ha, mainly with the magnetic method (Hašek 1999: 4). Among the most important projects, all combined with archaeological verification, was the complete tracing a ditch encircling the settlement at Makotřasy (Pleslová-Štiková *et al.* 1980; Marek 1983: 64-68) and the location of Neolithic circular enclosures, for example, at Bylany (Marek 1983: 61-62; Pavlů and Zapotocká 1983) and Lochenice (Marek 1983: 58-50; Buchvaldek and Zeman 1983).

The chief reason why the activity of geophysicists in Czechoslovakia was not reflected in Western archaeological-geophysical literature appears to have been political: science was closely controlled by the communist regime (much more strictly than in Poland, for

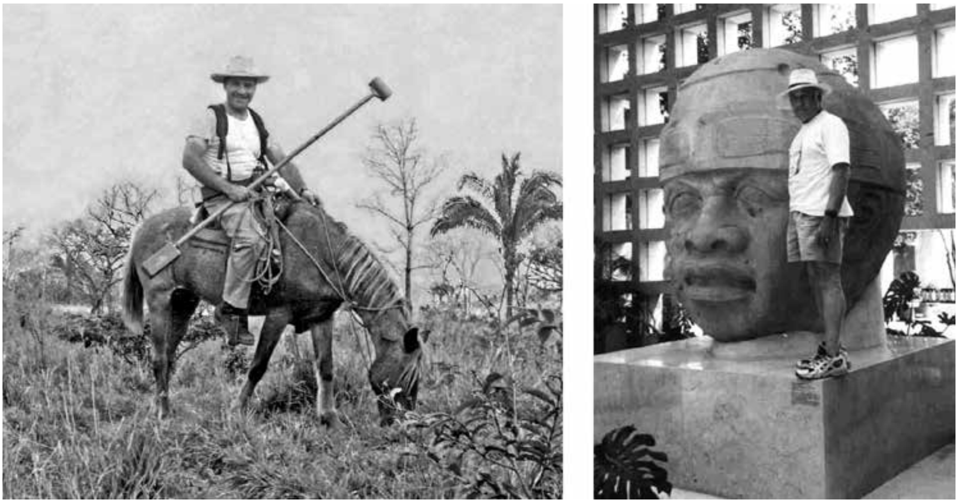

Fig. 21. Sheldon Breiner identifying areas of anomalous magnetic values at the Olmec Site of San Lorenzo, Veracruz, Mexico, with the use of a caesium magnetometer in an initial ("search" mode) phase of the magnetic survey, March 1968 (left) and standing in the Anthropology Museum in Xalapa, Veracruz state, by one of the Olmec heads found as a result of the survey (right). Archive of Sheldon Breiner

instance), results of research could be popularized outside the country only by scientists with political attitudes accepted by the regime. Geophysicists were in the minority in this case, hence the results were propagated mainly in archaeological circles, with little opportunity for wider presentation among archaeological geophysicists.

In the United States, the number of centres applying the magnetic method grew in the late 1960s and early 1970s. Sheldon Breiner, a geophysicist involved with developing applications of the then-new optically pumped instruments at Varian Associates (on whose behalf he participated in the research of the MASCA team in Sybaris, see above) created his own company Geometrics, and with a caesium magnetometer joined a research project at an important Olmec Site in San Lorenzo in southern Veracruz, Mexico. The project aim was to search for basalt carvings (with a minimum size of one cubic meter) that were presumed to be buried in the soil plateau. Laboratory research showed that the basalt blocks were characterized by a high induced and remanent magnetization, strongly in contrast with the total magnetization of the surrounding fill. In the first phase of the research, in 1968, the aim of the survey was to identify anomalies in the area (Fig. 21, left), excavate to confirm and divide the entire area into mappable grids. Measurements were carried out over a 2m grid , adjusted to the size of the sought-after basalt objects and to the range of anomalies created by them. A total of 80,000 measurements were taken; the survey located 17 objects of this kind in the area (including two colossal heads, Fig. 21, right), practically impossible to discover with traditional excavation methods: one of the heads was located at a depth of 5 m in the ground (Breiner and Coe

Fig. 22. John Weymouth (left) overseeing the magnetic survey at the Hopeton Site in the Hopewell Cultural National Historical Park, Ohio, in 2001. Archive of the National Park Service

1972). Breiner summarized his experience of working with portable magnetometers in a 58-page brochure, of which a million copies were printed (not counting copies translated into different languages e.g. Chinese and Russian) (Breiner 1973). The brochure was directed mainly at researchers working in geological exploration (using proton magnetometers), but also contained a chapter on archaeology (Breiner 1973: 45-48).

In the mid-1970s John Weymouth (Fig. 22) from the University of Nebraska began research on aboriginal occupation sites in the Great Plains of North America, using proton magnetometers to survey large areas. The most spectacular results came from a survey of the Sakakawea Village at the Knife River Indian Villages National Historic Site. Measurements covered 15 ha over a one-metre grid. A number of houses were observed in the magnetic record, each with a central anomaly. Areas between the houses with strong magnetic readings were middens, the house floors being less magnetic. The central anomalies in the houses corresponded to hearths (Weymouth 1986a: 353-356). Between 1978 and 1982 J. Weymouth's group investigated about 100 sites in the Dolores Archaeological Program alone (Weymouth 1986a: 362). J. Weymouth's work turned the University of Nebraska into an important centre for training in the field of archaeological geophysics (Weymouth 1986b). Large areas were also surveyed by teams from the University of Pennsylvania Museum (MASCA). By 1976 the number of sites surveyed by Elizabeth Ralph reached 49 in 13 countries. During this research 750,000 magnetic measurements were plotted and contoured by hand, an output which, according to Bruce Bevan (1995: 89), has never been equalled. Large-scale projects were continued: an interdisciplinary survey at the Valley Forge National Historic Park covered 20 ha with a caesium magnetometer over a grid from 2 to 0.5 m (Parrington 1979). In the Tombigee Historic Townsites Project in Mississippi approximately 44 ha were investigated in the course of three months; archaeological verification demonstrated that earth features were detectable only if the fill included ferrous fragments. Brick features (kilns, hearths and chimney walls) were also discovered as long as they occurred in concentrations (Weymouth 1986a: 367-368).

Sheldon Breiner's pioneering work in Mexico was followed by a survey carried out by other North American researchers. A team headed by geophysicist H.F. Frank Morrison form the University of Berkeley surveyed La Venta Pyramid. According to Luis Barba (personal communication) this is the earliest published research concerning the application of magnetometry in Mexican archaeology (Morrison *et al.* 1970). The magnetic method was also used by Mexican researchers: firstly in 1969 in the main plaza of Mexico City, near the cathedral, to search for large stone sculptures from the pre-Spanish era. Gravimetric and seismic methods were also applied. Sculptures were not found, but this was the first attempt to use geophysics with an archaeological objective in an urban environment in Mexico (Castillo-García and Urrutia-Fucugauchi 1974). Luis Barba then became a leading person in Mexican archaeological geophysics; his first use of the magnetic method took place in 1980 when he investigated the site of San Jose Ixtapa with a Varian caesium magnetometer. The anomalies detected (over a 5 m grid) suggested the presence of industrial remains, with excavation revealing a mercury production site dated to a pre-Spanish period (Limón and Barba 1981).

In the Soviet Union, the magnetic method was applied mainly to investigate industrial sites containing iron-smelting furnaces and pottery kilns, that is, features that were easily traced owing to the high amplitudes of anomalies observed in the Earth's magnetic field. The trend was set by a survey carried out in 1978 in Chernaya Gora in the Sebezh region, as a result of which the settlement site was reclassified as definitely an industrial site (Miklayev *et al.* 1986). Industrial site prospection became Tatyana

Fig. 23. From left to right: Tatyana Smekalova with an Overhauser magnetometer GSM-19WG by GEM Systems (Canada) and cesium magnetometer M-33 by Geologorazvedka (Russia), Olfert Voss and Bruce W. Bevan with MMP-60 proton magnetometer by Geologorozvedka on the iron smelting site of Snorup in Jutland, Denmark, in 1996. After Smekalova *et al.* 2005: 16

Smekalova's specialty in the USSR (later Russia and Ukraine). She was also invited to carry out magnetic surveys of iron-smelting sites in Denmark (e.g. Smekalova, Voss and Abrahamsen 1993) (Fig. 23).

In Japan, the magnetic method was introduced to archaeological prospecting in 1967. The first attempt – aimed at tracing burials and settlement remains – gave no result due to "inappropriate target selection and improper understanding of magnetic field nature" (Nishimura, personal communication). Soon after this failed attempt, the method was applied to investigate kiln sites by researchers form the National Research Institute for Cultural Properties, Nara (NRICP) (Iwamoto 1974; Nakamura 1974). Proton magnetometers, a Japanese-made instrument and a Geometrics G-816 were used, initially in a single mode, than in differential mode together with a more advanced instrument Geometrics G-826. The proton magnetometers, together with a fluxgate gradiometer by Plessey, were then widely used by Yasushi Nishimura (of NRICP) to investigate sites of industrial character. Proton instruments were used to locate features in deeper layers; fluxgate machines (from the mid-1980s, the FM18 by Geoscan Research) were used to obtain a more detailed image of structures (Nishimura, personal communication).

5. 1980S AND 1990S: RAPID DEVELOPMENT OF APPLICATIONS OF THE METHOD

5.1. Factors shaping the development of archaeological geophysics, including the magnetic method

The rapid increase in the number of projects applying the method in the 1980s and 1990s was due to a number of factors: technological development, changes in archaeological priorities and in conservation law, and finally changes in archaeology education programmes. The influence of these factors varied from country to country, affecting each differently. But the process itself was the same for all of the chief methods of archaeological geophysics used commonly in archaeological research, including the magnetic method.

Technological changes already taking place in the leading countries in the 1980s, undoubtedly spearheaded a qualitative advance: slow proton magnetometers were almost entirely replaced by instruments with shorter measuring times (of the order of 0.1 sec.) and accuracy in the range of 0.1 (fluxgate) – 0.01 to 0.001 nT (caesium), recording the readings in the instrument's memory. Automation resulted in accelerated rates of ground coverage, whilst higher resolutions resulting from more accurate measurements and increased sampling density led to a much higher level of feature identification than had previously been achieved. Better quality instruments and their ever-growing internal logging capacity (allowing longer periods of fieldwork between successive data downloads) were enhanced by progress in the computing power of a popular newcomer, the personal computer, which allowed for different ways of digital processing of data to assist with the reading of the geophysical image. Improved PCs supported new software for visualizing geophysical results, rendering on a map features that had not been visible in previous graphic presentations: in magnetometry, greytone maps gradually superseded dot density and contour images to become the standard form of presentation.

The process of change is best described in the case of Great Britain, ever a leader as far as application of geophysical methods is concerned. Here, the main driver of change from the early 1990s was the need to provide economic, rapid and large-scale non-destructive archaeological evaluation as a requirement in advance of land development. This coincided with an increasing appreciation of the value of prospecting methodologies for the broader investigation of landscape and context, rather than simply on sites in isolation (Heron and Gaffney 1987: 78). According to C. Gaffney and John Gater (2003: 20-22), the growing importance of landscape issues encouraged these changes but it was a different process that acted as a catalyst. Chris Gaffney and J. Gater wrote:

> "While the inevitable trickle down of technology into the discipline (…) created a platform on which to work, this in itself cannot be regarded as the reason for the subsequent explosion in activity. (…) the information required by archaeologists changed during this period – the rapid evaluation of large tracks of land became the norm, and where traditional avenues of investigation were weak, geophysical techniques were strong. In particular the development boom of the late 1980s/90s and the general absorption of archaeology into the environmental assessment of large-scale developments, provided great incentive for those attempting to establish geophysical techniques within the archaeological methodologies."
>
> (Gaffney and Gater 2003: 21)

Numbers best illustrate the changes of approach to archaeological geophysics: about 60 surveys were carried out in Great Britain in 1980, but ten years later this number had grown to about 250 per year. The reason for this was the recognition by developers, working to new Planning Policy Guidelines, that geophysical survey could identify areas of archaeological importance at less expense than large-scale evaluation by excavation (Gaffney and Gater 2003: 22). The methodology could be used to evaluate large areas and then to target sites for more detailed excavation.

The increasing influence of this commercial practice in Great Britain was also symptomatic of changes taking place in other countries. In 1980, about half of the geophysical surveys in England were carried out by the Ancient Monuments Laboratory (AML), the other half being conducted by others, including British Gas. In 1979 , British Gas employed a geophysicist on the routes of planned gas pipelines. By 1990 AML was estimated to have undertaken only about 10% of geophysical surveys in England, the rest being carried out by commercial groups (Gaffney and Gater 2003: 20, 23; Gaffney 2008: 315). J. Gater's and C. Gaffney's GSB Prospection was the largest of these groups; from

Fig. 24. Chris Gaffney (left) and John Gater after receiving a honorary degree from the University of Bradford, July 2006. Archive of Chris Gaffney

its establishment in 1986 to 2000 the group conducted over 1500 surveys, about 80% of which used the magnetic method (Gater, personal communication) (Fig. 24).

There is no doubt that the situation of archaeological geophysics was affected by developments in education and training. Prior to the wider dissemination of training in archaeological geophysics to archaeologists, researchers in archaeological geophysics were commonly geophysicists and physicists few of whom were actually employed full time in archaeology. Most of them were anchored in other fields, working in archaeology sporadically at best. Besides Bradford University, archaeological geophysics as part of the regular study *curriculum* was made available at Glasgow and Durnham Universities. An undergraduate degree in archaeological sciences became obtainable from Bradford in 1975, turning the university into a leading centre for British archaeological geophysics (Gaffney and Gater 2003: 19). A postgraduate masters course devoted to archaeological prospection alone was initiated at Bradford in 1995.

British experience demonstrated the effectiveness of using surveyors with archaeological background and basic expertise in geophysics. This created a new and economically advantageous situation: an archaeological graduate, trained to use geophysical methods, has lower financial expectations than a geophysicist who could be working for a geological company with a budget unimaginable in archaeology. A growing body of specialists capable of carrying out measurements and interpreting them properly lowered the costs of survey, thus making it more easily accessible.

The other factor contributing to progress in applying geophysical methods in archaeological research was from the sphere of what could be called "scientific communication". Archaeological geophysicists carry out surveys as part of the entire research process, including the analytical stage as well as synthesis and formulating conclusions. They can therefore adapt and change the research methodology to achieve greater effectiveness in given conditions. Practice has demonstrated repeatedly that results offered by researchers with just a geophysical background, uninformed by archaeological context, often proved unintelligible or of limited value to those who commissioned the survey. This made some archaeologists wary of geophysical methods in archaeology: disappointed once, they were not inclined to continue research with the use of such methods.

Changes in other countries applying geophysics to archaeology followed a similar scenario, although the impact of the two factors mentioned above: economic and "scientific communication", was different and occurred at different times. Commercial groups appeared in Germany and France two decades later than in Great Britain. In Poland the process was another decade late and kick-started only in the beginning of the 21st century. In Great Britain the developed structure of archaeological geophysics helped to avoid the painful misunderstandings that occurred, for example, in Germany, France and Poland, between geophysicists anchored in geology and archaeologists commissioning archaeological surveying.

It has already been observed that landscape research was an important beneficiary of the more extensive surveys in Great Britain. In other countries, large-area surveying did not arise from methodological debate but from conservation law: for example, the geophysical laboratory of the Bavarian State Department of Monuments and Sites in Munich used magnetometry to determine site extent for preservation purposes, that is, to establish areas under absolute protection.

The methods were also popularized thanks to the effective exchange of knowhow. The first such forum to be established was the *Archaeological Prospection* conference, organized biannually from 1995 and specifically dedicated to archaeological geophysics. Previous to that the subject had been presented at *Archaeometry* conferences, which were also biannual, but which were focused on material analysis and dating methods, leaving geophysics on the fringes. In the early 1990s, annual assemblies of the European Geophysical Society became an important forum, but archaeological geophysics remained marginal with regard to the mainstream, as at the *Archaeometry* conferences. The 1999 *Archaeological Prospection* conference in Munich set a standard for publishing abstracts of papers or extended versions in the form of short articles with references and illustrations (Fassbinder and Irlinger 1999). This has turned out to be an excellent review of the current situation in archaeological geophysics, giving insight into the work not only of big research centres but also commercial groups which, unlike the latter, are not obliged to publish their results.

The second forum of information exchange was provided by the journal *Archaeological Prospection*, which is dedicated to archaeological geophysics (with only minimal input from other prospection methods). It was the first periodical after *Prospezioni Archeologiche* to deal with the discipline exclusively. Groups of researchers associated with Bradford University called for the establishment of a periodical of this kind at the *Archaeometry* conference in Ankara in 1994. The first issues, edited by M. Pollard and A. Aspinall, was published with the date of November 1994.

Important monographs were published at the turn of the 1980s and 1990s: Tony Clark's (1990; revised edition 1996) introduction to the theory, history and practice of geophysical methods for archaeologists, illustrated with cases of practical application of the methods; and a study by I. Scollar, A. Tabbagh, A. Hesse and I. Herzog (Scollar *et al.* 1990) laying emphasis foremost on the theoretical principles of methods used. In 1995, the Ancient Monuments Laboratory (now part of the English Heritage) drew up and published guidelines on geophysical survey in archaeological evaluation (English Heritage 1995), intended to help achieve standardization of applied geophysical methods in archaeology.

5.2. Changes in magnetic method measurement methodology

The principal change in magnetic method measurement methodology which occurred in the 1990s was the development of multi-sensor mobile systems, moved either on carts or carried by the operator. The multi-sensor idea was generated in order to accelerate working speed; it permitted changes of magnetic field intensity to be recorded simultaneously along a number of measuring lines. The leading centres were based in Munich (Helmut Becker's lab), in Vienna (group drawing on the experience of Peter Melichar, directed by Wolfgang Neubauer) and in Kiel (Harald Stümpel and his team in the Institute of Geosciences/Geophysics, University of Kiel). H. Becker's definition of the "3 s rule": sensitivity, speed and spatial resolution (Becker 1999a: 100) triggered the work on multi-sensor designs. Systems based on caesium magnetometers and fluxgate gradiometers were selected for development in order to achieve the most precise images.

The Munich group's testing ground for developing caesium magnetometer prospection was ancient Troy. Here, measurements with a fluxgate gradiometer (Jansen 1992) demonstrated the effectiveness of the magnetic method for identifying the Roman city (Troy X) but could not trace features belonging to earlier phases in the existence of the town. Measurements with a caesium magnetometer, began by H. Becker and J.W.E. Fassbinder, recording the total field values with a resolution of 0.1 nT were designed to reach the deeper-lying layers. They did in fact trace architecture from Late Bronze Age Troy VI, providing in effect a map of the town from that age, extending over an area of at least 18 ha with an estimated population of 6000 inhabitants (Becker 1999c). Information about this mapping of Homeric Troy made the news, catching the attention of Robert Pavlik, constructor for the Picodas company, who offered to build an instrument with picotesla sensitivity, creating in effect the most sensitive system yet used in archaeology: CS2/MEP720 (Scintrex/Picodas). It enabled measuring with an accuracy of up to 1 picotesla (0.001 nT) (Becker 1995). Initially, the system operated as a one track gradiometer or variometer configuration of sensors. It was tested in 1994 at the site of Monte da Ponte in Portugal and in the same year again in Troy. H. Becker wrote:

"It took the author almost two years [before] realizing that the two sensors of gradiometer CS2/MEP720 could also be moved parallel in fieldwork covering two tracks for total field measurement at same height above the ground. This simple "trick" doubles the sampling-

Fig. 25. Jörg Fassbinder taking measurements on Easter Island, using Smartmag SM4G caesium magnetometers by Scintrex, Canada. Archive of J. Fassbinder

speed. Every sensor added to the system multiplies the survey speed and opens a wide range for magnetic prospecting over large areas with limited time."

(Becker 1999a: 100)

Thus, by 1995, the system had fulfilled both the speed and sensitivity conditions. The key to this new measurement technique was the MEP720 processor with electronic bandpass filters of different frequency, adapted to cancel high frequency magnetic disturbances. A system of filters enabled a credible identification of manmade anomalies; the only anomalies which could not be removed were temporal variations with a wavelength compatible to the measuring time for surveying a 20 m line (measurements taken over a 20 m grid) (Becker 1999a: 102). The system was moved on a cart, limiting its usefulness only to sites where it could be wheeled. The next system to be constructed, Smartmag SM4G gradiometer by Scintrex, solved the issue of covering difficult ground. The system was mounted on a wooden frame carried by the operator and the probes were set 0.5 m apart. (Fig. 25) With a resolution 0.01 nT the sensors were less sensitive than in the CS2/MEP720 system, but still ten times more sensitive than the fluxgate instruments which dominated the market. This system also measured total magnetic field intensity. It was tested in 1996 at Monte da Ponte in Portugal (Becker 1999d). H. Becker and J.W.E. Fassbinder conducted dozens of surveys with the system outside the borders of Germany, within the framework of cooperative programmes with various archaeological institutes. Amogst the most spectacular mapping projects to be mentioned were the Ramesside capital of Egypt in the New Kingdom, Qantir in the Eastern Nile Delta, initiated in 1996 (Pusch *et al.* 1999; Becker and Fassbinder 1999a), the unknown architecture of the Hellenistic district in Palmyra in Syria (Becker and Fassbinder 1999b) and the Scythian settlement and mound burials (with complete grave furnishings) in Siberia (Becker and Fassbinder 1999c). The higher sensitivity system on a cart continued in use, mainly on sites in Germany or in the immediate vicinity of its borders (e.g. in Słonowice, Herbich and Tunia 2009). To

Fig. 26. Peter Melichar surveying a Roman villa in Zillingtal (Burgenland, Austria) using a Varian cesium gradiometer, autumn 1992. The cart with a mechanical distance measurement unit with 1 cm accuracy was developed by Friedrich Parisch. Data were stored on a logger developed by P. Melichar in 1986. Archive of the Vienna Institute for Archaeological Science, University of Vienna. Photo F. Parisch

increase the speed of fieldwork, Becker developed Smartmag's two-sensor system into a four-sensor one mounted on a cart, which he called a "magnetoscanner". With this instrument he completed several large-area projects, in Italy, e.g. Ostia (discovering among others an Early Christian basilica, Becker 1999b) and in Bavaria, e.g. Ruffenhofen (reconstruction of a complete plan of the Roman *castellum* with *vicus*, bath and cemeteries, Becker 2001: 10-12). In this last case, the measurement speed was of key significance in view of the fact that the site had to be covered within short periods between agricultural activities. The four-sensor system, however, did not earn the same regard as the manually carried two-sensor one which is still in use.

H. Becker and J.W.E. Fassbinder's work on important sites, covering large areas, brought spectacular information on these sites. There can be no doubt that the results, well published with excellent graphic presentation, helped to popularize the magnetic method, especially as they were also shown in media of broader scope (such as the film about Qantir for Discovery Channel).

The Vienna group also concentrated on developing caesium magnetometry, initially based on Becker's work. The group was interested in working with high resolution sensors in different configurations, mounted on carts by the operator (Doneus *et al.* 2001: 21-23) (Fig. 26). The combined efforts of researchers anchored in academic centres and in a private company (Archeo Prospections) created a group active in field prospection, at the same time perfecting ways of visualizing results and their archaeological interpretation (Neubauer *et al.* 1996; Doneus *et al.* 2001: 24). Their testing ground was Carnuntum, the Roman town near Vienna (Neubauer and Eder-Hinterleitner 1997). Surveying in

Fig. 27. Harald Stümpel (right) and Ercan Ercul of the Univeristy of Kiel surveying the Hittite site of Sarissa in Anatolia, Turkey, with a system of five fluxgate sensors mounted on a portable rack. Archive of H. Stümpel

different regions of Austria resulted in the discovery and mapping of dozens of Neolithic sites with characteristic ditched circular features (Neubauer and Melichar 2010).

The effectiveness of caesium magnetometers did not weaken the popularity of fluxgate gradiometer applications, chiefly because of the relative cheapness of these instruments and their easy use in the variant developed by Roger Walker, furnished with easy-to-use Geoplot software also sold by Geoscan Research. Until the introduction of the instrument constructed by Bartington (Bartington and Chapman 2004), the Geoscan fluxgate instruments dominated the British market and were also used in other countries. Despite being slower to use in the field compared to the multi-probe systems, these instruments were used on a large number of large sites such as at the Roman city of Wroxeter (using Geoscan magnetometers: Gaffney *et al.* 2000).

In the 1990s, a multi-probe system produced by Förster, a German company producing fluxgate gradiometers, was introduced in archaeology. The system did not grow from archaeological experience (as was the case of the caesium systems), but was developed for military needs, that is, primarily to locate unexploded ordnance. The instrument was adapted for archaeological purposes by a team from the Institute of Geosciences/Geophysics, University of Kiel in 1992-94 (Stümpel 1995; Jöns 1999). A system with five probes mounted on a portable rack carried by two people was employed to map the Hittite town of Sarissa in Turkey (Trinks *et al.* 1999) (Fig. 27). The system was improved over a number of years, with the sensors being mounted on a cart pulled by a small tractor, leading to a spectacular mapping of the entire site (65 ha) of the Greek colony of Selinus (Selinunte) in eastern Sicily (Erkul *et al.* 2003a; 2003b).

6. CONCLUDING REMARKS

The popularization of the magnetic method at the end of the 20th century and its application as a standard in surveying extensive areas led to considerable changes in the nature of archaeological projects. This process is illustrated very well by the changes which have taken place in Egypt, a country where archaeology is well advanced, but where the geophysical tradition was not so well grounded previously. The introduction of magnetic prospection laid the ground for a new field of studies, that is, ancient Egyptian urban planning. In the 1960s there were still researchers persuaded that, unlike Mesopotamian civilization, Egyptian civilization had no established towns (Wilson 1960: 126-127). Extensive excavation in the second half of the 20th century, especially in the Delta, demonstrated the falseness of this assumption. But it was the magnetic method which proved to be the ultimate tool in successfully tracing urban development processes and changes in urban planning over large areas. The best illustration of this situation has been provided by research in the complex of capitals of Egypt from different periods, located at Tell el-Dabᶜa/Qantir in the Eastern Delta of the Nile, where measurements have covered more than 2 km^2 in Qantir (Becker and Fassbinder 1999a; Becker 2001: 8) and 1.5 km^2 in Tell Dabᶜa (Forstner-Müller *et al.* 2007; Forstner-Müller *et al.* 2015: 157-161). Combined with knowledge drawn from excavations and source studies, the survey has permitted urban analyses of various parts of this area at different time periods (Pusch *et al.* 1999; Forstner-Müller 2010; Bietak and Forstner-Müller 2011).

Fig. 28. Manfred Bietak explaining the topography of the New Kingdom palatial complex at Tell el-Dabᶜa in the Nile Delta, Egypt, October 2004 (magnetic map by Tomasz Herbich and Christian Schweitzer, survey 1999-2001). Author's archive

Common use of the magnetic method for surveying large-area sites where there was virtually no surface expression of buildings (especially in areas of agricultural cultivation), had one other practical aspect. Archaeologists were now able to understand sites in their broader context, within a landscape setting, and were no longer dependent on the restricted key-hole view provided by excavation of just 1-10% of a site. Magnetic maps are perfectly suited to presentations of site topography within the original landscape (Fig. 28).

The section titles of this article render the nature of developments in the application of the magnetic method over forty years from proton magnetometers and magnetic balances to fluxgate magnetometers, from slow development in the 1960s and 1970s to the boom of the 1980s and 1990s. Apart from describing more or less known applications of the method, the author has made an effort to highlight research which has so far not made the history books or has been mistakenly appraised due to the complete lack of, or restricted contact between scholars on either side of the Iron Curtain (depending on country and historical circumstances). So deeply grounded were such opinions that Helmut Becker's expressed conviction (2009: 131) was that that archaeological geophysics in the Czech Republic and in Slovakia had not started before 1990, while the truth of the matter was that not only were geophysical methods being applied to research on local sites in the 1960s (see above), but they were also used in Czechoslovakian research on sites abroad, as for example in the important work carried out with the magnetic method in the complex of pyramids from the Old Kingdom at Abusir in Egypt (Verner and Hašek 1981). There is still a need for summary evaluation of applications of the magnetic method in countries where it was definitely being used by local researchers; however, access to these source materials is restricted, not the least because of language issues. Our knowledge in this respect has been augmented by two papers of a historical nature published in 2011. One of these presented an account of the earliest surveying with the magnetic method in Poland (Herbich 2011), the other focused on the history of archaeological geophysics in Sweden (Viberg *et al.* 2011). One can only hope that researchers in other countries will take up historical studies of this kind as soon as possible, while the pioneers and their immediate successors can still have a part in their preparation.[6]

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[6] The conference "Pioneering Archaeological Prospection" organized at Laa an der Thaya (Austria) in October 2011 by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology in Vienna was an excellent initiative addressing the idea of recording the beginnings of archaeological geophysics.

by Prof. J. Jankowski never appeared, however this present paper is based largely on the first chapter of the study, outlining the history of the method's application in archaeological research. The other person who has played an inspirational role is Dr. Zofia Stoss-Gale, who informed me years ago that a dozen or so early volumes of *Archaeometry* were available free from the Research Laboratory for Archaeology and History of Art in Oxford. Thanks to her the volumes, which are not held by any library in Poland, came to be in my possession and have given me insight into early applications of the method. The author gratefully acknowledges remarks made by colleagues who have read earlier drafts of the article and shared their comments: Helmut Becker, Jörg W.E. Fassbinder, Chris Gaffney, Albert Hesse, Christian Schweitzer and Irwin Scollar. The following found time to answer my questions, written and oral: Luis Barba, Bruce Bevan, John Gater, Daria Hookk, Roman Křivánek, Yasushi Nishimura, Harald Stümpel, Alain Tabbagh and Sheldon Breiner. The author is also very grateful for helpful remarks (and linguistic correction) to Andrew David who, as well as Armin Schmidt, read the article at the editors' request. Separate thanks are due individuals and institutions providing images: Archaeological Museum in Kraków, Tadeusz Baranowski, Christophe Benech, Charles Henri Burglin, Sheldon Breiner, Steve De Vore, English Heritage, Jörg W.E. Fassbinder, Chris Gaffney, Geoscan Research, Albert Hesse, Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology in Vienna, the Museum of History of AGH University of Science and Technology in Kraków, Armin Schmidt, Tatyana Smekalova, Harald Stümpel, University of Pennsylvania Museum in Philadelphia.

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Uncovering Neolithic and Early Bronze Age landscapes: new data from southwestern Poland

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An increasingly important role in the study of prehistoric cultural landscapes is played nowadays by various methods of non-invasive archaeological prospection, such as aerial photography, remote sensing, airborne laser scanning and terrestrial geophysical surveying. In Polish archaeology, which has pioneered in many aspects the use of aerial photography and geophysical methods, investigations of this kind have a long history and can boast many successful applications, but the intensity of their use continues to be uneven. In the case of the region of Silesia (southwestern Poland), non-invasive prospection has been sporadic and hardly regular. However, recent projects have yielded data that will most likely increase the number of known Neolithic and Early Bronze Age sites in Silesia, especially ditch enclosures and other monuments. The implementation of modern archaeological prospection methods has often contributed to a better understanding of already recorded sites and has been beneficial not only in furthering knowledge about the past, but also in protecting the archaeological heritage.

KEY-WORDS: Silesia, Neolithic, Early Bronze Age, magnetic prospection, aerial prospection, enclosures, landscape

Cultural landscape as a space for interaction between the natural environment and past and present socio-cultural behavior is an important element of contemporary heritage protection doctrines, as well as the subject of research in the humanities, and the natural and social sciences. It also provides a unique platform for integrating various disciplines and research methods dealing with the study of contemporary cultural landscapes and their past transformations, and it is in this sphere that archaeology plays a fundamental role.

Cultural landscape surfaced as a topic of interest in the late 19th and early 20th century in German geographical studies. At the beginning of the 20th century this legacy gave rise to the American landscape school. At the same time, the French school of human geography, which derived from Durkheim's sociologism, was developed by Vidal de la Blache.

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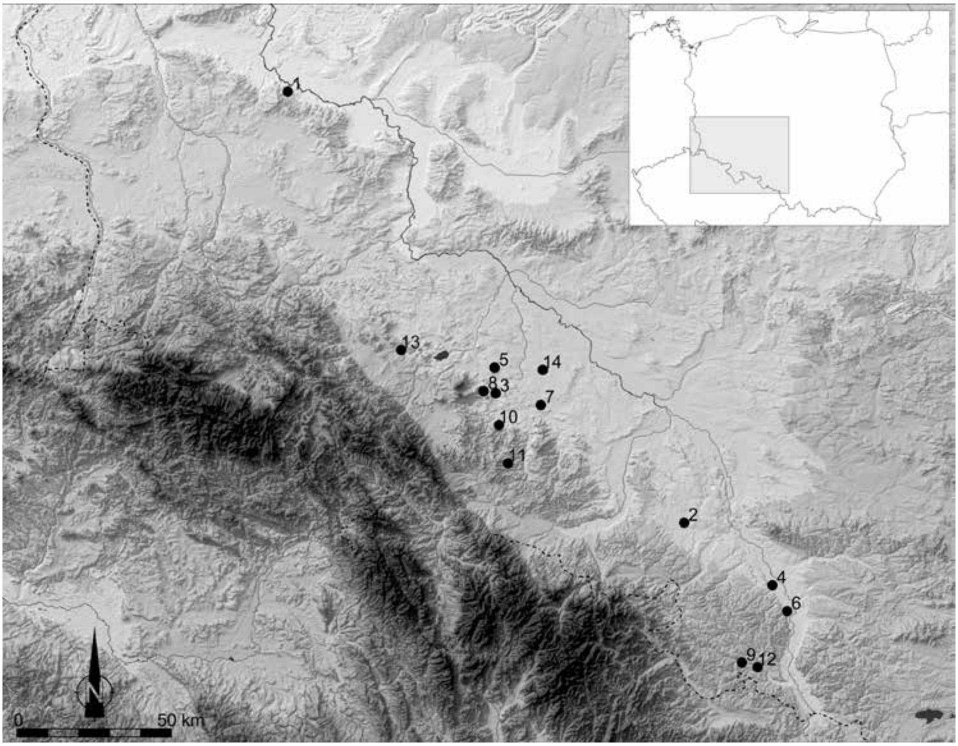

Fig. 1. Map of Silesia (southwestern Poland), showing sites mentioned in the text. 1 – Bodzów, 2 – Chrzelice, 3 – Dankowice, 4 – Dębowa, 5 – Dobkowice, 6 – Dzielnica, 7 – Górzec, 8 – Janówek, 9 – Kietrz, 10 – Księginice Wielkie, 11 – Muszkowice, 12 – Pietrowice Wielkie, 13 – Przyłęgów, 14 – Radłowice

These ideas were also backed by Polish researchers (e.g., M. Dobrowolska, L. Krzywicki, K. Potkański, E. Romer, F. Bujak, W. Semkowicz) (Myga-Piątek 2005).

The history of cultural landscape studies, especially the development of landscape archeology, is relatively short. The term was first coined by Mick Aston and Trevor Rowley in the mid 1970s (Aston and Rowley 1974); however, the intertwined relationship between man and environment, especially in spatial contexts, has a much longer history and is one of the more significant issues undertaken in archaeology. Landscape research began in the 1980s and developed rapidly in the following decade, taking advantage of methodological advances that confronted various empirical and conceptual approaches. The main focus initially was on analyzing transformations in time and man's relationship to his environment. More recently, landscape has started to be treated as more of an integral part of everyday social and cultural life rather than merely a backdrop for human activities (e.g., David and Thomas 2008)

The meaning of landscape and its significance is different for different groups and individuals operating in it and is a variable of the prevalent actions and practices implemented within it. For instance, the cultural landscape experience will be distinctive for the hunter-gatherer and for the farmer, its role not being reduced to aspects related to daily activity or economic behavior. The so-called Neolithic Revolution, often reduced to the opposition of the hunter-gatherer and agricultural economies, was focused primarily on symbolic and social transformations, in which the Neolithic sensory revolution, which was part of the new Neolithic 'mode of thought', played an important role (Tilley 2007). Hunter-gatherer communities treated themselves on the whole as part of the cultural landscape and their contribution to its physical transformation was minimal. With the advent of agriculture man's attempt to master his surroundings became apparent as he began to clear forests, build houses, tombs and ceremonial objects.

Non-invasive archaeological prospection plays an ever more important role among the different approaches to the study of prehistoric cultural landscapes. Aerial photography, remote sensing, airborne laser scanning and terrestrial geophysical surveying are among the methods used. These techniques have proved successful in discovering and documenting previously unknown forms of archaeological sites and features. A number of recent and ongoing projects are proof of their multifaceted usefulness. Examples include:

– BREBEMI Project, aimed primarily at evaluating the threat to archaeological resources by planned road construction. The systematic use of non-invasive methods provided a vast amount of new information useful in the study of changes in the cultural landscape (Campana and Dabas 2011).

– Stonehenge Hidden Landscape Project, carried out in a study area with a long history of intensive archaeological investigations, but still capable of uncovering many previously unknown elements within a unique landscape formed by the Stonehenge surroundings (Gaffney *et al.* 2012).

– Tripilye Megasites Project, large-scale recognition of "mega structures" of Tripilye Culture using magnetic prospection techniques, prociding at the same time new data for demographic, economic and social studies (Rassmann 2014).

In Polish archaeology, which has pioneered in many aspects the use of aerial photography (e.g., Biskupin; Nowakowski *et al.* 2005; Kobyliński 2005) and geophysical methods, investigations of this kind have a long history and can boast many successful applications, but the intensity of their use continues to be uneven. In the case of the region of Silesia (southwestern Poland), aerial and geophysical prospection has been sporadic and hardly regular compared to that in Małopolska or Wielkopolska, this despite a highly complex and diverse cultural landscape resulting from favourable conditions related to the presence of numerous natural resources and fertile soils. The potential for the recognition of this landscape through the application of non-invasive techniques is high and has been confirmed by recent studies of Neolithic and Early Bronze Age communities, designed to take full advantage of non-invasive prospection as a fundamental element of the applied research methodologies.

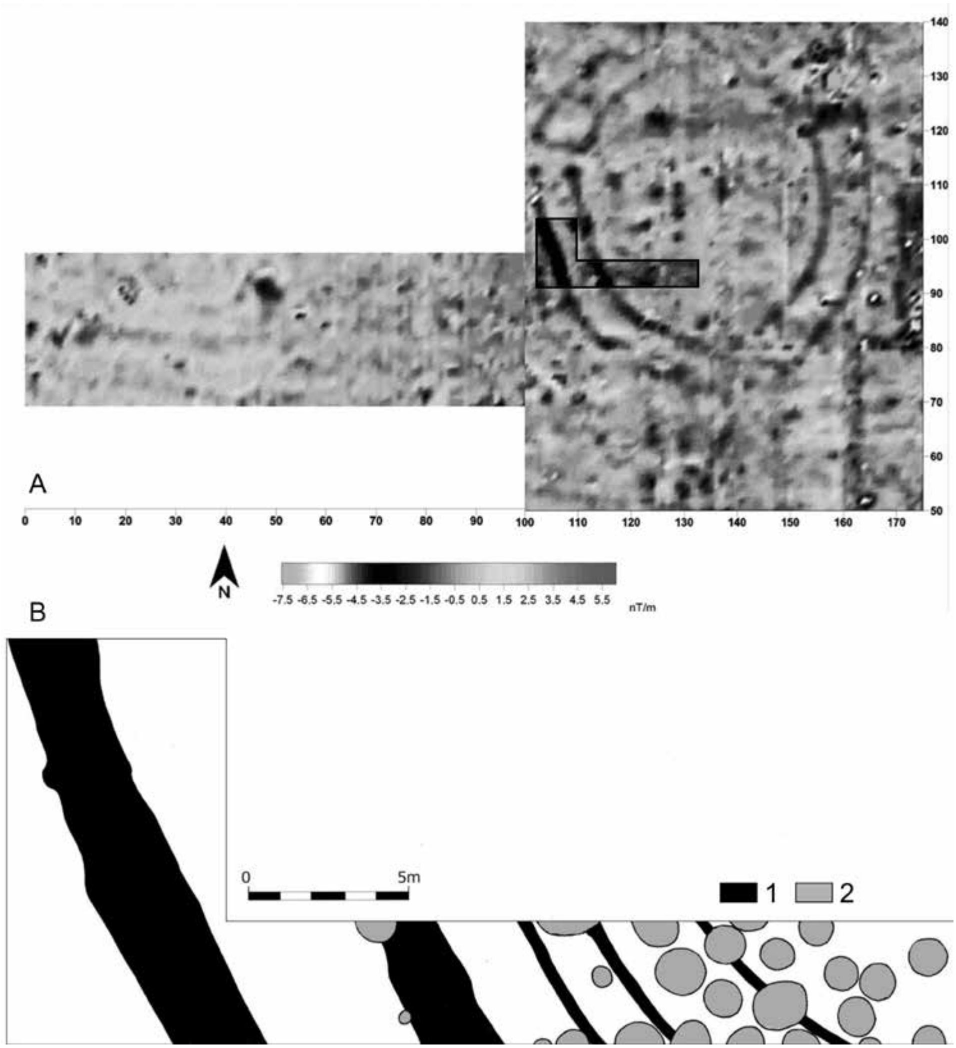

Fig. 2. Bodzów (Lubuskie province). A rondel-type enclosure of the Stroke-Ornamented Pottery Culture. A – magnetic map; B –trench plan: 1 – Neolithic ditches and palisades; 2 – later pits (after Kobyliński *et al.* 2012)

Silesia was one of the first regions in modern Polish territory to be settled by prehistoric agricultural communities. Initial settlement took place on soils most agreeable to farming activities. With time the ecumene gradually grew in proportion to the demographic growth. Between approximately 5300–5200 BC and 1500 BC, the trajectory of social and economic transformation was reflected in the functioning of the past cultural landscape. These changes, both anthropogenic and natural, were recorded using non-invasive methods of prospection, especially aerial photography, geophysics and to a lesser extent geochemical methods.

Ditched enclosures are among the settlement activities from the Neolithic and Bronze Ages that have attracted particular attention. These features are very diverse in terms of form, size, layout and chronology. The interpretation of their function is also a source of controversy and ongoing debate. Until recently Silesia and Poland in general were pointed out as having a disproportionately low number of known ditched enclosures compared to other parts of Europe. Only three Neolithic ditched enclosures: Racibórz-Ocice (Silesia province), Tyniec Mały (Lower Silesia province) and Zarzyca (Lower Silesia province), were marked on a map published at the end of the 20th century (Andersen 1997). Excavations since then have added a few more sites to this map: the Neolithic site in Dobkowice (Lower Silesia province; Czarniak 2011), as well as Early Bronze Age fortified settlements in Jędrychowice (Opole province), Nowa Cerekiew (Opole province) and Radłowice (Lower Silesia province) (Gedl 1985; Kosińska 1985; Lasak and Furmanek 2008). Earth resistance surveys were carried out in 1978 in Tyniec Mały (Lower Silesia province), a site associated with the Jordanów culture, but failed to help in determining the form of the site (Noworyta 1986).

A turning point in the application of non-destructive methods in Silesia came in 1998 with the discovery by Otto Braasch of a circular ditched enclosure in Bodzów (Figs 1 and 2). Further research in Bodzów, including magnetic and earth resistance surveys, took place in 2006–2009. Excavations confirmed the existence of a rondel-type enclosure, consisting of two concentric ditches with a diameter of 64 m and 55 m, as well as three internal palisades (Kobyliński *et al.* 2012). The discovered structure was associated with Stroked Ornamented Ware culture communities and classified in terms of morphology as a Lochenice–Unternberg rondel-type enclosure (according to Podborský 1999). Currently, there are approximately 150 rondel-type enclosures known from Central Europe, most of them discovered through the application of non-invasive techniques (e.g., Trnka 1991; Podborský 1999; Kovárnik *et al.* 2006; Melichar and Neubauer 2010; Kuzma and Tirpák 2012; Literski and Nebelsick 2012). They are characterized by a diameter of over 40 m, palisades on the inner side of the trenches, V- or Y-shaped ditches with few artifacts in the fill, one or more regularly spaced gates/entrances and a lack of notable architecture within the enclosure. Their chronology requires further research based on radiocarbon dating, but was most likely relatively short and can be placed between 4850 and 4700 BC. These structures are assumed to have some kind of ceremonial function, playing an important role related to social integration and remembrance.

A large circular soil mark observed in 2009 to the south of Księgienice Wielkie was assumed to be a rondel-type enclosure (Fig. 1; Czarniak *et al.* 2011). The discovery requires archaeological verification as soil marks are often not open to unambiguous interpretation and may in fact attest to natural geological activity. Another circular structure located near Przyłęgów (Lower Silesia province) was noted during a 2014 aerial survey

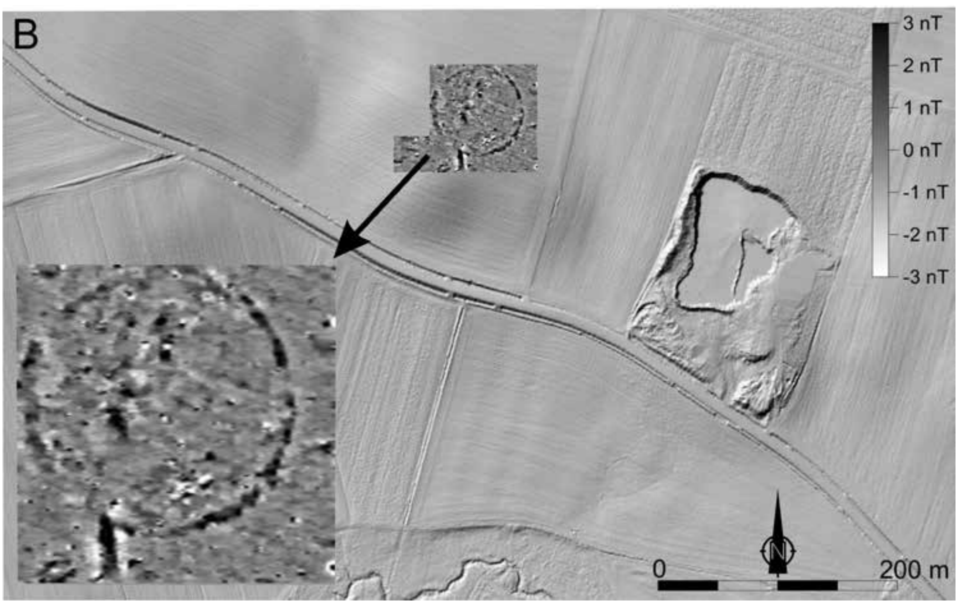

Fig. 3. Przyłęgów (Lower Silesia province). The Eneolithic or Early Bronze Age circular enclosure. A – aerial image (Piotr Wroniecki); B – magnetic map

(Figs 1 and 3). It was a regular circular crop mark, about 80 m in diameter, indicating the existence of a single ditch enclosure. A magnetic survey conducted in the same year verified the aerial data without revealing traces of further ditch features. The width of the ditch was approximately 4–5 m and it was truncated symmetrically in two places, at the southeast and the northwest. There was no evidence in the results of the magnetic prospection either of inner buildings or of an inner palisade. Test trenches confirmed the presence of a single moat with U-shaped profile. The few and very fragmented potsherds discovered in the ditch were hardly a sufficient chronological indicator. Most likely, it was not a typical rondel-type enclosure, but rather a later feature, dating to the Bronze Age or Eneolithic, sometimes referred to as rondeloid-type enclosure. Sites of this sort consisted in most cases of circular ditches, one or more concentric ones (although semi-circular structures adapted to the ground relief are also known, e.g., Hrušovany) and no architecture inside them. In some cases, however, post-built structures and burials or small cemetery enclosures were discovered. They differed from their Neolithic counterparts primarily in the U-shaped sections of the ditches. The assumption is that these structures may have served similar social, symbolic and ceremonial or funeral purposes (Kovárnik 1999; 2003; 2004; Trnka 2011; Spatzier 2012).

Another circular structure that can be dated to the Early Bronze Age based on finds from test trenching was located near Pietrowice Wielkie (Silesia province) through an analysis of publicly available satellite imagery from Google Earth. Magnetic surveying of 2.68 ha revealed that the structure consisted of two concentric ditches, the outer one with a diameter of 190 m and the inner one of about 120 m. The ditches had a width ranging from 8 m to 10 m. Gaps in the ditches in two places suggested the existence of entrance ways. Finally, a smaller linear anomaly located on the inner side of the smaller ditch could be interpreted as a palisade. This anomaly was also truncated in the same places as the ditches, providing further evidence of a passage function (Figs 1 and 4). A large number of diverse magnetic anomalies, other than ditches and palisades, was also registered within and beyond the ditches. A 10 m wide swath near the inner part of the ditches had a much less intensive occurrence of anomalies, suggesting the existence of ramparts in this area. The few visible point anomalies may be associated with features of a different chronology than the ditches and alleged embankments.

Most of the registered point anomalies are oval or circular in shape and possess a diameter of approximately 1–3 m. They are present along the outer edge of the two ditches, particularly in the space between them, as well as in the central part of the site. Excavations revealed as their source trapezoidal pits that may be interpreted as relics of storage pits, which were subsequently turned into places of ritual activity involving animal sacrifices. Other anomalies are to be interpreted most likely as relics of sunken dwellings and production facilities (such as hearths, kilns etc.). Not all need to be related to the enclosure and could represent chronologically different settlement horizons.

Despite the circular morphology of the structure, which may imply association with the previously mentioned Early Bronze Age rondeloid-type enclosures, the large number

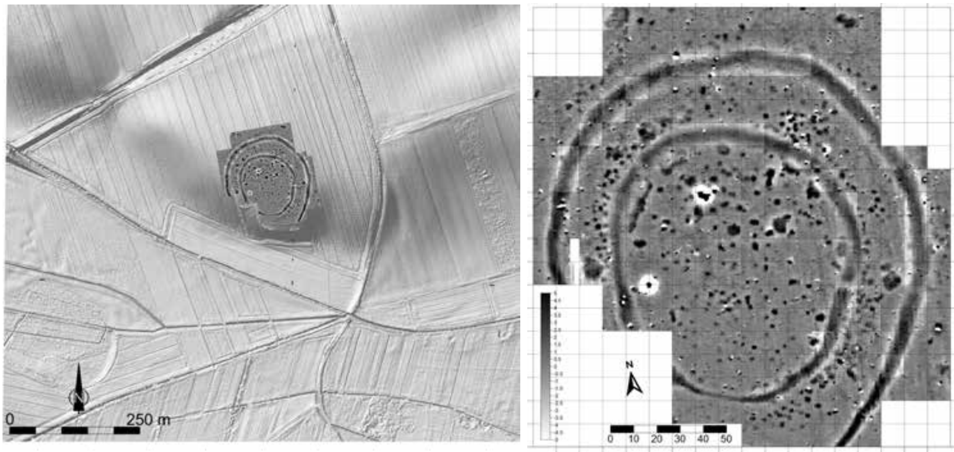

Fig. 4. Pietrowice Wielkie (Silesia province). The Early Bronze Age enclosure, magnetic map

of features revealing settlement activities clearly distinguishes the Pietrowice Wielkie site. The current state of research does not allow for an unambiguous interpretation of functions and forms, but the accumulation of storage pits, especially their concentration in the space between the ditches, is extremely interesting. This may suggest the existence of a centralized system for the storage of agricultural produce, which was common at the time in different parts of Europe and was linked to the advent of social complexity, stratified society, a structured settlement system and division of labor. The Pietrowice Wielkie structure most likely had a defensive function, but its main aim was associated with centralized control over agriculture and craft production. This does not preclude symbolic, social or ritual activities taking place there. Fortified settlements from the same chronological period are known from various parts of Europe, including the immediate neighborhood of Pietrowice Wielkie (e.g., Nowa Cerekiew, Jędrychowice), but they seldom took on the form of regular, circular structures (e.g., Vráble-Fidvár, Budmerice; Bátora *et al.* 2008; 2012; Jelínek *et al.* 2013).

Non-invasive prospection has also brought forth new information about other, mostly irregular sites from the Neolithic, Eneolithic and Early Bronze Ages. One of these, located in Dobkowice and associated with the Jordanów culture, was subjected to a magnetic gradiometry survey (Figs 1 and 5), which covered an area of 1.59 ha (Furmanek *et al.* 2013). The survey recorded a significant number of magnetic anomalies, which could be attributed to diverse human activities as well as possibly geological formations. Of particular prominence was a system of elongated anomalies revealing most likely the presence of ditches or elongated pits. These could be interpreted as remains of a vast enclosure with two ditch/elongated pit systems. The full extent of this enclosure remains unknown as the survey needs to be continued in the northern and western parts of the site.

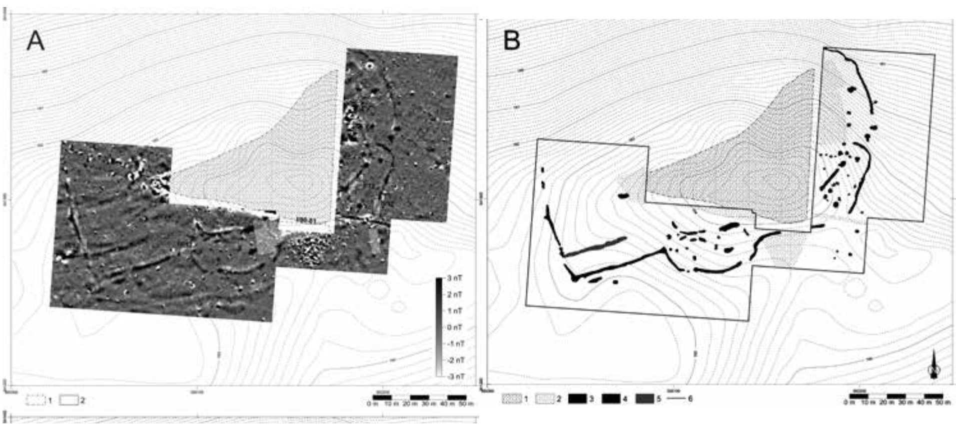

Fig. 5. Dobkowice (Lower Silesia province). Plan of the Jordanow Culture enclosure. A – magnetic map: 1 – location of 1980–1981 excavation trenches; 2 – location of 2012 excavation trenches; B – magnetic survey interpretation: 1 – destroyed area; 2 – modern anomalies; 3 – ditches; 4 – other pits; 5 – possible ditch; 6 – extent of the magnetometer survey

A similar ditched enclosure in Dzielnica (Silesia province) comes from around the same time, but related to the Upper Silesian communities of the Lengyel culture; it was studied with the extensive use of geophysical and geochemical methods (Furmanek *et al.* 2015).

Previous to these investigations the Dobkowice site was interpreted as a corral for cattle (Czarniak 2011). Other settlement features (containing very little remains typical of permanently settled areas) were considered as evidence of temporary camps visited by cattle breeders, only in some instances giving protection to bigger groups of people. Nowadays, there is reason to think that the structures in question played some role in social interactions and ritual activities. This supposition is supported by the presence of burials within the enclosed area and in the ditches, allowing places of this kind to be considered in terms of funeral areas, post-consumption deposits dominated by cattle bones, which may be regarded as remains of feasting, low levels of phosphate content in ditch infill, presence of feather grass (*Stipa* sp.) utilized as decoration or ornament possibly in social and symbolic context Summing up, although it cannot be denied that the enclosed areas might have played a considerable role in the local taskscapes, it is also certain that they were used as places for different social events (burials, feasts etc.).

The results of recent aerial prospection campaigns have yielded new data that will most likely increase the number of known Neolithic and Early Bronze Age ditch enclosures in Silesia. These results, though promising, require however further field verification, especially with regard to their chronology (Figs 1 and 6). Among the candidates for new enclosure sites are structures located in Chrzelice (Opole province), Dębowa (Opole province), Dankowice (Lower Silesia province) and Górzec (Lower Silesia province), which often occupy surprisingly large spaces.

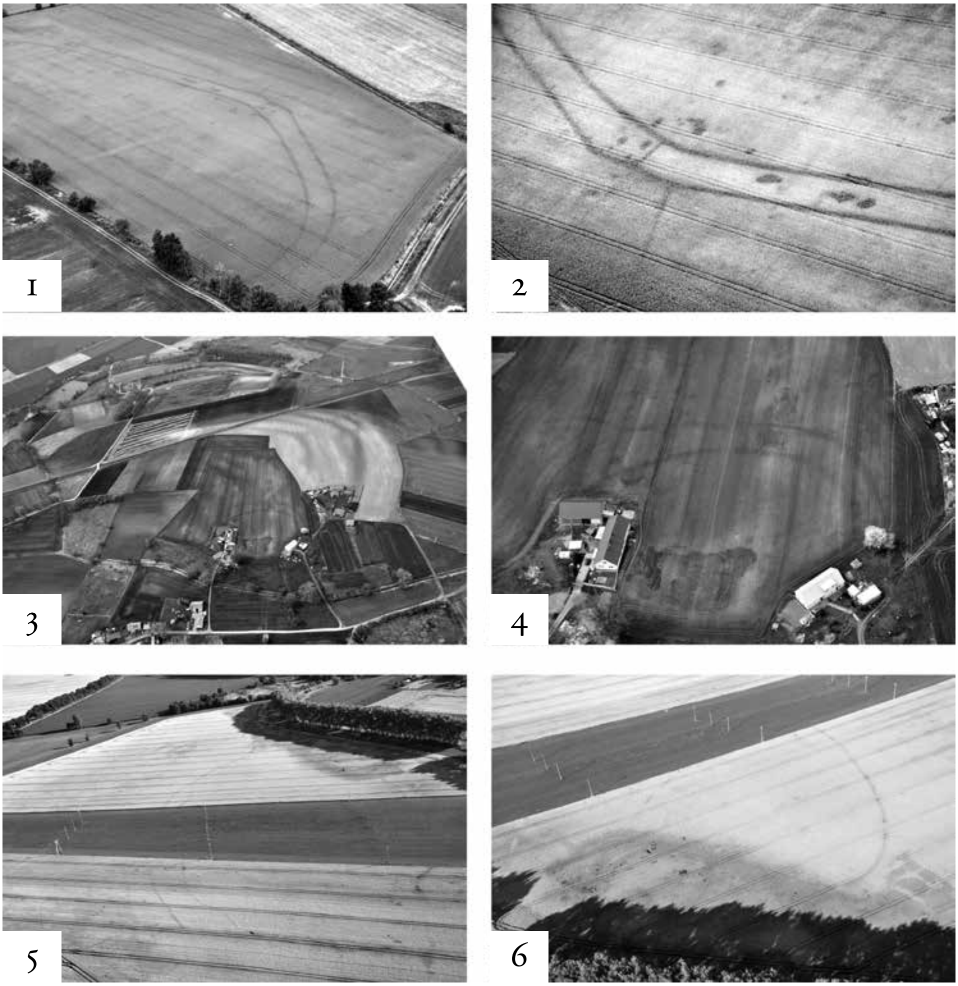

Fig. 6. Examples of recent aerial prospection results: 1–2 – Chrzelice (Opole province), 3–4 – Dębowa (Opole province), 5–6 – Górzec (Lower Silesia province) (Piotr Wroniecki)

The aerial surveys have also helped to better understand places that are known and studied. One such site is located in Janówek (Lower Silesia province) and was occupied by representatives of the Lengyel, Funnel Beaker and Únětice cultures (Figs 1 and 7; Wojciechowski 1973). Traces of known settlement were registered on a promontory that was cut off from the edge of a plateau by a system of ditches and palisades discovered recently and visible as crop marks. These alleged defensive features were positively verified by a small-scale magnetic survey (Figs 1 and 8). On another Neolithic (Funnel Beaker

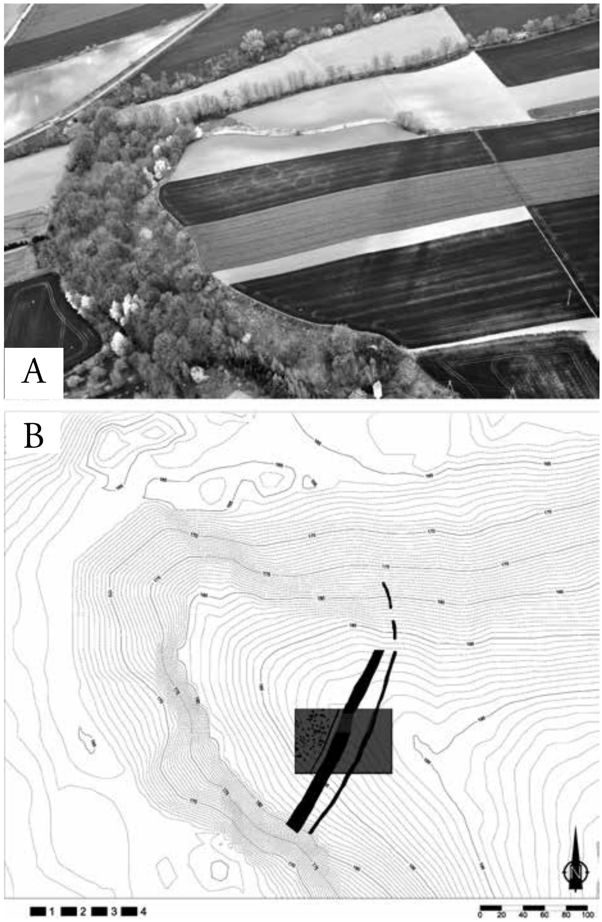

Fig. 7. Janówek (Lower Silesia province). The Neolithic and Early Bronze Age site. A – aerial image (Piotr Wroniecki), B – interpretation of the aerial and magnetic prospection: 1 – extent of the magnetometer survey; 2 – possible settlement pits; 3 – possible ditches (based on cropmarks); 4 – possible ditches (based on the results of the magnetometer survey)

culture) site located in Kietrz (Opole province), the magnetic survey noted, among others, dense clusters of point anomalies forming an oval the size of 35 m by 50 m (Fig. 8; Furmanek *et al.* 2015). These boundaries suggest that the space could have been initially delimited in some way (e.g., palisades, fences) and the features causing the anomalies were created over a relatively short period of time and were associated with similar well-defined activities. Excavations revealed the presence of a diverse range of probable storage pits with few artifacts and some human bones. This area probably did not function as a living

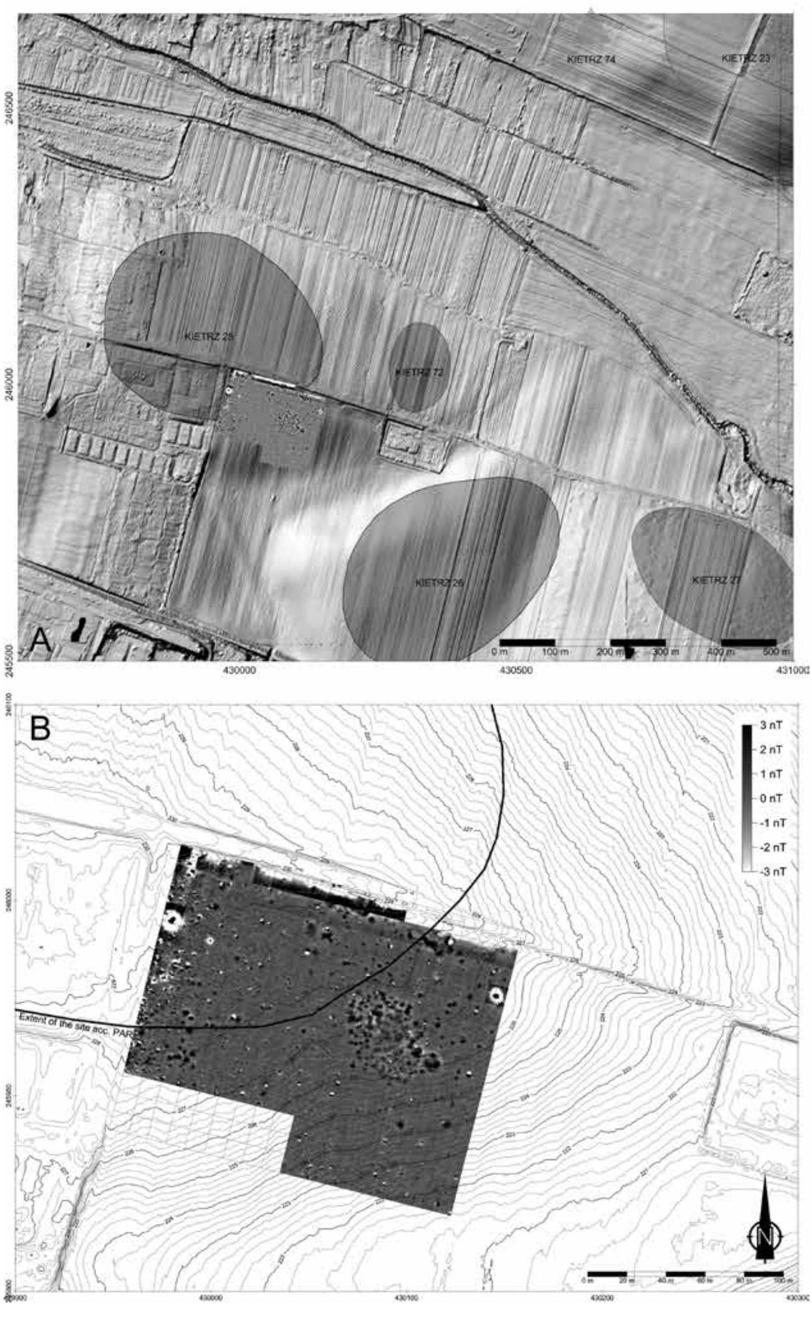

Fig. 8. Kietrz (Opole province). The Neolithic and Early Bronze Age site. A – location of the magnetometer survey, B – magnetic map

space, but rather was associated with the initial processing or storage of agricultural crops. The presence of human remains may also suggest ceremonial activities.

Extremely promising information was also obtained for the Únětice culture defensive settlement in Radłowice (Lower Silesia province). New aerial images show that previous interpretative attempts based on archival aerial imagery and excavation data require a thorough reevaluation (Lasak and Furmanek 2008). The settlement form was probably much larger and more complex than previously thought and covered an area of almost 50 ha.

New research perspectives have also opened for forested areas thanks to the widespread development of Airborne Laser Scanning (ALS) technologies and methodologies. ALS data formed the basis of the Muszkowice Forest project and yielded particularly interesting results (Furmanek and Przybył 2011; Przybył 2014). Until recently megalithic tombs, which are a characteristic element of the European Neolithic landscape, were not known from Silesia. The first megalithic tombs were investigated, or more precisely rediscovered, in Muszkowice in the 1990s. With the application of ALS the number of known monumental cemeteries associated with the Funnel Beaker culture within the Muszkowice forest complex (about 850 ha) increased to 16; within these, at least 26 earthen longbarrows were documented. Three cemetery sites were selected for magnetic surveying and confirmed the presence of megalithic tombs, providing data about their subsurface structural elements, such as stones and boulders that made up the tombs, both *in situ* and displaced as result of subsequent damages. Determining the original shape and size of the tombs was also possible as the currently preserved earthworks are more often than not the result of subsequent destructive natural processes. This was crucial in the verification of previous interpretations of social organization, according to which the size of the tombs and overlying mounds marked the rank and status of the buried individual.

While the effectiveness of both geophysical and aerial prospection in the discovery, documentation and study of monumental Neolithic and Bronze Age features and sites is beyond dispute, these techniques are also capable of registering spatial patterns within settlements and their ranges. Although registration of residential features, particularly timber houses, is problematic, it is possible to discern buildings that followed strict, regular and duplicative rules. Such houses were not only residential structures, but also played important roles in society. Their form and the activities that took place within them, related to their construction, use and ultimately abandonment, were concerned with various aspects, such as identity creation, for example. Thus, even everyday common structures became part of the Neolithic cultural landscape. The morphology of buildings and accompanying features may even be attributed to specific cultural and chronological units, such as Linear Pottery culture. In this case, even if traces of structural elements (evenly spaced timber posts) do not show up in non-invasive survey results, the arrangement and orientation of long pits located alongside houses suffice for an analysis of the settlement layout, as well as for interpretations regarding demographic and social aspects. This is evidenced by numerous examples of Linear Pottery culture settlements surveyed in Europe. In Silesia, the magnetic prospection in Dzielnica (see Furmanek *et al.* 2015) made it possible to determine, despite the large number of anomalies connected with later habitation phases, the extent of residential forms associated with Early Neolithic farmers; the results revealed at least three rows of buildings and enabled an estimate of the number of houses.

An important effect of the application of non-invasive methods is the possibility to document with greater precision the site extents. This is crucial not only for cultural landscape studies, but also for the protection of cultural heritage. In Poland, archaeological resources are evaluated based on the results of extensive fieldwalking surveys as part of the Polish Archaeological Record project (AZP). The implementation of aerial and geophysical prospection (along with large-scale rescue investigations) has demonstrated that many archaeological sites go in fact beyond the recorded extent. The sites presented in this paper all had areas of past human activity that fell beyond the officially registered site ranges. This constitutes the best empirical reason for implementing different methods of non-invasive prospection, such as geochemical, remote sensing and geophysical techniques alongside fieldwalking.

The implementation of modern archaeological prospection methods has produced results that have demonstrated the methods' surprising effectiveness in the study of Neolithic and Early Bronze Age communities. Their application has led to the discovery and documentation of many new, previously unknown archaeological sites, including structures believed not to exist in the Silesia region. They have often contributed to a better understanding of already recorded sites and have been beneficial not only in furthering knowledge of the past, but also in protecting the archaeological heritage. At the same time, they have become equally important as a supplier of multi-faceted empirical data for use in archaeological excavations, not only as basic information about the site, but also as evidence with considerable potential for interpreting social, economic, symbolic and demographic issues. Data obtained by non-invasive techniques are an important, sometimes even fundamental source for the study of prehistoric communities, irrespective of the paradigms applied by researchers.

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Magnetic survey of the abandoned medieval town of Nieszawa

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New Nieszawa was a 15th century medieval urban settlement, covering approximately 22 hectares on the Polish–Teutonic border. The exact location of the town was forgotten until its discovery through aerial prospection in 2006. In just 40 years the town grew into an important economic entity, competing for trade on the Vistula river until its relocation (1460–1462) during the Thirteen Years' War. The site is unique in that it has not been overbuilt by later structures as is common with medieval foundations. It is located in a flood plain approximately 2 km from the urban center of Toruń. Regular non-invasive surveys have revealed the spatial organization of the town in its untouched state from 550 years ago. The Łódź branch of the Scientific Society of Polish Archaeologists carried out three consecutive projects of non-invasive prospection in 2012–2014, using a Bartington Grad 601-2 instrument (0.5 m x 0.25 m sampling) to cover an area of almost 40 ha stretching for more than 1.6 km. The magnetic survey revealed anomalies located on the spot of observed crop marks, and extending far beyond the area open to aerial observation. It verified the existence of subsurface magnetically susceptible deposits indicative of a typical medieval town plan in Poland.

KEY-WORDS: medieval town, aerial photography, magnetic method, heritage protection

INTRODUCTION

Nieszawa is a settlement that changed its location many times during the course of history (Tęgowski 1983). It is currently a small, relatively little known town on the western bank of the Vistula in its middle run (Fig. 1: A), but many times in the past it was witness to, as well as key player in Poland's tumultuous Middle Ages. It was founded as a medieval stronghold in what is now Mała Nieszawka, west of Toruń (Fig. 1: B). In 1230, Duke Konrad I of Mazovia gave it together with the surrounding land to the Teutonic Order, for which it became a strategic command, being the southernmost outpost controlling two crossings across the Vistula (Domagała and Franczuk 1983). It is still not clear whether the brick castle that was built then stood on the older fortifications or in an entirely new location.

In the early 1400s, relations between the Kingdom of Poland and the Teutonic Order soured again. This period of conflict culminated with one of the largest medieval battles

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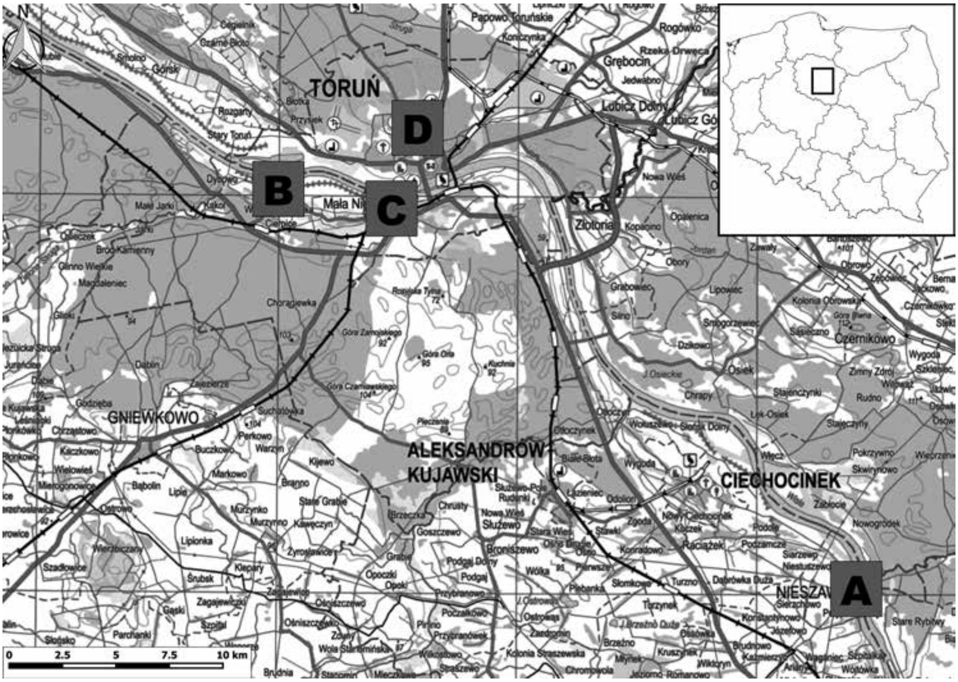

Fig. 1. Map showing the known locations of the Nieszawa settlement within a broader geographic context. A – modern Nieszawa; B – presumed medieval stronghold and ruins of a Teutonic castle, currently Mała Nieszawka; C – location of New Nieszawa, currently in Toruń; D – Toruń historical centre

in Europe that took place near the village of Grunwald/Tannenberg (currently northern Poland). In consequence of these events (Nieszawa's commander was among the prominent Teutonic leaders slain in battle), the armistice treaty between the two warring states was signed at Nieszawa. The Polish kingdom demanded the return of the Nieszawa territory to the Polish state and the issue became another source of armed conflict. In 1422, after another period of warfare, a peace treaty was signed, in the wake of which the Order finally lost its possessions in Kuyavia, including among others the Nieszawa commandry and its estates (Domagała and Franczuk 1992). The stronghold and its fortifications were disassembled by mid 1423, but this did not mark the end of conflicts in the region.

During this period of turmoil, Toruń (Fig. 1: D), a prosperous Teutonic city and a member of the Hanseatic League, dominated the region, profiting from the Vistula trade (timber, wheat, salt, lead). To weaken Toruń's position, in 1425, the Polish king Władysław II Jagiełło located a settlement on the opposite bank (Jóźwiak 2002a; 2002b), only 2 km from Toruń's main square. This new site became known as New Nieszawa/Nowa Nieszawa (Fig. 1: C) and its rise in the immediate neighbourhood of Toruń was the source of economic rivalry between the two states. Although the newly founded settlement was protected by Dybów Castle (erected after 1427, Jóźwiak 2002a), it was raided and destroyed by the joint forces of the Toruń merchants and the Teutonic Knights in 1431 (Domagała 2002). The territory returned to the Polish state in 1436 (Tęgowski 1983). New Nieszawa was also where the Statutes of Nieszawa were signed in 1454 by Władysław's son, Kazimierz IV the Jagiellonian (Jożwiak 2002b), an event that was crucial in the formation of the post-medieval Polish socio-political system.

New Nieszawa became a thriving urban organism, utilising the potential of its location to the fullest. By 1440, it was already exporting more wheat than Toruń, whose merchants started losing their river trade monopoly in the region. Over the course of years Teutonic commander of Toruń repeatedly fell in debt (Janosz-Biskupowa 1954; Jóźwiak 2002b) and historical documents record loans to the Order from New Nieszawa's Jewish community (Jóźwiak 2002b). In 1440, merchants from Toruń and other Teutonic cities formed the Prussian Confederation, a resistance movement aimed against the Teutonic State, which led to open revolt in 1454 and the surrender of Toruń and its commercial potential to the Polish Kingdom. This in turn prompted the events of the Thirteen Years' War (1454–1466). In 1460, Kazimierz IV issued documents relocating New Nieszawa more than 30 km upstream, away from Toruń's mercantile activities (Janosz-Biskupowa 1954; Uziembło 2002). New Nieszawa was relocated between 1460–1462 and as time passed, memory of its location sank into oblivion.

PRESENT TOPOGRAPHY AND PREVIOUS RESEARCH

The development of flood protection infrastructure in the vicinity of Toruń in the 19th century led to the construction of a flood embankment that separated a strip of land along the west bank of the Vistula. This narrow strip, unsuitable for settlement, was turned into farmland (Fig. 2). On the southern side of the embankment, driven by Toruń's expansion

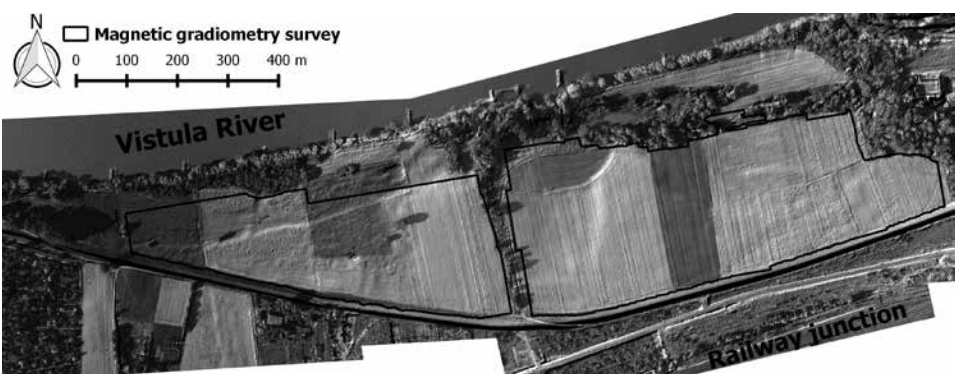

Fig. 2. Current topography of the New Nieszawa site

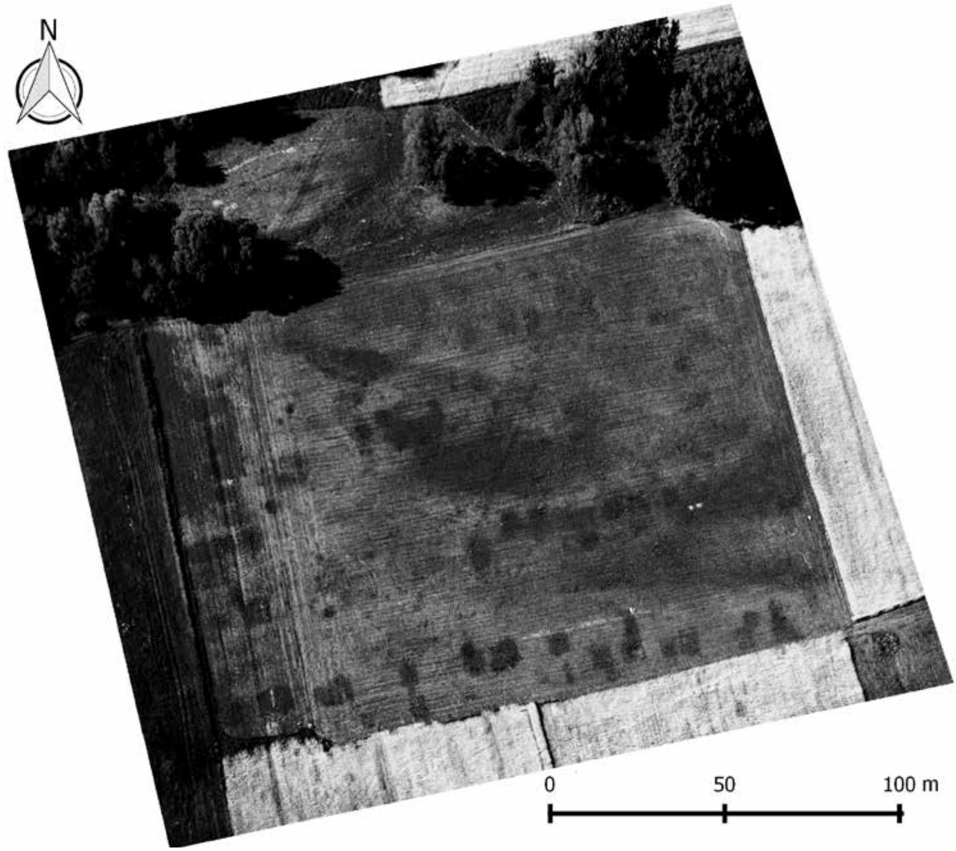

Fig. 3. Rectified aerial image revealing rectangular cropmarks from 2006 (photo W. Stępień)

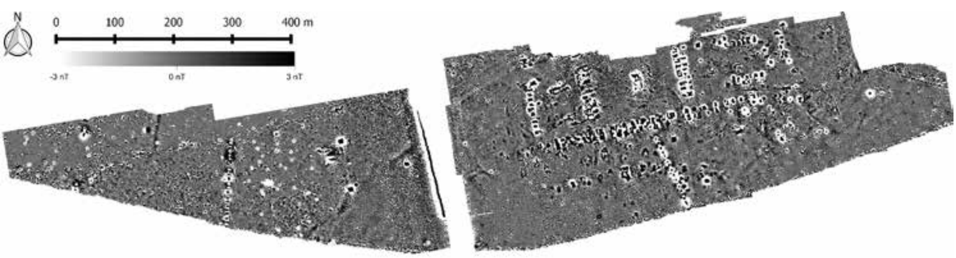

Fig. 4. Grayscale visualisation of magnetic data

and incorporation of the former Podgórz town in 1934 as one of its districts, urban and industrial development followed. Presently an important railroad junction exists south of the embankment, making any archaeological surveying in this area impossible.

Beginning in 2001, aerial prospection paired with systematic monitoring of the area was conducted by Wiesław Stępień. The aerial survey paralleled a research project carried out by archaeologist Lidia Grzeszkiewicz-Kotlewska, who tested the fields between the Vistula River and the embankments in 1999–2001, searching for traces of the medieval city. Multiple trenches were explored, some over 100 m long, recording interesting artifacts and traces of architectural structures from the Middle Ages, but no direct indications of a once prospering city (Grzeszkiewicz-Kotlewska 1999a; 1999b). In 2006, the aerial survey revealed a series of crop marks of various sizes, forming a system of rectangular outlines that called to mind the layout of a town square surrounded by buildings (Fig. 3). Further geophysical work proved that this was not in fact the central main square, but a part of the town.

Interestingly, at about the same time another abandoned medieval town, Stare Szamotuły, was discovered in similar circumstances, that is, aerial discovery followed by non-invasive prospection (Dernoga *et al.* 2007: 131–133). That work was in fact a model for the Nieszawa non-invasive project.

MAGNETIC PROSPECTION

Starting in 2012, three projects for non-invasive prospection of medieval Nieszawa were granted to the Łódź branch of the Scientific Society of Polish Archaeologists by the Ministry of Culture and National Heritage. In the course of three years, an area of almost 40 ha stretching more than 1.6 km was subject to magnetic prospection conducted with a Bartington Grad601-2 gradiometer at a sampling rate of 0.5 m x 0.25 m (Fig. 4).

The studied area was relatively clear of modern interference, except for two pipes associated with field usage and a strong signal stemming from a sewage pipe. Magnetic surveys revealed anomalies located on the spot of the observed crop marks as well as stretching far beyond the area open to aerial observation. Anomalies revealed the existence of subsurface magnetic deposits that formed a pattern indicative of a typical medieval town plan in Poland (Fig. 5). Numerous point anomalies suggested the presence of debris and artifacts (bricks, ferrous items) with high magnetic properties, traces of past and present (including destructive ploughing) anthropic activity.

The most common rectangular anomalies, approximately 6 m by 15 m, have their source probably in the burnt fill (daub, wood, waste from higher levels and in some places perhaps bricks) of house cellars, possible half-timber structures to judge by earlier archaeological work (Grzeszkiewicz-Kotlewska 1999a; 1999b).

Linear anomalies may trace a moat and palisade, perhaps even a town gate (Fig. 6: A), but, interestingly, they do not encircle the town. Either it was not fully enclosed or these features

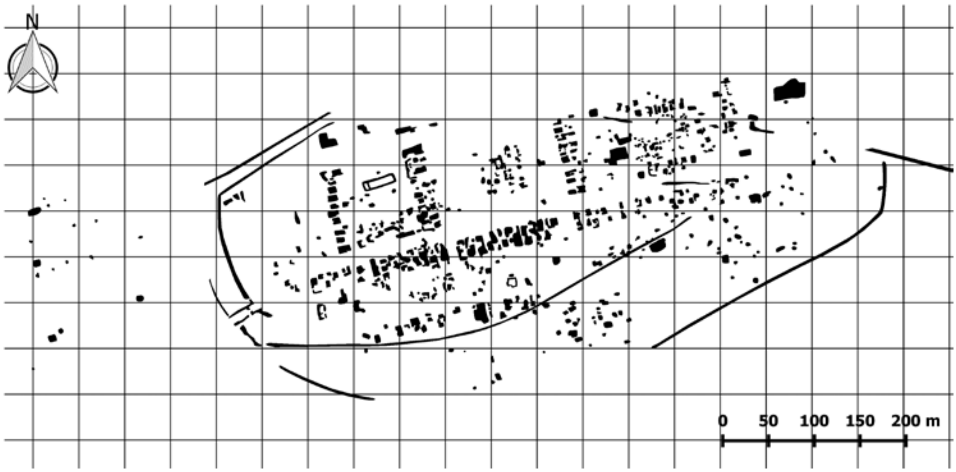

Fig. 5. Interpretation of magnetic and aerial data

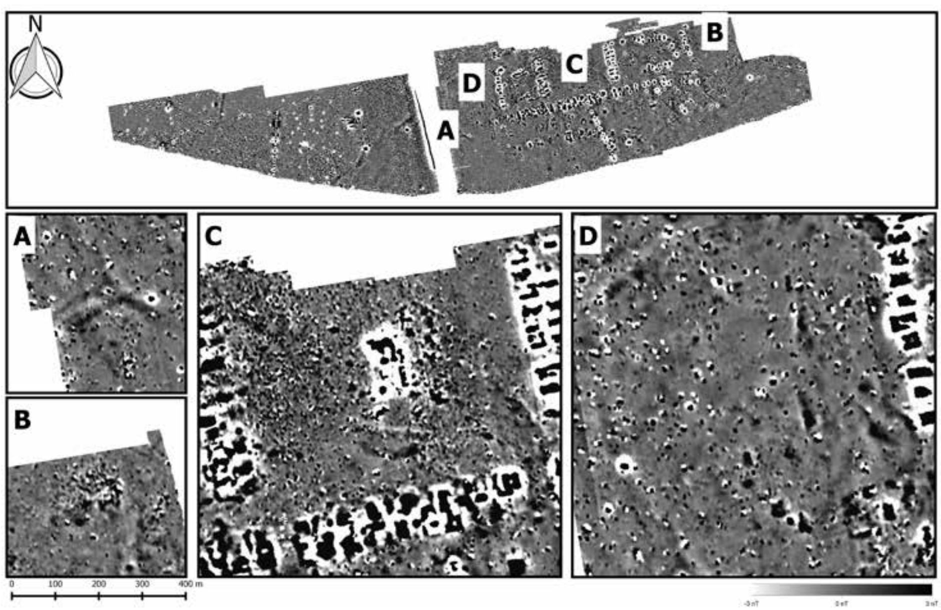

Fig. 6. Selected anomalies: A – possible town limits with bridge/town gate; B – church identified in earlier excavations; C – main town market square; D – possible secondary market area

were destroyed when the anti-flood infrastructure was constructed. More work is needed, especially as features of this kind seldom survive into modern times.

Some of the anomalies can be identified as buildings examined earlier in the 1999–2001 excavations by Grzeszkiewicz-Kotlewska, i.e., the brick church of St. Nicolaus (which was disassembled in the 19th century) with its graveyard (Fig. 6: B).

The central point of medieval Nieszawa was its main square with accompanying buildings, presumably town hall, market stalls and municipal building (Fig. 6: C). The area interpreted as the square (measuring approximately 140 m by 140 m) is surrounded on all sides by magnetic anomalies interpreted as architecture fronts (except for the northern side where the presence of trees prevented the area from being surveyed). A northern frontage may be presupposed based on a few registered anomalies and historical analogies. This area is also heavily contaminated with point dipolar anomalies, which are often associated with modern debris. In this case, the spatial arrangement of these anomalies within the main square suggests that they may be relics of intensive past occupation of this area. Taking into account that town squares functioned as meeting and trade hubs, they may be either remnants of trade and production activities or perhaps destructs of pavements or higher class architecture that most likely existed in the area. This part of the site is currently not ploughed and surface observation could not yield any further clues as to the provenance of the anomalies.

There are many areas within the town limits, which are characterised by stable magnetic vlues. One such area between the presumed town gate and main square may be identified as a probable secondary market place (Fig. 6: D). This area was probably just outside the denser urban district. The location of other buildings known from historical sources, such as, for example, church structures and the church of St. Hedwig (moved to modern Nieszawa in the end of the 15th century), is still unknown and remains an open matter.

The urban layout of the town was highly organised. Streets running parallel to one another led to the south, west and east (to Dybów Castle), starting at the corners of the main square and creating the main communication arteries of the town. Urban plots with structural remains were located between them. They were rectangular in shape, and their arrangement was probably compact in order to maximise the utilisation of available space. The results of the magnetic survey allowed for an initial reconstruction of plot size at 11 m by 40 m. The further away from the main square, the less intensely overbuilt and organised the plots seem to be. The features within the plots located in the main square generate much stronger anomalies and are in general larger than those further away, perhaps owing to higher social standing, of the residents, their prosperity and hence the size of the homesteads.

SUMMARY

New Nieszawa was a thriving medieval urban organism, covering approximately 22 hectares on the restless border between the Kingdom of Poland and the Teutonic

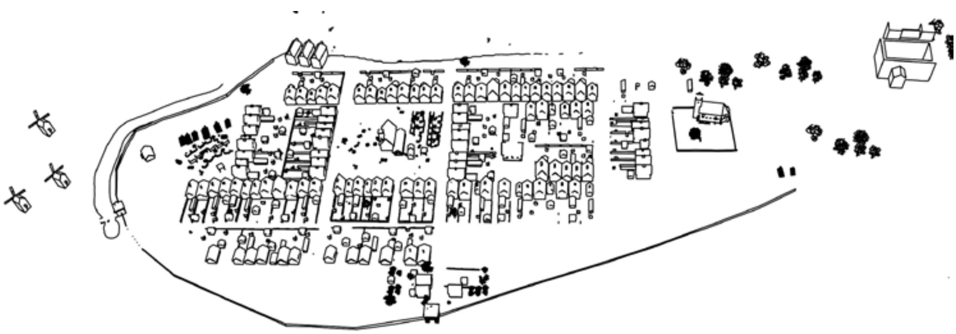

Fig. 7. Artist's reconstruction of New Nieszawa based on non-invasive data (image J. Zakrzewski)

Order (Fig. 7). It was a place were real estate was at a premium, acquired by, among others, bishop Stanisław Ciołek (1382–1437), Royal Secretary and Vice-Chancellor to Władysław II Jagiełło (Janosz-Biskupowa 1954). In just 40 years, the town grew into an important economic entity, successfully competing in trade on the Vistula until its relocation during the Thirteen Years' War.

The uniqueness of this site is indisputable as earlier foundations of other medieval towns are often overbuilt by later structures. In this case, the site is located on a flood plain and has historically been unattractive for investment and settlement. The circumstances of its conservation were fortunate at the very least. Located approximately 2 km from the centre of Toruń, the site exists separated from the ongoing development and urban sprawl, ironically at the same time protected and endangered by the floods of the Vistula for over half a millennium. The situation is changing however. New Nieszawa has yet to be written into the national monument registry and endangered by modern development. One such threat is the ever-growing number of people using metal detectors as a hobbyist free-time activity, looking for artifacts in various places, including archaeological sites. Located within the boundaries of Toruń, the Nieszawa site presents a convenient opportunity for such activities. Furthermore, the location of magnetic anomalies corresponding to a presumed medieval town gate directly next to a newly built sewage pipeline highlights the threat of irrreversible destruction of cultural heritage wherever archaeological supervision is lacking; it also shows the threat to non-invasive prospection in the future (due to the strong magnetic field of the installation and disturbance of subsurface strata). In this case, again by chance, the sewage pipeline missed the supposed town limits by just a few meters. This is an alarming example of how once non-endangered archaeological sites such as New Nieszawa are currently becoming liable to destruction and require a re-evaluation of heritage resources and their protection strategies.

Regular non-invasive surveys also reveal the effort that was put into the spatial organization of the town, showing this large state investment in a nearly ideally petrified state from 550 years ago. These rare circumstances, extremely beneficial from the point of view of archaeological prospection, provide a means of understanding Nieszawa in the grander scheme of things. It was not just another failed local investment, but part of a larger political gamble initiated by the Kingdom of Poland in the centuries-old conflict with the Teutonic State, both states vying for dominance in the region.

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Magnetic prospection in the service of uncovering the Hellenistic and Roman port of Berenike on the Red Sea in Egypt

Iwona Zych[a] and Tomasz Herbich[b]

Magnetic prospection was chosen as a non-invasive survey method for covering the expanse of the Hellenistic and Roman city and port of Berenike on the Red Sea in Egypt. A test run in 1999 confirmed the potential of the method in the specific conditions of the site and its geology; since 2008 the Polish–American project excavating the site has completed a full-site prospection, revealing surprising data for consideration in the interpretation of site topography and individual architectural remains. The article gives background on the topography of the site and explores three areas of the site: the western district, the southwestern bay and the urban mound in the east, where the results of magnetic prospection have been particularly telling and where, combined with archaeological feedback, they have contributed to a new understanding of the ancient remains. The discussion also poses ideas concerning the interpretation of site topography overall and follows up with prospects for the surveyors in the coming seasons.

KEY-WORDS: magnetic prospection, Berenike, port, fortifications, urban insulae, street grid, Hellenistic fort

INTRODUCTION

The port of Berenike Trogodytica, as it was known to the ancients, was said to have been established by Ptolemy II Philadelphus in the first quarter of the 3rd century BC (Pliny, *Natural History* 6.33.168) (Woźniak, Rądkowska 2014: 507) and there is reason to believe that the idea for the undertaking was at least conceived shortly before the death of the king's mother and wife of Ptolemy I, Berenike, after whom the town was named (before 279 or 268 BC). The harbour was part of a strategic plan to network the western coast of the Red Sea (and the Nile Valley via a desert road) with the distant lands beyond the Horn of Africa, from whence issued the wealth of the kingdom, whether it be gold, slaves or live elephants used as veritable 'tanks' in Hellenistic warfare.

Over the next 800 years or so the city was a player in the rising and ebbing global trade that passed through the Red Sea, connecting first the Ptolemaic kingdom of Egypt

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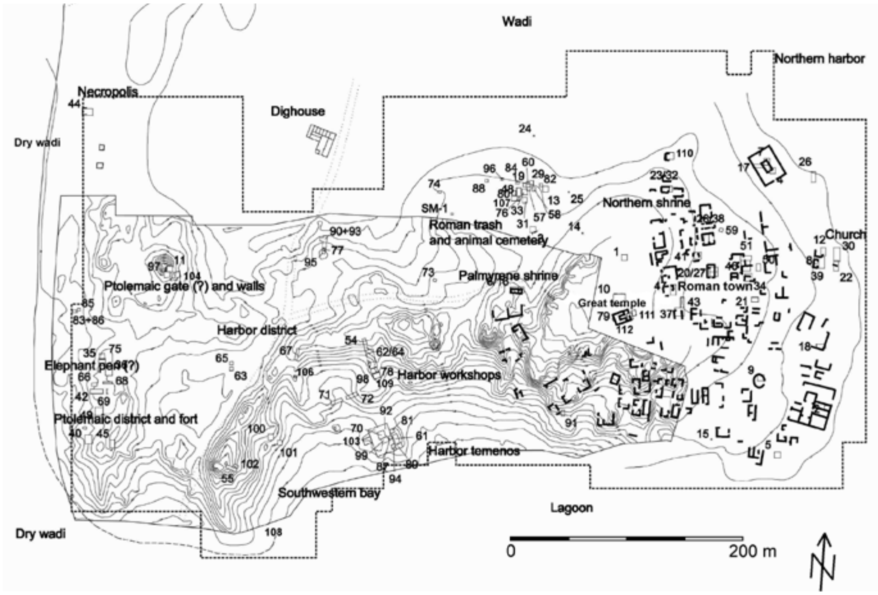

Fig. 1. Map of the site with localization of archaeological trenches and location of walls in the urban area according to a topographical survey carried out in 1994 (Aldsworth *et al.* 1995). The extent of the magnetic survey is outlined with a dashed line. The trenches are marked with numerals, which appear in the text preceded by the abbreviation BE and respective season, from (19)94 to (20)15 (the first trench dug by the Polish–American project was BE09-54. Plan update B. Wojciechowski, 2014)

and then the Roman Empire with the nearer regions of Arabia Felix and East Africa and the more distant and exotic lands around the Indian Ocean. Its role is highlighted by numerous mentions in ancient written sources, e.g., Strabo, *Geography*; Pliny the Elder, *Natural History*, *Periplus of the Erythraean Sea*, and its location was marked in a number of ancient maps and itineraries, suffice it to mention Claudius Ptolemy's *Geography*, the *Tabula Peutingeriana* and *Itinerarium Antoniniana*. The latest source speaks of the town still existing in the early 6th century, on the eve of the first wave of the plague that decimated Egypt in this century. There is no direct evidence for why the port was abandoned in this period; all that is clear is that other harbours to the north and south of Berenike took over its role in the early Islamic period (Sidebotham 1999).

The magic of the name drew explorers in the Modern Age, the first to attempt to identify its location being the Portuguese Dom João de Castro in the mid-16th century and the French J.B. Bourguignon D'Anville in the 18th century. The first explorer to write at length about the site was Giovanni Belzoni, who visited the site in 1818 (Belzoni 1822). Close in his footsteps came the Englishman John Gardner Wilkinson, who produced the first and notably accurate plan of the town in 1826. He also excavated the site of the Great

Fig. 2. View of the urban mound. Tops of walls are marked by low ridges covered by coral heads (Photo T. Herbich)

Temple, giving it the monicker of the Serapis Temple (Wilkinson 1835), an identification that has recently been put into doubt (Sidebotham, Zych forthcoming b).

In 1994, an American–Dutch expedition from the Universities of Delaware and Leiden started regular investigations of the site. The team concentrated on the visible remains around the temple (Fig. 2) as well as testing the area immediately to the west of the city mound. Following a break in the work due to external circumstances beyond the archaeologists' control, excavations were taken up again, in 2008, by a Polish–American expedition from the Polish Centre of Mediterranean Archaeology of the University of Warsaw and the University of Delaware. A total of sixteen seasons to date in the field (and the project is ongoing) have confirmed beyond all doubt the identification of the city in epigraphic sources and its far-flung commercial network extending from the Roman Mediterranean to Arabia, Africa and distant India.

UNDERSTANDING SITE TOPOGRAPHY PRIOR TO THE MAGNETIC SURVEY

The 19th and 20th century ground surveys, rounded off with a geological appraisal of the location carried out primarily in the 1995 season by James A. Harrell (1996), situated the urban site on a on a presumed fossil-reef promontory, between the 'pincers' of two large wadis emptying into the sea. Nowadays, the highest parts of this mound, covering the roof of the Great Temple, have an altitude of 7.18 m a.s.l. According to Harrell (1996: 112), the original ground surface on which the first settlement was

Fig. 3. Satellite image of the site. A – western district; B – southwestern bay; C – urban mound. Arrows mark the ridge. Dashed line marks the extent of the magnetic survey (Google Earth, processing T. Herbich)

built would have been less than 2 m a.s.l., thus the accumulations forming the urban mound run more than 5 m deep in the highest parts on the central-western fringes of the mound, that is, where the ruins of the Great Temple are preserved right up to and including the roof of the original structure.

Sand captured in the ruins of the abandoned town has formed a soft blanketing layer over the walls of buildings that were constructed of coral heads, the irregular cobble-sized elements of a fossil reef that were used prolifically in Roman times in wall construction, reinforced at the corners with squared blocks of gypsum anhydrite. The sand accumulated slowly allowing the tops of the walls, unprotected once the presumed wooden roofs had collapsed, to melt and scatter, leaving discernible rows of coral heads marking building layouts (Fig. 2). A thorough topographical survey of the site in 1994, when the Dutch–American project initiated research, produced a plan of the site that recorded all remains visible on the ground surface, set within a topographical grid that has been used by the project ever since (Aldsworth *et al.* 1995) (Fig. 1). A preliminary interpretation of the town layout was based on this survey and was subsequently verified in point excavations conducted between 1995 and 2001 (Sidebotham, Wendrich 2007).

The highest part of the urban mound encompasses houses organized along at least one major *decumanus,* leading from the Great Temple toward the sea, and at least two major *cardines* intersecting with it, as well as a number of lesser streets organized on a fairly regular grid. To the north, east and south of this city center, proved by excavations to contain the nuclear late Roman city, the present ground surface descends rather abruptly toward the *sabkha* or salt flat that forms the present coastline.

To the west of the Great Temple site, extending in a sweeping arc, is a ridge that is evident both on the ground and in satellite imagery (Fig. 3). The top of this ridge is roughly 5 m a.s.l. and even today it is the most convenient passage from the urban area to the western outskirts of the site. It encloses a bay (referred to as the southwestern bay of Berenike) that appears to have been a natural landing place used during early Roman times, as demonstrated by the results of recent excavations and core-drilling (Sidebotham, Zych 2010; 2012; forthcoming a). The ridge is distinct despite a very gentle falling off on either side and it curves in markedly at the southern end. A kind of 'island' with remains of coral-head architecture was evident from the start in the center of the bay, already close to the edge of the silted up wadi. The course of both wadis encircling the site is marked by the presence of characteristic bushes and turtleback' formations.

Beyond this ridge to the west and northwest rises a rocky plateau separated from the ridge on the east by swathes of sand and delimited on the west by the shallow valley of the wadi, which can be marshy in places even today and which generally shows the cracked dried surface of water-driven seasonal deposits silting it up regularly during the winter seasons. The flatness of this plateau is broken only by occasional small mounds barely rising above the ground in the northern part; the one marked mound in this area has been excavated and proven to contain substantial architectural remains from the Hellenistic and early Roman periods (Sidebotham, Wendrich 1995: xx–yy). An elongated rise in the ground, cut through by the modern road, which is also in all probability the ancient caravan trail leading into the harbour town, conceals the remains of mausolea and masonry tombs, including at least one deep rock-cut shaft and burials in rock-cut pits (Sidebotham, Wendrich 2002: xx). More tombs were identified in 2015 on a rock outlier rising west of the Berenike site, at a distance of some 100 m beyond the western wadi (Sidebotham, Zych forthcoming a).

The lie of the land to the north of the described bay ridge and west of the town mound recalls a gentle hollow that extends all the way to the rising ridge of the cemetery in the west and passes gently into the plateau on the west. Surface finds from this area, especially the northeastern and central parts, suggested from the start that the rubbish dumps of the town were located here. Since the caravan road leading from the Nile Valley led straight into this area, through a dip in the ridge with the ancient necropolis (as described above), it is conceivable that the infrastructure necessary to service the

Fig. 4. General view across the site of Berenike; archaeologist/geophysicist Dawid Święch directing his two-man team of Ababda workmen during the prospection of the site in 2009 (Photo I. Zych)

transport industry to and from the harbour — at the very least, the water and fodder, as well as temporary shelter for animals, and the loading and unloading of goods and their provisional storage — had been located here. On the surface, however, there is nothing to be observed, except for gentle mounds marked with middens of broken seashells and potsherds indicative of occupation in the Hellenistic and Roman periods.

TRYING MAGNETOMETRY

The ancient site, including the necropolis, tops 30 ha in area, making it a herculean effort to even try to investigate the whole town by classical archaeological methods. Even as the American–Dutch expedition started to explore the ancient remains, concentrating on detailed interdisciplinary research of finds coming from small-sized trenches, the magnetic method was starting a slow but highly effective march through field archaeology in Egypt (Herbich 2003). By 1999 the time the situation turned for considering geophysical prospection in Berenike. Two methods were logistically possible at the time in Egypt: electrical resistivity and magnetic prospection. However, the dryness of the location and the geological make-up, that is, highly resistive sands and gravel, excluded the former of the two methods. As for the latter one, it seemed that magnetic susceptibility of fossil coral heads and gypsum anhydrite blocks, which were proved by excavations to be the chief building material in Berenike, was too low to contrast them with the sand and gravel matrix, in which they lay concealed. In 1999, a test of the method was carried out, choosing the western part of the site where no traces of architecture could be observed on the surface, but where there was sufficient evidence of slag and copper to suggest some kind of industrial activity. Industrial remains in the form of hearths and furnaces generate high-amplitude anomalies that are easy to trace with the magnetic method (Gaffney, Gater 2003: 156-157).

A Geoscan Research FM36 gradiometer was used for the test. The results proved satisfactory beyond all expectations. Not only were traces of presumed industrial activity observed

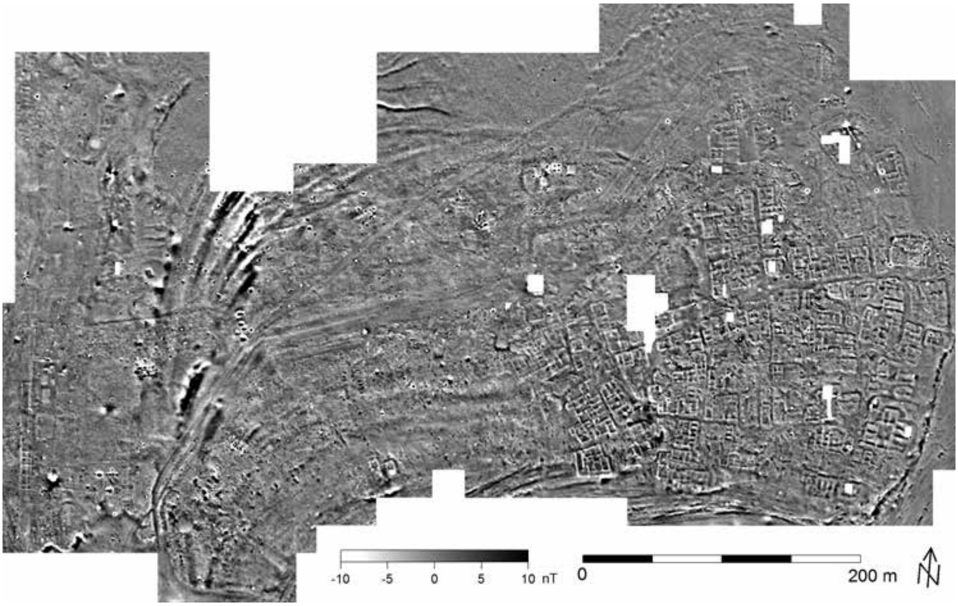

Fig. 5. Magnetic map of Berenike 1999, 2008–2015. Fluxgate gradiometers Geoscan Research FM36/FM256; sampling grid 0.25 x 0.50 m, parallel/zigzag mode. Measurements Tomasz Herbich, Dawid Święch, Robert Ryndziewicz, processing T. Herbich

on the magnetic map, but a surprisingly clear arrangement of architectural remains was also discovered (Herbich 2003: 50-52; 2007). These structures were verified archaeologically and shown to be constructed of large gypsum anhydrite blocks with absolutely no magnetic properties. It was the sand matrix enveloping it that turned out to contain substantial amounts of iron oxides of magnetic susceptibility high enough to make the walls stand out as strong negative anomalies. The test demonstrated the potential of the magnetic method in the investigation of the town topography and only the unfortunate termination of the American–Dutch project in 2001 stopped the survey from flourishing into a full-scale project. When work became possible again with the Polish–American team, magnetic prospection was considered as one of the top priorities. Between 2008 and 2015 practically the whole site (roughly 26 ha) was covered with the survey (Figs 3 and 5) and the results were successively verified in point excavations as well as used to plan further digging.

REVEALING AN UNKNOWN BERENIKE

Archaeological feedback from follow-up excavations has helped to answer questions concerning the interpretation of the survey results. But the opposite has also been true with characteristic magnetic anomalies aiding archaeologists in re-directing their thinking regarding

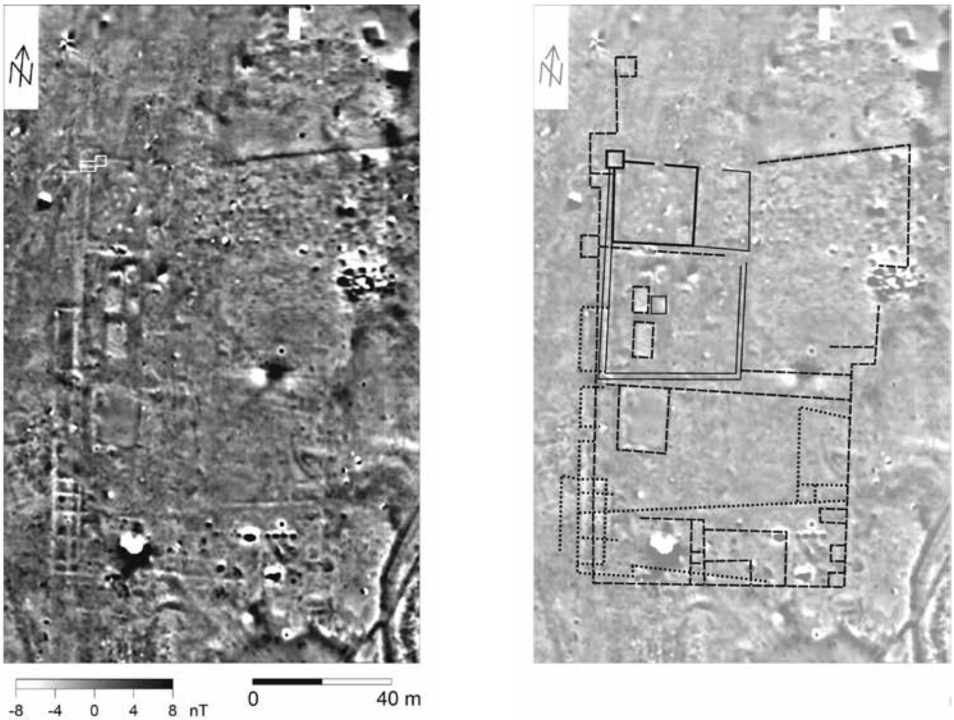

Fig. 6. Western district with the Hellenistic fort and associated architecture. Left: magnetic map; white box - BE12-83/85/86; right: reconstruction of building phases based on an analysis of the magnetic map, supported in a limited extent by archaeological feedback. Solid line – earliest phase (*tetrapyrgion*); dashed line – second phase with elephant pen; dotted line – latest phase (Reconstruction of development phases after Woźniak, Rądkowska 2014: Fig. 8)

Fig. 7. Foundation trench of the northwestern corner tower of the *tetrapyrgion* fort, view after excavations; the stone wall was robbed out completely, leaving pracctically only the trench outline (BE12-83/85/86) (Photo S.E. Sidebotham)

the urban planning of the harbour town and its development over time (e.g. Sidebotham 2011: 60–61, 205; Rądkowska, Woźniak 2011). A more detailed look at three areas of Berenike: the western plateau, the southwestern bay and the town mound, explores the interrelation of archaeology and geophysics on this site and the results that the combined application of magnetic remote sensing and archaeological testing can lead to.

The western plateau: Hellenistic fortifications

The magnetic prospection of the western plateau brought results that left no doubt as to the usefulness of the method. The strong negative anomalies that were revealed in the test and followed up in the survey carried out in 2010 demonstrated not only the presence of substantial architectural remains, but also that these anomalies formed evident, "readable" layouts that could be studied and interpreted. There is nothing on the surface in this part of the site (except for a few low mounds with scatters of coral heads in the northern part of this area) to suggest the presence of what now is believed to have been the core of the early Hellenistic military foundation.

Archaeological feedback during the original test in 1999/2000 made it clear that the architecture consisted of large, dressed gypsum anhydrite blocks. Based on this conviction, archaeologists opened in 2012 a trench (BE12-83/85/86) to explore a square feature that promised to be a corner tower of a larger establishment, possibly a fort (Fig. 6). This idea was proposed by Marek Woźniak based on his knowledge of early Hellenistic military architecture. The surprising feedback from this trench was that the same strong negative anomaly was produced by 'ghost' walls, meaning shallow foundation trenches cut in bedrock and backfilled with material that was different from the surrounding sand and gravel matrix (Woźniak, Rądkowska 2014: 516ff. and Figs 6–7). For now and based on other examples from the site (see below), it seems that the holes left by the salvage of good quality building material for other construction projects (presumably sometime in the early Roman period, that is, the late 1st century BC or early 1st century AD) were filled with drifted sand that quickly hardened into an impermeable layer thanks to precipitating salt. These concreted sand 'caps' have been found consistently in all the trenches and may be the effect of climatic change occurring in the first centuries AD when global temperatures appear to have cooled and a greater humidity apparently ensued.

Hellenistic amphorae with stamped handles, chiefly an early 3rd century Rhodian "button" stamp, fortuitously dated the original building foundation to the period when the fort known from the written sources was established. Woźniak's combined interpretation (Figs 6 right) of the results of the magnetic survey, the excavations and his analysis of the feedback from earlier trenches dug on the western plateau led him to suggest that the tower was part of a *tetrapyrgion*, a typical rectangular fort that was practically routine-built by Greek army engineers wherever necessary on the fringes of the Hellenistic realm (Woźniak, Rądkowska 2014: especially Fig. 8, on the far left). He has also suggested at least two further phases in the development of the original foundation (Woźniak, Rądkowska 2014: especially Fig. 8, center and far right), encompassing an area surrounded by a V-shaped ditch (three trenches dug along two sides of this installation) and interpreted tentatively as the outer perimeter of an animal pen intended in all probability for the live wild elephants that were disembarked from ships bringing them in from hunting locations in East Africa. The ditch was shortly filled in and less substantial walls were built instead, parts of which have survived, because they were constructed of smaller broken stones that did not excite the imagination of the early Roman builders who salvaged building blocks for more substantial architecture. In any case, these later walls coupled with the backfilled ditches marked off by the concreted salt deposits can be traced on the magnetic map.

Excavations in another trench located on the spot of a Hellenistic waste dump (BE13-90/93 Fig. 1) furthered the positive feedback regarding interpretation of various linear anomalies crossing the neck of the promontory, from the western plateau in the west to the urban site on the east (Fig. 5). The unexpected discovery of a huge stone wall, mostly robbed out sometime at the turn of the eras, was matched up with anomalies observed on the magnetic map and subsequently traced over most of this area (Zych, Sidebotham forthcoming). It now appears that the early Hellenistic foundation consisted of the fort and attached "elephant pen" (assuming the correctness of this interpretation), a natural landing place in the southwestern bay or lagoon and the expanse of land to the north of the bay and toward the promontory made of the fossil reef, protected from the landside with a regulation wall reinforced with towers.

The most recent part of the magnetic survey conducted around the northern part of the urban mound has revealed distinct linear anomalies, almost like a casemate structure, turning a right angle, as if sheltering the promontory where the civil city was located (Figs 5 and 13 for close-up). Archaeological testing is planned to establish the nature and dating of the feature(s) that have produced this image. They may well be part of the original Hellenistic walls fortifying the site.

As an aside, one can point out distinct irregular, sinuous "spills", looking somewhat like claws, leading away from this anomaly to the west, toward the rubbish dumps of Roman times (Fig. 13). They are present also in other parts of the magnetic map and appear to reflect natural erosion of a slope, caused by heavy water surges carving their way through deposits on the edge of a plateau or higher ground; the material taken down with the water seems to have been of high magnetic susceptibility. In this case, the solitary anomaly along the entire length of this as yet unrecognized linear feature could mean that it had constituted a solid obstacle with just one gap (intentional?) at this spot.

The southwestern bay: early Roman landing place

The southwestern bay, as a highly promising location for the harbour, was mapped during the topographic survey in 1994. The survey revealed a pincer-like rectangular form (see Fig. 1)

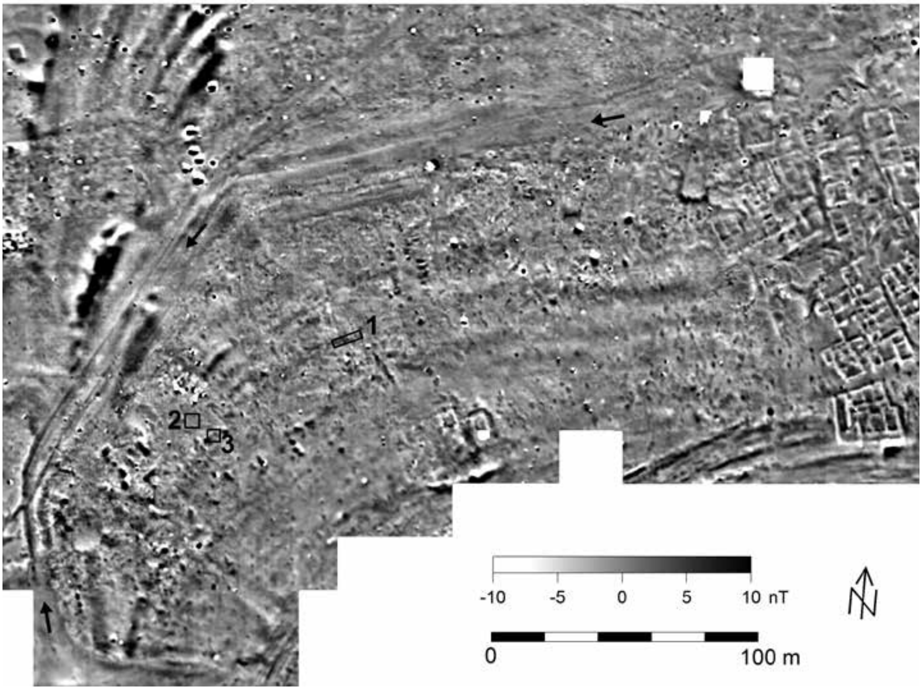

Fig. 8. Southwestern bay, magnetic map. Arrows mark the anomalies corresponding to the ridge. 1 - trench BE11-71; 2 - BE14-100; 3 - BE14-101

that was fondly though of initially as a built port with masonry waterfronts, resembling better known Mediterranean harbours. This hypothesis (used in reconstructions, e.g., Sidebotham *et al.* 2008: Fig. 7.18; see also Sidebotham, Zych 2011: xx–yy). lasted until the excavators realized, based on archaeological stratigraphy, that the sea could not have come up this far into the bay, up to the crescent-shaped ridge at the northern edge where the archaeological remains were recorded at 4–5 m above sea level.

The bay was designated as a priority when the Polish–American project reopened research at the site in 2008. The magnetic survey showed linear features, indicating clearly the presence of manmade(?) features within the ridge which runs around the southwestern bay, its top at an altitude of roughly 5 m above sea level (Fig. 8). The top is wide enough even today to act as a roadway, something like the Alexandrian Heptastadium, if it may be said so, running for about a quarter of a kilometer and turning in at the southern end to shelter the natural landing place within the bay from the rapid flow of rainwater down the western wadi, emptying into the lagoon. Flash floods continue to be a real hazard even today, so the southern sheltering arm of the bay may have imaginably protected whatever boats had docked on the beach. It is still

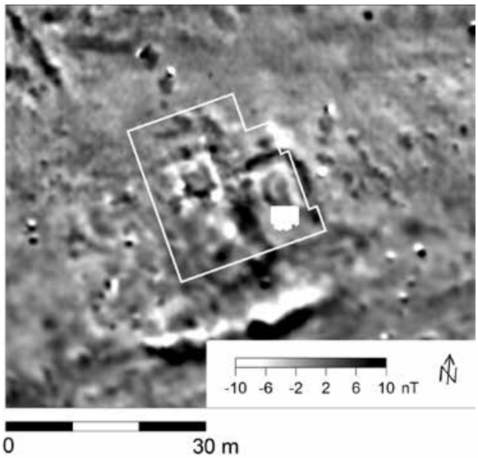

Fig. 9. Magnetic map of the harbour island temenos in the southwestern bay (box outlines area excavated or cleaned)

Fig. 10. The Lotus Temple on the harbour island temenos, original phase from the late 4th/early 5th century AD; view from the south (Photo S.E. Sidebotham)

not clear what this structure was constructed of and to what extent it may have used the fossil reef that has been shown to lie at its base at least in the southwestern part.

The magnetic image of the bay in its lower, southern part shows long parallel anomalies that give the impression of the waterline, possibly at different tide levels. Coring done in the harbour as well as excavations in trench BE11-71 revealed the beach level from the Ptolemaic period. It left no doubt that the sea never reached too far into the bay and that the landing place was a natural sandy beach. The special "elephant" ships, which presumably had flat bottoms, more like a barge, could have easily run ashore and the wild animals, mostly the smaller subadult specimens, could have been disembarked via broad wooden ramps. Later, in early Roman times, ships stayed outside, on the anchorage east of the city or in the deeper waters of the lagoon, while goods were ferried in and out in small rowboats. The loading and unloading took place on the natural beach. Just off the beach but still inside the ridge, sheltered by whatever structure formed this enclosure-like feature, were small workshops and stores, flimsy huts with walls and roofs of palm ribs mounted on low foundation walls of stones and coral heads, fitted with mats and earth floors, set around larger courtyard spaces that were occasionally paved, containing workshop installations, including a mysterious deposit of very finely burned charcoal and ashes up to a meter thick at the deepest place and spreading over an area of about 5 m in diameter (Sidebotham, Zych forthcoming a). All these paltry remains appear on the magnetic map as a an area of disturbed values, with a great deal of point anomalies, which do not form any particular pattern. In the western part of the bay a careful analysis of the map uncovered the remains of a large rectangular complex, possibly units surrounding a large courtyard. Excavations located exactly on top of presumed walls (BE14-100 and BE14-101) expected to uncover the stone-wall remains of this building of apparent substance. However, all that was found was a 'ghost' wall, that is, a trench from which the stone blocks were salvaged at some point and the remaining hollow was filled with deposits concreted into a hard mass by salt precipitation, as in the remains of the Hellenistic tower described above.

More importantly, the combined magnetic prospection and archaeological excavations have yielded data on the nature of the landing place that was apparently the main port of Berenike in the early Roman period. The beach levels uncovered in trench BE11-71, coupled with two structures located in the mouth of the bay, at an altitude not quite one meter above the modern sea level have provided strong evidence in favor of the hypothesis that no significant changes in the sea level have occurred in historic times. The sea ingressed as far as the parallel anomalies on the magnetic map indicate, at high tide, in Hellenistic and early Roman times, before the alluvia flushed down the wadi gradually filled in the lagoon forming the kind of *sabkha* plain that is now found further out. The architecture filling the southwestern bay extended up to the ridge, running no deeper than about 2 m (trenches have been dug in a row, giving a section aligned roughly north–south about 40 m long) and resting on culturally sterile sand, rising from the beach toward the ridge

Fig. 11. Magnetic map of houses on the eastern shore of the southwestern bay and location of trench BE13-91 (white box)

Fig. 12. The corner of a house with steps on either side of a wall (in trench BE13-91), view from the south (Photo S.E. Sidebotham)

surrounding the bay. The more humid climate in the later Roman era may have resulted in a more marshy environment here. In any event, for whatever reason, the landing place went out of use by the 3rd century AD and the port shifted most probably to the eastern and northeastern shores of the urban mound.

Standing out in this landscape were the two structures mentioned above as situated in the mouth of the bay. The eastern of the two structures was evident on the ground surface, the walls rising roughly about a meter high, enveloped in sand. The western structure was difficult to trace (Figs. 5 and 9) on the ground, but it has come up as a regular square feature in the magnetic image. Surprisingly, while the standing walls were well delineated, substantiating the belief that walls of gypsum anhydrite blocks correspond to negative anomalies in the magnetically susceptible matrix surrounding them, the collapsed walls of the structure, pushed down on all four sides of the building and forming a continuous surface in each case of the whereabouts of 20–30 m^2, have left absolutely no trace on the prospection map. A thorough analysis of the anomalies around the two structures have allowed the archaeologist to delineate an island temenos (Rądkowska *et al.* 2013; Zych *et al.* 2014) (Figs 9 and 10). The anomalies are enough to suggest the presence of structures, but are not sufficiently distinct to be able to imbue the results with any intelligible sense. Excavations in the 2015 season (BE15-103) uncovered some coral-head architecture, but without determining either layout or function of these features or installations (Sidebotham, Zych forthcoming b).

This is not the case regarding standing architecture on the eastern shore of the south-western bay. Here the houses are extremely well delineated, the plans clear and distinct, showing entrances, passages, corridors, rooms with apses and alleys between building complexes (Figs 5 and 11). The latest-phase architecture can be mapped practically without excavation, giving a very good idea of the urban layout of 5th century AD Berenike. An exploratory trench situated at the entrance to a house with a main hall ending in semicircular apses at either end and long units resembling storerooms (BE13-91) has demonstrated that the house had a flight of steps leading up on the outside of a wall lining the entrance passage and another flight of steps on the opposite side of the same wall, inside the room (Fig. 12). The corner of the walls, which were built of coral heads (while the steps were of gypsum anhydrite slabs), were exactly where the anomalies on the magnetic map had suggested they would be. Moreover, point anomalies in the entrance passage proved to be oven-like installations and hearths in use in the last occupation phase of the structure (Zych, Sidebotham forthcoming).

The urban mound: the Late Roman city

The urban sprawl of Berenike, situated on a mound at the eastern end of the site and with direct access to the sea (today limited somewhat by the spread of the *sabkha* sand flat), was evident to the first explorers and the site of the Great Temple obvious enough for J. G. Wilkinson to have started his excavations there (Sidebotham *et al.*

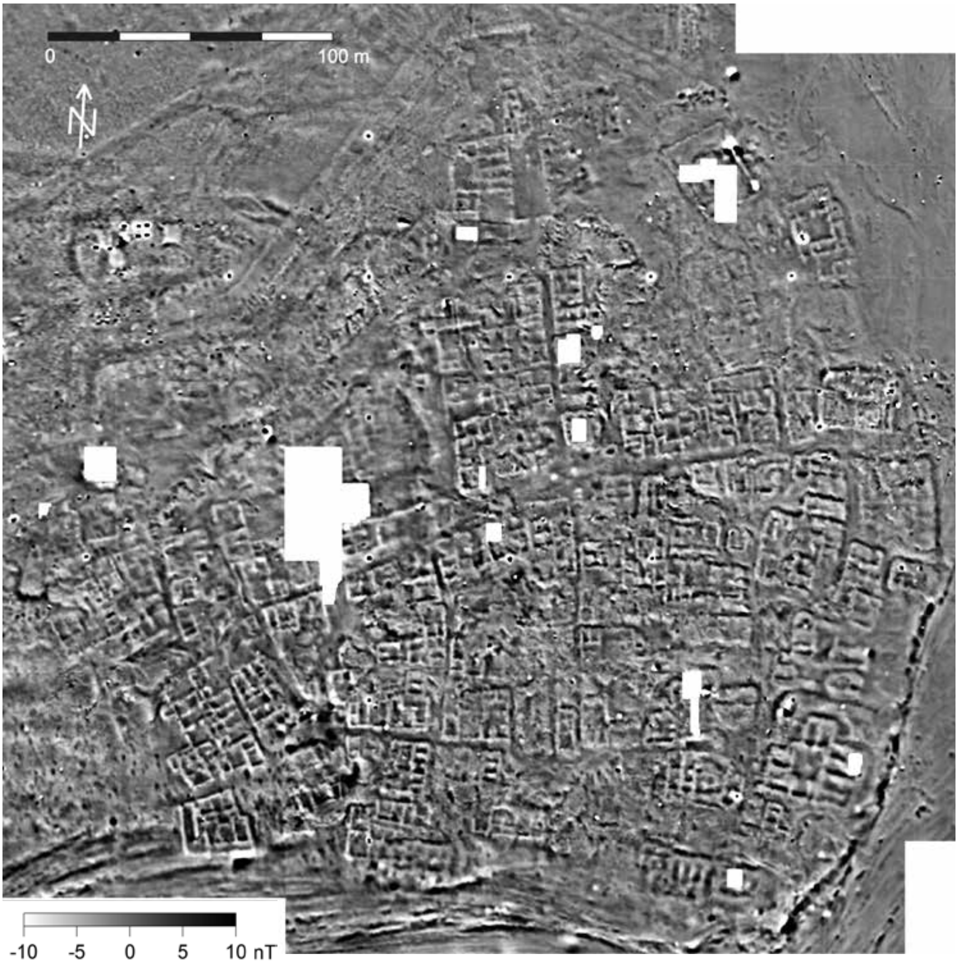

Fig. 13. Magnetic map of the town mound as completed in 2015

2008: Fig. 7.9, see also Figs 6.20 and 6-21; 2011: 60–61, 259 ff.). The American–Dutch project started off in 1994 with the first limited trenches in this area, producing at the same time a topographical plan that largely recognized the layout, so well were the ruins preserved under an obscuring blanket of drifted sand.

The magnetic prospection of this area (leaving out trenches dug earlier and the larger area west of the Great Temple where a huge archaeological dump is located) helped to draw a clearer picture of individual houses and whole insula complexes, already suggested by the topographical plan (Figs 13 and 14), while contributing tidbits of evidence to round off the interpretation of areas where there was nothing on the ground surface to

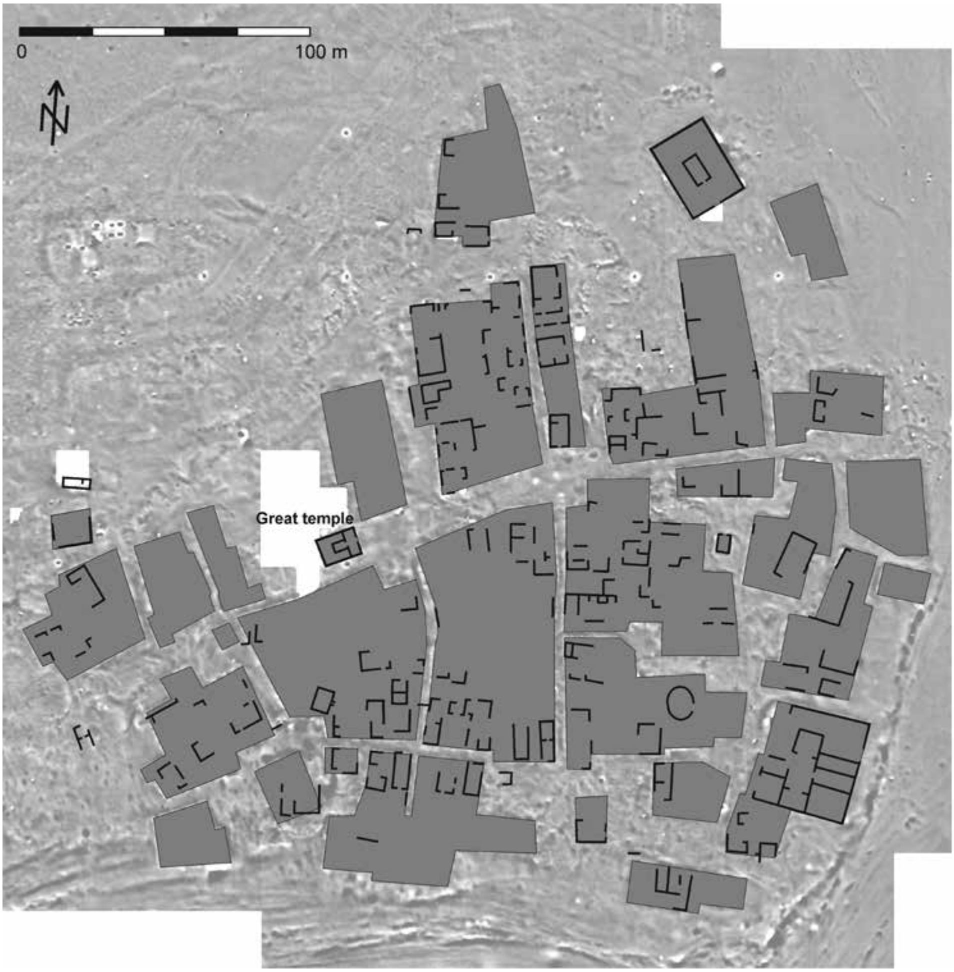

Fig. 14. Magnetic map of the town mound with superposed position of wall fragments recorded during the topographic survey of 1994 (walls after Aldsworth et al. 1995 inserted plan); shaded boxes show presumed insulae

consider (the slightly blurred image of structures in the center, just north of the Great Temple, is the effect of bulldozing activity by the Egyptian military in the 1970s, which was stopped fortunately before too much damage was done). Moreover, in the specific conditions of Berenike the magnetic method allowed structures in the near-surface layers to be registered, practically no deeper than 0.5–1 m, and in the case of the main town of Berenike archaeological evidence has already shown that the buildings from the early Roman and quite possibly late Hellenistic period go down at least 5–6 m in the highest

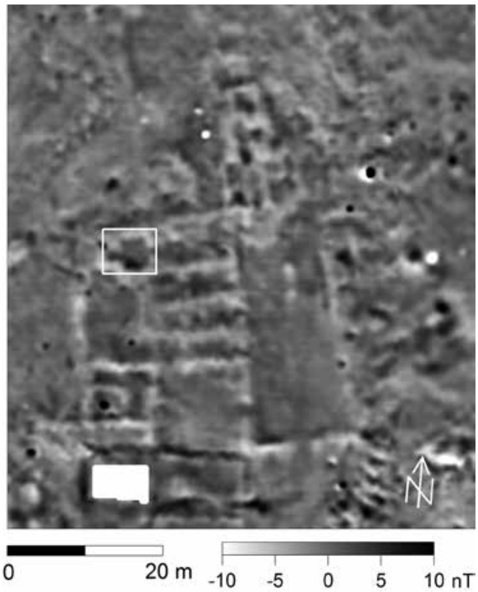

Fig. 15. Magnetic map tracing a building complex located at the northern end of the town mound; location of trench BE15-110 marked

Fig. 16. Square room with niche excavated in the 2015 season in BE15-110. View from the south-east (Photo S.E. Sidebotham)

point of the mound. Excavations have suggested a fair continuity of the Late Roman house layouts compared to the early Roman remains, on which they were superposed, using the old walls partly as foundations for the new structures. To what extent the early Roman architecture followed the earlier Hellenistic structures cannot be said for now, just as it is not clear whether the Great Temple, obviously early Roman in its foundation, had a Hellenistic predecessor on the site. (Recent evidence of fragmentary Pharaonic-age steles found in the late Roman rubble of the temple suggests the possibility of a shrine having existed on the spot in Berenike in the Middle Kingdom/inception of the Second Intermediate Period, that is, around the 18th century BC, see Sidebotham, Zych forthcoming b). Perhaps the fact that the Great Temple does not fit the rectilinear street grid visible in the central part of the mound is proof that it predates the later Roman city (from the 4th/5th century AD?). Another possibility is that it is connected rather with the westernmost insulae, which appear to follow a different grid, at a distinct angle compared to the rectilinear grid in the central district.

An evident crossing of streets in this district gives rise to the latitudinal street which skirts the Great Temple on the south and hits a big *decumanus* that continues straight to the eastern shore, finishing off at the waterfront with the Christian church located to its north. It intersects with a *cardo*, forming a rather large of irregular square marked by three point anomalies characterized by negative values. The three circular anomalies stand at the corners of a square, the fourth being faint, possibly somehow obscured by a wall. It has yet to be verified archeologically whether the anomalies could correspond to some kind of tetrapylon structure at the most important city crossroads. The *cardo* led to the north between densely constructed houses to a large complex consisting of a long rectangular courtyard preceding a number of small units in a row, aligned with the long axis of the complex, and a number of parallel rectangular units positioned laterally, the northernmost giving access to a square room with niche (Fig. 15). This unit started to be excavated in 2015 (BE15-110) and proved to have a large rectangular niche with surviving fragmentary marble facing on a lateral wall and evidence of some kind of wooden framing of the niche opening (Fig. 16). So far a late Roman squatter's phase has been established for the room, but it seems very likely that the original complex was early Roman. More importantly, it closed off the *cardo* and may have towered to some extent over the northern part of the site, the ground falling away to the north rather abruptly. The complex seems to have been fitted snugly into the corner formed by a feature corresponding to the unrecognized linear anomaly that turns at sharp angles in the northern part of the site.

The general impression is of a city that cascades down from the highest point to the south and southwest, opening itself onto the lagoon and southwestern bay (before it silted up), while turning its back on the prevalent northerly winds coming from the direction of the Ras Benas cape. To the east, the buildings also descended to sea level, but the architecture that can be reliably reconstructed based on a very clear magnetic image looks

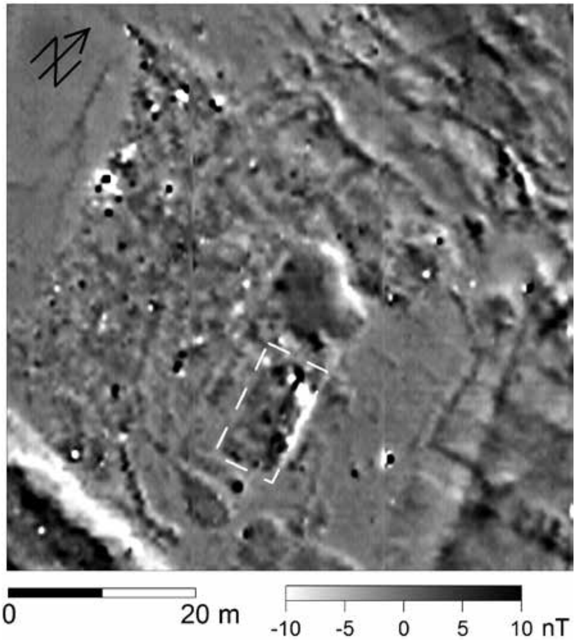

Fig. 17. Magnetic image of the mysterious building with three podia discovered through analysis of Corona satellite imagery (marked location of trench BE15-105)

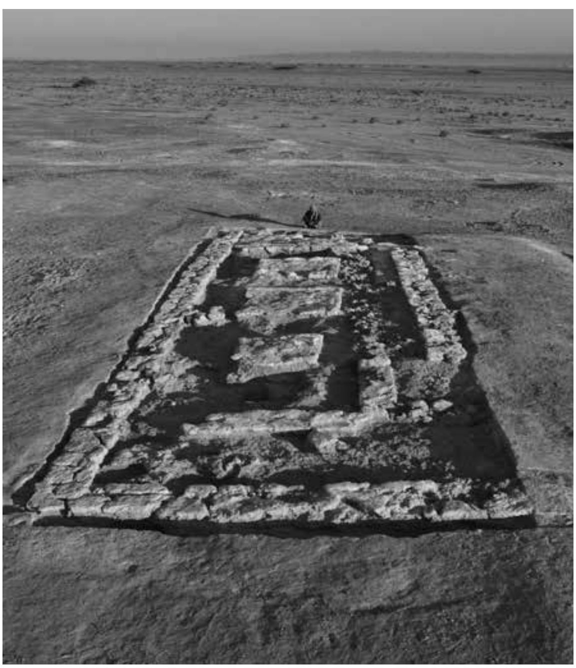

Fig. 18. The building with three podia after cleaning, view from the south (trench BE15-105) (Photo S.E. Sidebotham)

generally more like the warehouse and industrial type. It is also possible that the easternmost fringes of the urban mound may have been developed urbanistically, the ground being artificially leveled and built up with fill from other parts of the site and the eastern coastline transformed into a masonry waterfront for dealing with the intense maritime commercial trade with India among others, known to have taken place in Berenike in the 4th–5th century AD. The southwestern bay was no longer in use and there is no other apparent place where trading could have proceeded on such a scale. Early excavation at the southeastern corner of the site (BE94-5) even uncovered a structure that may have served as a kind of lighthouse or signals tower. Other trenches dug along the northern part of the shoreline revealed earthworks on a massive scale leaving an upturned stratigraphy with loads of fragmented early Roman amphorae being used to create a reinforced platform. The roughly linear anomaly running at an angle around the southeastern part of the urban mound may attest to a similar kind of reinforced waterfront. The curious thing is that this waterfront seems not to have continued beyond the church to the north. Indeed, the entire northeastern quadrant of the urban mound is loosely occupied and one might wonder whether, being on low-lying ground compared to the rest of the urban mound, they were also set off by water, either continuously or at least at high tide (Sidebotham 2011: 60–61). The nature of the magnetic map image immediately to the west of a rectangular enclosure of a temenos nature, as well as around it, could suggest such a situation with access to the evidently important enclosure being via rowing boats perhaps. It could well be the northern and more important harbour of Berenike where officialdom concentrated, leaving the southwestern bay (in early Roman times) as a ship repair and supply yard or else a secondary bay for use perhaps by a given ethnic group of merchants or a given group of merchants with shared business interests.

An added point of interest is the appearance on the magnetic map of the southern fringes of the site. The anomalies here form densely parallel, gently arching lines that follow a sinusoidal line along the shore of the anticipated lagoon (Figs 5 and 13, See also Herbich 2011: 14, Figs 2.3 and 2.4). At the present stage of research, it is reasonable to interpret these anomalies as the steeply falling edge of a fossil reef that formed the promontory on which the town was founded. The same kind of anomalies can be seen also at the southern edge of the western plateau, also suggesting a sudden rocky drop-off of the shore in this area. The strong positive anomalies that run in a flamboyant swoop toward the northeast along the crescent-shaped ridge of the southwestern bay are definitely not anthropic in character. Archaeological testing on the spot of one of these anomalies gave absolutely no evidence of anything that could give such a strong result. Digging to depth of roughly 1.50 m, revealed nothing but pure sand, culturally sterile below the top layer associated with an early Roman midden and cemetery of dogs (see Zych, Sidebotham 2010). It seems, therefore, that these anomalies reflect geological events of a much more distant past than archaeologists digging in Berenike can hope to be interested in and so they will not be considered in the overall interpretation.

PROSPECTS FOR THE FUTURE AND CONCLUSION

The magnetic map of the site is practically complete excepting the northwestern quarter where the cemeteries are located. Some prospection in this area as well as the results of limited archaeological excavations (BE01-44 Sidebotham, Wendrich 2002) have also proven the potential of this method for mapping the mausolea that existed on the land side of the city in the 4th and 5th centuries AD for sure.

A new discovery resulting from an analysis of publicly available Corona satellite imagery, which led to the identification of a curious complex of three podia within a large enclosure, inside a naos apparently facing the sea, was immediately put to the test with a sample magnetic survey. On the ground it was possible to trace extensive walls of gypsum anhydrite blocks and these were faithfully imaged on the magnetic map. Subsequent excavations (BE15-105) demonstrated the most standard arrangement as far as Berenike is concerned: strong negative anomalies corresponding to walls of gypsum anhydrite, even if preserved just one block deep, contrasting with the magnetically susceptible matrix of sand and gravel (Sidebotham, Zych forthcoming b Figs 17 and 18). Just as the excavators thought that they had completed a full survey of the site, these new developments demonstrated that geophysicists will be coming for a few more seasons.

The results of the work, extended magnetic prospection combined with excavation of trenches pinpointing specific locations of interest on the map of magnetic anomalies, exemplify the nature of the cooperation between archaeologists and geophysicists. The archaeological feedback that comes in a continuous stream from current explorations leads to improved and occasionally ingenious interpretations of registered anomalies, which in turn cannot be underestimated in reconstructing settlement processes in ancient Berenike.

Moreover, the results of the magnetic survey at Berenike should persuade all the doubtful critics that field testing of geophysical methods is of paramount importance, even if conditions for applying such methods seem to be definitely unfavorable. Had one gone by the theory of what the effectiveness of the magnetic method should be in the specific geological conditions of the site, knowing how the building material used in Berenike has no magnetic properties whatsoever, the prospection would have never taken place. The loss to science would then have been substantial, what the authors of the present article are convinced of and tried to show above.

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Past - present - future

From proton- to caesium-magnetometry – my 40 years in archaeological prospection

Helmut Becker[a]

KEY-WORDS: proton/caesium-magnetometry, nanotesla, picotesla, digital image processing, Troy, Qantir-Piramesse, Cornesti

After military service in an artillery reconnaissance unit (1963–1965) I had a rather early start in archaeology at "Cerro de la Virgen" (Orce, Granada, Spain) doing topographical work (1965). From 1965 to 1977 I studied at the University of Munich, taking courses in physics, geosciences (mainly geophysics), altogether 19 semesters, and archaeology (prehistory and Roman archaeology), a total of 13 semesters. For my diploma and doctorate, I went to northeastern Iceland, measuring with two Askania-Gfz-torsion balance-magnetometers the vertical component on several profiles crossing a neo-volcanic zone (about 1000 km with 50 m point distance) to get a first verification of seafloor spreading on land.

In 1973–1974 I was invited to work for an archaeological project directed by Barthel Hrouda from the University of Munich at the site of Isin in Iraq. On my way back I met Manfred Korfmann at the German Archaeological Institute in Istanbul and the result was my participation in the Demircihoyük project in western Turkey, conducting a topographical survey and excavation in 1975–1976. It was my first experience in proton-magnetometry used for archaeological prospection and I was using an Askania GPR-1 instrument in variometer mode. I excavated a Middle Bronze Age ceremonial structure outside of the Early Bronze Age tell.

In 1976, I traveled to meet Irwin Scollar (Bonn), Emile Thellier, Albert Hesse and Alain Tabbagh (Garchy) and Martin Aitken (Oxford) in preparation for the Volkswagen project "Archaeo-Prospection and Archaeo-Magnetism" at the Institute of Geophysics Ludwig-Maximilians-University in Munich. At this time Irwin Scollar had a system with two proton-magnetometers and automatic data recording on punched paper-tape in a running VW-Bus and he was interested in my plans for archaeomagnetic dating. The project, run by the Institute and the Geophysical Observatory Fürstenfeldbruck, operated in 1977–1982. I still had not aquired the caesium-magnetometers, but I managed a double proton-magnetometer in conjunction with Askania GPR-1, measuring in the Landshut-Hascherkeller project in 1978. It opened my way to using, as a medi-

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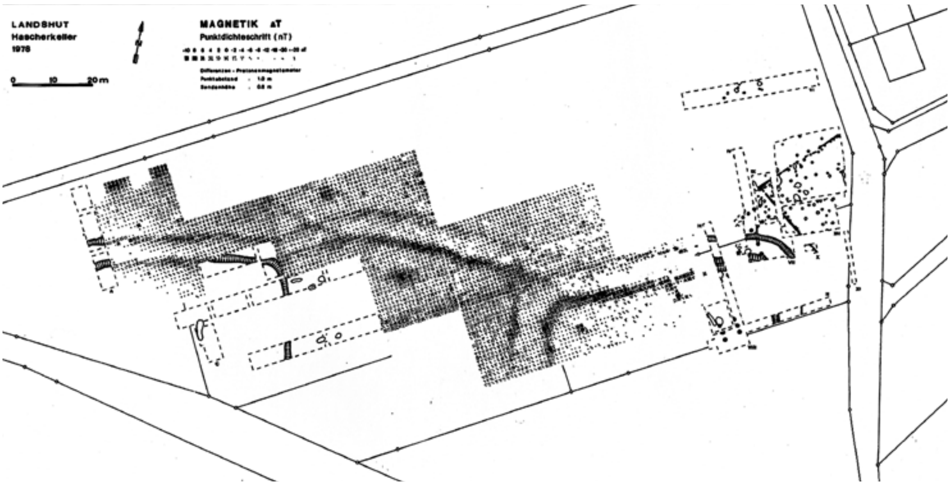

Fig. 1. Landshut-Hascherkeller (1978). Manual dot-density plot of a Hallstatt periode enclosure. Proton-magnetometry with two Askania GPR-1 in variometer mode, 20 m-grids, -10/+20 nT

eval archaeologist, ground magnetometry in combination with aerial archaeology for the Bavarian State Department for Monuments and Sites (Bayerisches Landesamt fur Denkmalpflege, BLfD).

The manual dot-density plot achieved in the Landshut-Hascherkeller project (1978) persuaded Rainer Christlein to plan a combination of ground magnetometry with aerial photography (Otto Braasch) at the Bavarian State Department for Monuments and Sites.

Starting from 1981–1982 I used a double-proton-magnetometer for measurements mainly in Greece, Bulgaria and Turkey, e.g., Tiryns, Kastanas, Kalapodi, Durankulak, Hassek-Höyük and Bogazköy (Hattusa), and managed to obtain archaeomagnetic samples at Tiryns, Bogazköy, Acem-Höyük, Masada for a reference-curve for the 15th–12th century BC. At Demircihoyük I procured a long sequence of samples for the variations of the geomagnetic field in the 3rd millennium BC.

In February 1982, at the very end of the VW project, I managed to complete my magnetic prospecting system with two caesium-magnetometers Varian V-101 and automatic data recording on a digital cassette still financed by the Volkswagen foundation. Rainer Christlein, Director of the Archaeological Department at the BLfD, gave me the chance to establish the Laboratory for Archaeological Prospection and Aerial Archaeology (ultimately comprising a staff of 12 persons, including Jörg Fassbinder, who is now the director of the unit). In 1985, I mounted two caesium Varian V-101 gradiometers on wheels and established an Epson HX20 handheld computer for data logging mainly in variometer-configuration of the sensors. This configuration became our main working tool until 1993.

In 1992, caesium magnetometry helped to uncover the Early Bronze Age fortification of Troy-VI (Heinrich Schliemann's so-called "Lower City"; Schliemann had not succeeded in finding the wall described by Homer in the *Iliad*). This was another turning point in the development of caesium magnetometry, because following the worldwide coverage that the detection of the

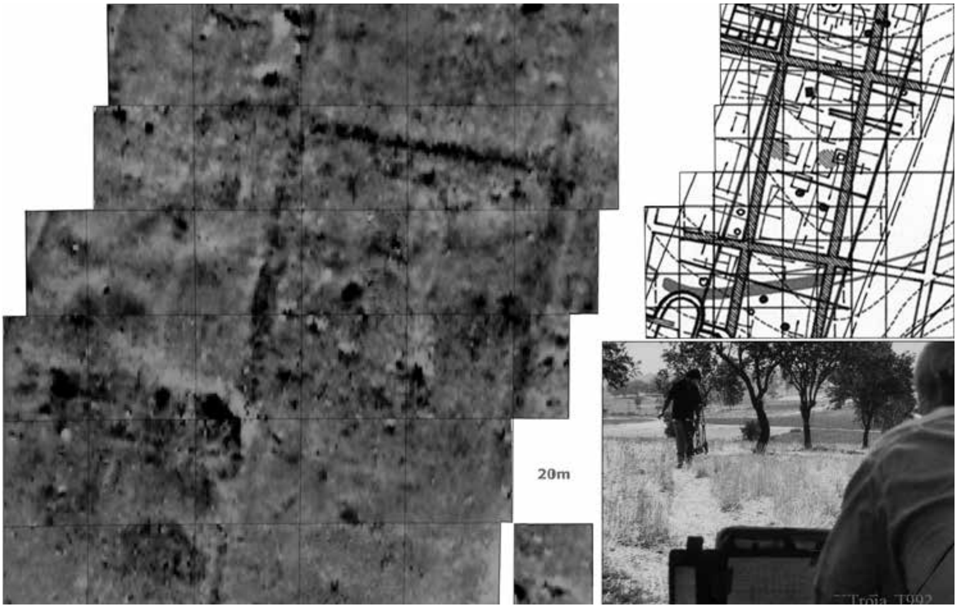

Fig. 2. Troy: magnetic map (1992–1993) measured with a Varian V-101 by H. Becker and J. Faßbinder. Caesium-magnetometry Varian V101 and CS2/MEP720; interpretation with Roman insula (Troy IX, Hellenistic Illion (Troy VIII) and the gate of the "Homeric" fortification of the Lower City (Troy VI); the plan of the citadel after W. Dörpfeld (1902); 20 m-grids, -20/+30 nT (black to white)

Lower City of Troy received, Bob Pavlik of Picodas contacted me with an offer of a caesium-magnetometer with picotesla sensitivity Scintrex CS2 /MEP720 (Picodas) and an Olivetti subnotebook for data logging.

FROM GRADIOMETER/VARIOMETER MODE TO A DUO-SENSOR CONFIGURATION

Looking at the screen of the Olivetti subnotebook showing the signal of both sensors sparked the idea of using the two sensors not only for a gradiometer/variometer mode, but also for a two-track sampling of the total magnetic field. The reductions of time variations of the magnetic field can also be done by a 40 m-line mean and full square mean without loss of linear structures that were exactly parallel to the traverses. With this very simple trick, the speed of magnetic prospection can be doubled. The hand-held duo-sensor configuration allows about 1.5–2 ha/day; the quadro-sensor on wheels ("magnetoscanner") about 3–4 ha/day (0.5 m tracks with 0.1 m samples, resampled to 0.5 m x 0.25 m) depending on the surface conditions.

In 1996, the Scintrex-Smartmag-SM4G-Special caesium-magnetometer (long cable version) 20 pT at 1/10 Hz (10 measurement per second, about 10–12 cm sampling on the line, inbuilt filter for high frequency signals) became available. It was first used at Monte da Ponte, Alentejo, Portugal, in 1996.

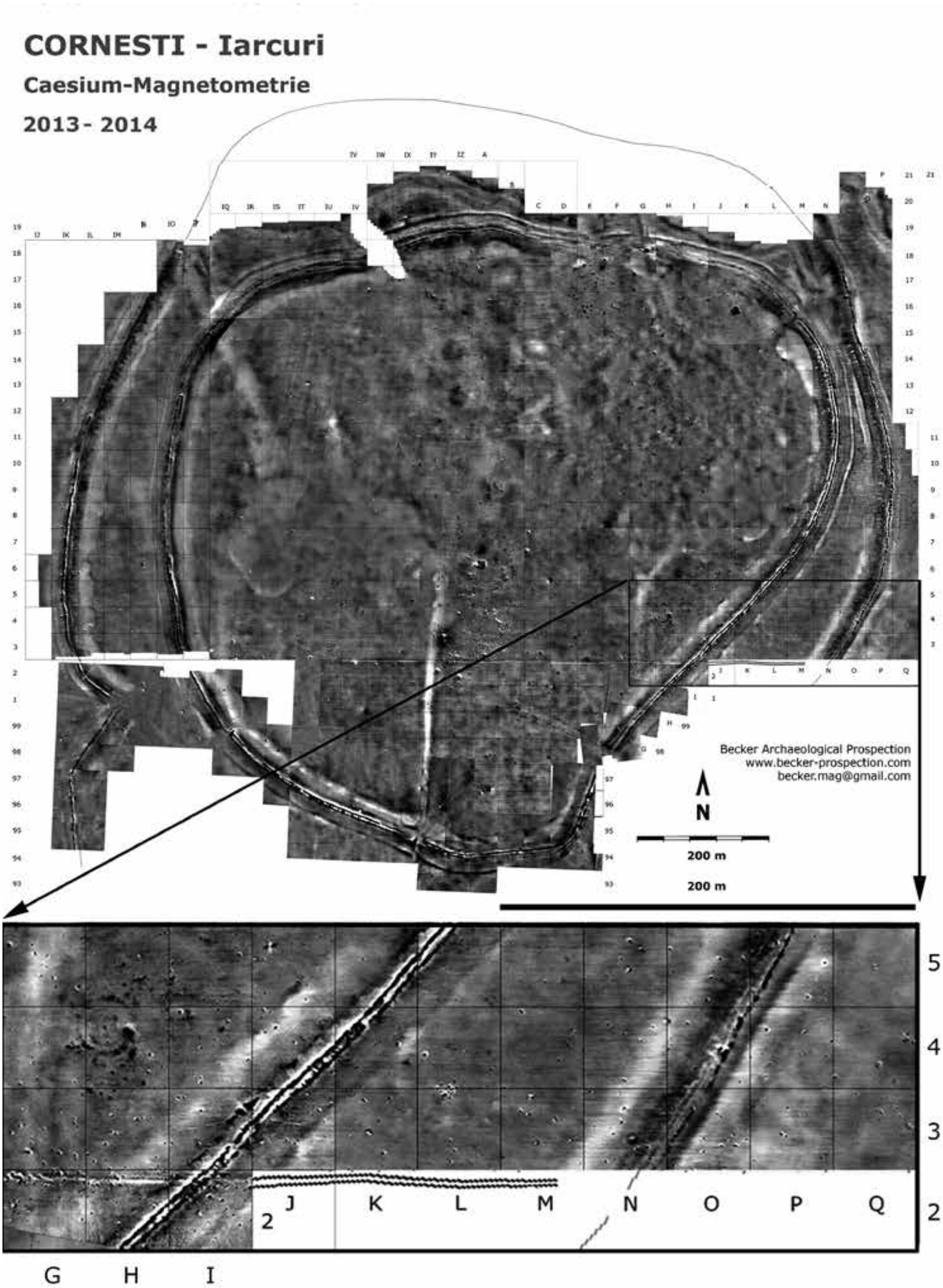

Fig. 3. Cornesti (Timis, Romania) 2008–2014, northern part of wall I and wall II, excavation in grids G-H / 4 in 2014, four Geometrics G-858G, 40 m grids, interval 0.5 x 0.25 m

Almost the entire development and adaptation of the various caesium magnetometers for archaeological prospection occurred in 1994–1996 at the Chalcolithic site of Monte da Ponte in Alentejo-Portugal.

One of the biggest projects at the BLfD was Qantir-Piramesse in Egypt, the capital of Ramesses II, with about 1.5 km2 (150 ha) measured from 1996 to 2001. Measurement was possible only using the handheld duo-sensor-configuration owing to intense agricultural activity (flooded rice fields).

Back to Bavaria. One of my last projects at the BLfD was the complete plan of the Roman castellum Ruffenhofen in Franconia with *vicus* and cemetery covering an area of about 40 ha, using four Scintrex Smartmag SM4G instruments mounted on wheels.

FOUNDATION OF "BECKER ARCHAEOLOGICAL PROSPECTION" WITH CAESIUM MAGNETOMETER GEOMETRICS G-858G

After my retirement from the BLfD in 2005, I founded, in 2007, "Becker Archaeological Prospection" which uses two Geometrics G-858G caesium magnetometers. Projects have taken me to many places in the Old World from Portugal to China, e.g., projects with the University of Ravenna (Maurizio Tosi) in Central Asia, Oman, India, etc., projects in the Celone Valley (Italy), Ras al-Hamra, Zukait, Ras al-Jinz (Oman), Lothal (India), Zazargan, Kala Kafir (Uzbekistan) and Takirbay, Murghab Delta, Togolog (Turkmenistan) — all these projects were carried out before 2008. Within the frame of the cooperation with NIA-ERA Lisbon, the following sites were surveyed in Portugal (mainly Chalcolithic enclosures), between 2009 and 2013: Perdigoes, Morreiros 2 (Chalcolithic woodhenge), Xancra (Chalcolithic moon-calendar), Monte do Olival, Monte da Contenda, Montoito ellipse.

Recent surveys, carried out between 2013 and 2015, comprise prospecting of Chalcolitic and Copper age enclosures in Romania (Cornesti, Timis) and Spain (Azutan, Province Toledo and Valencina de la Conception near Sevilla). Huge areas to be prospected there have kept me active — and will do so for some time. Many thanks to my wife Anne-Sophie Flade-Becker, who is helping me in my crazy life with walking magnetometry.

Early experiments with the use of new surveying methods in the archaeology of the Nile Valley

Albert Hesse[a]

KEY-WORDS: Nile Valley, Egypt, Sudan, archaeology, geophysics, survey

Except for a short visit to England in 1961, my long stay in Sudan during the winter 1965–66 was my first opportunity to experiment with geophysical methods outside France. I am very much indebted to Jean Vercoutter and André Vila for inviting a young inexperienced researcher

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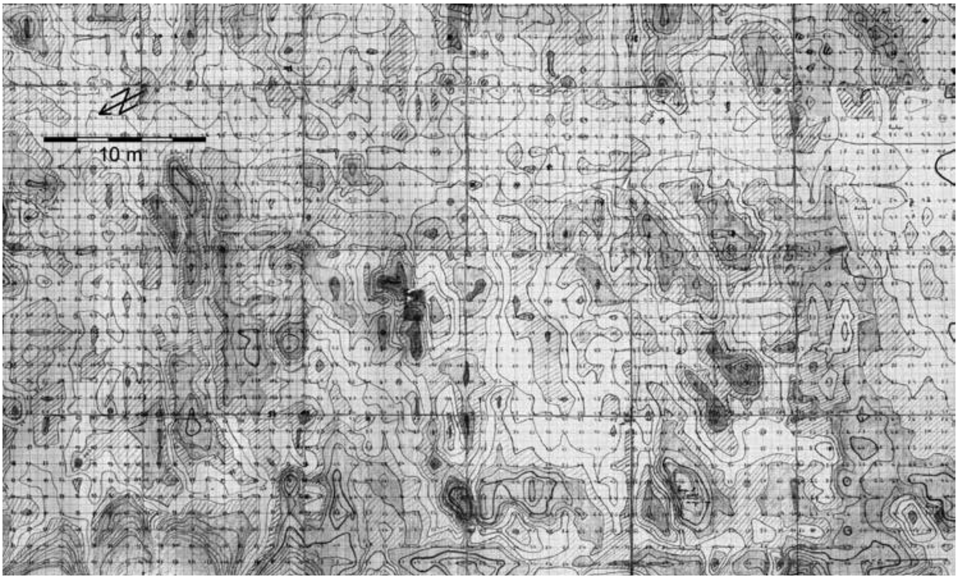

Fig. 1. Section of a "handmade" magnetic map of Mirgissa fortress dating from the Middle Kingdom (Sudan). Readings of the total magnetic field in gammas (nanoteslas) were written after correction of the diurnal variation and lines of equal value drawn by interpolation between the data and smoothing on the edges of each couple of the adjacent 10 m by 10 m squares (one measurement every meter on both x and y directions of the map)

like me to participate in such an archaeological context: the rescue of archaeological remains to be flooded by the waters of the Aswan dam.

The site of Mirgissa on the second cataract of the Nile was for me a kind of huge laboratory where I tried to use all the easily available geophysical methods of the time, that is, principally resistivity and magnetometry (Hesse 1970). I succeeded in performing a few electric soundings in the sand, but better results were obtained with a proton magnetometer. I was able to demonstrate that significant anomalies over mud-brick walls were caused by the high magnetic susceptibility of Nile silt used to make the bricks, compared to the aeolian sands in which they lay. Despite the low accuracy of my instrument (Elsec Littlemore Engineering) (see Fig. 7, page 131 in this volume) without differential readings and problems raised by the local environment (low latitude, hot climate and magnetic storms), I was able by using a kind of primitive handicraft filtering to give a sketch map of the internal organisation of a huge Middle Kingdom fortress (more than 1 ha) with its main streets and blocks of buildings. This needed about 10,000 readings to be plotted several times by hand (Fig. 1)!

While doing this, I noticed the incredible amount of pottery sherds scattered on the surface of this fortress and other sites. I was quickly convinced that considerable archaeological information could be deduced from such easily available and often neglected material. Then I decided to dedicate a part of my time to collecting, sorting and mapping a selection of these remains. At that time, my methodology was not very sophisticated, but several interesting

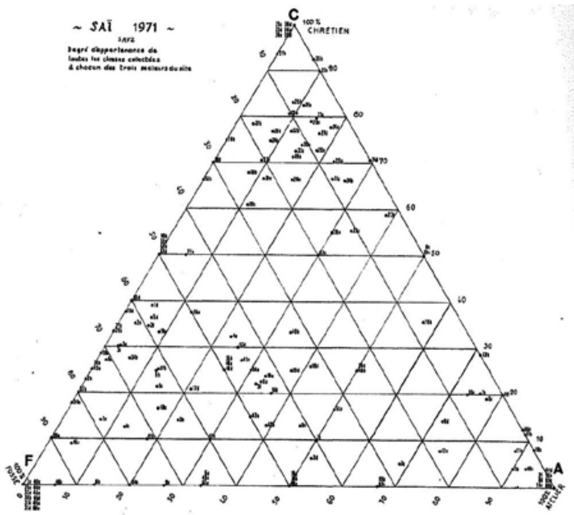

Fig. 2. Representation on three scales of a triangular graph of all the classes of objects collected on the surface of the camp site SAV2 on Saï island (Sudan). Each coordinate corresponds to the percentage of presence of each class in three different and significant sectors of the site: F inside the camp site limited by remains of a New Kingdom ditch; A in the area of a pottery workshop; C in the area of Christian occupation. Good clustering of points confirms land division and contemporaneity of close classes of objects

archaeological results were obtained, mainly concerning different types of Nubian non-thrown pottery compared with Egyptian ones: their different distribution on the surface was significant of differences of period and/or of culture (Hesse 1971).

My following research with the *Mission archéologique française au Soudan* took place a little later, in 1977, on the island of Saï, when almost everything of Mirgissa had disappeared. This area again was fascinating with almost all ancient periods represented from prehistory until the Turkish occupation. Some limited investigations with an electromagnetic device (EM 15 Geonics) was paralleled mainly with a surface collection survey. At the campsite called SAV2, I was still missing an appropriate process for analysing the data. However, I improved my methodology by introducing a sorting technique of the different classes of collected objects: the triangular graph that was in current usage among geologists dealing with the granulometry of sediments (Fig. 2). It turned out to be powerful enough to distinguish and localise accurately different occupations of the site: the original one dating from the Middle Kingdom, a later pottery workshop and then a partial Christian reoccupation. At the time other scholars were developing new processes and algorithms and, as a mater of fact, I discovered that I had been using unconsciously a kind of very primitive "factorial analysis" (Hesse 1985). The method was so powerful that I used it again on another very large space (SKP1) on the same island of Saï: this new survey revealed a very clear distribution of the remains in a kind of horizontal stratigraphy, ranging from the Khartoum Variant Neolithic (observed there for the first time) on the high ancient terraces through to the Christian occupation just behind the present bank of the Nile (Hesse 1996).

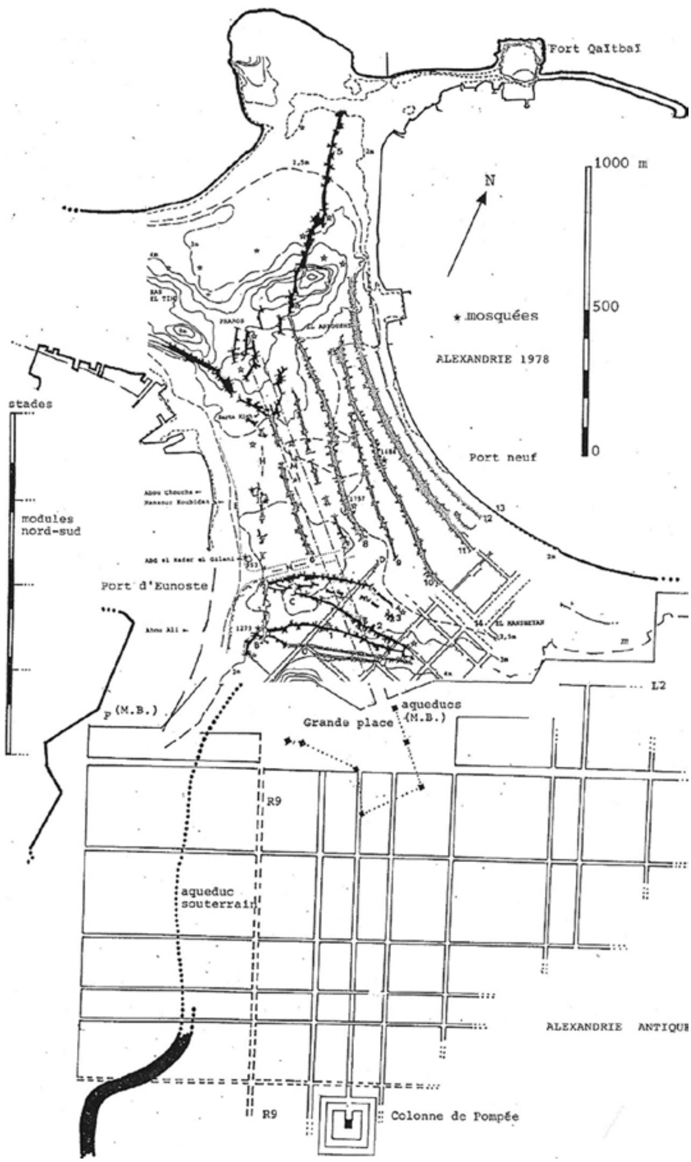

Fig. 3. Final map of the survey searching for the course of the Heptastadium in Alexandria (Egypt). Strabo described this way as joining the antique city (bottom of the sketch) to the island of Pharos (top of the figure). Among several possible courses of this major axis, only one was found to fit perfectly the results of a series of investigations (including geophysical surveys) on the isthmus between the island and the city. It can be identified in the figure on the same axis as one of the antique streets, starting from a clear crossroads and finishing at the south corner of Pharos, with an exact length of seven stadia (scale on the left side of the figure)

Later on I had the opportunity of more surveys of this kind on several sites in different countries (France, Italy) and along the Nile Valley again, in Egypt, on the Predynastic site of Adaïma in 1989 (Midant-Reynes *et al.* 1990). The archaeological efficiency of the method was always confirmed by checking in the field.

In 1993, I came back to Egypt to train some colleagues who wanted to search for possible remains of a river port just below the Ramesseum (west bank of the Nile at Luxor) with a resistivity survey (Guillaume *et al.* 1995).

Collection of surface remains was not my last contribution to Saï archaeology: the most ancient occupation on SKP1 had left an incredibly large number of pits dug into the Neolithic levels. In 1994, the Saï mission restarted under Francis Geus, who was like myself interested in the intact features of this type still visible on the ground. Topographic mapping over such a large area was inconceivable. At that time, the use of remotely piloted aircraft systems for photographing the earth surface was not as commonplace as it is nowadays. Bernard-Noël Chagny was already making a name for himself in kite photography and thanks to such light equipment, I could carry out with him a very original survey of this prehistoric settlement located in such a remote area. At the same time we made a few flights over the Kerma necropolis (3rd millenium BC) and obtained the first legible and magnificent views of this unique site with its large tumuli (40 m in diameter) strengthened by several concentric circles of black and white stones (Hesse 1996).

Tomasz Herbich was responsible for other geophysical experiments in the Nile Valley. It was during the relatively early times of radar investigation in archaeology, when I was conducting research in Alexandria in 1997 to reconstruct the course of the Heptastadium (see below). Since we had ground-penetrating radar at our disposal, Michel Dabas and myself tried to answer his question concerning a possible structure under the chapel of Hathor at Deir el-Bahari. The results were not very successful, but the trip was an opportunity to check the instrument in the long corridor of Seti the First's tomb in the Valley of the Kings in Luxor in search of a possible empty space somewhere under the floor. We were luckier there with a very interesting response that, as far as I know, is still to be checked (Dabas and Hesse 1998).

Last but not least, Jean-Yves Empereur asked me to reconsider Mahmud Bey's surprising but duly accepted conclusions of 1870 concerning the Heptastadium, this major axis leading from the antique city of Alexandria to the island of Pharos, as described by Strabo. The examination of many different factors (history, ancient city maps, old building analysis, field surveys in the streets including topography and geophysical data, such as EM and electrostatic resistivity, GPR and seismic, obtained with the help of an efficient team of colleagues) allowed me to suggest a new course of this famous way (Fig. 3). It is much more (I must say "absolutely"!) in accordance in length (seven *stadii*), orientation and position with the grid (Hippodamian) plan of the Alexandrian city and is currently accepted by archaeologists (Hesse *et al.* 2002).

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Archaeology and remote sensing technologies: (un)happy couple with prospects?

Włodzimierz Rączkowski[a]

KEY WORDS: archaeology, remote sensing, technological determinism, critical approach, visualisation

INTRODUCTION

Remote sensing technology has penetrated into archaeology with increasing boldness and has gradually taken over archaeological thinking. One could ask why: Is it that these new methods and sophisticated technologies are seen as enhancing the study of the past?

The growing interest in noninvasive methods in archaeology is largely due to the Valetta Convention, which highlighted the destructive nature of excavations and underscored the need for protecting archaeological heritage *in situ*. The dilemma that archaeologists faced was whether to dig and collect empirical data for the purpose of learning about the past, but destroying (in a sense) the object of research in the process, or to desist from digging, shutting off any chance at developing knowledge about past societies. Noninvasive methods, already known at the time, offered a third opportunity: empirical data (of a different kind) could be obtained without destroying the heritage. Tying archaeology in with technology can be assumed to be the road to success, guaranteeing progress in the process of learning about the past.

This optimistic view is voiced frequently in analyses of modern trends in archaeology. Technology is present in archaeology not only at the stage of data collection in the field, but also in analytical pro-

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cedures (e.g., archaeological science) and at the level of data management (e.g., GIS). Jeremy Huggett (2015: 87) has encapsulated this thinking as follows:

"Archaeology sits on a cusp between the humanities, the social sciences, the 'hard' sciences, and the biological and material sciences, and this interdisciplinary character has fostered a wide-ranging set of methodologies and a highly critical approach to data collection and to methods of machine-based processing, manipulation and interpretation."

TOWARD A CONCEPTUALISATION OF REMOTE SENSING TECHNOLOGY IN THE SCIENTIFIC DISCOURSE

In my thinking, Huggett's optimism is unfounded considering the practice of remote sensing technology applications. Let me start with the question of what is technology (remote sensing technology in our case)? Referring to Martin Heidegger, one could assume that technology is directed at *discovery* using means offered by the nature sciences (Warzeszak 2002: 235). The discourse at once opposes naturalism and anti-naturalism in science methodology (Rączkowski 2011) and has far-reaching consequences for the nature of research questions and methods of solving cognitive issues. The naturalistic approach assumes for one that technology is neutral, value-free (e.g., Heidegger 1977; Huggett 2012). It offers data collection and analysis (perhaps even being restricted to a description, presentation of results), leaving the process of interpretation to the last stage of the research. Thus, remote sensing technology is commonly considered as a means of getting information about the world, the ancient world in this case. However, it can and should be treated also as a means of communicating scientific results, indeed a rhetorical form of the discourse about the past. This opens the way to a discussion of how the world is visualized, to semantic issues etc. (e.g., Barthes 1995a; 1995b). The question that arises, however, is: Are we telling the audience about the past that is 'behind' the visualization? Or do we leave the audience alone with the generated image?

The communication aspect of remote sensing technology gives the opportunity to consider its role in the modern world (the world of the archaeologists as well) from a tetrad-analysis perspective (McLuhan, McLuhan 1988; Sui, Goodchild 2003: 9). According to the four laws of McLuhan, modern technologies: 1) enhance/intensify selected aspects of actions taken by individuals or social groups within specific cultures; 2) make obsolete certain skills of individuals or social groups; 3) retrieve social activities that have already been pushed to the margins of social practice, and 4) reverse into an opposing form, when taken to the limit (Fig. 1). Here is not the place for a detailed discussion of all of the effects identified by McLuhan, but I would like to focus, even if in a restricted scope, on the first and second ones.

DATA AND THEIR VISUALIZATIONS AS 'ENHANCEMENT' OR 'OBSOLESCENCE'?

Remote sensing technology has broadened significantly our capacity to obtain specific forms of data, which can be interpreted through their connection with past human actions or formation processes. Data procurement and processing methods allow for various analyses (often spatial) and modeling. Moreover, the process of working with the data can liberate specific emotions and engage the researcher, reaching far beyond the pure application of sophisticated algorithms.

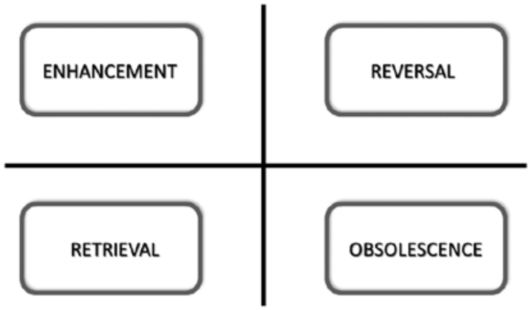

Fig. 1. Tetrad-analysis model according to McLuhan's laws

Data are not persuasive by nature, hence visualizations take on different form are as a rule the depending on the consequences of the processes applied to their analysis. They (visualizations) are the end effect of research procedures as a rule. They lead to the 'black box' effect (second law of McLuhan), eliminating many thought processes and concentrating on *doing the thing right* instead of *doing the right thing* (Sui, Goodchild 2003: 11). On the other hand, the persuasive side of data visualization leads to a fascination with remote sensing technology potential and has its part in fetishizing technology in archaeology (Huggett 2015). Snowballing new technologies, computer software, suggested visualizations (devoid of a deeper narration as a rule), which are the 'black box' effect, may be referred to as the 'locust of information' (Lem 1996). This creates a situation in which access to extended content (visualizations) is not tantamount to its assimilation owing to limited attention-focusing capacity (Szpunar 2013: 113). These aspects of remote sensing technology (and visualizations) are linked to Heidegger's view that the greatest threat of this technology is shaping attitudes whereupon technology is treated as providing the obvious solution and alternative solutions are no longer sought (Sui, Goodchild 2003: 13).

REMOTE SENSING TECHNOLOGIES AND ARCHAEOLOGY

Remote sensing technologies have been present in archaeology from the start (first use of aerial photographs at the turn of the 19th century). Their application depended on acknowledged theoretical ideas (Rączkowski 2002), but they owed their popularization to processual archaeology and the associated systems theory. Within this trend, remote sensing methods were supposed to provide a scientific explanation of phenomena from the past. The approach to data and methodology in processual archaeology, as well as in cultural–historical archaeology which preceded it, was indicative of a naturalistic approach, meaning that methods were value-free and so the data supplied were consistently neutral. Both trends also accepted a technological determinism (e.g., Huggett 2012) observed in a fascination with and dynamic development of 'archaeological science', GIS applications, etc. In practice, the application of remote sensing technologies reflected the conviction that questions about the past and its reconstruction would be answered by a sheer application of data technology. Data description/visualization was frequently considered a sufficient result. To cite McLuhan again, cultural-historical archaeology theory and critical reflection made obsolete in the discourse on both the data and the past. In consequence, the popularization/cementing of the practice of using remote sensing technology in archaeology has effectively kept us conceptually in the 1930s. New and refined technologies do not change in essence the ways in which we think about archaeology and about the study of the past, because we have not ceased to use the same cognitive categories (see also Michalik 2014).

CONCLUSIONS

From my point of view, it is essential to part with a naturalistic approach to remote sensing technologies and to take critical measure of the data, their processing, the analytical processes and the interpretation. The challenge is to think beyond technology (tools). Critical approaches have appeared in many fields associated with computer technology and even remote sensing (e.g., GIS - Lock 2001; Digital Archaeology - Huggett 2015; aerial archaeology - Rączkowski 2002; Brophy, Cowley 2005; LiDAR - Opitz, Cowley 2013). The debate in these circles postulates a metaphoric application of archaeology to learning about what lies behind the facts/data (see also Banaszek 2014), deconstructing the 'black box' and observing the cultural embroilment of the researcher in the cognitive process. Cultural embroilment of the research process also calls for a broader range of questions. We should be asking not only about the nature of the data or the limitations of the method, but also what we are doing, how and why, how we present and communicate what we are doing and how others understand what we do.

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Snapshots concerning the role of archaeology/ archaeometry in the birth and progress of geophysical exploration

Alain Tabbagh[a]

KEY-WORDS: archaeological prospection, electrical method first experiment, electromagnetic induction surveying, electrostatic method

FIRST SNAPSHOT

Following a series of tests made in the basement of the Ecole Nationale des Mines in Paris, Conrad Schlumberger carried out his first field test in September 1912, establishing the distribution of an electric potential at the ground surface when a direct current was injected through two electrodes (A and B in Fig. 1) (Schlumberger 1912). This test represented the true groundwork for the development of applied geophysics. Conrad Schlumberger had no specific interest in archaeology, since his aim was to describe the geological structure of the underground for mining applications. However, this initial experiment was carried out on an archaeological site: that of the Val Richer abbey in Normandy (France), which at the time was his family domain. This was the first Cistercian abbey in Normandy. It was founded in 1146 and stood until the French Revolution, at which time the religious wings of the buildings were destroyed and their stones sold, leaving only the abode and the barns untouched. In 1836, the property was purchased by François Guizot (historian, minister of state education and prime minister). His granddaughter, Marguerite de Witt, who was Conrad Schlumberger's mother, inherited the domain. Thus, the first experiment in geophysical exploration, which was not intended to be an archaeological survey, was in fact made on an archaeological site. Figure 1 shows a superposition of the 1912 voltage contours and the 2014 resistivity measurements.

SECOND SNAPSHOT

As electrical resistivity is known to be the ground's most variable physical property, it is logical to apply the DC resistivity method to archaeological prospection. However, the use of this technique is restricted by the need for a sufficiently good galvanic contact between the electrodes and the soil. As in mining prospection, researchers turned their attention towards electromagnetic induction (EMI)

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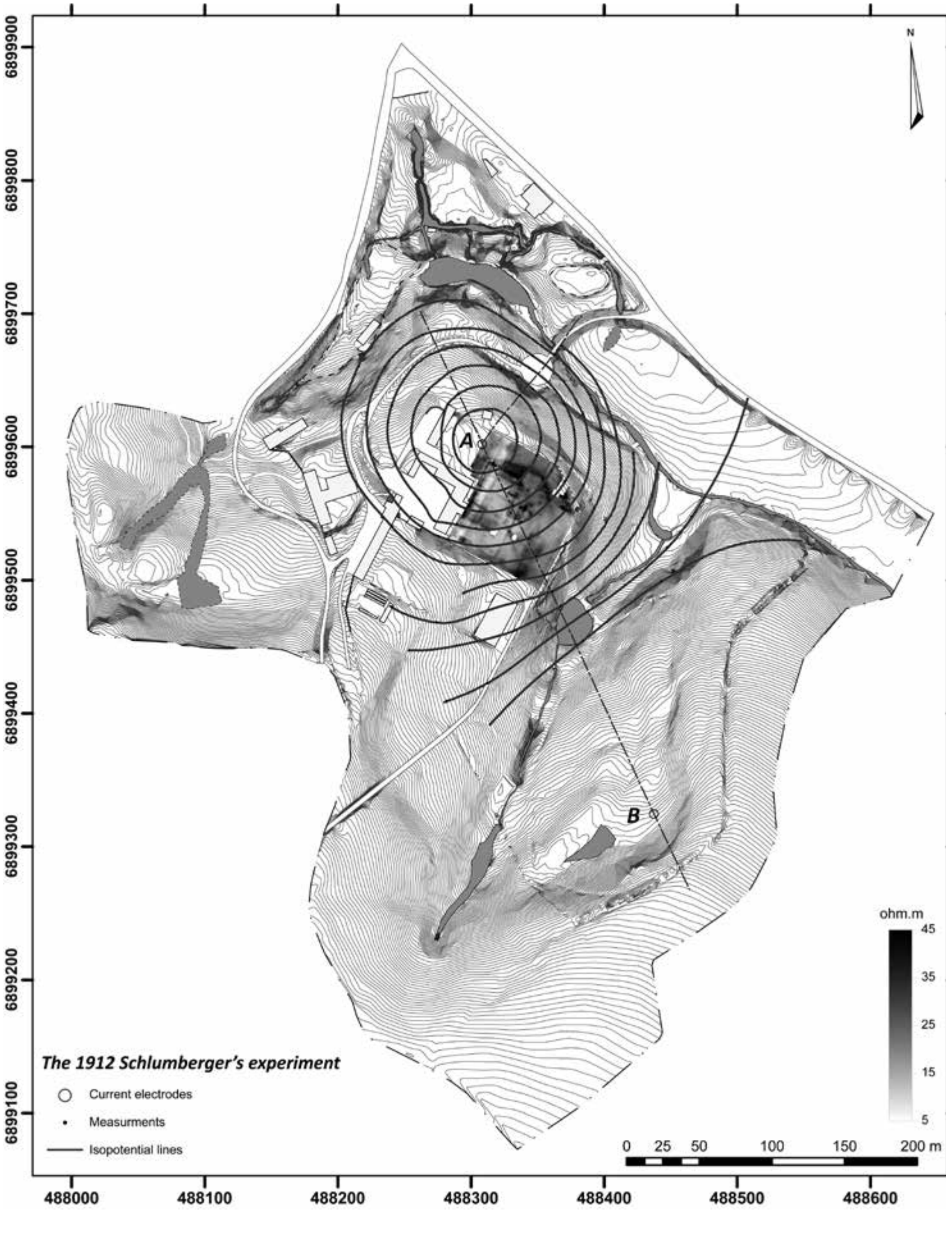

Fig. 1. Val Richer (Calvados, France). Superposition of the terrain elevation, building position, 1912 voltage contours drawn by Conrad Schlumberger and 2014 resistivity map (topographic survey: J.-B. Vincent; geophysical survey: G. Hulin, A. Tabbagh)

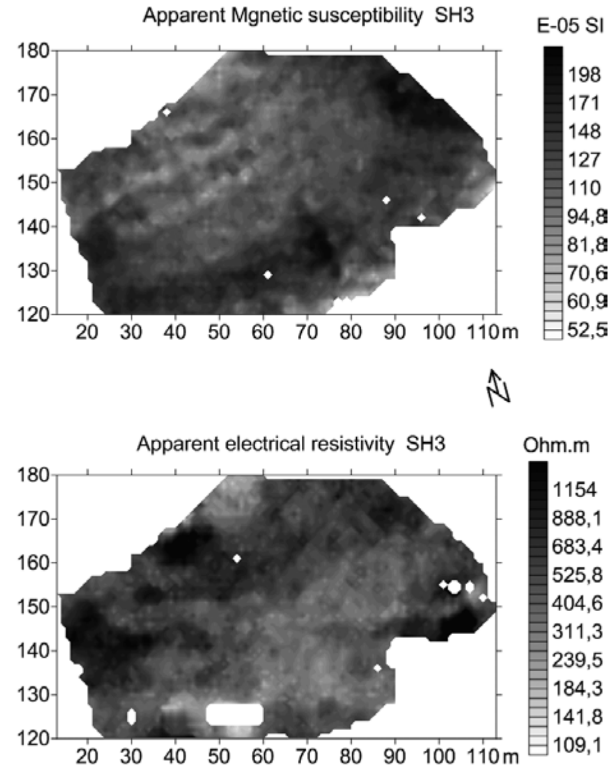

Fig. 2. Camp de Bierre (Merri, Orne, France) Late Bronze Age site. Apparent resistivity and apparent susceptibility maps measured using the SH3 instrument (1.5 m coil separation, PARA coil orientation)

techniques in order to overcome this limitation, and using Wait's theoretical formulas (1958), Scollar (1962) defined the characteristics of a matched apparatus. When EMI instruments were tested on archaeological sites using both frequency domain (FDEM) and time domain (TDEM) devices, a correlation was observed with the magnetic measurements but not with the resistivity measurements; the ground's magnetic properties were found to dominate the responses (Tite and Mullins 1969; Colani and Aitken 1966). In the case of FDEM instruments, it was recognized that electrical conductivity measurements can be made by taking the phase of the secondary field into account: for a commonly encountered range of soil conductivities and instruments with metric dimensions, the induction number can be much smaller than unity if the frequency is lower than 100 kHz (the induction number, $\sigma\mu\omega L^2$, is the product of conductivity, magnetic permeability, angular frequency and characteristic geometric dimension of the device). The conductivity response is thus in-phase quadrature, and the in-phase magnetic susceptibility can be determined from the in-phase response. The SH3 instrument (Parchas and Tabbagh 1978) successfully performed these two simultaneous measurements (Fig. 2). Later, exploration geophysicists working in mining prospection recognized the presence and significance of the magnetic component of EM responses, which allowed signifi-

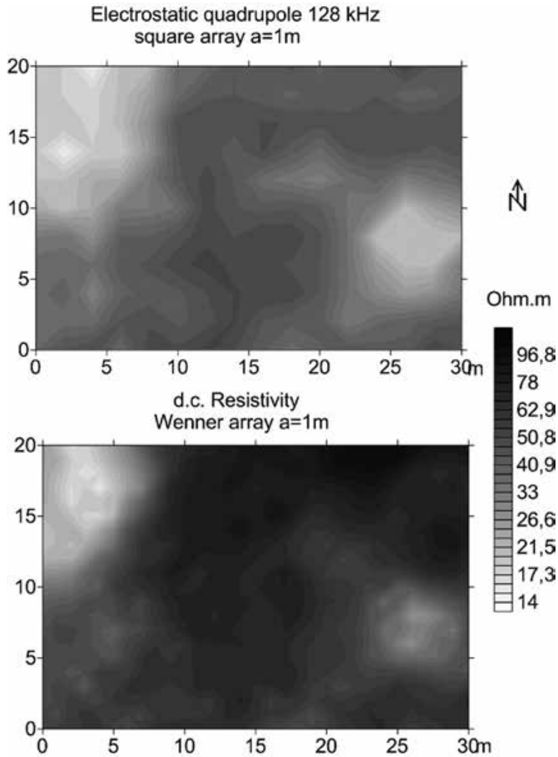

Fig. 3. Garchy (Nièvre, France) test site. Comparison between the resistivity map obtained with a 1 m square array, using the direct current resistivity method, and the resistivity map obtained with an electrostatic quadrupole of the same geometry at a frequency of 128 kHz

cant improvements to be achieved in the interpretation of both FDEM and TDEM signals (Buselli 1982; Beard and Nyquist 1988).

Instruments of this class are thus able to simultaneously measure and map two independent properties: electrical resistivity and magnetic susceptibility. They also open new paths for a joint interpretation of these susceptibility maps and the earth magnetic field variations recorded using the magnetic method.

THIRD SNAPSHOT

Although the EMI instruments provide a solution to the galvanic contact limitation, they fail to produce good results in contexts of high ground resistivity, and suffer from major disturbances in the presence of any metal. Other solution(s) thus merit consideration. An electric field can be produced directly by an open capacitor, of which the first plate carries an electrostatic charge +Q and the second plate has an electrostatic charge –Q. However, when such a field source is placed near the ground surface, a series of questions arises: what is the field distribution inside the ground, which property(ies): electrical conductivity, σ, and/or dielectric permittivity, ε, intervene, what are the roles played by the clearance above the ground's surface and the frequency? To answer these questions, theoretical approaches were adopted based on the image method (quasi-static assumption) and Maxwell's equations, and a quadrupole device was built, comprising two open capacitors, of which the first generated an electric field, and the other was used to measure the resulting voltage difference. The results of the first experiments made in 1988 are presented in Fig. 3 (Grard and Tabbagh 1991). Both experiments and theory allowed us to establish that when the induction number remains low and the displacement currents negligible, $\sigma >> \varepsilon\omega$, the results and the interpretation process are the same as for the direct current resistivity method. This electrostatic method (also called capacitive resistivity) opens up considerable possibilities for the surveying of urban areas, as illustrated by the results obtained during the Heptastadium research project carried out in Alexandria, Egypt (Hesse *et al.* 1998; 2002).

Beside these snapshots, other innovations, for example the introduction of vertical pseudo-gradient measurements in magnetic prospection (Tite and Aitken 1962), could be raised to demonstrate the influential contribution of archaeological prospection to the progress of applied geophysics.

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From WW1 to World Files: collaborative work in archaeology through the use of Internet technologies

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KEY-WORDS: WW1, trenches, Unexploded Ordnance, craters, Web-GIS, collaborative platform

INTRODUCTION

The example of two big projects in France will be used to show the use of a collaborative platform (Web-GIS) for the display, dissemination and interpretation of the data. The first example is a 220-hectare project in Northern France for the laying of a high-voltage power cable. The second project, carried out near Lens, aimed at characterizing soil heterogeneity for civil engineering before the construction of a development zone (ZAC), but also at identifying, before the mechanical stripping took place, any obstacles deriving from archaeology, pollution or World War One-related activities. We will show that for both projects located at the forefront of the WW1 front line, war-related remnants play a major role in soil spatial and physical heterogeneities. Beside the massive use of high resolution geophysical technologies, a major advance was the use of web-GIS technologies for the analysis and display of a huge amount of data (geophysical maps, aerial photos, historical battlefield maps). In addition, the platform not only made possible the display of non-geographic data (reports, videos, hyper-links), but also made possible interactions between the different partners by giving the possibility to interact on the maps.

FIELD APPROACH

RTE project

The aim of the RTE (main company delivering electricity in France) project is to lay a high-voltage power cable in Picardy. A series of high spatial resolution geophysical surveys was undertaken over the entire surface of the project (strip of 100 m by 22 km= 220 ha). This project is unique in that it has used a systemic approach, required for understanding complex projects. The different threats associated with different problems were not studied separately, but as a whole, thanks to a set of different geophysical maps. A similar project in terms of size was carried out in Italy, but only for an archaeological purpose (Campana, Dabas 2011). All geophysical methods were towed by All Terrain Vehicles (ATV), enabling high-speed data acquisition together with sub-metric spatial resolutions (ARP® electrical method, AMP magnetic and EMP electromagnetic) and centimeter position accuracy (RTK GPS). This innovative approach enables the assessment of different risks linked to different stakeholders: Unexploded Ordnance (UXO), geological risk (cavities, decompaction zones, etc.), archaeological risk. The data volume to handle consists of approximately 160 million points corresponding to the three

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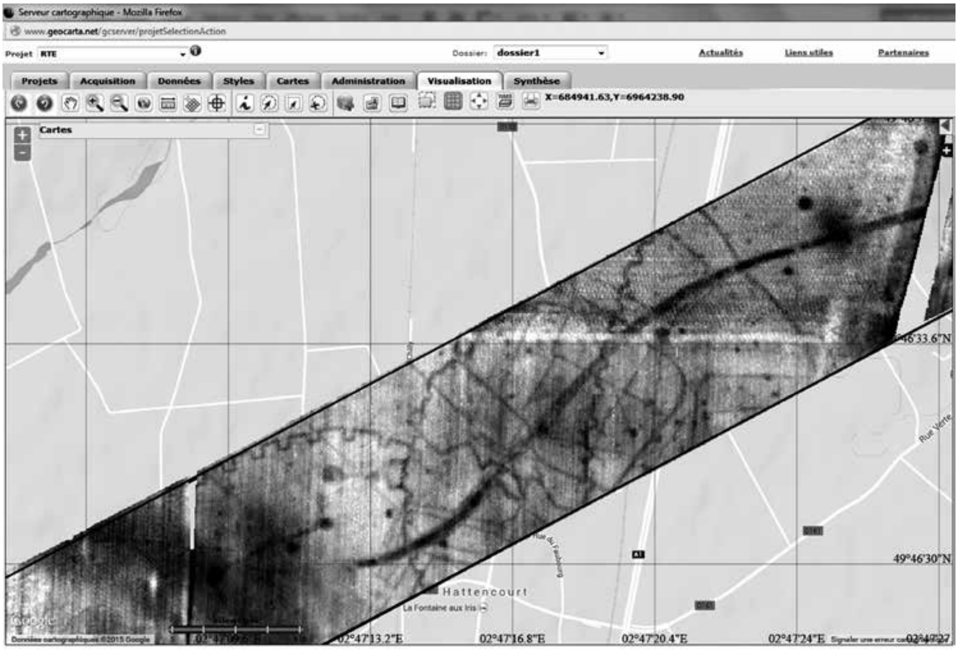

Fig. 1. RTE project: overlay of Google street maps and ARP® apparent resistivity in GCserver

data sets (resistivity at three depths for magnetometry and EMI at six depths). The output of the project was the definition of the best trajectory (50 cm wide, 22 km long) for laying the power line within the 100 m swath, taking into consideration all the threats discovered by the geophysical measurements and of course the engineering constraints for such a project.

Sallaumines project

Sallaumines is a smaller project (18 ha) but the methodology and the goal are identical to the RTE project. The only difference is that the site is situated within a town. The output of the project was to define the best location for different kinds of boring for the following geotechnical missions: lithology, permeability, piezometers and also knowing in advance diverse threats related to possible WW1-related voids, unexploded ordnance (UXO) and potential archaeological remains.

BACK OFFICE APPROACH

Both projects were possible thanks to the use of two types of GIS: i) a real-time data acquisition GIS (GCOffice) developed by Geocarta since 2001, ii) a collaborative web-GIS (GCserver) developed also by Geocarta since 2010. The first software is able to monitor all the data acquisition steps regardless of the geophysical method. Positional data are acquired through the output of a RTK GPS system. This system includes navigation software to guide the operators in the field, following a pre-defined sampling strategy. Quality is also checked in real time together with all

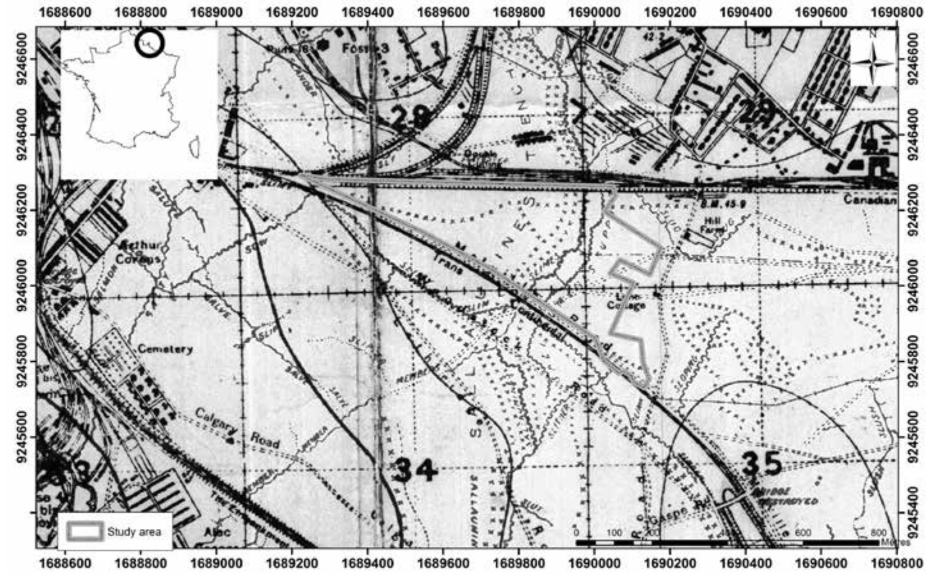

Fig. 2. Sallaumines project: trench maps from December 1917 (white lines) and the extent of the project (black line)

geophysical parameters. The same software is also used after the completion of the survey for the different processing steps in the office.

This software is also used in the field in order to test map quality as well as show the first results to the archaeologists. The procedure turned out to be very laborious for complex projects where several actors are involved. In the RTE project, for example, more than fifty actors were involved and at Sallaumines, more than five types of engineers were interacting with the town municipality. For this reason, it is no longer possible to show individually the results on a screen or through paper maps. Also, the documentation produced by us and the different actors evolves at a rapid pace. Finally, most of the actors do not have the software or skills to visualize data or have the ability to 'play' or even interact with it.

This is why we have developed a web-GIS solution (GCServer) for sharing all documentation and maps through the web with secure access that may be configured as a function of the end user's profile. This platform is also a collaborative platform, because it is possible for every actor to download or upload data, but also to interpret or insert comments directly on the maps which can then be shared with the whole community. The advantage of using a web-based application is that you do not have to install specific software on your computer; all you need is a simple web-browser … and an Internet connection.

Both projects are situated near the WW1 frontline. An analysis of the first geophysical results clearly indicated that most of the anomalies were related to war remains (Fig. 1). Trenches, the most obvious structures, were perfectly delimitated by resistivity, as were shells and mine craters.

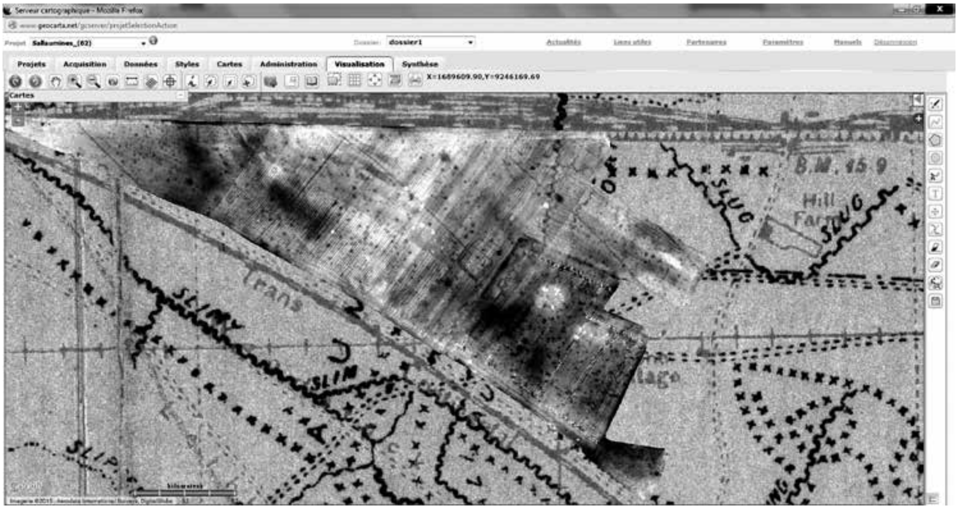

Fig. 3. Sallaumines project: overlay with GCserver of trench maps and apparent resistivity

Archaeological remains of greater antiquity were also discovered. The scope of the paper is not to compare the information brought by each method, but to state that the resistivity maps gave the most detailed information, whereas magnetics and EM maps were usable, but nearly saturated by all the metal artifacts. GPR (Ground Penetrating Radar) could be very successful as well (Saey *et al.* 2015), but its use would not have been economically feasible on such a scale and it would have been hindered by the presence of clay soil.

It became clear that WW1 trench maps were needed to corroborate our results with the written records (or *vice-versa*). Different war maps can easily be found on the Internet and rights to use them can be acquired. Many trench maps of the Western Front, for the period from mid-1915 until the end of the Great War, are available and with a scale, for the most precise of them, perfectly suited for our projects (1:10,000). The most useful of the posted map and aerial images were those from December 1917 (Fig. 2). These maps were subsequently georeferenced and superposed on geophysical maps (Fig. 3). The overlay of the historical maps fits perfectly well with the anomalies found. Interactions between the partners of the project were possible thanks to the online drawing tools and the ability to add text or videos over the maps.

CONCLUSIONS

Both projects have emphasized the benefits of using both GIS in the field and web-based GIS in the office for the management of big land development or archaeological projects. Beside the massive use of high resolution geophysical technologies in the field, the use of web-GIS technologies for the analysis and display of a huge amount of data (geophysical maps, aerial photos, historical battlefield maps) proved to be successful in terms of communication between the different actors, and precision of the follow-up of both projects.

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A geophysical survey at Schlumberger's Val Richer residence: between archaeology and the history of science

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KEY-WORDS: Schlumberger, Val Richer abbey, resistivity survey, history of science

The Val Richer (Calvados, France) property, which became the family domain of Conrad Schlumberger, is recognised as being the place of origin of applied geophysics. During the summer of 1912, Conrad Schlumberger tested for the first time a new method designed to map out the electrical resistivity of the subsurface. These encouraging tests led the Schlumberger brothers to develop this type of prospection and to create first an engineering office in 1920 and then the Société de Prospection Electrique in 1926, the Compagnie Générale de Géophysique (CGG) in 1931, the Schlumberger Well Surveying Corporation in 1934, and Schlumberger Limited in 1956, which has become the largest multinational company in the oil service industry (Robin 2003).

A hand-drawn blueprint made by Conrad Schlumberger, which is well known in the geophysics community, describes this experiment (Fig. 1). It shows the electric field distribution together with a hand-written comment describing the difficulties encountered and the solutions retained.

Nearly 100 years after this founding experiment, a research project was initiated at the same place where Conrad Schlumberger's measurements were carried out, with its main objective being to discover the remains of the Val Richer abbey. The Schlumberger family residence is indeed built at the same location as this abbey, right in the heart of Normandy. As a consequence of the destruction resulting from the French Revolution, there are currently no remaining relics.

In 2014, the implementation of a geophysical study made it possible to unite two inseparable stories from Val Richer. By applying the principles developed by the Schlumberger brothers, it was possible to find the location of the abbey's religious buildings, which are now totally destroyed (Fig. 2). The interpretation of the geophysical survey, in the light of archival sources and current knowledge of the

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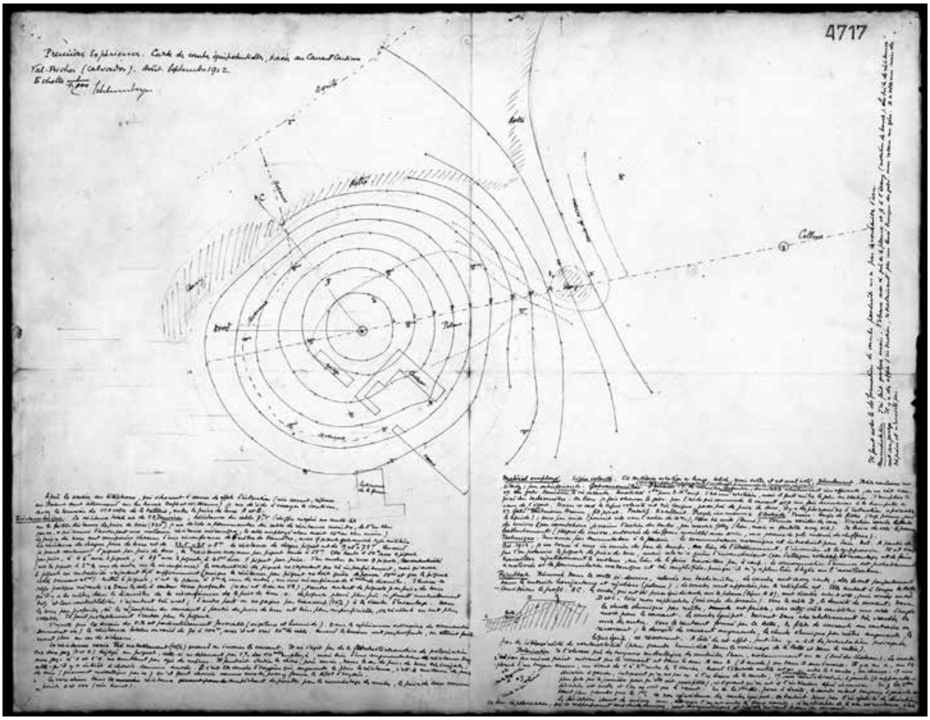

Fig. 1. First map of equipotential curves: Val Richer, August-September 1912
(Schlumberger 1912)

Cistercian abbeys of Normandy, has completely revived our vision of the Val Richer abbey and enabled an accurate outline of the plan of this monastic settlement.

In parallel with this archaeological study, it has been possible to analyse the 1912 blueprint to a level of detail which, to our knowledge, had never previously been achieved. A complete analysis of this account and associated drawings was carried out in order to transpose the solutions adopted by Conrad Schlumberger to the context of current knowledge and practice in resistivity survey. In particular, he described the type of apparatus, the type of cable, as well as the electrodes used. He also described signal acquisition problems, in particular induction phenomena related to the length of the cables as well as the contact resistance of the current probes. Finally, he described the results and tried to interpret the local anomalies observed.

There are thus two sections of Val Richer, *a priori* distant, which are recombined by this study (Fig. 3), demonstrating the usefulness of the multidisciplinary approach that was so well defined by Conrad Schlumberger, and that can readily be transposed, when needed, to applications in archaeometry.

"La prospection électrique rentre dans cette catégorie d'études mixtes qui s'appuient sur des notions très variées, ne sont ni chair ni poisson, et déplaisent aux chercheurs sagement spécialisés

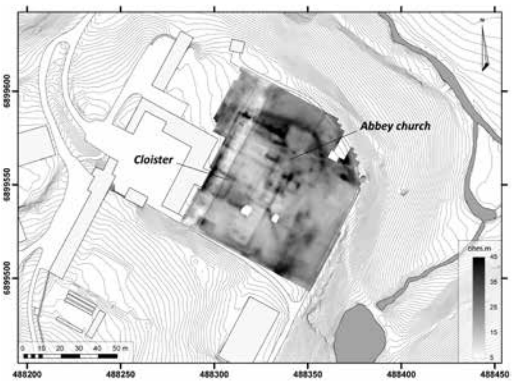

Fig. 2. Resistivity survey: Val Richer, June 2014

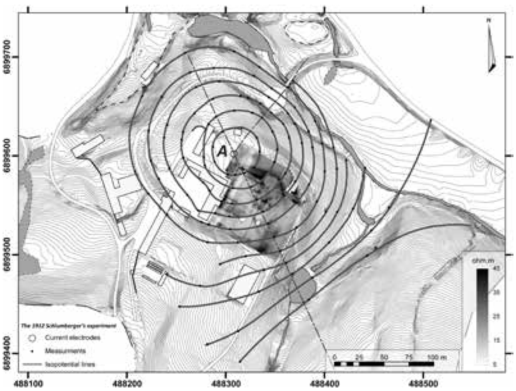

Fig. 3. Superimposition of the terrain elevation, building position, 1912 voltage contours drawn by Conrad Schlumberger and the 2014 resistivity map - Val Richer. For the complete figure, see Tabbagh Fig 1, 133 in this volume

dans un classique compartiment scientifique. En effet, il faut être un ingénieur mathématico-physico-technico-géologue, avec le goût de l'expérience et du grand air, pour aborder volontiers le problème. Le hasard qui m'a chargé d'un cours de physique dans une Ecole des Mines m'a logiquement presque forcé à rechercher pendant les longues vacances de l'ancien régime, les applications de la physique à l'art des mines en général et à la prospection en particulier. C'est ainsi que je me suis engagé en 1912 sur ces sentiers peu battus et que j'y ai progressivement entraîné plusieurs collaborateurs qui partagent aujourd'hui avec moi la bonne et la mauvaise chance. Des connaissances élémentaires suffisent parfaitement. Encore faut-il les avoir, ou désirer les acquérir, et cela ne doit pas être si fréquent puisque le domaine n'a encore que peu été étudié, malgré l'importance des perspectives ouvertes. Je tiens à rester un technicien qui va plus loin que l'étude du caillou."

Conrad Schlumberger, *Le puits qui parle*, Paris, 1921

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Interdiciplinary archaeological prospection at unprecented scale and resolution. The first five years of the LBI ArchPro Research Initiative 2010–2015

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The Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro) together with its partner the Central Institute for Meteorology and Geodynamics (ZAMG) has developed motorized magnetic prospection systems to survey entire archaeological landscapes within reasonable time at high spatial sampling resolution. With these novel prospection systems the LBI ArchPro has successfully surveyed in total more than 32 km^2 over the past five years, resulting in magnetic maps containing millions of anomalies. While data collection, data positioning and the processing of the data have been automated (with exception of the operation of the survey vehicles), the outlining (data segmentation and classification) and interpretation of the prospected magnetic anomalies has become in regard of large amount of generated data a tedious, very time consuming, so far manually conducted task. In order to speed up the interpretation process we have therefore developed a workflow and algorithms for the automatic detection, outlining and classification of magnetic anomalies. Relevant magnetic prospection anomalies are automatically classified into two classes, which are "iron litter" objects that are located closed to the surface, and deeper reaching individual "pit" objects. Based on this classification we calculate several physical and geometrical properties for each object and export this data to a Geographical Information System (GIS) for further interactive classification and subsequent data interpretation.

KEY-WORDS: arge-scale, high-resolution, near surface geophysics, remote sensing, interpretation, virtual archaeology, digital documentation

The Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro) was founded by the Austrian Ludwig Boltzmann Gesellschaft in Vienna in April 2010. The institute is dedicated to the development of new techniques and methodological concepts for landscape archaeology, combining high-resolution geophysics, aerial imaging and remote sensing, computer science and geomatics in order to develop efficient and universally applicable tools for the non-destructive detection, documentation, visualisation and interpretation of cultural heritage at unprecedented scale. Having started with 15 employees in 2010, the institute now employs 33 young scientists and support staff. 17 PhD projects are connected to the LBI ArchPro through close collaboration with the Initiative College for Archaeological Prospection of the University of Vienna.

An important part of the LBI ArchPro are its twelve European partner organizations, representing academic institutes, national archaeological and geophysical research departments, governmental cultural heritage agencies as well as commercial archaeological prospection service providers and

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Fig. 1. Staff of the LBI ArchPro and PhD students of the Initiative College for Archaeological Prospection in Vienna

SMEs. Partners are the Norwegian Institute for Cultural Heritage Research (N), Vestfold County administration (N), Province of Lower Austria (A), Archaeological Contract Service of the Swedish Central Heritage Board (S), Roman-Germanic Central Museum in Mainz (D), Vienna University of Technology (A) with the Institute for Computer Graphics and Algorithms and the Institute for Photogrammetry and Remote Sensing, University of Vienna with the Vienna Institute for Archaeological Science and the Department for Prehistoric and Historical Archaeology (A), IBM VISTA laboratory at the University of Birmingham (UK), Airborne Technologies (A), Central Institute for Meteorology and Geodynamics (AUT), and 7reasons Medien GmbH. Collaboration agreements exist with academic institutions, museums, as well as manufacturers of latest measurement technology, prospection sensors and survey systems.

The LBI ArchPro studies and develops non-invasive archaeological prospection and digital documentation methods in a wide range of research areas. In the field of airborne archaeological remote sensing the topics of aerial photography (e.g. auto-rectification of ortho- and oblique photographs), airborne laser scanning and specialized data processing and airborne imaging spectroscopy are researched in detail.

Regarding geophysical archaeological prospection, highly efficient motorized survey systems consisting of dense arrays of Fluxgate and Cesium magnetometers, and GPR antennae as well as electromagnetic sensors are developed and applied at unprecedented scale and resolution.

In the field of archaeological data interpretation and virtual archaeology, the semi-automatic data segmentation and classification as well as integrated data analysis and interpretation and virtual/augmented reality simulations are the foremost research focus. For the purpose of digital site and landscape documentation, multi-scale data capturing methods, such as terrestrial and airborne laser scanning and image based 3D modelling, are being investigated and advanced.

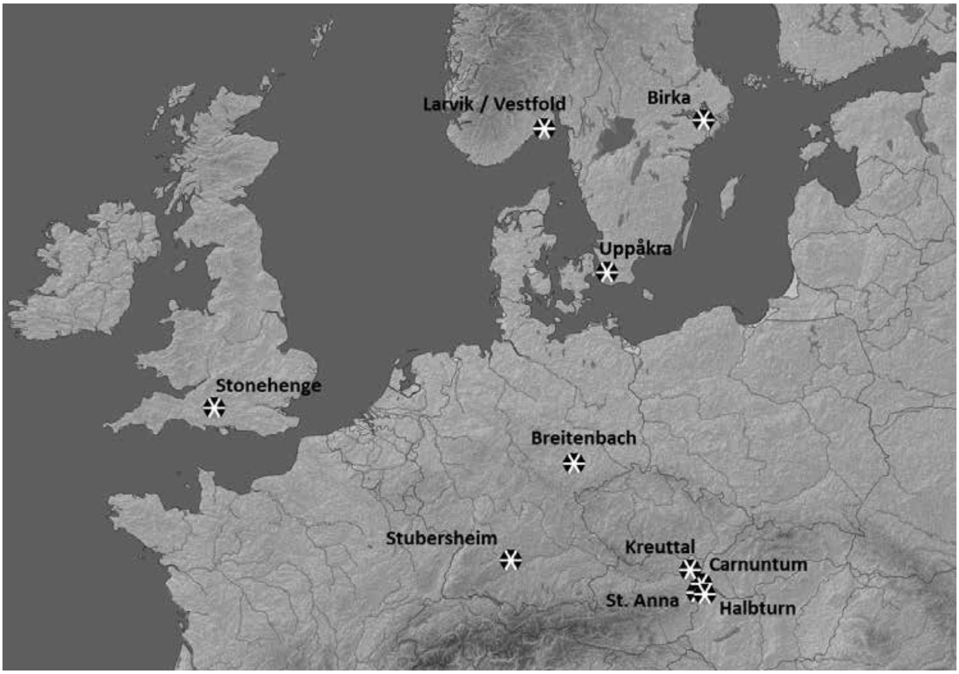

Fig. 2. Overview of the LBI ArchPro case study areas

Within the LBI ArchPro research programme various geographical areas have been selected together with the partners in order to provide different archaeological landscapes for distinct case studies, in which the technological and methodological developments are tested and applied on a large scale.

Investigated case study areas are the UNESCO World Cultural Heritage sites Birka-Hovgården (S) and Stonehenge (UK). In the latter case, the entire area within the so called "Stonehenge Envelope" was prospected within the frame of the Stonehenge Hidden Landscapes Project. Furthermore, the Iron Age and Viking Age sites of Borre, Kaupang, Gokstad and Oseberg, among others in Vestfold County (N), as well as the central Iron Age site of Uppåkra in Sweden, the Roman town of Carnuntum in Austria, the Kreuttal region north of Vienna, the rural landscape of Stubersheim on the Swabian Alb in Germany and of Halbturn in Austria are being investigated. Additionally, pilot studies have been conducted at Flavia Solva (A), St Anna (A), Kilianstädten (D), Bassianae (SRB), Bisenzio (I), Osor (HR), Tanum (S), Akrotiri (GR) and Hala Sultan Tekke (CY).

The following research and development results have been achieved so far.

- Highly efficient motorized magnetometer and GPR survey systems have been developed and tested under harsh conditions on an unprecedented scale and resolution.
- Software for motorized magnetic data acquisition and smart navigation has been developed, tested and optimized.

- Appropriate, highly efficient data processing software for large-scale near-surface geophysical prospection data has been developed, involving exact data positioning algorithms, new processing algorithms for the removal of vehicle-induced noise, and smart interpolation of irregularly sampled GPR and magnetic prospection data.
- Algorithms for automatic and semi-automatic data segmentation, classification and interpretation for the efficient treatment of large quantities of high-resolution prospection data have been developed.
- Novel GIS tools for efficient data management, handling and archaeological interpretation have been developed.
- Numerous new important archaeological discoveries have been made within all case study areas.
- Efficient workflows for comprehensive case study management have been designed.
- A number of large third-party funded research projects have been generated and realized.

Highlights of 2010–2015 include the discovery of a school of gladiators in Carnuntum (listed among the top ten archaeological discoveries of 2011 by the Archaeological Institute of America), the detailed mapping of the hidden Stonehenge landscape and numerous known and only presumed prehistoric monuments (n. 1 on the Archaeological Institute of America's list of top ten archaeological discoveries of 2014), a high-resolution integrative prospection of all accessible parts of the Roman town of Carnuntum, detailed digital documentation of the archaeological site of Akrotiri on Santorini with support from the National Geographic Society, using laser scanning (850 scan positions) and thousands of photographs, mapping of a total of more than 33.5 km^2 with high-resolution Fluxgate magnetometer measurements (with 25 cm crossline and 10 cm inline sample spacing), coverage of a total of 9.17 km^2 with ultra-high definition GPR surveys (8–10 cm crossline and 4–8 cm inline trace spacing), and a honorary mention for best poster presentation at the 2012 Society of Exploration Geophysicists Conference in Las Vegas.

The work of the LBI ArchPro has so far resulted in 31 peer-reviewed scientific papers, 24 non-peer-reviewed articles, 27 book chapters, two edited volumes, 121 conference proceedings, 53 talks of which 24 were invited talks, 20 poster presentations, three master theses, eight movie productions (including a comprehensive documentary aired on BBC/Smithsonian TV) and countless media reports. Over 111 academic courses related to archaeological prospection have been taught by LBI ArchPro staff at university departments since 2010 and 13 visiting researchers have been hosted. The 10th International Conference on Archaeological Prospection 2013, as well as the first workshop on "Pioneering Archaeological Prospection" were organised by the LBI ArchPro.

For more information on the LBI ArchPro and its activities and publications see *http://archpro.lbg.ac.at*

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Special session on archaeological feedback

Emptyscapes: filling 'empty' Mediterranean landscapes, mapping the archaeological *continuum*

Stefano Campana[a]

KEY-WORDS: landscape archaeology, emptiness, archaeological continuum, large-scale geophysics

Research in the Mediterranean area reflects a real gap between archaeological recording and broader aspects of interpretation. This was not just historically conditioned, but also results from the natural characteristics of the Mediterranean landscape. Architecture and urbanism in the ancient cities lend themselves very well to investigation. By virtue of their monumental importance, artistic value and easy accessibility, the ruined remains of ancient structures have always been a focus of research. This is also true of the preserved remains of Greek field systems and Roman centuriation, which have been recorded from the ground and from the air more than half a century ago for the first time. By contrast, sites and landscape features outside the ancient urban centres, most of them now completely buried and therefore invisible to the naked eye, have been investigated less frequently. A new interest in landscape studies developed in the Mediterranean area about the end of World War II. Since the mid 1970s there has been an explosion of activity providing coverage of archaeological research in the majority of circum-Mediterranean countries (Alcock and Sherry 2004). The main approach in this revived research direction has been (and remains) fieldwalking survey, within a variety of project-based strategies. This pioneering post-WWII and later field survey work has produced dramatic data that has made significant contributions to a reconstruction of the past. Virtually every region that has been explored has produced results, which demanded the revision or review of existing ideas (Broodbank 2013).

However, going into the detail after millions of hectares of Mediterranean landscapes have now been surveyed by terrestrial reconnaissance, it is legitimate for us to ask: which questions have been answered? In essence, the general contribution is quite clear to summarize. There are two main fields where a substantial impact has been achieved: settlement and trade patterns, both mainly from the Mediterranean to the regional scale; and contributions

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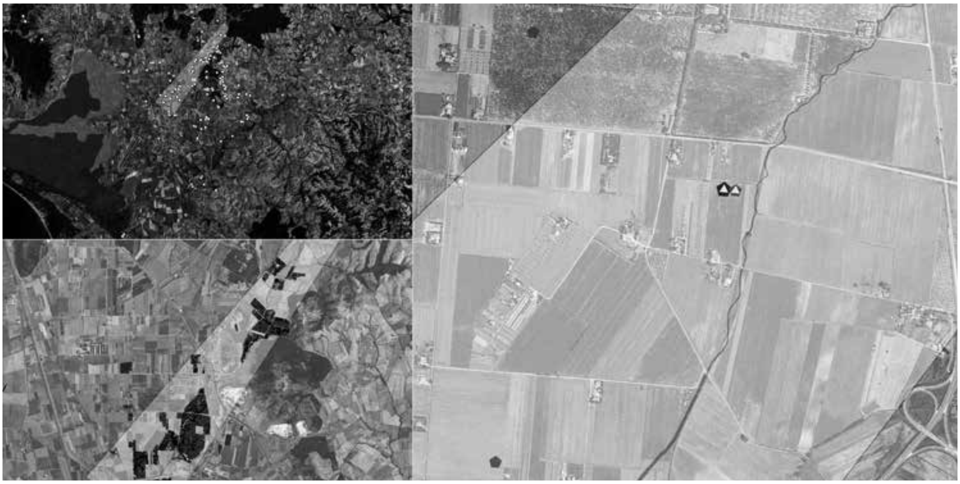

Fig. 1. The Rusellae/Grosseto study area. Top left. Distribution map (grey dots) of fieldwalking survey and Lake Prile (dark grey), which occupied part of the Rusellae/Grosseto study area during the first millennium BC and up to the end of the Middle Ages. The pale-grey area represents the sample transect now under study, with dark grey for the areas already covered by geophysical prospection. Right. Closer view of part of the sample transect showing the results of a traditional archaeological survey

to specific chronological phases, above all higher impact on to the Roman period should be recognized. By contrast, the surveys have produced generally poor results for the pre-Roman and mediaeval periods, although the degree of impact has varied from area to area. Moreover, the reconstruction of settlement patterns represents only one element in landscape complexity; this framework, for instance, generally reveals little about environmental transformations and human interaction (pedology, land-use etc). As a consequence a wide variety of questions belonging to the sphere of archaeology, history, anthropology and environment are seriously prejudiced by this approach. Furthermore, the reliability of fieldwalking survey has been debated for decades without much being achieved in resolving inherent methodological weaknesses in comparing the results of different surveys and establishing relationships between the survey results and demographic trends (Alcock and Sherry 2004).

There are further biases that affect the results of landscape study based on fieldwalking survey. Two decades ago, Barker, in his introduction to the Biferno valley (1995), outlined how Braudel (1972) in his opening chapter (part one of *La Mediterranée*) lamented how the low land has tended to dominate most previous analyses of Mediterranean history. Archaeological survey has failed to confront or resolve this bias since the application of fieldwalking is strongly influenced by present-day land-use and is therefore mainly restricted to ploughed land, which for the most part corresponds to the low land. Higher land is mainly wooded or put down to pasture, which is less responsive to fieldwalking survey. Moreover, it is worth commenting in this context that about 50% of the European Mediterranean landmass falls into this category (FAO 2006). Despite

Fig. 2. The Rusellae/Grosseto study area. Left. Part of the sample transect with red to show the results of traditional archaeological survey. Right. The same area showing integrated remote sensing survey and GIS-based data mapping. Grey scale mapping drawings show the various kinds of natural and archaeological features identified so far. The quantitative and qualitative improvement in the landscape database is clearly visible, making it possible to ask, and eventually to answer, new archaeological questions about field systems, communication routes, settlement patterns, and former water courses that may have conditioned settlement and land-use within the sample area. The smaller-scale inset in the top left corner of the diagram shows the areas of completed geophysical prospection in dark grey, clearly demonstrating the correspondence between detected features and the adopted survey method

these obvious weaknesses historians as well as archaeologists use fieldwalking data to support models, patterns and large-scale landscape transformations. The answers to big historical questions are still for the most part sought through textual analysis and archaeological excavation rather than through landscape studies (Witcher 2006).

In the last two decades, a central role in the continuing debate about methodology within archaeology and landscape studies has been provided by at least three long-term European research projects: the POPULUS project (1995–2000), the Radio-PAST project (2008–2013) and the Archeo-Landscapes Europe project (2010–2015), all strongly associated with universities and other institutions belonging to both the continental geographic sphere and the Mediterranean area.

Emptyscapes is a two-year project funded by the European Union under the Marie Curie scheme. The research is designed and aimed to stimulate changes in the way in which archaeologists (in Italy in particular, but also more generally in the Mediterranean world) study the archaeology of landscapes, moving from an essentially site-based approach to a truly landscape-scale perspective. The project focuses on the rural landscape between Rusellae and Grosseto (Figs 1 and 2) and the once urban historical landscapes of Veii (Fig. 3) in Italy and is aimed at prompting the development and wider application of new paradigms for landscape analysis, based on an interdisciplinary programme integrating 'traditional' approaches (fieldwalking survey, aerial photography etc.), environmental studies (palaeo-environment, geoarchaeology, bioarchaeology) and new technologies in the form of high-precision, high-speed, large-scale geophysical survey and the collection and analysis of high-resolution LiDAR data.

Fig. 3. Left. Magnetic survey of the plateau of the ancient city of Veii. Right. Archaeological interpretation

In its first year the *Emptyscapes* project has clearly demonstrated the effectiveness of this approach to landscape studies also in the Mediterranean environment, showing that archaeological features are potentially present everywhere. Moreover, following increased research, the gaps in time and space are progressively disappearing or being significantly reduced: the absence of past human activity seems to be in reality an exception rather than the rule.

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Closing the loop. Extracting more value out of archeogeophysical surveys in the Raganello Basin

Martijn van Leusen[a]

KEY-WORDS: methodological studies, landscape archaeology, Mediterranean, confident interpretation of anomalies

INTRODUCTION

To make optimal use of the money, time and expertise that goes into archeogeophysical survey, geophysicists and archaeologists must ensure that their interactions are truly interdisciplinary — not multidisciplinary as is still often the case. Collaborations must start in the research design phase and continue all through the analysis, synthesis and 'further work' stages of a typical research program. In particular, geophysicists and archaeologists alike must learn what they can from invasive field tests (coring, topsoil stripping, test pits, full excavation) about the true character of a wide range of anomaly types. I will present the work of my own landscape archaeological research program in the basin of the Raganello river as a model for interdisciplinary work, discussing some of its successes and failures and what we should learn from them.

Groningen University's *Rural Life in Protohistoric Italy Project* (RLP, 2010–2015) studies a selection of small protohistoric sites that were recorded in earlier systematic fieldwalking surveys in the basin of the Raganello river (northern Calabria, Italy), but the main import of the research is methodological: namely, the development of approaches for the analysis and interpretation of dispersed rural sites, as recorded in field surveys all over the Mediterranean. The research builds on geophysical experiments conducted in 2006 (van Leusen *et al.* 2014) and detailed models of how slope processes affect the preservation and visibility of archaeological sites (Feiken 2014).

The research aims to produce a scientific description of site types that are usually ignored because they are of no culture-historical interest, but by their very ubiquity are of great socio-economic significance. A second aim is to develop a fast site assessment method, useful to both researchers and managers of the archaeological heritage. The Project uses an explicit sampling framework to determine the smallest number and type of sites that must be investigated in order to derive conclusions with a sufficient degree of confidence, and employs three stages of increasingly intensive and, at the same time, selective investigation: surface survey – geophysical survey and coring – trial trenching. A GIS environment is used for field recording and project data integration.

RESULTS

The *Rural Life Project* has conducted a substantial number of experiments to determine which geophysical mapping methods work in the specific Mediterranean geoenvironment, which types of geological and anthropogenic anomalies occur, and how the latter relate to subsurface archaeological reservoirs. The results are currently being prepared for publication

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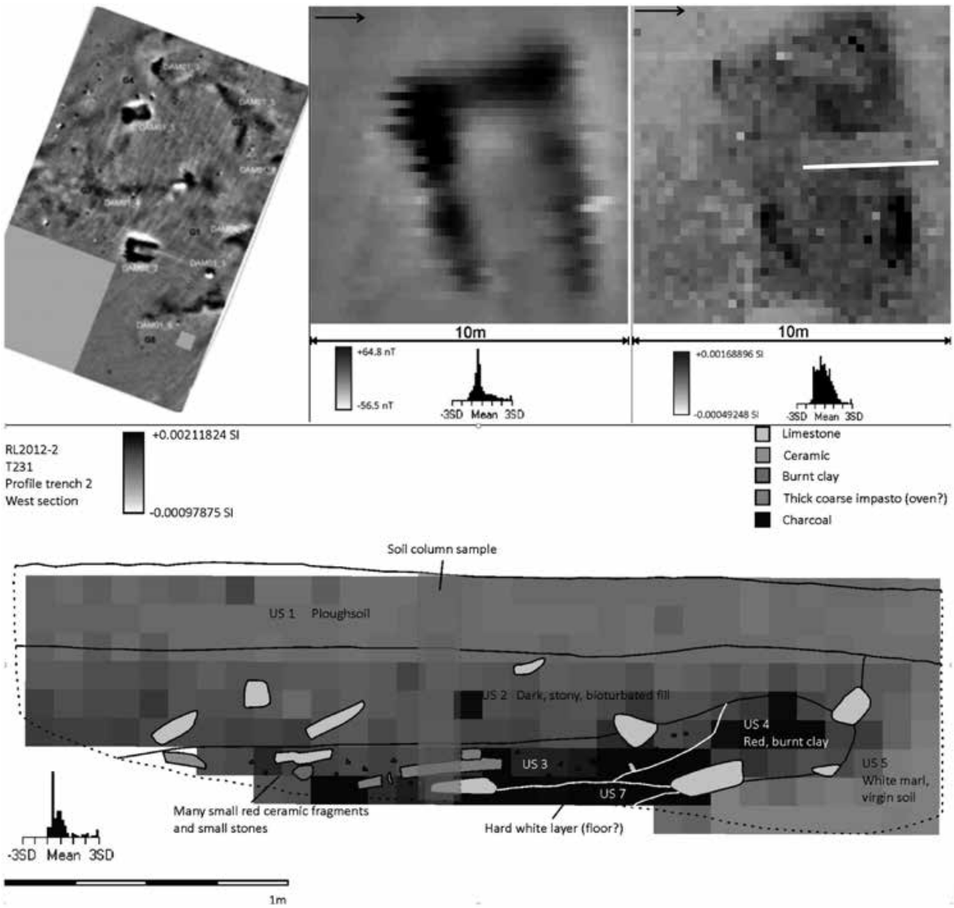

Fig. 1. Magnetic data collected at site T231. Top left: 60 m x 90 m magnetometer survey (T231 is just below the center). Top right: magnetometer survey data over land surface and stripped surface. Bottom: magnetic susceptibility (MS) data in 10 cm grid across section in test pit, highlighting destruction layers

in a substantial volume (Armstrong and van Leusen 2015), but these are not the topic of this paper. Instead, the focus will be laid on lessons learned about the role of feedback between the project archaeologists and geophysicists, as well as between the two disciplines.

FEEDBACK BETWEEN ARCHAEOLOGISTS AND GEOPHYSICISTS IN THE RURAL LIFE PROJECT

After the pilot geophysical work conducted in 2005–6 (van Leusen, Kattenberg, Armstrong 2014), our first practical experience with geophysical mapping came in 2010, when Eastern Atlas conducted a magnetic gradiometry survey for us. Discussing these data, we were surprised:

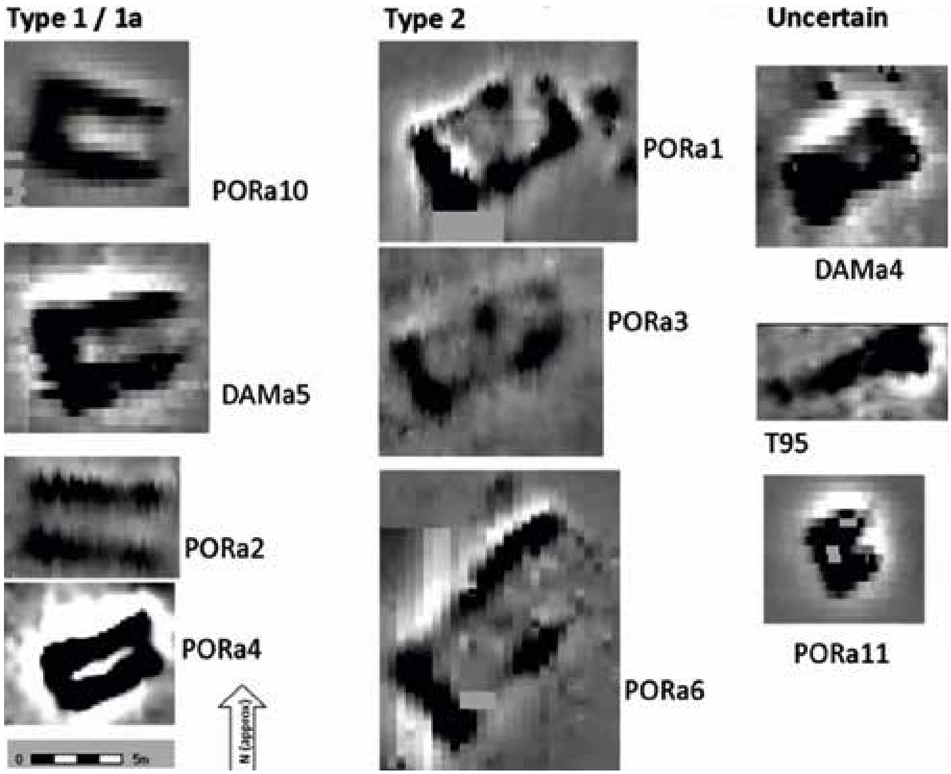

Fig. 2. Towards a 'library' of archeogeophysical anomalies. Shown here are (partial) rectangular gradiometer anomalies surveyed in the first year of the RLP, displayed at the same scale and with original orientation. Although this preliminary typology is now out of date, it shows how a new rectangular anomaly could be assigned to a type with excavated examples from the same region and geology, potentially leading to a more confident interpretation as, e.g., a Late Bronze Age house plan

- how few confident interpretations the geophysicists were willing to provide;
- how little feedback there is, during and after invasive studies of geophysical anomalies, between archaeologists and geophysicists;
- how little interest there seems to be in studying the *application* of geophysical methods to different archaeological and geological situations; geophysics is typically employed by archaeologists only to 'map' sites that have already been discovered, and innovation in archaeological geophysics centers on the technological improvement of measurement apparatus.

During the subsequent fieldwork, in which we worked with both Eastern Atlas and the geophysics team of the British School in Rome, we learned the following lessons on which this paper will focus:

1 Integrating archaeological and geophysical fieldwork as in the RLP requires feedback at a very basic level, regarding equipment and logistics:

- Making sure that both teams use the same measurement system, including local fixed points, for work conducted over extended periods (even across field seasons), and that field owners are fully aware what they give permission for;
- A timely exchange of georeferenced data and interpretations, using a GIS platform, so that the field strategy can still be adapted;
- Making sure that geophysical equipment is suitable for use by non-experts and in difficult field conditions. Once the local survey conditions are well understood, there is no reason that the data collection should not be done by trained archaeology students, if this is more convenient or cheaper. Equipment should also be sufficiently robust (e.g., no snagging cables) and user friendly (e.g., no buttons that require constant bending over) to allow efficient and effective data collection.

2 Stripping off the plough layer after geophysical survey, and sampling the emerging features for MS both at the surface and at regular depth intervals in cores, helps establish the precise dimensions of these features and helps understand why a particular shape and strength of anomaly was measured. Feeding back this information helps the archaeo-geophysicist reach more correct/confident interpretations of anomalies in the future.

3 Stripping and further invasive study (such as in test trenches) also highlights any inconsistencies in the evidence, such as the absence of a visible feature beneath a measured anomaly, the measured MS being insufficient to explain the measured anomaly (indicated remanent magnetization), and georeferencing errors. Feedback about such inconsistencies leads to a better assessment of what is/is not achievable with specific geophysical equipment in a specific landscape context, and often points to further research avenues.

4 Test pits at sites such as T231 (see Fig. 1) provide the stratigraphic information and MS data needed for the construction of forward models of selected anthropogenic and geological feature types (very much still in the pilot phase), ultimately leading to more confident interpretations of these feature types.

PRELIMINARY CONCLUSION

Geophysicist feedback to the archaeologist currently perforce relies on his/her own experience — not a very professional state of affairs. We need to be sure that information about similar anomalies, in similar landscapes, is available to guide geophysicists in their interpretations, and that a mechanism is developed to feed results of invasive archaeological studies of these anomalies back to the geophysicist. Some kind of 'library' of geophysical anomalies plus all relevant physical and archaeological data seems the best solution (Fig. 2), and I propose to apply for ERC grant funding for this. Any partners?

ACKNOWLEDGEMENTS

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Archaeological and geophysical survey of Tell el-Dab^ca, an ancient town in the Nile Delta

Irene Forstner-Müller[a], Tomasz Herbich[b] and Christian Schweitzer[c]

KEY-WORDS: Ancient Egypt, Nile Delta, magnetic prospection, electrical resisitivity prospection, paleolandscape

Tell el-Dab[c]a, a site located in the eastern part of the Nile Delta in Egypt, has been known to Egyptologists since 1885 thanks to Edouard Naville's excavation. The site was investigated later by Mohamed Hamza in 1928, Labib Habachi in 1941–42 and Shehata Adam in 1951–54. The Austrian Archaeological Institute in Cairo has been investigating the site since 1966, first under the direction of Manfred Bietak (1966–2009) and now Irene Forstner-Müller (since 2009).

The site can be identified with Avaris, capital of the Hyksos in the Second Intermediate Period (15th Dynasty,) and with the southern part of Piramesse, the Delta residence of the Ramesses. By the middle of the second millennium BC, Avaris was not only the capital of the Hyksos rulers, but also one of the largest and most important cities in Egypt and the Ancient Near East. It occupied around 260 ha and had an estimated population of between 29,000 and 34,500 persons. Its strategic position on the route out of Egypt to the east gave it the status of a hub and gateway between the Nile Valley proper and the Mediterranean and the Ancient Near East.

The town was founded on now buried sand mounds (*geziras*) on the southeastern bank of the ancient Pelusiac branch of the Nile. The *geziras* were preferred for settlement for they remained unflooded during annual Nile inundations. At present the whole area is cultivated and remains of ancient settlement mounds survive in only a few places. From the late 1980s to the beginning of the 1990s, the ancient landscape of Tell el-Dab[c]a/Qantir was reconstructed over an area of 12 km^2, based on about 800 core drillings (Dorner 1994). His map of the reconstructed historical landscape with the old Pelusiac branch, the river system and turtlebacks sets the framework for all prospective work in Tell el-Dab[c]a.

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Fig. 1. General magnetic map of Avaris. © Austrian Archaeological Institute

Fig. 2. Magnetic map of the Hyksos palace. © Austrian Archaeological Institute

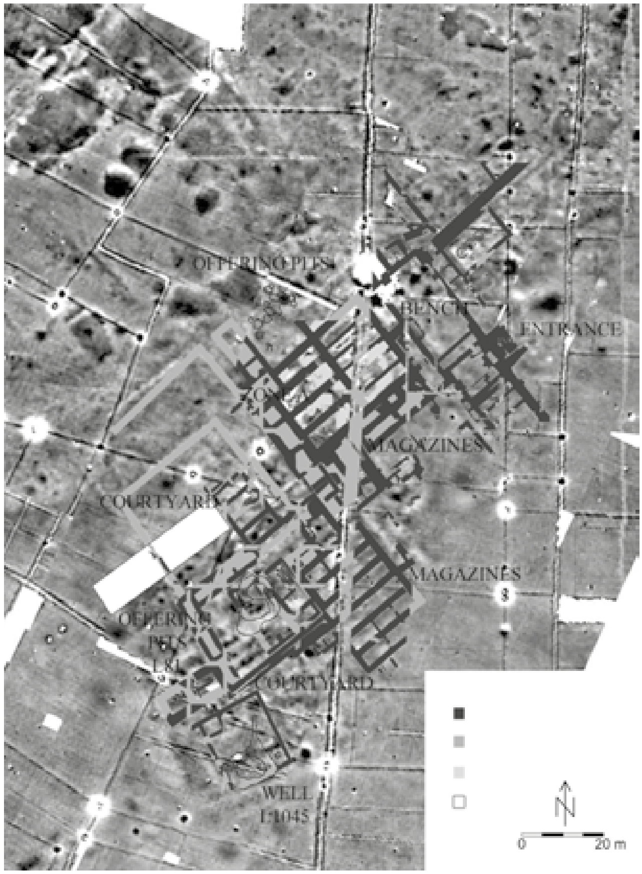

Fig. 3. Archaeological map of excavated structures superimposed on magnetic map. © Austrian Archaeological Institute

Taking into account the size of the site, classical archaeological excavation methods were of no use for the reconstruction of the urban plan, necessitating the use of other surveying methods. The survey carried out by Helmut Becker and Jörg W.E. Fassbinder in neighbouring Qantir showed the efficiency of the magnetometer prospection method applied to this kind of research (Pusch *et al.* 2000). In 1999, Tomasz Herbich began a magnetic survey of Tell el-Dab^ca using a fluxgate gradiometer (Herbich 2001). Since 2002, the survey has been continued with two different magnetometers: fluxgate and caesium (by Christian Schweitzer) with two sensors set in parallel mode measuring the total value of the Earth's magnetic field intensity. Starting from 2010, a resistivity survey has been carried out in VES version.

The area surveyed with the magnetic method covers 150 ha and is bounded to the west by the longitudinal section of the ancient Pelusiac Nile branch and to the south by the latitudinal stretch (Fig. 1). To the east, the survey encompassed an area east of [c]Ezbet Rushdi, reaching at [c]Ezbet Machali almost to the southwestern edge of the area surveyed by H. Becker and J.W.E. Fassbinder in Qantir.

In the northwestern part of the old town of Avaris (ᶜEzbet Helmi), the survey revealed remains of the Tuthmoside palatial platform (palace G), remains of a Hyksos wall (section of buttressed wall, Bietak *et al.* 2001; Herbich 2003; perhaps part of a late 15th Dynasty city wall, Forstner-Müller 2013) as well as remains of a large wall from the Late 18th to Early 19th Dynasty. The magnetic survey east of ᶜEzbet Rushdi revealed an Early Middle Kingdom settlement with orthogonal layout (Forstner-Müller *et al.* 2005). To the south, remains of the town from the 15th Dynasty have been mapped. In area F/II (between ᶜEzbet Helmi and Tell el-Dabᶜa), a palatial complex from the Hyksos period was discovered (first published in Bietak *et al.* 2007). The dating of these structures is known from earlier excavations (orthogonal settlement at ᶜEzbet Rushdi) or verifying testing following the magnetic survey (palatial complex in F/II). The survey on the mound of Tell el-Dabᶜa revealed remains of large buildings dating to the Late and Ptolemaic periods (Forstner-Müller and Müller 2007). In the area neighbouring with the earlier excavation in F/I, remains of tombs of the Late Middle Kingdom and Second Intermediate period were registered.

Recently, an electrical resistivity survey (VES) undertaken to trace the fluvial system and Nile branches has brought interesting results (recently Forstner-Müller *et al.* 2010). Combined with the magnetic survey, it has allowed structures registered along the Nile edge to be interpreted as reinforced banks and harbours (Herbich and Forstner-Müller 2013).

The survey with caesium magnetometers has provided a clear picture of the paleomorphology of the Nile Delta showing the Pelusiac main branch with river banks and deep water sediments, less rapid flowing side branches and lagoon areas with limnic sedimentation. Combination of these and VES results gave a precise estimate of the extent of the areas that were above water level during the annual Nile inundation (giving a picture slightly different than that obtained from the corings).

These survey methods, especially the magnetic research, have not only provided an overview map of ancient Avaris, but have been a breakthrough in understanding the spatial structure and organisation of the town.

ACKNOWLEDGMENTS

The survey was done within the program framework of the Austrian Archaeological Institute in Cairo, whereas the resistivity survey was done in cooperation with the Institute of Archaeology and Ethnology of the Polish Academy of Sciences.

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Contribution of geophysics to research on city planning in the ancient and classical Near East

Christophe Benech[a]

KEY-WORDS: city planning, Near East, spatial analysis, magnetic survey, Bronze Age, Classical period

The study of ancient city planning in archaeology requires information over wide surfaces to understand the main characteristics of urban layout and the spatial organization of the social, cultural, economic and political city networks and their evolution through time. Until recently, our knowledge of the cities of the ancient Near East was based mainly on huge excavations carried out during the first half of the 20th century. These excavations revealed significant parts of different city quarters, as in Dura-Europos (Rostovtzeff 1938) and Ugarit (Yon 1997) in Syria, but they were also often poorly documented in terms of keeping proper records of the stratigraphy and excessively approximate periodization of the different phases of occupation. Excavations in past decades have produced more efficient data, partly making up for the shortage of data from the old missions. But meticulous excavations of this kind cannot be applied over big areas, making the study of the urban situation problematic.

The development and evolution of geophysical tools appeared like an ideal way of exploration to acquire new data and to 'dust' the information from old excavations. For more than twenty years different geophysical methods have been used to retrieve occasionally very impressive results

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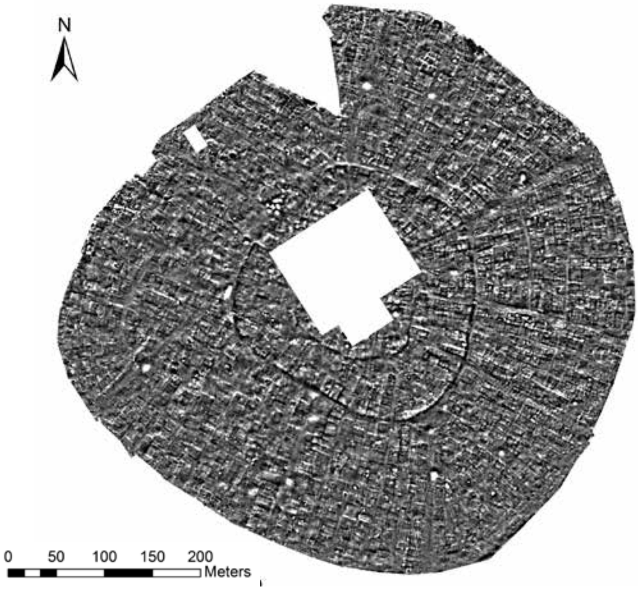

Fig. 1. Example of radio-concentric city planning: magnetic map of the Early Bronze Age site of Tell Sh'airat (Syria) (scale white/black -10/+10 nT/m)

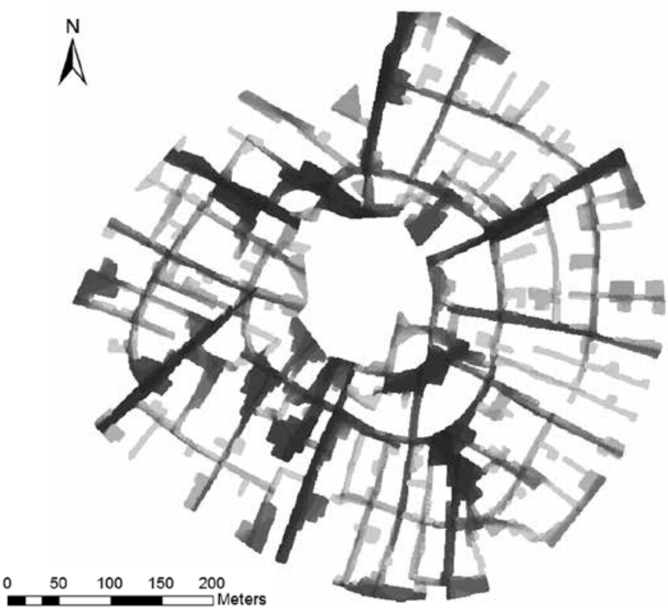

Fig. 2. Visibility Graph Analysis of the street network at Tell Sh'airat (Syria) (scale min white/max black)

Fig. 3. Example of orthogonal city planning: magnetic map on the site of Apamea on the Euphrates (Turkey) (scale white/black -10/+10 nT/m)

about the spatial organization of the ancient cities. In the Near East, this has touched on two periods representing significant phases of urbanisation of the region: firstly, the Early Bronze Age with the development of circular cities in Northern Syria and at the limits of the arid margins to the west, known as the second urban revolution of the region (Akkermans *et al.* 2002), and secondly, the Hellenistic period after Alexander's conquest, with the diffusion of an orthogonal city-planning model inspired by the Hippodamian plan, which had appeared in Asia Minor in the 5th century BC (Martin 1974). Impressive results have been obtained on numerous sites like Tell Chuera (Meyer 2010), Tell al-Rawda (Gondet and Castel2004) for the Early Bronze Age or Apamea (Gaborit *et al.* 1999), Dura-Europos (Benech 2007), Cyrrhus (Abdul Massih *et al.* 2009), Palmyra (Becker and Fassbinder 2001) concerning the Hellenistic foundations. These geophysical maps have undoubtedly changed the perception of these cities and have helped to contextualise the old excavations in the overall spatial organisation of the urban layout. They have also changed archaeological excavation strategies to locate more precisely forthcoming digging projects designed to confirm and understand what the geophysical maps have revealed.

However, all these geophysical surveys have also generated substantial documentation of city planning, which is far too big to be properly explored and validated by excavations. Essentially, specific tools of analysis need to be developed for documentation that may not necessarily be validated by archaeological digging (Johnson 2013). The question is, therefore, to what extent these surveys have actually changed our knowledge of different models of city planning and whether there are new research methods, inaccessible to the traditional approach of excavations or field survey, that can be developed specifically in agreement with the nature of the geophysical data. For instance, different protocols of spatial analysis have been applied for this purpose, depending mostly on the quality of the geophysical data (Paliou 2014) and they have brought variable results in different geographical areas and historical contexts.

For almost twenty years now, the use of the space syntax tools has met with a growing interest in archaeological studies, particularly with regard to domestic space (Brusasco 2004; Grahame 1997; Westgate 2007). This kind of analysis, based on a visual perception of space, was particularly adapted to the nature of the geophysical data, but Spacial Syntax has also proved a powerful tool for the study of street networks, once they are clearly traced on a geophysical map, emphasizing street hierarchies deriving from their spatial accessibility (Benech 2010). The "more traditional" methods of space analysis are also a viable tool for the study of the evolution of historic towns (Arnaud 2008), allowing the evolution of the cadastral plan to be studied. Tools of this kind highlight the main steps of the evolution of analysis of city planning based on a 2D map.

In the case of the Ancient Near Eastern cities, it is interesting to review the situation concerning the progress in our knowledge of city planning from the Bronze Age to the Classical cities and to evaluate the contribution of the geophysical survey in this domain.

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Geophysical survey or archaeological prospection? A plea for archaeological feedback

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KEY-WORDS: archaeological feedback, comparison of geophysical survey and excavation, interpretation, anomaly classification

CONCEPT OF FEEDBACK

The feedback between geophysical prospection and archaeology works both ways. On the one hand, feedback from an archaeologist may change the layout or instrumentation of a survey or modify the interpretation regarding developing archaeological questions. On the other hand, feedback from a geophysicist can lead to modified excavation strategies or to new archaeological insight deriving from seeing the archaeological results in a geophysical context (Benech 2003). Thus, a successful collaboration between geophysicists and archaeologists stems from a feedback circuit that goes both ways. It could lead to a better understanding of archaeological and geophysical inputs and an improved interpretation of archaeological structures.

DIRECT AND INDIRECT FEEDBACK

"Direct" feedback is when geophysical data and excavation results are compared. This can be done on-site with geophysics helping to excavate features that might otherwise go undetected (Fröhlich *et al.* 2003), by a detailed examination of single features (Leckebusch and Rychener 2004) and by comparing geophysical anomalies and archaeological features on a larger scale (Buthmann *et al.* 2012); finally, by a systematic study evaluating more than a hundred sites surveyed and excavated (Bonsall *et al.* 2013). These case studies compare the physical properties (matter, size, depth) of a geophysical anomaly and the corresponding archaeological feature on different scales and levels of abstraction.

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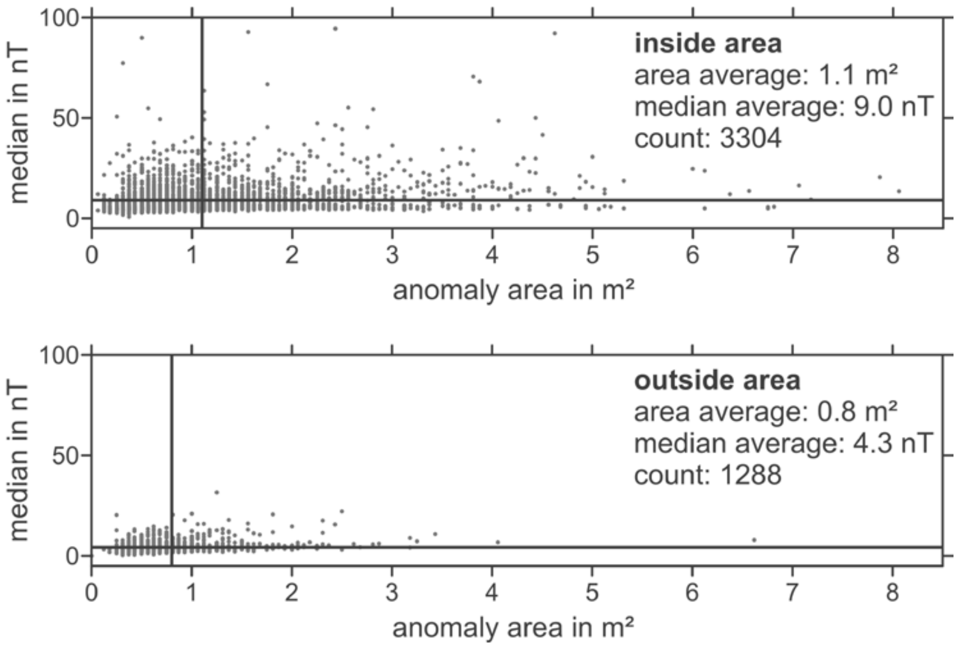

Fig. 1. Haithabu (Busdorf, Schleswig-Flensburg), magnetometer survey in 2002; distribution of two anomaly properties in two areas: inside and outside the rampart

"Indirect" feedback addresses survey strategies and the method and scope of the interpretation. In these projects survey results and excavation of different sites are used concurrently for research and for heritage purposes (Olivier and Kovacik 2007; Kastler 2015). In these projects, the focus is not on the single feature revealed by geophysics, but on larger-scale structures and patterns.

INTERPRETATION

These projects are a starting point for a discussion of how the quality of geophysical data interpretation influences the archaeological potential of geophysical surveys. Therefore, the interpretation of survey data should be the main field for archaeological feedback. But interpretation today is seldom comprehensible especially if it is nor clear how to move from a geophysical anomaly to an archaeological feature. Moreover, there is no commonly accepted methodology of interpretation that one could refer to.

The main factor in the archaeological interpretation of geophysical data is the categorization of anomalies. The first step is to classify anomalies by their physical characteristics, shape, size and spatial reference to other anomalies. This classification will be comprehensible, only if it is documented explicitly, that is, the constituent attributes for each category are named and described. In a second step, the resulting anomaly categories have to be translated into archaeological categories (Buthmann 2015: 297–298). On one hand, it is a process of aggregation, from single measurement values to categorized anomaly, and on the other hand, a process of deconstruction, from one archaeological site to a large number of feature categories.

There are already some examples of this kind of intensive interpretation, but the discussion of the issue is at an early stage (Verdonck 2013).

INTERPRETATION EXAMPLE

One specific part of the interpretation of a magnetometer survey of the Viking-age emporium of Haithabu (Hilberg 2007) will serve as a starting point for the present discussion. Several areas inside and outside the rampart had been prospected. A high density of anomalies occurred in two directly adjoining areas, separated by the rampart wall. To answer the question of whether both areas were occupied in the same way, the magnetometer data for all interpreted features were examined. The values of size and median of all measured points inside each anomaly were plotted together with their average (Fig. 1). The statistical distribution demonstrated that the anomalies outside the rampart had a smaller statistic spread and were weaker and smaller than the anomalies inside the rampart. This was one argument for classifying the outside anomalies as being of geological/pedological origin.

PROPOSAL FOR A RESEARCH PROGRAM

Following from this rather simple example, one may propose a more sophisticated approach to a comprehensible and reliable categorization and transformation and, thereby, interpretation. To arrive at a better understanding of the anomaly-to-feature transition, the categories on both sides should be examined in depth. Each anomaly category should be described statistically, as suggested above. The excavated features have to be classified by the documented properties and their archaeological interpretation. These two sets of classes can then be compared. Where do they differ and where are they similar? Is it possible to create a more detailed classification of the anomalies, with a more precise archaeological interpretation or a more differentiated interpretation of the features by the detected geophysical properties? A corresponding pedological research program seems to be necessary. Excavations targeted specifically on the understanding of geophysical anomalies as well as on specific archaeological features could be very helpful in this respect.

Applied on a broad scale, this approach might lead to a better understanding of the constituent elements of particular categories and how their function and history is reflected in the geophysical data.

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Creating a new standard: medieval town(s) within a remote sensing perspective

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KEY-WORDS: aerial photography, magnetic method, electrical resitivity method, GPR, medieval town, heritage protection

INTRODUCTION

Recent years in Poland have been marked by spectacular discoveries of medieval towns: Szamotuły (Dernoga *et al.* 2007; Pietrzak and Rączkowski 2009), Nieszawa (Jaworski *et al.* 2013)

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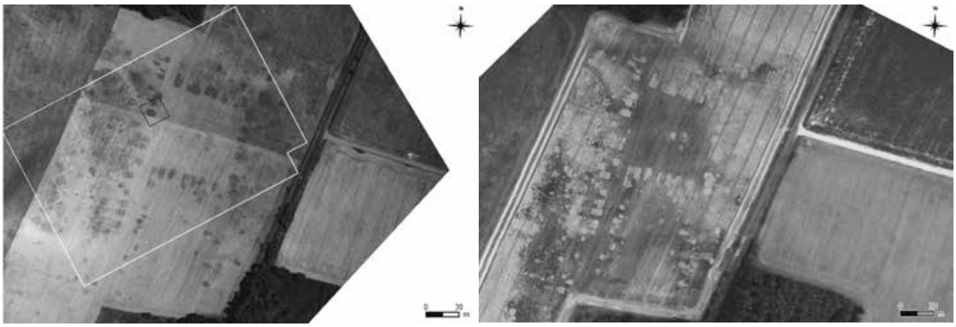

Fig. 1. A – extent of the geophysical prospection marked on a rectified aerial photo from July 2006. Continuous white line – extent of the magnetic survey; dashed white line – extent of the electrical resistivity survey, black line – extent of the GPR tests. B – rectified aerial photo from July 2011

and Dzwonowo (Krzepkowski and Moeglich 2014). In all these discoveries occurring in succession, aerial prospection played an important role. Distinctive differences in the plant cover observed in aerial images, triggered the finds, although each time in different contexts.

In Szamotuły, the search for a medieval church known from written sources necessitated the use of aerial reconnaissance as one of the methods. In 2006, this led to the identification of the entire original town foundation, which had preceded its relocation in a new place in the 14th century. With regard to Nieszawa, historical sources had told the story of the relocation of the town on a new spot in 1460–1462, the political decision being made in an effort to resolve a conflict existing with nearby Toruń since 1424/1425. The original location on the left bank of the Vistula was identified finally by Wiesław Stępień in 2008. And Dzwonowo was discovered thanks to an analysis of vertical aerial images accessible through a geoportal.

Each of these more or less surprising discoveries has confirmed the usefulness of aerial images in archaeology. Their spectacular nature evidently changed the low evaluation of aerial photography that had been current in Polish archaeology (Kobyliński 2005). Moreover, the action undertaken after the discovery of these towns also exceeded current standards adopted by the archaeological and conservation services. Szamotuły were the first to "experience" the new strategy and its application.

AERIAL PHOTOGRAPHY

The search for the medieval church in Szamotuły village started in the 1990s. Trial excavations followed the initial ground surveying, but without satisfactory results. Aerial reconnaissance, introduced as a technique in 2005, produced results already the next year. The spatial foundation of the medieval town was identified, revolutionizing what was known about the town (including its history). The importance of the find triggered widespread interest on the part of the state conservation office, as well as among archaeologists and the local community. Pressure grew to carry out archaeological excavations, the local community considering digging as the only true archaeology and archaeologists perceiving an excellent opportunity for recovering a comprehensive set of artifacts of material culture. The Wielkopolska Province Conservator's Office in Poznań differed in opinion, believing it necessary

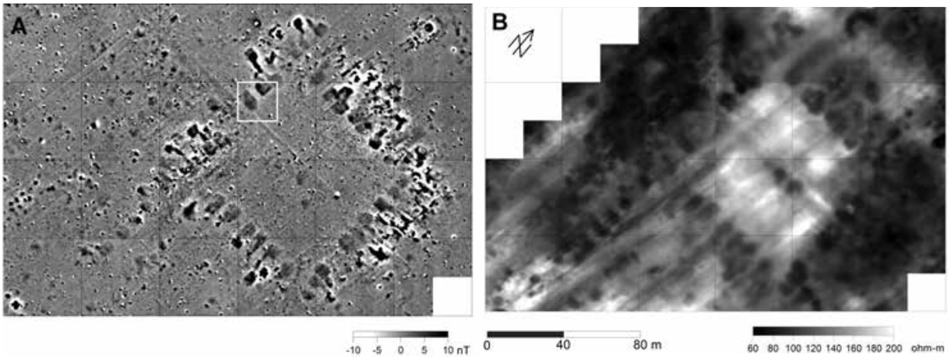

Fig. 2. A - Magnetic map. Fluxgate gradiometer Geoscan Research FM256. Sampling grid 0.25 x 0.50 m, parallel mode. White box - GPR test. B - Resistivity map. Twin probe array, AM= 0.5 m. Sampling grid 1 x 0.50 m

first to inscribe a site of such importance — it was at the time the only medieval city with a layout known to be from the 13th century — as a cultural heritage monument. This required additional data confirming the character of the site (distinguishing features in plant cover observed in aerial images are not considered as binding confirmation of the presence of cultural layers), leading to two test pits being excavated (their location was chosen in effect of an analysis of the 2006 aerial reconnaissance results) (Dernoga *et al.* 2007) and an extensive program of archaeological geophysics.

GEOPHYSICAL PROSPECTION

Geophysical prospection started in the fall of 2006 and was continued with intervals until 2015 (Fig. 1). Magnetic and electrical resistivity methods were applied (in 2006, 2007 and 2013), followed by a radar survey (2009, 2014–2015). All distinguishing features in the plant cover recognized earlier in aerial images were reflected on the magnetic map as anomalies of the intensity of the Earth's magnetic field (Fig. 2A). A number of features recorded as changes of plant cover corresponded to an amplitude of magnetic field intensity values that was much higher than expected of features corresponding to architectural building remains. Falling in the range –30/+110 nT, this high amplitude is generated usually by features formed of strongly burnt materials (overfired clay, ash, slag?). Considering their typical location, usually in the back or central part of individual land plots, they can be considered as remains of features associated with a production of some kind (furnaces?). The marketplace was reflected as an area of fairly stable magnetic field intensity values (changes in the range 2 nT); similarly stable values were recorded beyond the strictly urban zone next to the marketplace. The results of the electrical resistivity survey were similar, although not as clear. Mapping of the ground resistivity results showed up a zone of lowered values (less than 300 ohm-m) corresponding to the architectural zone around the square (Fig. 2B). A series of anomalies characterized by lower values (up to 200 ohm-m) were interpreted as house remains, but the picture of particular features was much less clear than that coming from the magnetic survey. The electrical resistivity results also indicated the presence of features with raised resistivity values (from 400 to 600 ohm-m) in the market place. This could be stone pavement (or gravel?).

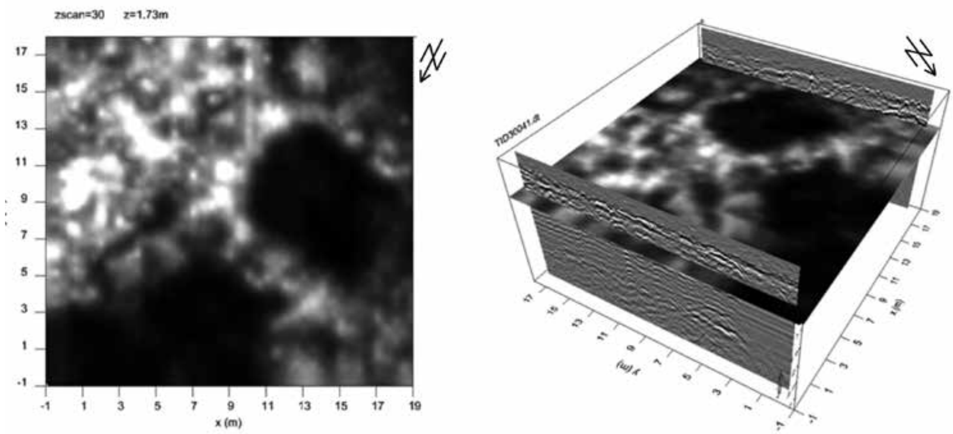

Fig. 3. GPR result in test area. Timeslice, 1.0–1.7m. Data obtained by Gispro, processed by A. Novo Lamoso

Testing by the radar method (2014) gave good results as well, uncovering in the surveyed area two houses that had already been observed in aerial images and confirmed by the results of both the magnetic and electrical resistivity surveys (Fig. 3). Measurements yielded a picture that was just as distinct as that obtained by the other methods, while contributing additional information on the deposition depth of particular layers.

NON-INVASIVE METHODS ... AND WHAT NEXT?

The unique nature of the discovered complex suggested a different approach than that which is used as a rule in Polish archaeology. Further research by non-invasive methods was programmed, the decision being to limit any physical intervention in the cultural layers to the test trenches dug in 2006 (Kijowski *et al.* 2010).

First in line is an aerial prospection of the site. Successive sets of photos will be taken consistently every year in order to identify new features and to create a unique dataset for studying environmental conditions behind the appearance of cropmarks (humidity, crop variety, pests and crop diseases, see Rączkowski 2011). Conclusions deriving from a regular aerial reconnaissance have demonstrated that the cropmarks are not only the effect of an overall humidity balance, but also changing conditions during the vegetative cycle. An apparently good year (projected based on current knowledge, see Wilson 1982) does not necessarily impact clearer cropmarks and *vice versa*. Short-term humidity changes at specific periods of the vegetative process play a significant role as well. Another important observation is that cropmarks not always reveal all the elements of a structure, the parameters of a structure being not the least one of them. It means that feature measurements based on cropmarks may be biased due to local impact of the fill found inside an archaeological structure.

Once the entire architectural zone around the marketplace is tested with the radar method (in 2015), magnetic prospection will continue using different techniques (cesium instruments, measuring total magnetic field intensity). Investigations with the seismic method and soil chemistry analyses are programmed. Research should benefit from the new possibilities provided by LiDAR data, infrared photography, satellite imaging, multi- and hyperspectral imaging. Detailed data analyses will permit more extensive understanding of archaeological structures and their spatial interrelation, as well as formation processes, state of preservation etc. The results of these investigations will support decisions concerning site protection principles and project popularization.

A broad range of non-invasive methods applied to the study of the Szamotuły medieval town site will supply data for comparative research on the data itself, supporting critical approaches to the data as much as to the potential and limitations of particular methods.

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What you see is what you get: some reflections on the impact of geophysical data on the strategies of archaeological fieldwork, based on case studies from Iran and Azerbaijan

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KEY-WORDS: magnetometry, excavation strategy, self-reflexive, Iran, Azerbaijan

This paper aims to provide a reflection on some fifteen years of collaboration between archaeologists and geophysicists and the ways how these two disciplines have interacted, but also influ-

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Fig. 1. Arisman, Central Iran. Magnetic map of the site, with a concentration of anomalies in the eastern part; view of excavation in that area, where anomalies turned out to be fired pits (measurments J. Fassbinder and H. Becker, 2001. Photo B. Helwing)

enced each other. It is maintained that geophysical surveying has become an indispensable tool in archaeological inquiry, in particular under time constraints in rescue and preventive archaeology but also in problem-oriented research, allowing to focus on neuralgic points of investigation. This same strategy, however, also bears the risk that archaeologists may let themselves be guided so closely by the results of geophysical prospection as to narrow their own perspectives onto features made visible in these maps. These risks can be outbalanced by continuous communication and the application of additional means of field exploration. This paper examines some case studies of firsthand experience from projects in Iran and Azerbaijan with the aim to point out possible future directions.

CASE STUDIES

Throughout the last fifteen years, geophysicists from various institutes have collaborated with us on fieldwork in Iran and Azerbaijan. One common parameter in all these works is the situation of working in a foreign research environment together with local colleagues, meaning that all necessary equipment has to be transported back and forth. Our geophysicists therefore always chose to work with portable instruments, which also enable them to be flexible in the often rugged terrain.

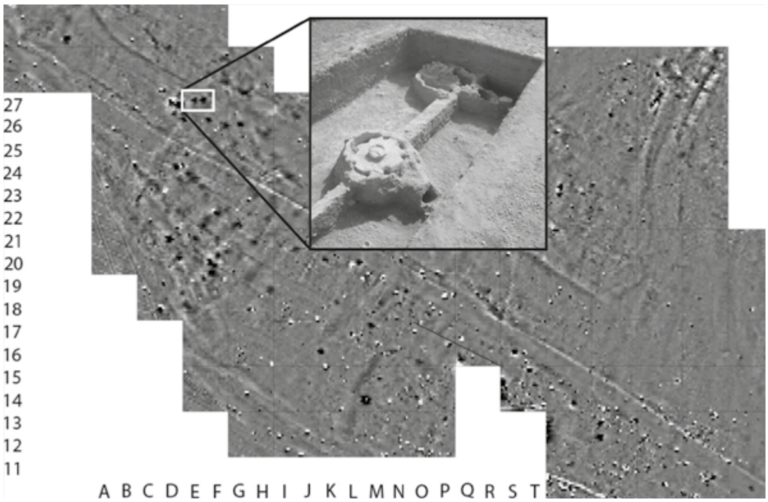

Fig. 2. Site TB 73, Bolaghi Valley, Fars Province, Iran. Magnetic map of the site and excavated pottery kilns in square E27. White square indicates location of excavation; seven other pottery kilns are discernible in the map (magnetometry Baoquan Song, 2006. Photo B. Helwing)

Case study 1: Arisman, Central Iran, work in 2001

At Arisman, an extended metal-producing site of the 4th to early 3rd millennium BC, Jörg W.E. Fassbinder and Helmut Becker conducted intensive magnetic prospection over a larger part of the site (Becker *et al.* 2011). The site is located on gypsum soil and contained enormous amounts of copper slag. The results of the prospection showed practically no traces of the ancient architecture that was constructed of local mud brick. Several larger anomalies appeared in isolated zones, and in the eastern part of the site there was a concentration of roundish anomalies that were interpreted as possible furnaces for copper smelting. Subsequent excavations focused on that zone and resulted in the discovery of burnt pits, no doubt somehow used in the metallurgical processing, but no furnaces. Other isolated anomalies were investigated as well and resulted in the discovery of single features with strong signal, like a pot burial wedged into its pit with fragments of a crucible. Had the focus of the excavation been solely on the magnetometry mapping, emphasis would have certainly been placed on the zone with the burnt pits, and the discoveries found in the extended proto-Elamite architecture would have been missed, as none of this was visible in the magnetometry.

Case study 2: Bolaghi Valley, South Iran, work in 2006

Archaeological fieldwork in the Bolaghi Valley in 2005 and 2006 took place under rescue work conditions as the valley was scheduled to be flooded by a dam (Helwing *et al.* 2010). Our group was responsible for the documentation of four sites with 5th millennium BC material, which were all also covered with historical stone architecture. In the second year, Baoquan Song undertook systematic magnetic prospection on two sites: TB 73 was investigated before

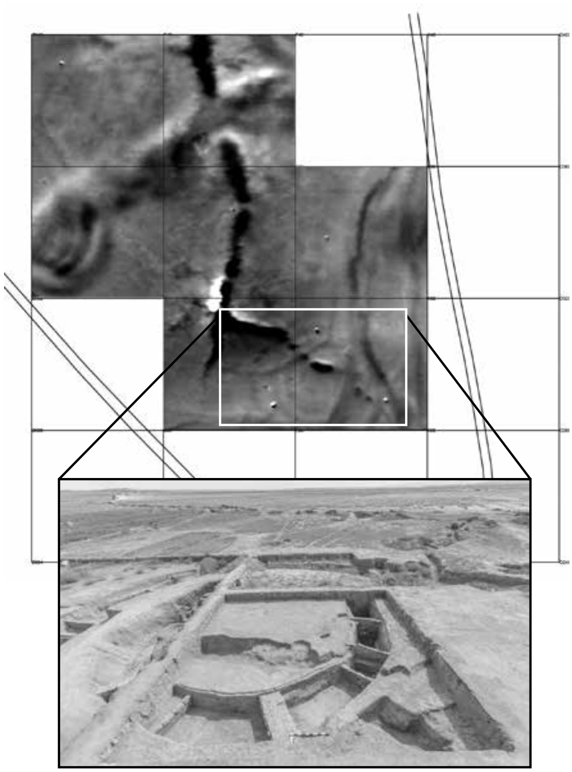

Fig. 3. Site MPS 4, Mil Steppe, Azerbaijan, magnetic map; white square indicates location of concentric ditch system, view shows ditch system in 2014, partly excavated and seen from the North (measurments by J. Fassbinder 2011. Photo J. Krumnow)

excavation, TB 91 had already been excavated the year before, and site TB 131 was discovered only later and was surveyed by Babak Aminpour.

The magnetometry allowed an extensive documentation of historical architecture. It also revealed underlying geomorphological features, like a landslide, and water channels that seem to have supplied the historical settlements in the valley. But the most obvious features were strong punctual anomalies, which imaged prehistoric pottery kilns. At site TB 91, where a prehistoric pottery kiln had already been found in the earlier excavations, another kiln was documented under a wall of historical date that had shaved the largest part of the kiln. At TB 73, where the anomalies were a major feature, five kilns were excavated and another four were inaccessible under a modern road. When the excavated kilns were selected for block recovery, the trenches had to be considerably enlarged, and this led to the discovery of a human skeleton and of traces of house structures preceding the kiln phase. In retrospect, the excavation process was significantly guided by the magnetometry results, which most probably caused other prehistoric features to be missed.

The late discovery of site TB 131, once a mounded site visible in the valley and later-on leveled by the local farmers, only allowed short-term prospection. No architectural features were visible on the magnetometry map, but a few larger anomalies of unclear contours looked worth investigating and turned out to be rather geological than anthropogenic features. The most significant discoveries at this site were a number of prehistoric burials that were not visible on the magnetic map.

Case study 3: Mil Plain site, Republic of Azerbaijan, work since 2010

Ongoing research in the Mil Plain focuses on the documentation of prehistoric settlement patterns, with intensive fieldwalking and related excavations and testing on various sites in a region with still excellent conditions of preservation that are today, however, threatened by rapid land development schemes (Helwing *et al.* 2012). Jörg W.E. Fassbinder regularly participates in the field seasons with the aim to identify sites previously recorded in surveying and to identify types of sites and buried features (Fassbinder, in Lyonnet *et al.* 2012). This allows sites to be preselected for investigation by auguring and excavation. However, the discovery of the first concentric ditch monument in the Southern Caucasus happened by accident, and was only subsequently confirmed in the magnetometry, where a faint anomaly had been overlaid by other, more obvious features. The adopted work flow of survey – magnetometry – auguring, followed by excavation, allows the results of the geophysical survey to be checked, whereas the magnetometry data also helps in identifying features that are sometimes barely visible to the naked eye.

RESULTS

The continuous collaboration with geophysicists has greatly changed the approach to archaeological fieldwork and has led to significant discoveries, which may have otherwise gone unnoticed. For geophysics, the "ground-truthing" provided by subsequent excavation serves as an important corrective of preliminary interpretations. From the archaeological perspective, the danger of being seduced to plan excavation strategies by obvious and visible features in the magnetometry map is imminent. A larger scheme of excavation remains a desirable scheme in order to avoid seeing only what one wants to see. A regular check-back and communication from both sides remains an important and necessary approach to this type of successful interdisciplinary inquiry.

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Do magnetic and electric survey results correlate with archaeological evidence? Case studies

Nadine Dieudonné-Glad[a]

KEY-WORDS: electric survey, magnetic survey, iron metallurgy workshop, buildings, hearth

When a geophysical survey is performed before an archaeological excavation anomalies are interpreted jointly by archaeologists and geophysicists and assumptions are made. But excavation results are seldom discussed afterwards with geophysicists to compare the initial hypotheses with the subsequent discoveries. This paper discusses the case of geophysical survey data in a number of research programs where hypotheses are based on geophysical anomalies that were sometimes confirmed by excavation, and sometimes not. Occasionally, there was a clear explanation for the discrepancy between the hypothesis and the excavation results.

SETTLEMENT STUDY

The small Roman town of Vendeuvre-du-Poitou (Vienne, France) was surveyed by the electric method on 40 ha and by the magnetic method on 3.5 ha; a surface area of 0.3 ha was excavated (by Johan Durand, PhD student, University of Poitiers). The excavated zone was previously surveyed by both electric and magnetic means. The excavation showed that streets and walls built of stones with mortar bonding induced easily discernible anomalies of high resistivity. However, the structures composed of walls that were made of mud, even when resting on stone flashing, did not generate anomalies strong enough to be properly identified on the resisitivity map before excavation. This has significant repercussions on the interpretation of the results of the electric survey for the entire town. It in fact shows anomaly-free zones inside some blocks or at the edges of an area that may not be empty of buildings, especially at its northern outskirts, where the ground was fairly covered with ceramics.

The use of the magnetic method is not straightforward for drawing the overall layout of Vendeuvre-du-Poitou, even if on the whole the streets are clearly perceptible as are the blocks. Nonetheless, the interpretation of the magnetic anomalies is less easy to translate into types of remains expected during the excavation. Some fairly limited strong anomalies were, as could be expected, caused by the presence of a domestic hearth made of tiles, but the discovery could not be anticipated, owing to the relatively large number of such anomalies on the magnetic map.

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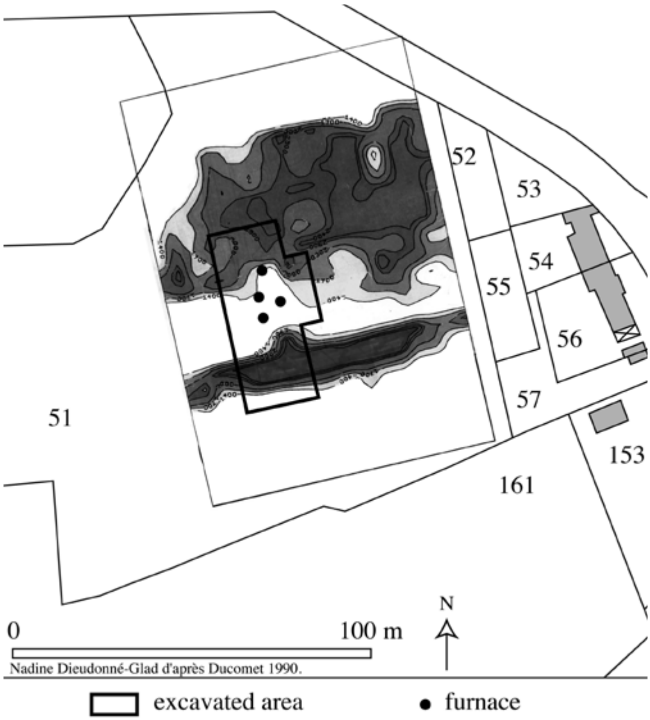

Fig. 1. Electromagnetic survey of the Oulches iron smelting site. Black dots: location of the workshop furnaces. Grey: high magnetic susceptibility areas (Surveyed by G. Ducomet)

Fig. 2. One of the furnaces discovered at the Oulches smelting site. Its external diameter is around 2 m. It was filled with burned clay (Photo N. Dieudonné-Glad)

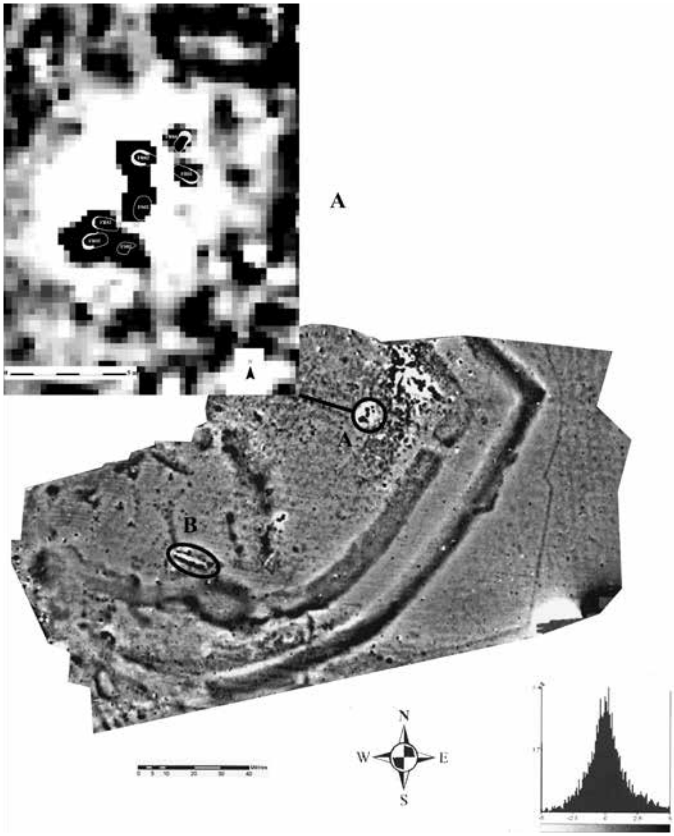

Fig. 3. Magnetic survey of a Gallic farm dated to the 2nd–1st century BC and of iron metallurgy workshops dated from the mid 6th–mid 5th century BC (Meunet-Planches, Indre, France). A. Workshop structures in white, B. *Murus gallicus* magnetic anomalies (Surveyed by Géocarta)

IRON METALLURGY WORKSHOPS STUDIES

Waste from iron metallurgy workshops is highly magnetic: it consists of iron ore residues, slag, metal fragments. It induces magnetic anomalies that can be higher at ground level than the anomalies created by the baked clay of buried furnace structures. For example, at Oulches (4th century AD smelting workshop, Indre, France), anomalies recorded during the electromagnetic and magnetic survey highlighted the presence of waste, but failed to disclose the location of four furnaces, arround 2 m in diameter, buried between the iron ore disposal in the southern part of the site and the slag disposal in the northern part (Figs 1 and 2).

In other cases, when slag was trapped in the furnaces and slag waste around the furnaces was scarce, the magnetic anomalies showed very precisely the location of the furnaces (Fig. 3: A), e.g., Meunet-Planches (mid 6th – mid 5th century BC smelting and smithing workshop, Indre, France). On that site, a ditched celtic farm surrounded by a *murus gallicus*-type wall later replaced the iron metallurgy workshops. A set of highly magnetic anomalies was interpreted at first as evidence of another iron workshop, but with a different layout (Fig. 3: B). The excavation revealed only the presence of the *murus gallicus*, from which five typical iron nails were retrieved. It is still not clear why the magnetic anomaly created by these five nails weighing less than 200 g each was almost similar to that of tens of kilos of slag waste.

Another case of misinterpreted magnetic anomalies was understood after the excavation. The magnetic survey inside a Roman military fort at El Deir (Kharga Oasis, Egypt) showed a particularly high magnetic rectangular anomaly (15 nT) in one of the buried barracks of the site (magnetic survey by Tomasz Herbich, Oasis Project directed by Gaëlle Tallet, University of Limoges). The hypothesis was that the room housed the smithy of the fort. The excavation revealed a 2 m-thick ash layer with very thin fragments of baked clay from fireplace trash containing ceramics. It filled the unit up to the ceiling. It seems, therefore, that a 2 m-thick layer of that kind can create a magnetic anomaly as significant as a 10 or 20 cm-thick layer of metallurgical waste. This explanation is consistent with the theory of magnetic survey, but has rarely been verified to that extent in the field. This experience has led us to reconsider the interpretation of the magnetic survey as a whole and has shed new light on the inside layout of the fort.

The multiple benefits of archaeological geophysical prospection in Salzburg. Ten years of archaeological feedback in retrospect

Raimund Kastler[a]

KEY-WORDS: Roman *villa rustica*; integrated geophysical methods; verification of old excavations; typology of sites and buildings

The first use of archaeological geophysical prospection (abbreviated AGP in the following text) in the Salzburg province goes back to 2001. Remains of stone structures were visible in a field next to a rescue excavation carried out on a Roman rural site partly destroyed by road construction in a new commercial zone at Neumarkt-Pfongau. Among various other features, AGP detected four auxiliary buildings of a Roman rural villa, which have subsequently been excavated since 2008 (Kastler *et al.* 2013; 2014).

Part of the features, interpreted as putlog ditches or as pits, detected by magnetometry and clearly visible in the acquired data, could not be verified by excavation (Fig. 1a). The discovery of such soil features during excavations is dependent on factors, like climate and soil consistency (Kastler *et al.* 2012), but measured data from AGP constitute an independent source of data.

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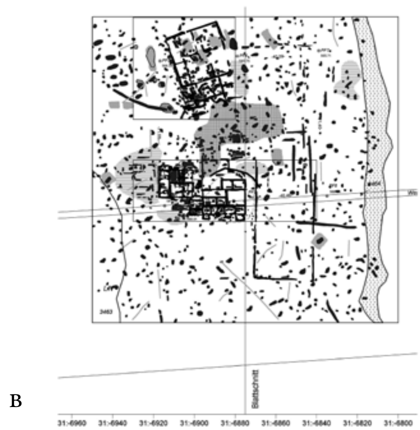
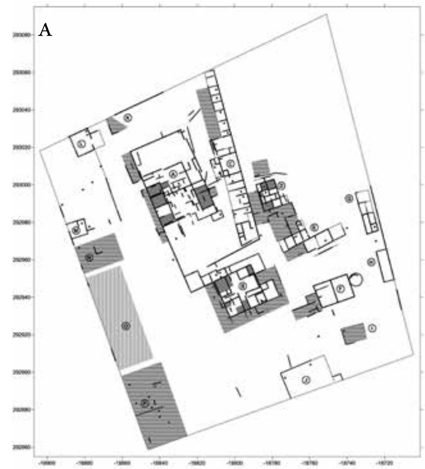


Fig. 1a. Pfongau I: Interpretation of AGP (Archeo-Prospections® ZAMG 2001); underlying plan of excavation results 1988–2014 (E. Binder, Landesarchäologie/Salzburg Museum)

Fig. 1b. Pfongau II: Interpretation of AGP, archeological features only (Posselt and Zickgraf Prospections, Marburg)



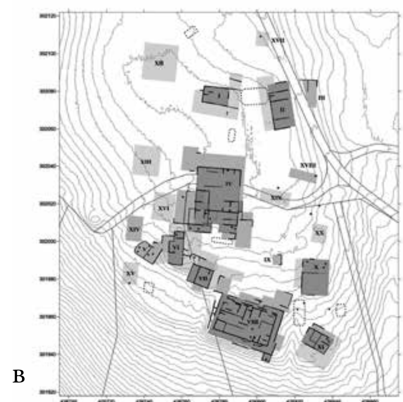


Fig. 2a. Glas: Interpretation of AGP, archeological features only (Posselt and Zickgraf Prospections, Marburg)

Fig. 2b. Kerath: Interpretation of AGP, archeological features only (Posselt and Zickgraf Prospections, Marburg)

On the contrary, AGP of a late Iron Age rectangular enclosure at Oberndorf north of Salzburg displayed only part of the subsoil structures that were identified in the trial excavation of one of the corners of the enclosure (Kastler *et al.* 2014). The monument was leveled in the late 1960s, when the ditches were filled with soil from the ramparts in order to facilitate modern agricultural work.

Both case studies show the need for an integrated methodological approach in order to cover all the existing archeological features of a site. Therefore, AGP is to be used not only as

A

B

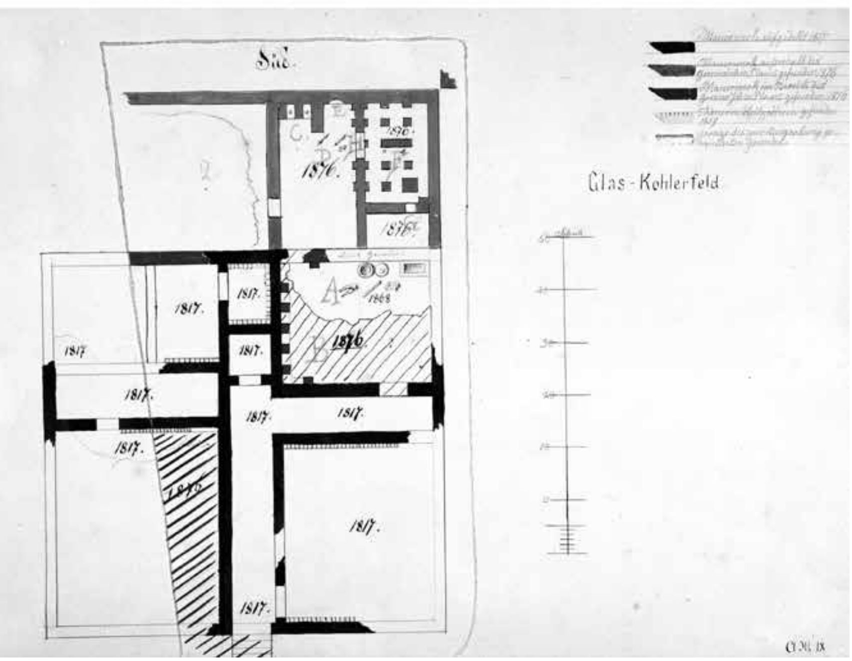


Fig. 3a. Glas, South Building: Interpretation of AGP, archeological features only (Posselt and Zickgraf Prospections, Marburg)
Fig. 3b. Glas, plan of excavations in 1817 and 1876 (G. Pezolt, Salzburg Museum, Collection of Graphics, Inv. No. 15108-49)

a comprehensive method of prospection, but also as an independent approach to the archaeological evidence of a site.

Based on positive experience with AGP surveys, a series of other sites known primarily from documentary evidence (old notification of finds and/or surface finds from metal detectors) was targeted. To date, 17 sites mostly of Roman date, have been explored by magnetic survey in cooperation with Posselt & Zickgraf Prospections GBR (Figs 1b, 2). The focus on Roman rural settlements is a consequence of their position in the alluvial landscapes north of Salzburg City, in places favorable to modern agriculture. Currently these regions are subject to fundamental changes in land use. Agricultural production is going to be superseded by spreading commercial zones (Kastler and Krammer 2007: 205–206). The responsible government body, the Federal Office for the Protection of Monuments, faces the significant threat of the archaeological record being destroyed without any documentation. Other scientific institutions, too, like the Salzburg Province Archaeology, are forced to integrate their research tasks with protective objectives to fulfill their scientific responsibility.

The additional benefit for research lies in filling a scientific void. Little was known about the structure of characteristic Roman villas and building types in the environs of Roman Salzburg, then called Iuvavum (Kastler and Krammer 2007: 205–206) and the available information relied foremost on the results of archaeological excavations. Until 2004 Salzburg State Archaeology was primarily involved in salvage excavations with the results being subject to the limitation of this specific kind of archaeological research. Generally, only small sections of complete villa sites or internal buildings were uncovered. Only a single Roman villa was completely excavated in the late 1940s. Thus, the archaeological documentation did not conform to the status of current research. Restrictions in sustainable use of archeological sites as much as in terms of the funding nearly ruled out the option of exploring a Roman villa site in full. In this situation one can hardly underestimate the value of AGP results for research.

New and decisive evidence was gained for the typology of sites and buildings. The investigation of different Roman rural settlements in the Salzburg area demonstrated that the "Streuhof" type was the predominant settlement layout around Iuvavum, like in most parts of Noricum. Occasional rectangular boundaries and the position of internal buildings seem to characterize regularly structured entities among the Roman villa sites surrounding Salzburg (Kastler *et al.* 2009: 96; Traxler and Kastler 2010: 233).

The evidence, collected in a comprehensive database, allowed for comparisons in both directions: Complete building plans, established by magnetic prospection, fostered the comprehension of fragmentary evidence from earlier salvage excavations and data from archeological excavations enhanced the understanding of the geophysical results. The geophysical survey also enabled a reevaluation of early 19th century excavations, known mostly from drawings and written reports. The comparison of historic archaeological data and the evidence acquired through AGP has proven to be more than a one-way communication. Reevaluation of the old documentation of excavations at Glas fostered the understanding of discrepancies between the archeological evidence from the 19th century and its present status as documented in the magnetic survey (Kastler *et al.* 2010). It turned out that parts of the foundations of the south building had been removed after the excavations of 1876 to allow for agricultural practice (Fig. 3). Another important effect is the extension of data beyond what archaeological studies in the narrower sense provide. Almost all the villa sites investigated by geophysical prospection proved to be far bigger and more densely built up than expected based on the earlier evidence. It will alter our perception of the economic potential of the landowning class of Iuvavum and of Roman rural economy in this part of northwestern Noricum in general.

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Archaeological feedback

The whole is greater than the sum of the parts: combining fieldwalking data and geophysical survey in the study of minor Roman centres

Kayt Armstrong[a], Tymon de Haas[a] and Gijs Tol[a]

KEY-WORDS: fieldwalking data, gradiometry, minor centres, Roman archaeology, Italy

The paper presents the results of work carried out in the project "Fora, stationes and sanctuaries: the role of minor centres in the economy of Roman central Italy" (funded by NWO Grant No. 360-61-030), and focuses in particular on how fieldwalking data and geophysical data have been used in the project in tandem to inform fieldwork strategies and interpretations. Although both the urban and rural landscapes of Roman Italy have received due attention in current debates on the Roman economy, this is less true for the highly variable group of intermediate sites, here conveniently labelled as 'minor centres', and their role within economic systems (Tol *et al.* 2014). Our research in Italy focused on two such minor centres, Forum Appii and Ad Medias, situated in the Pontine plain (Lazio, Central Italy) along the Via Appia (see Fig. 1). Our research aims to elucidate the function of these two road stations in both their local rural settlement system and within regional trade networks. In addition, these examples allow us to assess variations in size and function within the generic class of minor centres.

INTRODUCTION

The project uses an integrated non-invasive approach, common in the study of urban sites: a (GIS-based) desktop study of topographic and cartographic sources is combined with geophysical survey and systematic fieldwalking. Together, these methods allow us to reconstruct the layout and central place functions of these minor centres as well as their development over time. Here, we will specifically consider how the geophysical and fieldwalking data inform each other and allow richer interpretations of the archaeological evidence.

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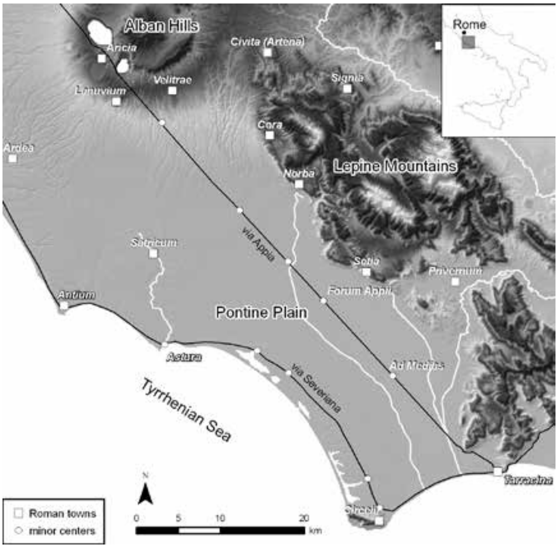

Fig. 1. The Pontine region with main sites, roads and rivers (Tymon de Haas/RUG/GIA)

METHODOLOGY

The geophysical surveys were carried out using magnetic gradiometry (fluxgate gradiometers[1]), and aimed to identify and interpret buried structural remains at both sites. The chosen technique is particularly suited to detect the type of features associated with the economic functions we are seeking to identify, such as local artisanal production (e.g., kilns) and trade-related facilities (e.g., warehouses, infrastructural remains). Such features typically include materials fired at high temperatures (e.g., kiln remains, slag and brick walls) and should thus be well-visible in magnetic prospection. We acknowledge that our chosen methodology has limitations in terms of what buried materials can be reliably detected; magnetometry will only reveal buried materials with contrasts in either magnetic susceptibility or a degree of remnant magnetism. However, it is routine practice to employ magnetic surveys first in areas where the archaeology is relatively unknown, as it is a rapid technique that can quickly cover large areas, and stands a good chance of detecting Roman-period archaeology. Further detailed geophysical work utilising earth resistance and ground penetrating radar can then be effectively targeted, as these techniques are both more costly in terms of time and expertise. Earth resistance surveys over key anomalies are planned for the next phase of research.

Fieldwalking applied a highly intensive methodology: grid units of 25 m x 25 m were walked at 25% coverage (three walkers), with each walker picking up all finds encountered in their respective lanes. After initial walking, each unit was inspected again at 100% coverage

[1] A two-sensor Bartington Grad601 and two single-sensor FM256 gradiometers (sometimes in dual density mode) were applied, covering small plots, using 30 m by 30 m grids, systematically traversed in 0.5 m intervals. Larger areas were then investigated by the Eastern Atlas Geophysical Prospection using a DGPS-located ten-sensor cart system.

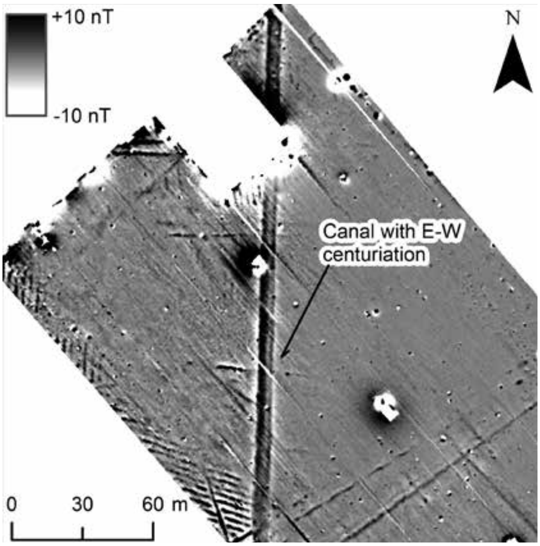

Fig. 2. Gradiometer data from Ad Medias, produced by Eastern Atlas GmbH, showing the canal and related anomalies, interpreted as part of the centuration system

in order to collect a supplementary diagnostic sample. Although resulting in the collection (and subsequent processing) of large amounts of material, recent experimental work shows that such an intensive sampling approach is necessary to answer detailed questions regarding infra-site functional zoning and chronological development (Tol 2012: chapters 3 and 5). In addition, large pottery samples provide a solid foundation from which to approach the position of the studied sites within trade networks. The grid size was chosen in order to accurately relate surface distribution to any anomalies showing up in the geophysical surveys.

RESULTS

This particular combination of geophysical surveys combined with intensive, systematic fieldwalking of the same areas yields complementary datasets. At Forum Appi, the geophysical data has shown evidence of craft production (metalworking and ceramics), as well as evidence for large buildings possibly associated with the transhipment and redistribution of goods. The finds associated with the anomalies allow a broad chronological characterisation of the geophysical anomalies. The earliest evidence for occupation consists of black gloss ware fragments, including stamped examples of the *Gruppo dei Piccoli Stampigli*, dating to the late 4th or early 3rd century BC (Morel 1981; Stanco 2009). The most recent pottery collected (forms in ARS D: Hayes 1972; Bonifay 2004) dates to the late 5th or early 6th century AD. The collected ceramic evidence includes large numbers and wide variability of imported goods, such as amphorae, a picture that is quite different from that recorded for typical 'consumption sites'. This suggests that the site occupied an important role in regional trade and may have functioned as a centre of (re)distribution of goods. There is evidence that within this lifespan, the site changed in extent and function; this detail could only have been recovered using the intensive survey methodologies adopted within the project.

At Ad Medias, the settlement seems to have been less extensive, both geographically and chronologically. The geophysical data reveals some possible tombs and industrial activity (which the slag suggests was related to metalworking). However, they also revealed unexpected large infrastructural elements, such as a north–south canal some 6 m wide (see Fig. 2 and evidence of centuration systems.). In this area, fieldwalking led to the identification of two discrete scatters of finds, both close to the *Decennovium* canal, southwest of the *Casale di Mesa*. The southernmost of these scatters lies next to a bulge in the canal and corresponds to the area where the geophysical survey recorded a noisy signal. The presence of slag (beside pottery and building materials) indicates that metal production took place in this area. The collected pottery dates the site between Late Republican times and the 4th century AD, whilst the presence of glazed ceramics indicates a post-Roman phase of occupation. The second scatter, situated slightly to the northwest, corresponds to the location of a rectangular structure visible in a 1:5,000 topographic map from the 1920s. It is larger than the first one and contains tile, pottery and building debris. These materials date mostly to the Republican period (4th to 1st centuries BC), although glazed pottery suggests that this area was also reoccupied in post-Roman times.

CONCLUSION

The combination of geophysical survey and intensive fieldwalking has yielded new insights into the form, function and local economic role of two minor centres in Roman-age central Italy. These insights were made possible by the close cooperation between the geophysical and archaeological surveyors, with results being fed back to inform and update field strategies in real time.

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Magnetic prospecting on Chalcolithic sites in north-eastern Romania: some considerations regarding intra-site spatial organisation

Andrei Asăndulesei[a]

KEY-WORDS: magnetic prospection, prehistoric sites, Cucuteni culture, north-eastern Romania

INTRODUCTION AND OBJECTIVES

This work is based on a study conducted by the Arheoinvest Platform from the Interdisciplinary Research Department – Field of Sciences of the "Alexandru Ioan Cuza" University of Iași, Romania. The main objective of this endeavour is to produce by means of non-intrusive investigation techniques an ample characterisation of the Chalcolithic archaeological sites from north-eastern Romania. Foremost, when systematic research is not financially or administratively sustained, the integrated employment of methods for archaeological prospecting becomes the only and clearly, the most definitely, the most efficient manner to acquire detailed and precise information on buried remains. This approach has been confirmed by a series of studies that have fulfilled the stringent demands of Romanian archaeological research, with notable results (Asăndulesei *et al.* 2012; Asăndulesei *et al.* 2013; Asăndulesei 2014a; 2014b).

The paper captures relevant elements for an overview of a model of spatial organization of Cucutenian settlements (in this case, the uni-stratified ones), based, at this stage of research, only on information obtained from interpreting magnetic data available for a number of case-study sites from the aforementioned area.

CASE STUDIES

As already mentioned, in order to obtain an image as clear as possible, coinciding with reality, our approach was based on the investigation of the uni-stratified archaeological sites. This study presents the results obtained from processing the data for the Cucutenian sites of Ripiceni–Holm (Botoșani County), Hândrești–Dăiceni II and Brătești–Dealul Chicera (Iași County).

The Cucutenian site Ripiceni–Holm is located in the north-eastern part of the Ripicenii Noi village, on the right bank of the Prut River (today the Stânca-Costești reservoir), at 1.2 km SSE of the site Ripiceni–Stânca, and 300 m SSE from the site Ripiceni–La Monument. The site sits on a backslope with an elevation of approx. 82 m. The current geomorphological situation is strongly modified by the construction at the end of the 19th century of a Ripiceni sugar factory, several brick kilns, the Stânca-Costești dam and reservoir, as well as of a number of gravel quarries. The NNE side is strongly affected by annual floods that "ruined" this part of the heritage site (about half of the area), washing away and decontextualizing most of the archaeological complexes and materials (Boghian *et al.* 2012).

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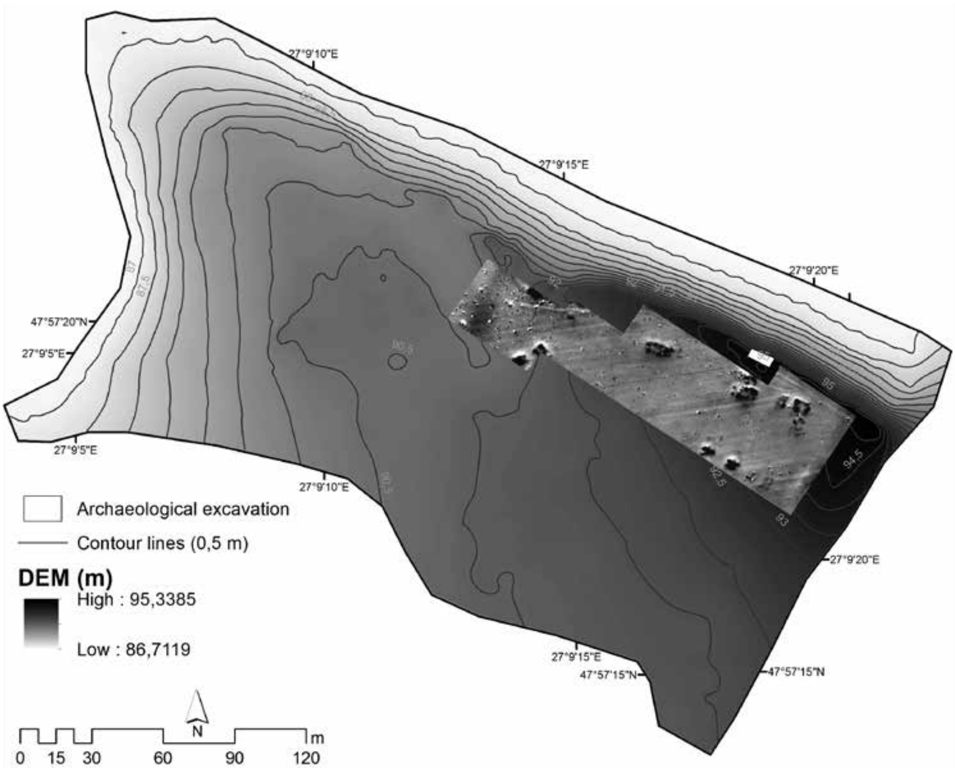

Fig. 1. Magnetic map of the Ripiceni–Holm archaeological site (-30 / +30 nT, white to black) overlaid on a detailed topographic map

The archaeological site at Hândrești–Dăiceni II is located on the terrace of the Dăiceni brook, south of the village of Hândrești, Oțeleni commune. Surface research in this area revealed the presence of a Cucutenian settlement (A–B phase, based on pottery and figurines) (Chirica and Tanasachi 1985: 298).

The site of Brătești–Chicera is found at the southeastern edge of Brătești village, on a plateau of the steep northward-facing slope of Chicera Hill. It is a hilltop settlement, with a relative altitude of 65 m and an absolute one of 340 m. The site, assigned to the B phase of Cucuteni culture, was discovered in 1983 during construction works (Chirica and Tanasachi 1985: 375).

METHODOLOGY

The methodology consisted primarily of magnetic prospection combined with archaeological topographic surveying. The present paper presents the most important results achieved so far, some preliminary, obtained through multi-faceted interpretation of data obtained with state-of-the-art tools.

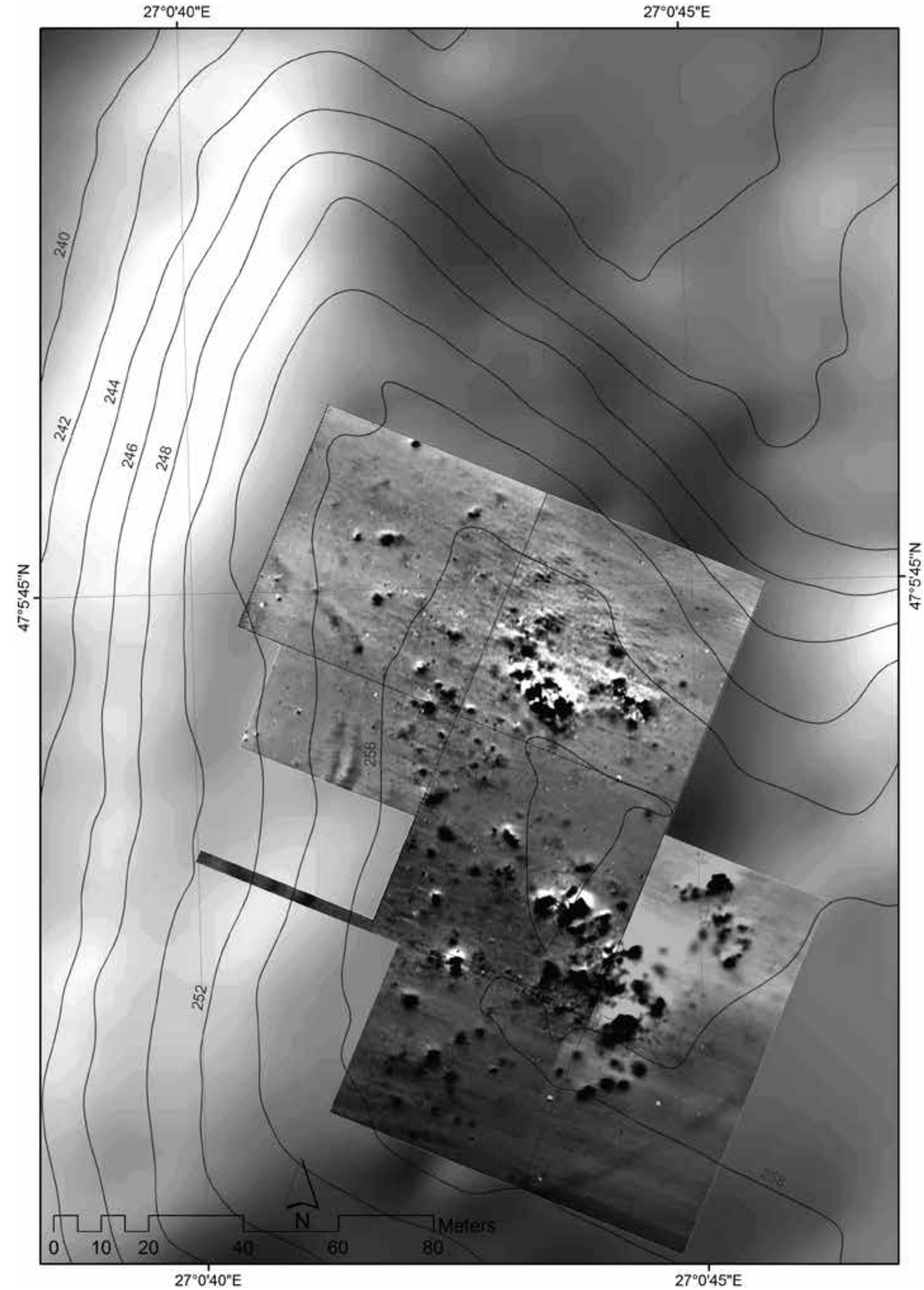

Fig. 2. Magnetic map of the Hândrești–Dăiceni archaeological site (-40/+40 nT, white to black) overlaid on a detailed topographic map

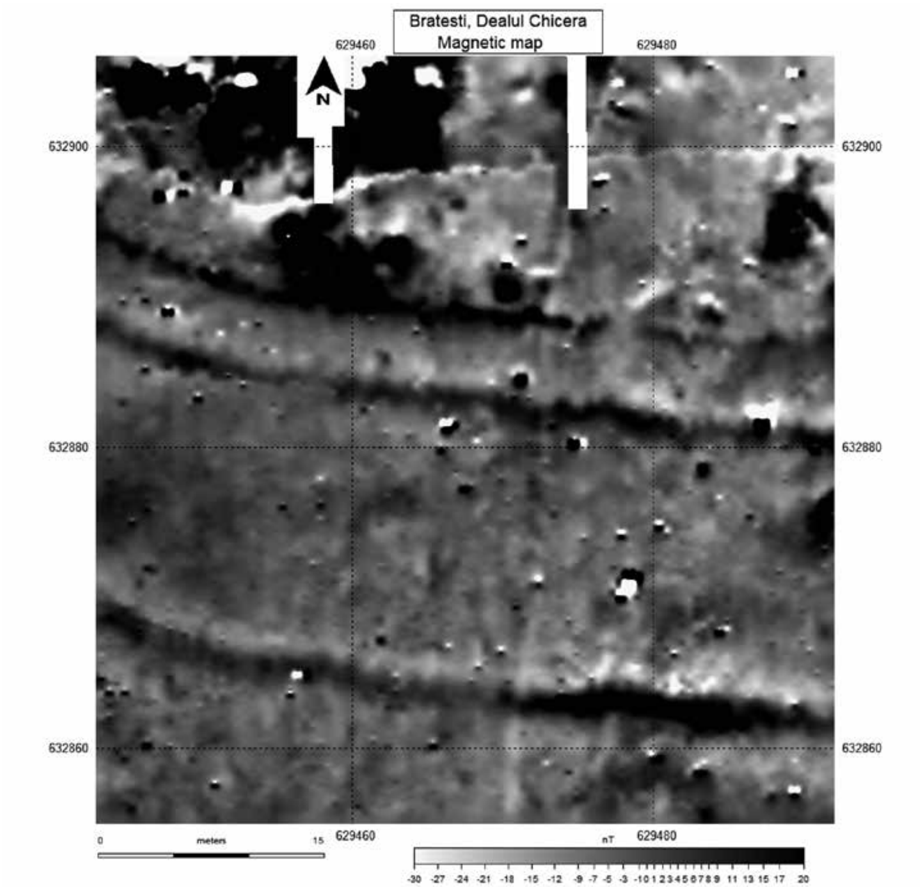

Fig. 3. Magnetic map of the Brătești–Chicera archaeological site (-30/+20 nT, white to black)

In the first stage, the sites were selected from dedicated literature, identified in the field and placed on a topographical map using GPS, followed by topographic surveys. Magnetic measurements were performed using a Geometrics G858 caesium magnetometer with two sensors, and the data was processed with the equipment native software.

RESULTS AND DISCUSSION

The magnetic method is very sensitive to changes in soil susceptibility. Likewise, it is very suited to environments that display a high contrast in thermoremanent magnetisation, specific to burned archaeological remains, such as kilns, hearths or, in our case, habitation structures. Because archaeological excavations in Cucutenian sites almost invariably produce dwellings that are very strongly burned, our results were consequently very satisfactory.

As such, with respect to our aim to establish a model of internal organisation of Cucutenian settlements, we first take up for consideration the new data obtained for Ripiceni–Holm. Alongside a series of small-scale characteristics, several rectangular anomalies can also be observed (which can be attributed to burned archaeological complexes, most probably dwellings), characterised by a strong positive signal, running along a NNV–ESE direction, in two relatively parallel rows. In this case, the interpretation is not definite, since the surface of the site did not allow for a full magnetic survey; future research will clarify this issue.

The situation of Hândrești–Dăiceni II differs from that of the previous case study. Thus, even though most anomalies identified are similar (i.e., characterised by an intense magnetic signal caused by burning), in this case they seem to group into several main clusters located, foremost, in the highest area of the site. These agglomerations consist of positive pyrogenous or non-pyrogenous anomalies of different sizes. Other anomalies of different shapes were also identified, most noteworthy two semicircular ditches along the northwestern side of the site, and one along the southeastern side, the latter seemingly delimiting the settlement on its exposed front.

The results obtained following measurements conducted for the last case study revealed, beside a heavily burned characteristic (probably dwellings) in the southern part of the site, which is not naturally defended, the presence of two large anomalies, parallel, forming a semicircle. They can be ascribed to defensive ditches, which alongside a much-narrower third anomaly to the inside (probably a palisade), constituted a complex fortification system that was often encountered in Cucutenian hilltop sites.

CONCLUSIONS

From the above it can be drawn that the planimetries of the uni-stratified Cucutenian sites can vary from one chronological phase to the other, or according to the type of settlement. Nonetheless, on the basis of the available magnetic data we can distinguish for northeastern Romania at least two types of internal organisation (in rows or in groups), often accompanied by fortification works in the form of one, two or three defensive ditches.

Although the present study was limited to the presentation and interpretation of results obtained by means of magnetic surveying, its continuation will undoubtedly make use of the other archaeological prospecting techniques, alongside input from older or newer archaeological excavations (Bem 2001; Lazarovici and Lazarovici 2007), which are mandatory for discerning the internal spatial organization of Cucutenian sites located in northeastern Moldavia or elsewhere.

Unfortunately, the investigation of our case studies has not been exhaustive, particularly due to the presence of crops on the sites or due to land ownership issues. We intend to complete the body of knowledge by completing magnetic measurements and, in the future, by integrating other prospecting methods (GPR, electrical resistance) that will contribute to our view of ancient Cucutenian communities.

ACKNOWLEDGEMENT

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Non-invasive prospection of two Iron Age sites in Michałowice, southern Poland

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KEY-WORDS: Przeworsk culture, Iron Age, microregional studies, magnetic prospection, non-invasive archaeology

INTRODUCTION

Non-invasive prospection was carried out and subsequently verified by excavation on two related archaeological sites (Fig. 1) dated to the pre-Roman and the Roman Influence Period in Michałowice (Czarnocin commune, Świętokrzyskie voivodship, southern Poland). On the two sites (a burial ground and a nearby settlement), magnetic gradiometry was the main geophysical method that was applied (Aspinall *et al.* 2008). It was deemed to be the most effective, taking into account soil conditions and the character of targeted features, that is, ditch enclosures, pits, production areas, urn graves with metal goods.

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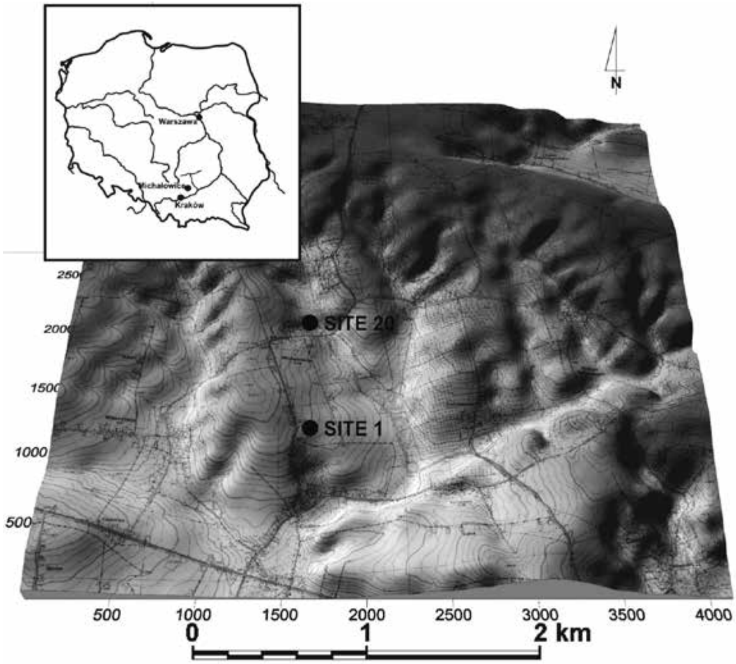

Fig. 1. Location of Michałowice site 1 (burial complex) and Michałowice site 20 (open settlement)

BURIAL COMPLEX (MICHAŁOWICE SITE 1)

The first of the studied sites, Michałowice site 1, is an interesting and rare burial complex with a unique set of small rectangular groove-type features (Pol. *obiekty rowkowe),* from 6 m to almost 14 m long. Urn or pit graves were often located inside the ditch enclosures (Zagórska-Telega *et al.* 2011: 195–225; 2012: 135–160; see also Gedl 1985: 159–190). On-site archaeological (invasive) investigations have been taking place regularly since the 1990s. In 2008, a small (30 m x 50 m) magnetic test survey (Fig. 2) was commissioned in an area believed to be a peripheral part of the burial site. Despite the small size of the survey, it yielded surprising results with the discovery of one of the largest groove-type features known at that point and a series of smaller features of the same kind (Wroniecki 2012: 161–170). In the following years, further magnetic prospection (over an area of approximately 4 ha) revealed more structures, both natural (loess gullies, sealed depressions) and anthropogenic, thus helping to understand the spatial arrangement of the site, as well as the surrounding, archaeological and natural landscape. This influenced excavation strategies. A series of trenches was opened on the spot of the anomalies in an effort to verify their anthropogenic character. It was proved that all of the rectangular positive magnetic anomalies were in fact groove-type features. Grave goods in urn burials were the source of many point dipolar anomalies. Well fired pottery vessels were also reflected on the magnetic map. A circular anomaly, 20 m in diameter, initially thought to be of anthropogenic origin, was excavated and identified as a sealed depression.

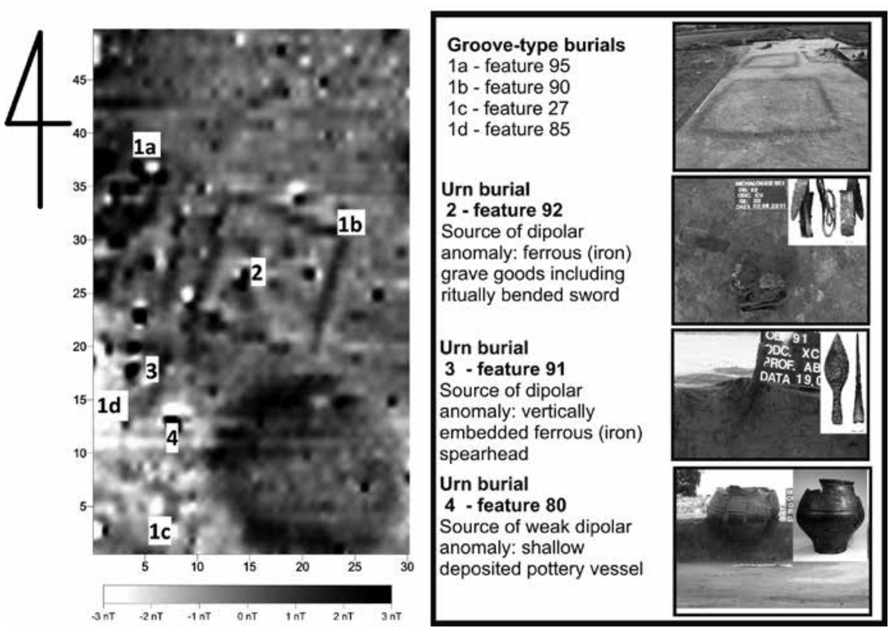

Fig. 2. Visualisation of the results of the 2010 magnetic survey and verification trenches excavated at Michałowice site 1

OPEN SETTLEMENT (MICHAŁOWICE SITE 20)

The second investigated site, an open settlement referred to as Michałowice site 20, was discovered during a field-walking survey in 2011. Archaeological surface finds linked the site to two cultural groups inhabiting this area in the Iron Age: the La Tène culture with still largely unidentified general settlement characteristics (Dulęba 2009: 11–34; 2014: 189–200) and the Przeworsk culture, which in this region is dated to the end of the 2nd century BC. Settlement lasted through the end of the 1st century AD as attested by the youngest archaeological material discovered so far. The site is most likely only a fraction of a settlement that underlies the buildings of the modern Michałowice village. Non-invasive prospection could be carried out on the valley floor used to this day as a field and meadow. A magnetic survey, funded by the Jagiellonian University, was carried out in 2012. Positive point anomalies registered during the prospection were interpreted as traces of past settlement activity. In the course of the following three years, excavations conducted to verify these anomalies uncovered production installations, such as lime kilns, as well as pit houses, refuse pits and part of a probable longhouse (Fig. 3).

DISCUSSION

The presentation focuses on micro-regional studies of the Iron Age landscape in the Michałowice area, which is in the southeastern part of Garb Wodziesławski separating the basins of the two major

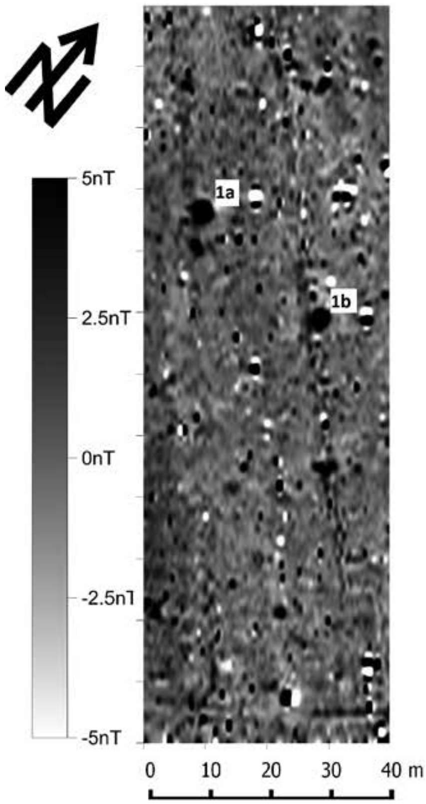

Fig. 3. Visualisation of the results of the 2012 magnetic survey (±5nT, light to dark) and verification trenches excavated at Michałowice site 20

tributaries of the Wisła river, Nida and Nidzica. The geological substrate is made up of solid rocks from the Cretaceous period. Above them lie deposits from the Pleistocene and Holocene periods, most prominently loess soils. River valleys are characterised by accumulated colluvial sediments, often of considerable thickness. Strong diluvial processes that continually change the landscape are also observed in the broader geographical zone. Strong erosion causes reduction of the topsoil cover in the upper parts of the hills, subsequently stimulating the accumulation of fertile soils in their lower parts (Kołodziejczyk 2003; Żyła 2007). This fact is of significance for non-invasive prospection in general and for magnetic prospection in particular.

The burial area in Michałowice is located near the hilltop, where the thickness of the topsoil ranges from 10 cm to 30 cm and loess soils underlie the ploughed horizon. Such conditions are favourable for magnetic prospection, mainly because of the geological background and the relatively high magnetic susceptibility of the fill. In this geological situation, it was possible to detect ditched features as well as other, often miniscule, anthropogenic and geological features. On the settlement site in Michałowice, however, the geological situation is different with the fertile subsoil (chernozem) reaching 110 cm in thickness. Few of the excavated features lay deeper, being dug into the underlying loess soils. This situation significantly reduced magnetic detection rates, the only features marked by anomalies being structures with evidence of thermal treatment.

This short case study is at once empirical proof of the possibilities of the magnetic method and its limitations in the context of the geomorphology of the Małopolska Upland. Further investigations at both the burial site and the open settlement in Michałowice should contribute to the development of non-invasive methodologies and interpretations in the region.

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Comparison of the results of magnetic and gradient surveys with the real situation in the field on the basis of excavations at Akrai/Acrae, south-eastern Sicily. New possibilities for the interpretation of geophysical maps

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KEY-WORDS: Akrai, Sicily, GIS, Polish excavations, GIS, magnetic survey

The archaeological site of Akrai (Greek Ἄκραι, Latin Acrae, Agris, Acrenses) is situated to the south-west of the modern town of Palazzolo Acreide, in south-eastern Sicily. The colony Ἄκραι was founded around 664/663 BC by Dorian colonists from Syracuse. The town emerged and developed in the shadow of the metropolis of Syracuse. Intensive development began in the 3rd century BC as attested by buildings: a theatre, bouleuterion, agora, stoa (Chowaniec 2013; 2015).

Research on the urban centre of Akrai concentrated on the public part of the town, only sporadically touching private architecture. The archaeological evidence has confirmed the functioning of the city in the time of the Roman Republic and the Empire. The town re-emerged in Late Antiquity, when the stone quarries were turned into early Christian necropolises with inscriptions carved therein, dated to the 4th and 5th century AD.

The city may have occupied approx. 35 ha, but its exact extent is still unknown. Unfamiliarity with the nature of the town and its history after the fall of Syracuse led to new archaeological investigations being undertaken. In cooperation with the Soprintendenza dei Beni Culturali e Ambientali di Siracusa, the University of Warsaw began research in 2009, starting with non-invasive investigations (survey, aerial photography, geophysical prospection). Archaeological excavations by different teams, off and on since 1816, have demonstrated that ancient ruins can be found directly beneath the surface.

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Fig. 1. Akrai. Results of magnetic caesium Geometrics 858 G (left) and gradient Bartington dual-Grad602 (right) measurements. Measurements K. Misiewicz

A preliminary analysis of the Warsaw team's first results, archaeological and geophysical (Chowaniec *et al.* 2010), confirmed the situation, indicating as well that the rubble ensconcing most of the standing remains consisted of the same stone building material as used in wall construction. Therefore, the general maps of magnetic and gradiometric surveys (Fig. 1) typically present values corresponding to what is described as magnetic debris; multi-layered features also result in similar registered values. Linear features, which are the most important for planning excavations, most probably represent architectural remains. These are narrow anomalies, showing in most cases higher values of magnetic susceptibility, either ferrous-induced, if the sources have traces of magnetite, or thermoremanent, if they are igneous in origin. Additionally, linear anomalies can form regular, parallel structures, sometimes with right angles. The disposition of recorded values (both in magnetic and gradient measurement) was described in a preliminary report as being typical of a multi-layer site containing architectural remains (Chowaniec and Misiewicz 2010). Remains can be expected to lie at different depths and to vary in their degree of preservation; moreover, entire buildings, mostly filled with rubble may be expected next to fragments of building foundations. Linear anomalies that were similar to those detected in the area of a street exposed during earlier excavations were also present. Their perpendicular arrangement to the known street suggests that the anomalies may reflect a street grid.

Excavations in Trench I confirmed the preliminary interpretations of the geophysical results (Fig. 2). The main anomaly detected here was a narrow linear feature aligned SE–NW, running through the southern part of the surveyed area, corresponding to nothing visible on the ground (Chowaniec, Misiewicz 2010). Earlier testing in a trial pit near Trench I uncovered a stone-paved street, 0.20–0.25 m beneath the surface (766.70–766.45 a.s.l.), and architectural remains to the west of this road (already in Trench I) (Fig. 3). The first layer (766.45 to 765.98 m a.s.l.) was formed mainly of small loose stones, making it difficult to recognize the source of the detected magnetic anomalies. The first feature capable of producing changes in magnetic field intensity was wall 2,

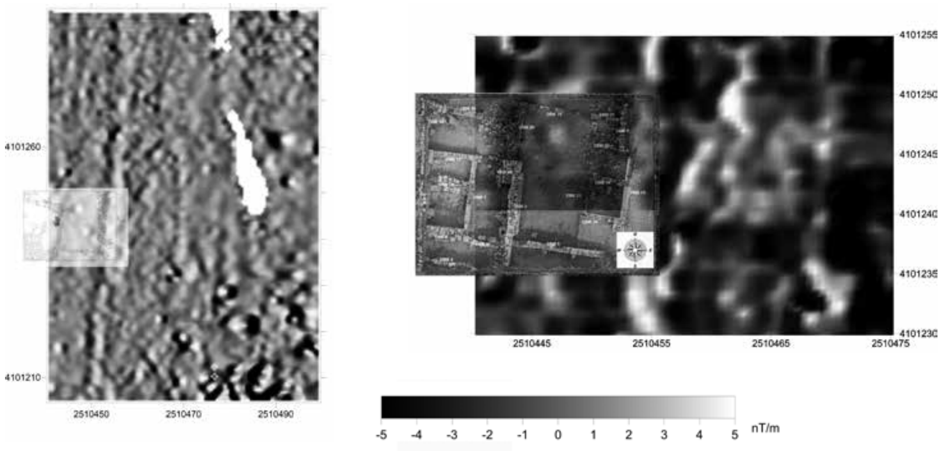

Fig. 2. Akrai. Comparison of geophysical map with the result of excavations in Trench I. Measurements and processing K. Misiewicz

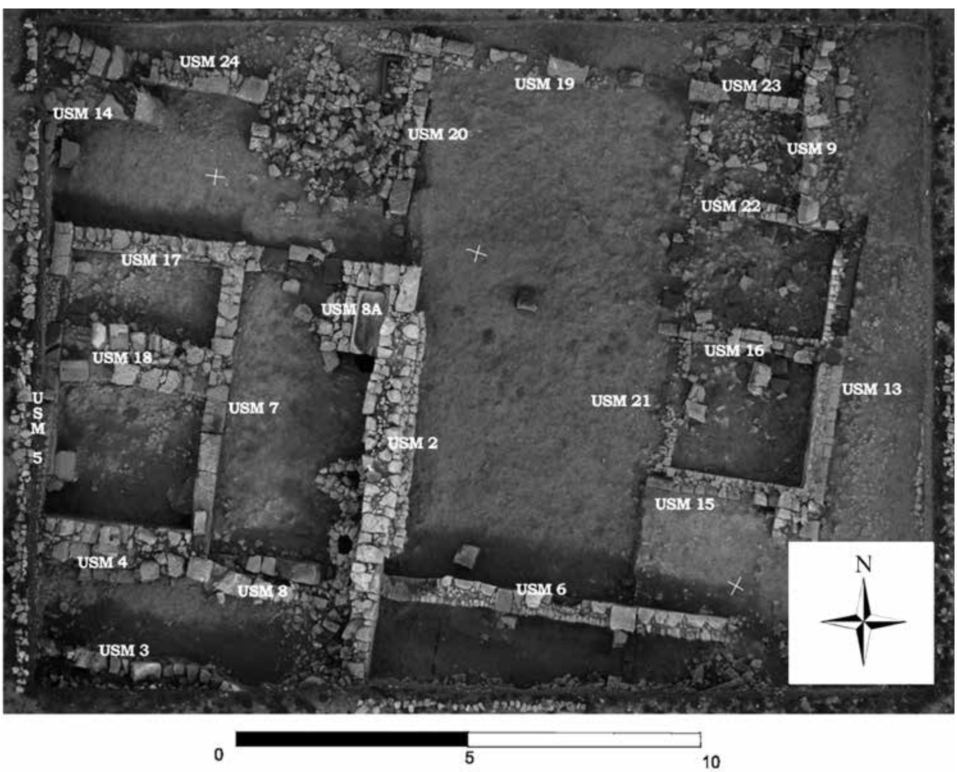

Fig. 3. Akrai. Orthophotomap of Trench I. Measurements and processing M. Bogacki and R. Chowaniec

found at a depth of 766.09–765.15 m a.s.l., surrounded by collapsed stone. A stone sarcophagus stood on top of the wall, directly under the surface (766.05–765.98 m a.s.l.). The wall and the sarcophagus were evidently later than the layer of small stones. However, the most distinct negative anomaly (from –4.6 to –5.9 nT/m) was caused by large stone slabs deposited close to the surface; it was observed on both the gradient and the magnetic maps. Similar loose stones, taken from the surface while plowing here decades ago, also shaped a subsurface layer in the western part of the excavated Trench I. In a layer about 0.9 m thick (766.30–765.28 m a.s.l.), there were the remains of walls aligned N–S, lying on the western border of the trench at 765.51 m a.s.l.

More walls were discovered in the trench: an E–W one at the southern border of the trench, its highest point being at 765.70 m a.s.l. (wall 3), and others, parallel to the first, 2.5 m further to the north, at a depth of 765.70–765.50 m a.s.l. (walls 4 and 8). Magnetic field intensity values for this part of the trench were generally lower and the contrast between the walls and their surroundings was too small to produce distinctive anomalies. The same could be said of the eastern part of Trench I, where another two walls were excavated, one aligned E–W at a depth of 766.00–765.59 m a.s.l. (wall 6) and the other N–S at a depth of 766.27–766.04 m a.s.l. (wall 9). The first wall could be the source of a dipole–dipole anomaly with values between -2 and -5nT/m on the north and from 1.5 to 2nT/m on the south. A linear anomaly with values from -1.5 to -2nT/m on the eastern side and from 3.5 to 5nT/m on the western side of wall 2 was also registered.

The results of the detailed analysis presented above should be a key to understanding the magnetic map prepared for the whole site.

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Searching for Celts in Upper Silesia. Verification by excavation of a geophysical survey in Samborowice

Przemysław Dulęba[a], Jacek Soida[b] and Piotr Wroniecki[c]

KEY-WORDS: Celts, La Tène culture, settlement, geophysical research, anomaly verification

INTRODUCTION

The presented case study is part of a wider research project that concentrates on the recognition of La Tène culture (commonly identified with Celtic tribes known from historical sources) settlement patterns in the Troja and Psina River basin microregion that constitutes a part of a vast mezoregion of the Głubczyce Plateau. According to the current state of knowledge (Jahn 1931; Woźniak 1970: 293–315; Chochorowski 1980), the studied microregion is place to the most intensive La Tène culture settlement activity within Poland's modern boundaries. Site 13 (Polish Archaeological Record project (AZP): zone 102-39/ site 117) in Samborowice, Racibórz district, is presumed to possess the largest cognitive potential in the area. It is located on a high fluvial terrace of the Psina river valley. The mezoregion abounds in spreading patches of excellent loess and loess-like soils which lie over sands and gravels, and have been intensively exploited and densely populated throughout most periods of prehistory. The study area is currently used for agriculture, and was limited by seasonal crops and a dirt road. Despite these drawbacks the area in general was characterized by a high level of ground availability and was suitable for geophysical study.

Based on surface finds, Samborowice site 13 could be classified in three phases associated with Lengyel, Lusatian and La Tène culture settlement activities. Our research project concentrated on registering features associated with La Tène settlement. The difficulty of the task lay in the fact that La Tène rural settlement patterns in the area of Central Europe are known to have a clear dispersion of residential areas, making them difficult to identify and comprehend solely through excavations. The scattering of surface pottery finds also established the extent of the settlement zone, which covered at least 6 ha. This state of things necessitated a large-scale spatial approach with the use of magnetic gradiometry as the fastest and the most cost-effective geophysical technique capable of detecting a wide variety of anthropogenic transformations.

MAGNETIC GRADIOMETRY SURVEY

The survey was conducted with the use of a Fluxgate instrument (Bartington Grad 601-Dual). The overall area of the survey amounted to 4.2 ha (Fig. 1). The survey grid was staked out with the use of a GPS RTK Trimble 5800 and included areas with high concentration of La Tène surface

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Fig. 1. Samborowice, site 13, Racibórz district. Plan of magnetic gradiometry survey (-2nT/2nT, light to dark) by P. Dulęba, J. Soida, P. Wroniecki

finds. As a side effect, the results of the survey clearly showed the cadastral divisions due to small field parceling. The acquired geophysical data was visualised in a grayscale convention. Geophysical measurements were processed in the *TerraSurveyor* and *Geoplot 3* software.

Data was subjected to filters (interpolation 0.5 m x 0.5 m, destripe, low-pass). The results were presented in the form of a visualization in different ranges of the grayscale convention. Magnetic maps derived from geophysical software were georeferenced in an open source GIS application. A polygon vector layer was derived from the magnetic maps with an interpretation of the data. Anomalies indicating the presence of probable archaeological features (such as pits, burnt features

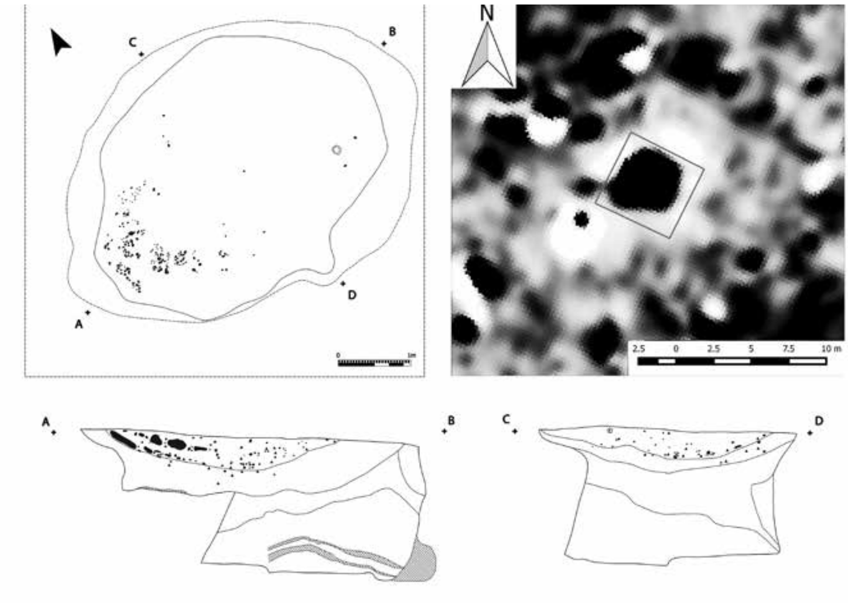

Fig. 2. Samborowice, site 13, Racibórz district. 1: Feature 5 (-2nT/2nT, light to dark). Processed by J. Soida

or anthropogenic soil sediments) were also similarly mapped. The geophysical research revealed numerous anomalies thought to be anthropogenic in their essence, manifested as both point and linear shaped increases in the value of the vertical component of the magnetic field. Anomalies of the first type may be associated most often with stratigraphic disturbances, cut features and other forms of soil disturbance, i.e., pits, postholes, foundations and pit-houses. Linear anomalies may be associated with ditch features. The outcome of the magnetic survey was compared with the results of earlier archaeological research, which in turn led to the interpretative model that draws from both non-invasive and excavation data.

ANOMALY VERIFICATION

Excavations in 2013–2014 covered an area of 330 m^2. Their aim was to verify various magnetic anomalies. Five trenches were opened, their layout and size conforming to the shapes distinguished by the geophysical survey. All point anomalies registered during the magnetic survey were confirmed to be archaeological features. The shape of these features coincided almost exactly with the outlines of registered magnetic anomalies. Undoubtedly, the presence of a loess soil cover proves to be an advantage for magnetic prospection research, because this type of aeolian sediment generates large contrasts with the magnetized fills of archaeological features.

In trench 1/14, an oval pit was registered (feature 5) with dimensions of 4.70 m x 3.56 m at the distinction level, which gave a very strong magnetic response (Fig. 2). This intensity could have been caused by the presence of highly burnt daub, most likely destructs of some structure that existed

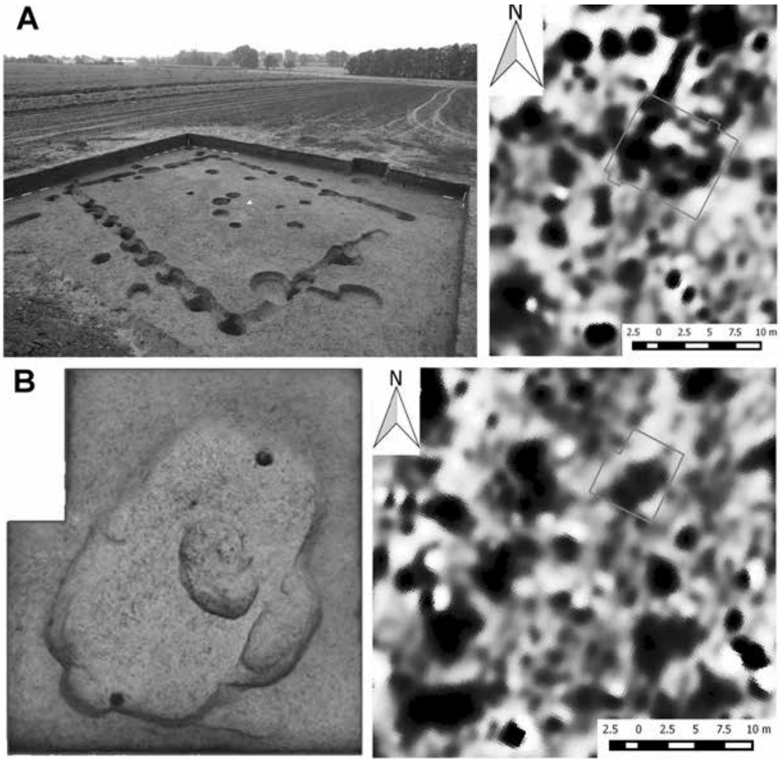

Fig. 3. Samborowice, site 13, Racibórz district. A: Posthole structure recorded in trench 2/14 (-2nT/2nT, light to dark). B: Feature 40. Processed by J. Soida

above or in the pit's vicinity. Feature 5 was characterized also by a relatively thick stratigraphic fill. In its eastern part a wide niche was found, 1.96 m deep. This feature may be interpreted as a storage pit.

In trench 2/14, a number of features that represent the structure of a long hut (post-hole construction) were uncovered (Fig. 3:A). The analysis of this type of architecture shows that most likely only a part of the hut was included in the trench (Pavúk 2012: Fig. 1-7). At the level of the distinction, a foundation ditch was noticed (7.82 m x 6.20 m), under which the relics of numerous posts were discovered that constituted the structure of the hut. On the basis of radiocarbon dating and archaeological material (pottery, stone tools, flint artifacts), feature 5 and the posthole structure of trench 2/14 should be dated to the Neolithic period and associated with the Lengyel culture.

Feature 40 was revealed in the eastern part of the site. It was a relic of a pit-house, 5.66 m by 4.30 m (Fig. 3:B). It had a flat floor, two postholes in the middle of both gable walls and two oval niches: one in the central part (which was probably a kind of "cellar") and another along the southern flank. The magnetic anomaly that pointed to the feature differed substantially from the anomalies associated with Neolithic deep-seated pits, such as feature 5. The intensity of this anomaly was much weaker, owing probably to fill that was only 0.42 m thick. Radiocarbon analysis and archaeological finds (pottery, metal artifacts) date feature 40 to the middle La Tène period.

CONCLUSIONS

Feature 40 is similar to many congruent dwelling structures found on the settlements of La Tène culture in Central Europe (Meduna 1980: 193–199, list 1). The function of such pit-houses has been the subject of debate, but the prevailing opinion is that these features were not typical residential buildings (Meduna 1980: 61). In Samborowice, similar anomalies are located near feature 40 (Fig. 1). If their source are also analogous structures, then such a cluster may be interpreted as traces of a farmstead. Based on an archaeological interpretation of the magnetic gradiometry data, it is possible to recognize at least two or three supposed farmsteads, scattered over a relative large area (Fig. 1). Such an extensive spatial arrangement is the dominant settlement pattern in the La Tène Period.

ACKNOWLEDGEMENTS

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Geophysical surveying in Egypt: periodical report for 2013-2015

Tomasz Herbich[a]

KEY-WORDS: archaeological prospection, archaeological geophysics, magnetic method, resitivity method, Egypt

The article reviews briefly prospections carried out by the author in Egypt from 2013 through the middle of 2015, adding to the cyclical presentations of research during AP conferences in the past starting from 1999 (complete list of references in Herbich 2013). The surveys in Berenike,

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Heliopolis, Buto and Kom el-Gir are ongoing projects, whereas the investigations in Dahshur, Tanis, Abu Billo and Plinthine are new initiatives (Fig. 1).

The magnetic and electrical resistivity methods were employed. Fluxgate gradiometers (Geoscan Research FM256) were used and sporadically a caesium instrument (Geometrics). Sampling density for the FM instrument was 0.5 m by 0.25m, the survey was carried out in parallel mode within a grid of 20 m x 20 m. The electrical resistivity method, both profiling and sounding, was based on a Polish-made ADA 05 (Elmes) apparatus.

OLD KINGDOM (2575 – 2134 BC)

DAHSHUR (German Archaeological Institute, project director Nicole Alexanian)

The survey was carried out around the valley temple of the Bent Piramid and on the southern side of the Red Pyramid. An area of 11.3 ha was prospected. Measurements to the north of the temple mapped in considerable detail a settlement that could be dated to the Old Kingdom based on a surface pottery collection. The network of anomalies clearly reflects fragmentary housing as well as the street grid, whereas the nature of these anomalies indicates the presence of mud-brick architecture (Fig. 2). Linear anomalies adjoining the temple on the north (extending its long sides) have been interpreted by Felix Arnold as the remains in all probability of an early dynastic funerary enclosure of the same kind as the ones discovered at Saqqara and Abydos. Prospection in the area of the hypothetical harbour, connected to the temple by a causeway, mapped mud-brick walls embracing the bay on the north and south (the southern wall had already been traced by H. Becker using a caesium instrument).

Surveying on the south side of the Red Pyramid was aimed at verifying two architectural complexes marked on Lepsius' plan from the middle of the 19th century and still faintly outlined in Google Earth images. The magnetic map of the better preserved eastern complex revealed a dozen or so long and narrow units. Their layout and size are analogous to the workmen's (pyramid builders) barracks at Giza. The surface pottery collection dated the complex to the Fourth Dynasty, which is the time of construction of the Red Pyramid. The indistinct image of the structures on the map is due to the fact that they were built of stone, a determination suggested by earlier limited excavations by the western complex and an analysis of surface evidence.

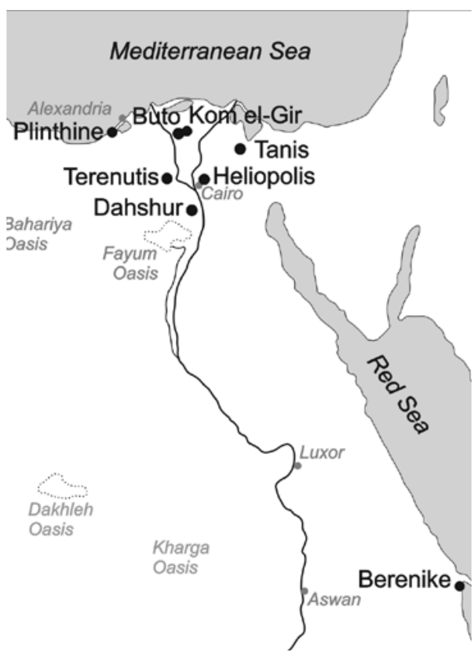

Fig. 1. Location of sites investigated in 2013-2015

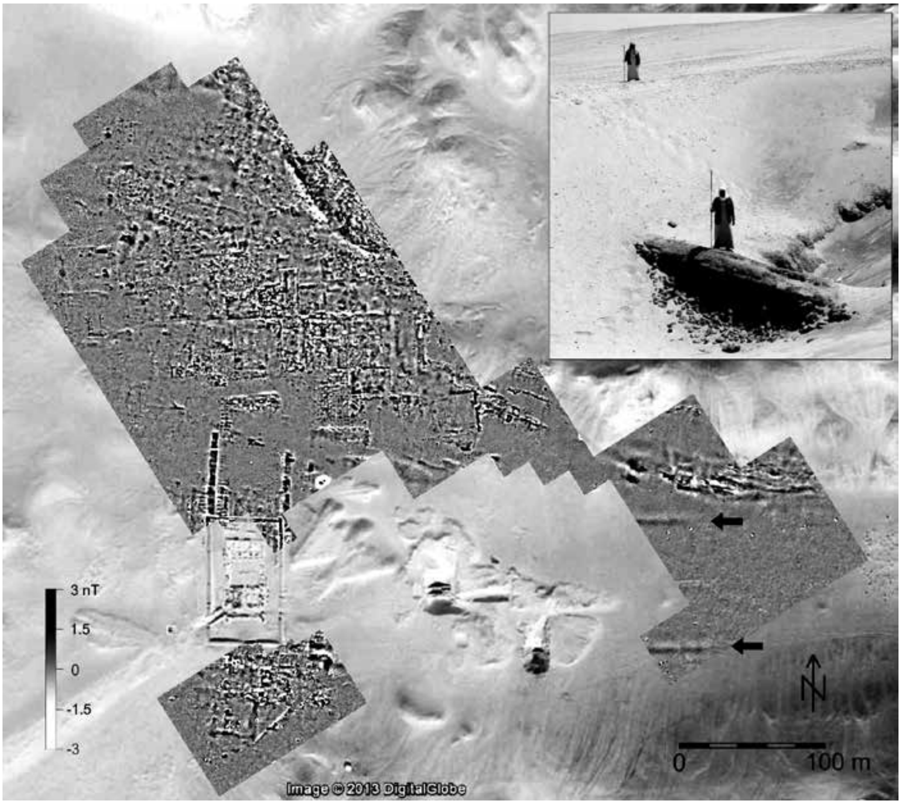

Fig. 2. Dahshur. Magnetic map of structures in the area of the valley temple of the Bent Pyramid. Arrows indicate the position of walls embracing the harbour. The wall depth (average of 4 m below ground level) was tested archaeologically on the south side (see photo in the box) and by core drilling on the north side. Sattelite image by Google Earth

NEW KINGDOM (1550 – 1070 BC)

Heliopolis/El-Matariya (Leipzig University, project director Dietrich Raue)

The investigations concentrated on the remains of a temple of Re-Horakhty and Atum in Heliopolis, covered by at least two meters of alluvial mud. The earliest remains of architecture reach down 8 m in places. The accruing rubbish dump (6 m thick in places; for earlier work, see Herbich 2013: 241–2) threatens the ancient remains, hence the need for this salvage project. Electrical resistivity profiling (with an asymmetrical Schlumberger arrangements, the probe settings being AM=5 (or 7) m and MN=1 m) was carried out with considerable difficulty due to hard field conditions: a dry and hard ground that did not allow for any measurements until an iron rod was used to break open holes and fill them with water to decrease contact resistance. The asymmetrical arrangement was employed owing to the small dimensions of areas available for surveying (part of the area was cleared of rubbish with a bulldozer).

Fig. 3. Tanis. Magnetic map of architecture from the Late Period in the southern part of the tell

Measurements uncovered a higher-resistance anomaly of elongated shape; coring established that it was caused by a limestone structure and that its foundations reached 4 m below ground level (and 3 m below the ground water table) (de Morgan and Herbich 2015). The structure will be excavated the coming season once a program of pumping has reduced the water table.

THIRD INTERMEDIATE AND LATE PERIODS (1070 – 332 BC)

Buto/Tell el-Fara'in (University of Poitiers, French Institute of Oriental Archaeology in Cairo and German Archaeological Institute, project director Pascale Ballet)

The magnetic prospection covered a total of 3.1 ha to the north, west and south of the temple enclosure, mapping remains of mud-brick architecture and industrial installations, presumably pottery kilns. Since 1999, the prospection has covered altogether over 25.5 ha (Hartung *et al.* 2009)

Tanis/San el-Hagar (École pratique des hautes études, project director François Leclère)

The new director of the French excavation mission at Tanis, the capital and principal Mediterranean port of Egypt in the Third Intermediate Period, initiated a program of non-invasive research aimed at reconstructing the urban layout on the tell (which is 1.5 km in diameter) and the paleolandscape around it. The magnetic method was employed to map the city, starting with an area of 30 ha in the nothern and central/southern parts of the tell. The results were so good that not only was it possible to reconstruct the street grid, but detailed plans of individual houses could also be drawn (Fig. 3). The architecture that was mapped was dated to the Late and Graeco-Roman periods based on an architectural analysis of the plans and the surface pottery collection. Landscape research concentrated on establishing the course of the defunct Tanitic branch of the Nile. A series of vertical electrical soundings (VES) was carried out (within the frame of an agreement on co-operation between EPHE and IAE), providing data for drawing sections in which areas of stable geological sequences were isolated from those characterized by a disturbed layer arrangement. Data interpretation will follow a program of auger drilling to verify the findings.

GRAECO-ROMAN PERIOD (332 BC – 395 AD)

Plinthine/Kom el-Nugus (French Mission to Taposiris Magna, project director Marie-Françoise Boussac)

The site, identified as ancient Plinthine, was considered the western gate to Egypt in the 7th and 6th centuries BC (analogously to Hebua on the east), until it lost its position to Taposiris Magna at the close of the Hellenistic period. A magnetic survey covered 2 ha on the slope and in the middle of a horseshoe-shaped kom as well as to the south of the latter, in an area where architecture has been excavated ever since the project started in 2013. Testing on the kom confirmed its anthropic origin as the accumulation of settlement deposits with architectural remains preserved in the subsurface layer. Structures in front of the kom were also mapped. The walls were constructed of non-magnetic limestone; their distinct image on the magnetic map is due to the higher magnetic susceptibility of the soil in which they are buried (of values up to 0.3×10^{-3} SI).

Kom el-Gir (German Archaeological Institute, project director Robert Schiestl)

The prospection continued a project started in 2011 (Herbich 2013), achieving a coverage of almost 80% of the structures on the main mound (12.8 ha). A rectangular structure measuring 170 m by at least 160 m was discovered as a result of the prospection; running around it was a wall 6 m thick, periodically reinforced with towers. It is most likely a Roman fort, the first to be discovered in the Nile Delta (Schiestl and Herbich 2013) (Fig. 4).

Berenike (University of Delaware and Polish Center of Mediterranean Archaeology of the University of Warsaw, project directors Steven E. Sidebotham and Iwona Zych)

A full magnetic map of the ancient city and harbour was completed, permitting a reconstruction of the street network, the urban layout of individual houses and a precise tracing of the town limits. A structure of monumental size, possibly a funerary mausoleum, was mapped in part where an analysis of old Corona satellite images located it, unexpectedly, on flat ground already outside the

Fig. 4. Kom el-Gir. Magnetic map of Roman-period architecture. Arrows point to anomalies that reflect the position of the northern and western corners of a hypothetical fort. Sattelite image by Google Earth

city limits to the west of the town (for more on the prospection, see Zych and Herbich 2015: 95-118)

Terenuthis/Abu Billo (French Institute of Oriental Archaeology in Cairo and University Lille 3, project director Sylvain Dhenin)

Excavations conducted at the site from the 19th century have identified occupation from the Old Kingdom (burials), followed by settlement not earlier than the Hellenistic period. A new project undertaken at the site in 2012 has prioritized fieldwalking, as well as topographic and geophysical research. Magnetic prospecting covered the western part of the site (around a Ptolemaic-age temple) and areas in the southwestern part, covering a total of 8 ha. An improved temple plan was traced based on the prospection results (the original plan had availed itself of an analysis of ground relief and fragmentary excavation) and at least two major building phases were identified. Dozens of tombs constructed of mud brick were also located; they have been dated to the Roman period based on excavation work that is carried out concurrently.

ACKNOWLEDGEMENTS

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The potential and limitations of geophysical measurements on archaeological sites partly investigated in the past: case studies from the Czech Republic

Roman Křivánek[a]

KEY-WORDS: magnetometry, non-destructive archaeology, archaeological investigation, Neolithic roundel, hillfort, monastery

INTRODUCTION

Geophysical measurements at archaeological sites in the Czech Republic (and in former Czechoslovakia) started 65 years ago. The first pioneer resistivity prospection was carried out in 1950 by Prof. F. Běhounek on the middle rampart of the Old Kouřim hillfort and in the context of archaeological research (Šolle 1977). Most of the geophysical surveys before the 1980s were designed to precede rescue archaeological excavations or were carried out in connection with an ongoing systematic investigation of important sites. From the second half of the 1980s, geophysical methods were used to test results obtained from aerial archaeology. In the last two decades, geophysical investigations have been expanded to include monitoring of sites where archaeological investigations have already been carried out, resulting in a modification of the

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ground relief. Most geophysicists will consider such areas unsuitable for surveying (due to the risk of significant changes of measurement conditions). However, the number of such sites is growing, especially large sites where excavations cannot be continued for lack of funds. Non-destructive geophysical (other) surveying will be necessary at many such sites in the future. In this paper, selected sites will be discussed to draw attention to several problems inherent to these methods and their application characterized by varying degrees of effectiveness.

CASE STUDIES

Neolithic roundel near Bylany

Systematic archaeological research started in the settlement area of LBK and STK cultures near Bylany in the 1950s. The newly identified inner double-ditch enclosure of the roundel in the Bylany 4 area was tested in 1980 by M. Zápotocká. Other parts of the inner enclosure and also of the third outer ditch of the roundel were probed in 1991–92 by I. Pavlů. Connected with this were the first two stages of the geophysical survey. The inner double-ditch enclosure was surveyed in 1980 (Faltysová and Marek 1983) and the outer area with the third ditch of the roundel and a new segment of another triple-ditch enclosure in superposition were prospected in 1992–93 (Majer 1995). In 2012–13, the third stage of the magnetic survey was carried out with higher data density and measurement precision over the whole area. The entrances in the ditches of the STK roundel were mapped along with remains of many older LBK long houses in superposition and the second roundel, found in superposition, characterized by a different shape, construction and probably date (Fig. 1). It was also possible to identify the location and scope of earlier archaeological probes as well as typical local concentrations or linear alignments of highly magnetic anomalies (corresponding to metal items). The full scale geophysical survey of the site resulted in the first complete plan of the two Neolithic triple-ditch enclosures. Monitoring of the site after 32 (or 20) years from the present investigations should offer the opportunity of observing the impact of long-term ploughing on sloping ground.

Prehistoric and early medieval hillfort at Hradiště in Pilsen

The hillfort is situated on an elevated plateau between the meanders of the Úhlava river. This strategic location was fortified first in the Bronze Age, then in the Hallstatt and the early medieval periods. The inner area was investigated in the 1930s, when a sand quarry threatened to destroy the site. In the 1960s, the archaeological site was found to be a flat meadow without any visible changes or pits. The main rampart of the fortification was tested again in 2012–13 by a team from the University of West Bohemia in Pilsen (partnerships in research and presentation of archaeological heritage). The results of a parallel magnetic survey of accessible parts of the hillfort confirmed the destruction of at least one quarter of the inner area by the sand quarry (Fig. 2). The subsurface layers in the vicinity of the defunct quarry also appear to have been severely contaminated by metal objects, leaving less than half of the inner area free of recent landscape changes or contamination. The combined magnetic and resistivity measurements confirmed a heavily burnt rampart fortification around the perimeter, damaged in the southeastern part not only by the quarry, but also by a modern road. The geophysical survey traced the actual extent of earlier damage to an archaeological and natural site that is currently under protection.

Fig. 1. Bylany, district Kutná Hora. Comparison of old aerial photography from 1954 and geophysical surveys of two Neolithic roundels (source: *http://www.kontaminace.cenia.cz;* surveyed area: approx. 7.5 ha; magnetic survey: R. Křivánek 2012–2013)

Medieval monastery at Podlažice

The Benedictine monastery at Podlažice in East Bohemia existed from the beginning of the 12th century until 1421, when it was destroyed by the Husites and never rebuilt. Only a new church of St Margaret was raised in the central part of the former monastery. The central area near the baroque church was investigated in 1908 and 1909 by prof. J Plaček; subsequently, in 2003, J. Frolík tested the narrow sections next to the St Margaret church. A geoelectric resistivity survey around the baroque church covered all of the accessible area, including earlier excavated ground. A comparison of resistivity results with a plan of the old and new archaeological excavations confirmed the larger extent of the monastery and the destruction of the stone perimeter

Fig. 2. Pilsen-Hradiště, district Pilsen-město. Comparison of aerial photography and contour plan with geophysical surveys of a prehistoric and early medieval hillfort (source of plan: University of West Bohemia in Pilsen; surveyed area: approx. 1.75 ha; magnetic survey: R. Křivánek 2012–2013)

wall, possible entrances and the original position of the older Gothic church (Fig. 3). Scattered remains inside the monastery showed that a great deal of the stone material from the monastery structures must have been removed following the earlier excavations and there was a landscaping of the area. A comparison of the resistivity results with an old cadastral map also confirmed extensive movement of the stone material to fill an extinct pond and water channel (Křivánek *et al.* 2011). The geophysical survey proved useful in identifying the limits of the former monastery and confirming serious local changes of the subsurface archaeological situation.

CONCLUSION

Each geophysical method has its advantages and limitations when applied to already investigated parts of archaeological sites. The biggest challenge for magnetometry is altered ground without layers preserved *in situ* and contamination of sites by metal items. Similar

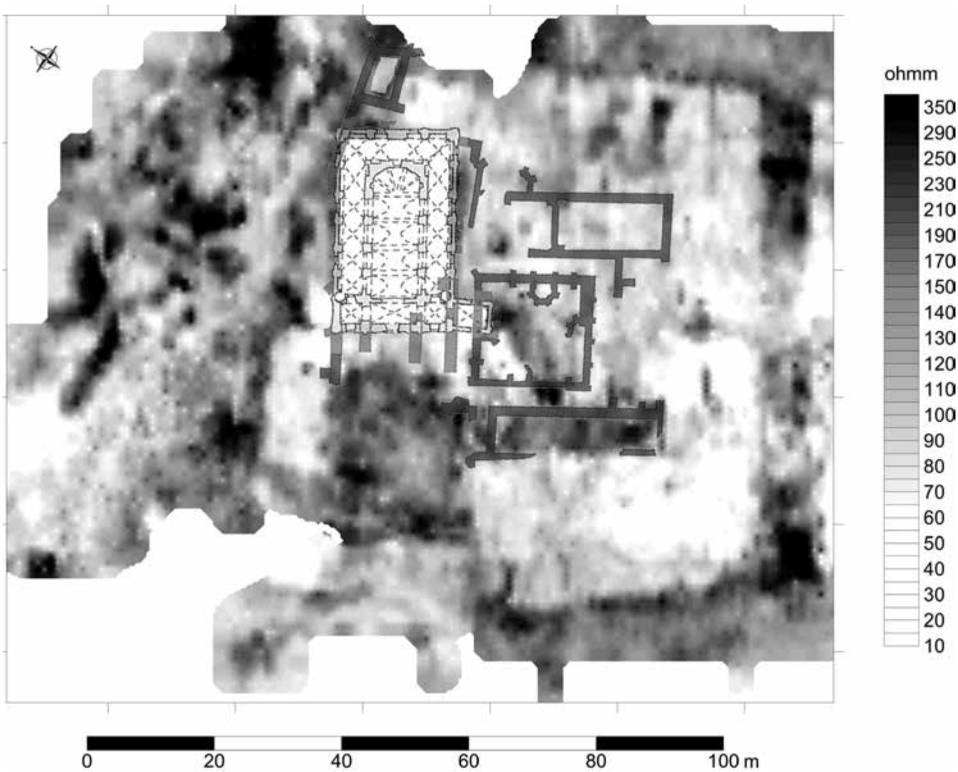

Fig. 3. Podlažice, district Chrudim. Comparison of a plan of earlier investigations and the results of a geophysical survey of a former Benedictine monastery (source of plan: J. Plaček, J. Frolík; surveyed area: approx. 1.1 ha; geoelectric resistivity survey: R. Křivánek 2006–2008)

limitations apply in the case of the electromagnetic method. For the geoelectric resistivity surveys, problems can be caused also by land use changes and modified humidity conditions in the subsurface layers of site. Radar application and its advantages can also depend on the depth and extent of terrain changes and the nature of the bedrock and of surveyed situations. Nonetheless, (post investigation) surveys of archeological sites with partly investigated and changed ground relief are possible in many cases. The extent, quality of results and informative value of particular geophysical method(s) reflect the specific type, condition and land use of the site.

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Geophysical prospection and rescue archaeological excavation of subsurface WWII remains in the foreland of brown coal mines in northwestern Bohemia

Roman Křivánek[a], Petr Čech[b] and Michal Soukup[b]

KEY-WORDS: magnetic prospection, World War II, rescue archaeology, high amplitude magnetic anomaly, firing position, northwestern Bohemia

INTRODUCTION

Geophysical methods have been used to survey the foreland of northern Bohemian brown coal mines for several decades, monitoring several dozens of sites, verifying by archaeological excavation and subsequently mining. Preliminary geophysical surveys contributed to the identification and efficient investigation of various prehistoric, early medieval, medieval and also modern settlements, burial grounds, various enclosed production and other areas (Křivánek 1999; 2001). Current archaeological research in the foreland of the Bílina mine, cadastre Libkovice, district Most, is aimed at uncovering remains of wartime activities from World War II. Magnetic prospection seemed to be a very useful geophysical method for monitoring former fields in the foreland of the mine, identifying subsurface relics of air defence units and other buildings and ancillary facilities.

HISTORY OF THE SITE AND ITS IDENTIFICATION

The air defence system east of Most city (German Sudetenland during WWII) was built in 1944, in the context of the extensive defences of the fuel-producing factory STW in Záluží near Litvínov. Anti-aircraft artillery emplacements were built in a number of strategic locations in the surrounding lowlands and in several places in the Ore Mountains. However, the Luftwaffe archive with written

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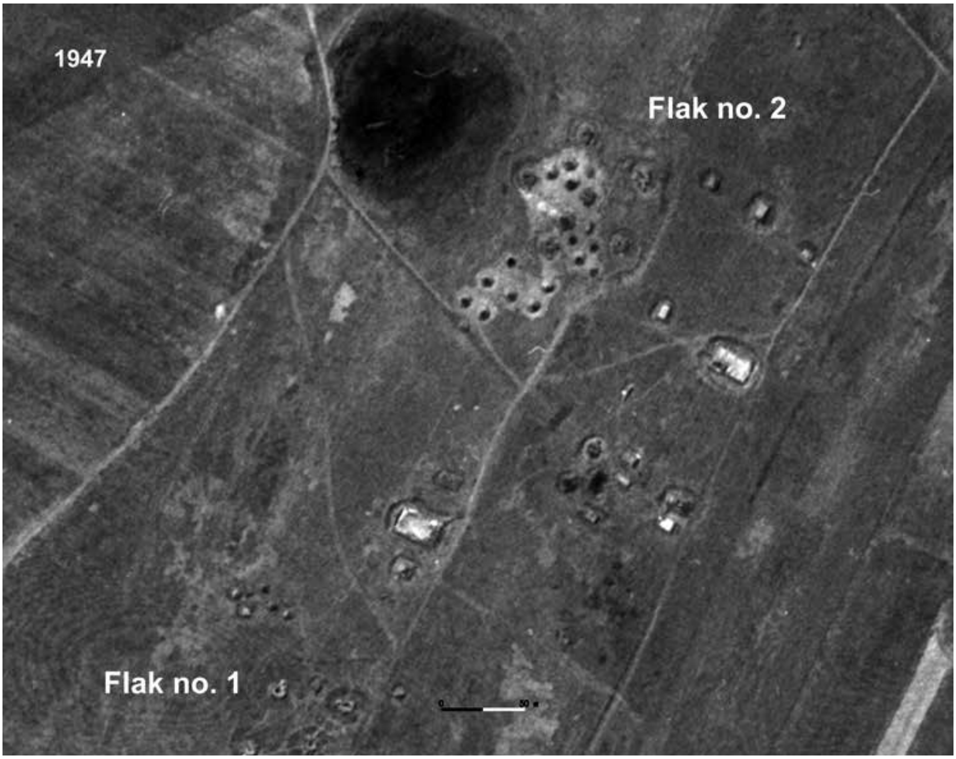

Fig. 1. Example of old aerial images from 1947 with visible soil marks of remains of anti-aircraft defences from World War II (source: Bílina mine)

sources, plans and documentation of the air defences was destroyed in Cheb in 1945. In 1944–45, the factory and its defences were intensively and repeatedly bombed by US Air Force and RAF aircraft. In the years following the end of WWII, the air defence facilities were largely dismantled down to the ground. Remains of artillery defences near Libkovice were distinguished as individual crop marks in aerial photographs from 1947 (Fig. 1) and 1953. Subsequent aerial photographs have not been equally distinct owing to long-term agricultural land use. Planned brown coal mining investment in the region in 2011 necessitated an accurate identification of no longer visible situations from WWII with rapid subsequent rescue archaeological excavation.

SURVEY METHODS

Geophysical prospection (as well as archaeological excavation) of surface WWII relics no longer visible on the ground is not one of the usual applications of geophysical methods in Czech archaeology. With an abundance of metal items in the topsoil well established (by surface artifact collections and metal detector surveys), the actual possibilities of magnetometry had to be tested first in this case.

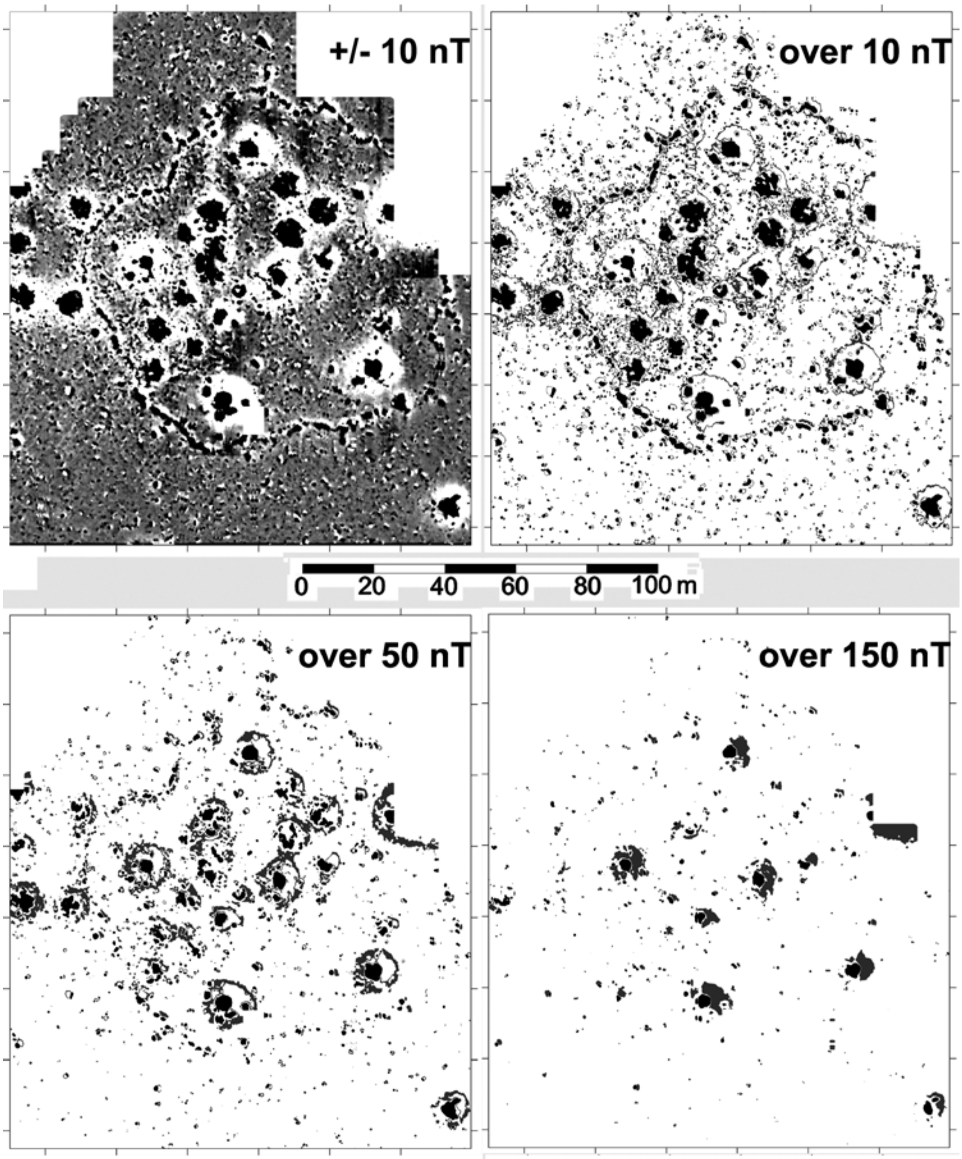

Fig. 2. Magnetic survey results on the spot of extinct anti-aircraft artillery (Flak no. 2) with separation of different amplitudes of high amplitude magnetic anomalies (presented area: approx. 1.35 ha; geophysical survey: R. Křivánek 2011)

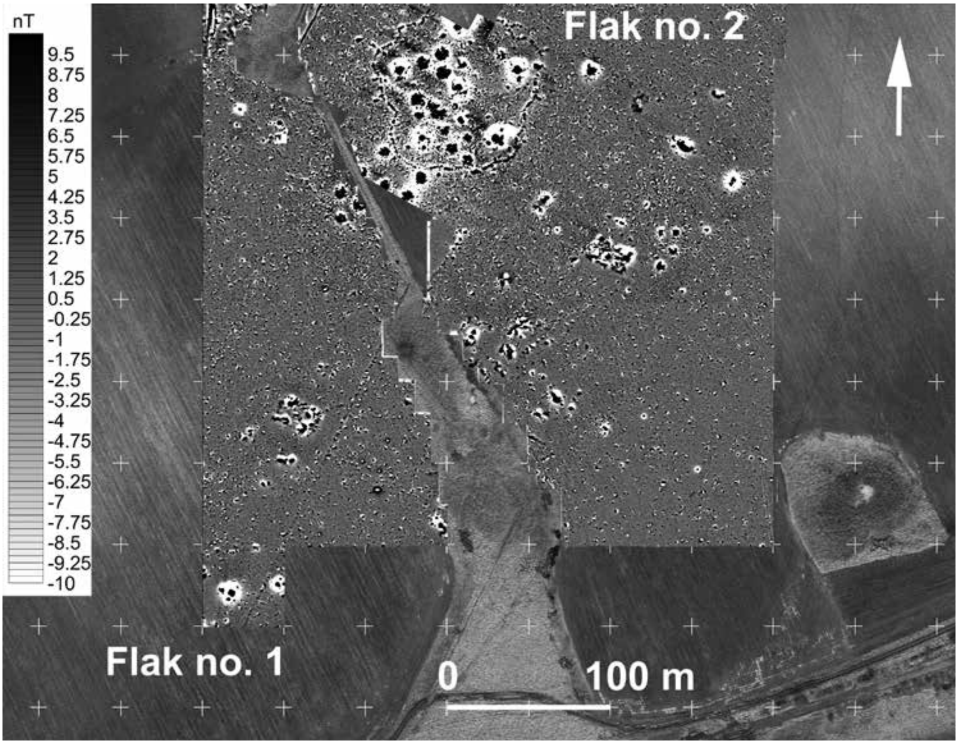

Fig. 3. Comparison of new aerial images and magnetic survey results (source: Bílina mine; presented area: approx. 11.3 ha; geophysical survey: R. Křivánek 2011–2014)

Despite the large number of smaller magnetic anomalies of different amplitudes, caused by minor metal objects (+/-1 to +/-10 nT), higher magnetic anomalies of larger metal components of military equipment and ammunition (common dipole anomalies from +/-10 to +/-100 nT) could be distinguished reliably in the results. A traditional field survey for sunken features with simple soil fill (not containing burned materials) would hardly be effective, but even despite the contamination, magnetic prospection was the optimal method for searching for various metal and military features over large areas of mine foreland. A five-channel Magneto-Arch magnetometer system with fluxgate gradiometers FMG-650B (Sensys) offered five parallel profile measurements with a data density 0.5 m × 0.2 m (testing with higher data density 0.25 m x 0.1 m did not produce better quality).

GEOPHYSICAL RESULTS

Magnetometric measurements in the foreland of the brown coal mines near Libkovice started in 2011, on the spot of a presumed anti-aircraft artillery emplacement (Flak no. 2). It proved possible to trace a nearly complete pentagonal ground plan of subsurface metal remains in the emplacement (Fig. 2). The highest dipole magnetic anomalies in the corners of the pentagon and in the centre identified sunken cannon positions. Isometric and oval magnetic anomalies of larger diameter and lower amplitudes inside the anti-aircraft defences and in the vicinity were identified as probable pits left by bombardment. Other subrectangular to oval magnetic anomalies, identified over a wider area, probably signified relics and other objects and scattered metals. Continued magnetic measurements in a broader zone around the investigated Flak no. 2 artillery gun distinguished other clusters of magnetic anomalies, showing the presence of other emplacements and ancillary facilities outside of the firing position. The total surveyed area around Flak no. 2 on the Libkovice cadaster plan is now 12.36 ha; other areas in the vicinity have been prospected as well.

ARCHAEOLOGICAL RESULTS

Intensive archaeological excavation of the area of Flak no. 2 has been conducted since 2013 (Čech *et al.* 2014). It enjoined cooperation with the Bílina mine and pyrotechnic experts from the Czech police and army in view of the threat of finding munitions. All five places in the corners of the pentagon and a sixth in the middle were identified in excavation, the latter as a sunken emplacement of the original anti-aircraft cannons with ferroconcrete base preserved at the bottom. Ancillary facilities were uncovered near the emplacements, including standby ammunition depots (with unexploded ammunition also) and an electrical installation in a brick channel. An electric generator and other remains of ammunition were also identified around the gun emplacement. In the case of larger isometric magnetic anomalies (with high magnetic inhomogeneous centres), the archaeological results changed a preliminary archaeo-geophysical interpretation. These were not pits left by the bombardment in 1944–45, but rather uncovered blasting pits used for the disposal of various types of ammunition after the end of World War II.

CONCLUSION

Archaeological investigation with important parallel work by pyrotechnic experts will be continued in the area of Flak no. 2 in 2015. More than 4.5 tons of active ammunition have been uncovered in the last two years. The total weight of collected metal remains was over 12 tons and artifacts of diverse other materials were also discovered. Moreover, magnetometry, subsequently verified by excavation, has brought results concerning layers underlying the heavily contaminated surface. Old aerial photographs and prospection in the field has also made it clear that similar forgotten places of anti-aircraft defence from World War II can be expected in the Libkovice region (for example, Flak no. 1 in Figs 1 and 3). A broad-scale magnetic survey will continue to precede brown coal mining in the region. The present results of the efficient conjoint use of different methods have shown that this is (and must be) an urgent issue not only for archaeology and for the brown coal mine industry, but also for pyrotechnic experts, police and specialists from military history institutes and museums.

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Successfully falsified… On epistomological problems of archaeological excavations and geophysical surveys

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KEY-WORDS: excavation, geophysics, methods, epistemology

PROBLEM

Archaeological prospectors using geophysical methods sometimes can get rather frustrated by the feedback they receive from archaeologists based on the results of follow-up excavations. Usually, when the prospection results and in particular their interpretation as provided by the prospector agree with the results of the corresponding archaeological excavation, then no further problem seems to arise, as it is considered that the excavation appears to "verify" the results of the geophysical survey.

But if the excavation unearths archaeological stratification or part of a stratification that had not been detected by the earlier use of geophysical prospection methods, or — even worse — which had not been interpreted correctly, archaeologists tend to question the integrity of the method of geophysical archaeological prospection as a whole. On the other hand, the employed methods of excavation and the interpretation results of the unearthed features and archaeological stratification derived at least to some degree subjectively,, are seldom questioned as a rule. It seems as if the archaeological excavation — no matter what methods are used or how well documented they are — forms an absolute source of knowledge about an archaeological site or part of it, in contrast to archaeological prospection, the credibility of which is often described as relying on verification through archaeological excavation. We are convinced that this approach and position is based on basic methodological and epistemological errors, which have profound implications on our profession and the uses and potential of non-invasive archaeological prospection. Furthermore, we believe that we can provide a simple and effective solution to the described problem.

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ARCHAEOLOGICAL EXCAVATION AS A SOURCE OF KNOWLEDGE

Archaeologists usually impose high demands on the quality of their excavations. Nowadays, it is widely accepted that excavation methods that are regarded as more scientific, especially the stratigraphic method, lead to a better understanding of a site's archaeological stratification, compared to inferior methods, such as for instance arbitrary excavation methods or hybrid forms of those two (Harris 1989; Gersbach 1998). All used methods result in a corpus of documentation that should represent the original, meaning the actual discrete form of the archaeological stratification prior to excavation. This would not be a problem, if we could look at excavations as reproducible processes that guarantee the repeatability of the scientific outcome. But as the very process of excavation implies a generally irreversible destruction of the object that is being investigated, all knowledge gained during an excavation later exists only in form of the respective documentation, as the process of excavating is not reproducible at all. This differentiates excavation methods from all non-invasive geophysical prospection methods.

Furthermore, there exists another fundamental methodological problem with excavations: all excavation work in archaeology is by definition interpretative (Tilley 1989). It is impossible to excavate and thus document the original form of the archaeological stratification sought after, because even the best methods used can lead only to an approximation of the original form.

GEOPHYSICAL PROSPECTION AS A SOURCE OF KNOWLEDGE

From the point of view of archaeological stratification, geophysical prospection methods show major advantages over excavations: they will not destroy the stratification, they are all repeatable and they will result in the same data after every single repetition, within given methodological errors. Repeatability and reproducibility of an experiment are basic requirements for qualification of an experiment or method as scientific.

The results of a geophysical survey in form of data or data images are *per se* not interpretative, but actually are a representation of the original form of the archaeological stratification of the surveyed site, limited to the material-dependent physical parameters and the limits of detectability and imaging resolution of the method(s) used. This means that an archaeological-geophysical survey conducted by an experienced surveyor, who uses geophysical methods appropriate for present soil conditions and geological as well as archaeological circumstances, will result in a scientifically documented data set that can subsequently be used for further discussion and interpretation.

ARCHAEOLOGICAL INTERPRETATION OF GEOPHYSICAL DATA

New problems arise when interpreting geophysical data. Just as the excavator interprets the physical data set of the archaeological stratification during excavation and documentation, the geophysical surveyor should interpret the geophysical data set into something archaeologists, who are inexperienced with the analysis of geophysical prospection data or images thereof, should at best be able to understand and work with. The quality of this interpretation is limited by the experience and knowledge of the person interpreting, again similar to the excavating persons. Therefore these interpretations will always be just as flawed and subjective representations of the real archaeological stratification as those derived from excavation. In any case, increasing experience and professional training will lead to better interpretations.

SOLUTION

As stated above, the solution to the problem is as simple as effective and will stop any unpleasant quarrels while improving the quality of the discourse. Whenever there is a mismatch between the documentation of an excavated site and the interpretation of geophysical data representing the same site, the basis of any further discussion must be the geophysical data set. Of course both methods can represent only an aspect of the original stratification, because by definition they are incomplete. But as described above, geophysical data are produced through scientific experiment and therefore show a more scientific representation of the original form of the archaeological stratification before excavating, than any documentation of the interpretative act of excavating ever could provide.

The key to the understanding of possible problems and to dissolving any mismatches in the interpretation is to sit down together and to discuss the results of either methods and to understand and accept their inherent limitations. It is not accusing each other of using insufficient or unsuited methods or questioning the integrity of an entire scientific discipline. Archaeological excavation is certainly not able to either verify or falsify the results of a geophysical survey; it is only able to question the quality of the archaeological interpretation derived from geophysical data.

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Sands of time: archaeo-geophysical prospection results from the Emirate of Sharjah

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KEY-WORDS: magnetic prospection, GPR, geoarchaeology, data interpretation, Arabian Peninsula, archaeometallurgy

Sharjah is after Abu Dhabi and Dubai the third-largest Emirate of the United Arab Emirates. Its territories extend from the Gulf to the edges of the Rub' al-Khali, the largest sand desert of

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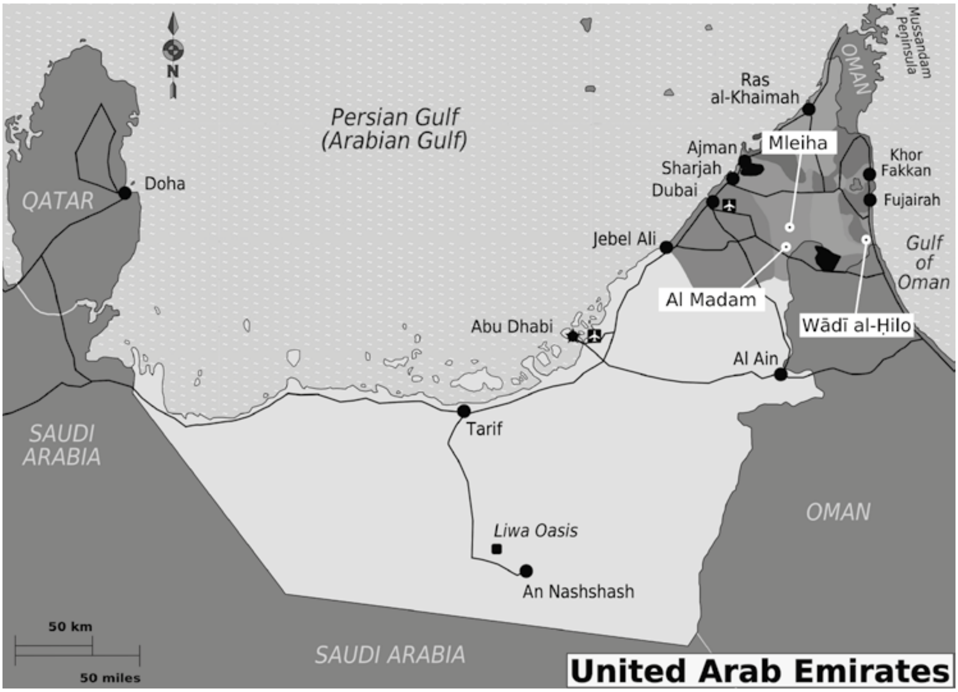

Fig. 1. Location of the investigated sites in the Emirate of Sharjah (UAE)

the world, and along the coast of the Gulf of Oman. Already in pre-Islamic times the region was criss-crossed by trade routes where merchants from the Arabian Peninsula, Mesopotamia, Sindh, India and China met. In addition, the Emirate of Sharjah is rich in Neolithic and Bronze Age sites. Three survey projects realised in the period between 2009 and 2014 are presented: the Al Madam project in cooperation with the Autonomous University of Madrid and the geophysical surveys in Mleiha and Wādī al-Hilo, both directed by the Directorate of Antiquities of Sharjah (Fig. 1).

AL MADAM IRON AGE SITE

Geophysical prospection works at large-scale sites started in 2009. Together with a team of archaeologists from the Autonomous University of Madrid, a hydraulic system, a *falaj* at the Iron Age site of Al Madam, was investigated. Magnetic measurements using the 8-probe gradiometer array LEA MAX were carried out on a surface of approx. 10 ha. Its objective was to localise the course of a subterranean water channel coming from the foothills of the Hajar Mountains, located 10 to 15 km further southeast.

The data revealed a fragmentary line of negative magnetisation indicating the channel itself running at a depth of 1 m to 3 m and the tops of air shafts of the *falaj*. In the area where this line disappeared in the magnetic data, several linear anomalies of assumed fills of open water channels were detected.

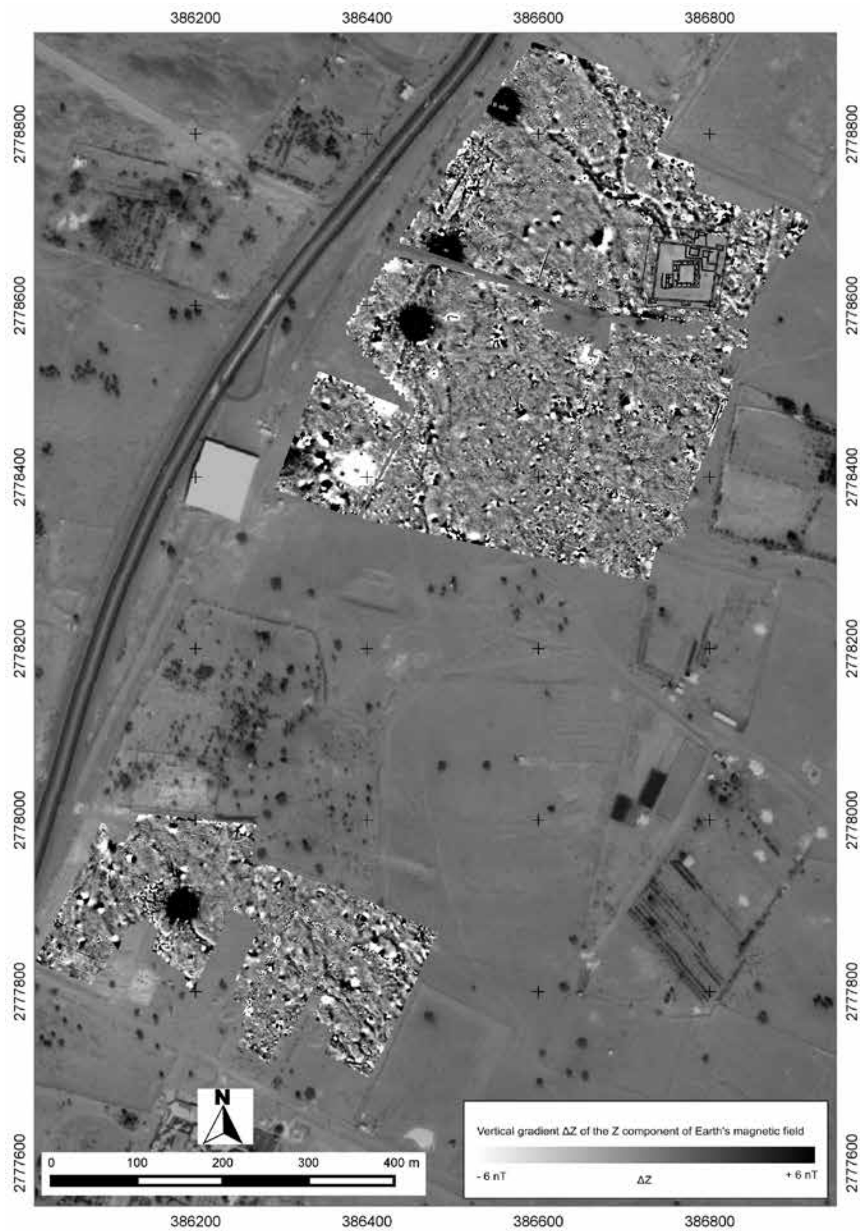

Fig. 2. Result of the magnetic survey in Mleiha (Sharjah, UAE) with 10-probe Fluxgate gradiometer array LEA MAX, total investigated area: 27 ha

It is presumed that the end of the *falaj* is located in an area of extensive agricultural use and that the fills reflect bifurcations of the main water supply for the distribution of water. In order to specify the characteristics of these secondary channels, GPR measurements were applied. The GPR data reflect a complex network of a water supply and distribution system. Subsequent excavations directed by Joaquín Córdoba proved this data (Cordoba 2011). Ceramic finds in the fills allowed the structures to be dated to the Iron Age. Based on these results, it emerged that already at this early time agriculture on sand by means of sophisticated irrigation systems was practised by the inhabitants of this arid region.

PREHISTORIC SETTLEMENT OF MLEIHA

The site of Mleiha (Jasmin 2001) is located on an agricultural inland plain at the western foot of the Hajar mountains, some 20 km south of the modem town of Al Dhaid and roughly 50 km east of the city of Sharjah. Mleiha is thought to have been one of the most important sites in the Oman Peninsula for the period of the last centuries BC. For the past two decades, the prehistoric settlement of Mleiha has been subject to investigation conducted by both national and foreign teams. Previous and ongoing systematic campaigns have led to numerous archaeological discoveries, contributing to the understanding of Mleiha´s history and archaeological background. As proposed by past research results, the main period of occupation is to be situated between the 3rd century BC and the 4th century AD, divided into four principal phases of occupation. The settlement remains extend over an area of 1.5 km^2.

In the course of the geophysical prospection project at Mleiha, directed by Dr. Sabah Jasim from the Sharjah Directorate of Antiquities, magnetic measurements were effected at two different large areas of a total surface of 27 ha (Fig. 2). A 10-probe gradiometer array LEA MAX was used for that investigation. The objective of the first large-scale investigation of the site of Mleiha included a considera-ble gain for the understanding of the overall ancient organization, as well as the detection of buried archaeological structures. The most important result of the magnetic measurements is the discovery of a large enclosure, probably made of mud brick, in the central part of the settlement. Subsequent GPR investigations in areas selected after careful analysis of the magnetic data revealed more detailed information on the detected and presumed archaeological structures. Circular and rectangular tombs as well as foundations of monumental buildings were located, using a GSSI SIR-3000 with 270 and 900 MHz antennas. The combined magnetic and GPR data proved the existence of a considerable number of as yet unidentified archaeological structures. It is expected that geophysical data together with excavation results will illuminate the process of progressive sedentarisation at a site offering water and mineral resources and well-suited for farming and animal husbandry.

COPPER-SMELTING SITE HLO-1 IN WĀDĪ AL-HILO

The geophysical prospection project at the Bronze Age smelting site of Wādī al-Hilo faced peculiar measuring conditions. The site named HLO-1 is located in the northern Hajar Mountains only about 15 km from the east coast. It is situated at about 350 m a.s.l. on the left-side wadi terrace at the western foot of a mountain ridge, which has an altitude of approximately 1000 m in this area (Fig. 3).

Fig. 3. View of the Bronze Age copper-smelting site HLO-1 located on a terrace of Wādī al-Hilo (Sharjah, UAE)

For several years, the archaeological site of Wādī al-Hilo has been investigated by a joint team of the Sharjah Directorate of Antiquities and the University of Tuebingen (Kutterer and Jasmin 2009; Kutterer et al. 2013). Excavations started in 2007, at a time when the potential of the site for the *in situ* preservation of installations for Bronze Age and Iron Age metal production was recognised. The discovery of dense slag accumulations containing pieces of Umm an-Nar pottery pointed to a prehistoric background of the site. The archaeological excavations unveiled the foundations of an Umm an-Nar watchtower and the stone foundations of a metal workshop.

In addition to the excavations, a geophysical prospection was carried out under the direction of the Sharjah Directorate of Antiquities in the spring of 2014. In order to localise possible sites of smelting furnaces and metal workshops, both magnetic gradiometry and GPR were applied. The main challenges for the magnetic survey were not only the stony and scrubby terrain, but also the high magnetisation of the bedrock, namely the Gabbro formations of the Semail ophiolithe complex. Nevertheless, some potential spots with typical magnetic anomalies of smelting places were identified. The additional GPR measurements gave evidence that a big part of the terrace was covered by buildings, presumably of workshops and dwellings. Again, the geophysical prospection proved to be an indispensable element of survey projects at archaeological sites of all kind.

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LEA MAX – multi-purpose gradiometer array in the fields of the Kaikos valley (Bergama, Turkey)

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KEY-WORDS: magnetic prospection, multi-sensor techniques, geoarchaeology

During the past decade magnetic surveys using multi-gradiometer arrays have proven to be an eminently suitable tool for the investigation of extensive archaeological sites and landscapes. By means of vehicle-driven devices areas of 10 to 40 ha can be surveyed at high data density in one day. However, in archaeological practice many factual constraints lurk not only beneath the surface.

Mediterranean landscapes with long human settlement history are especially often characterised by intensive agricultural use and sprawling industrial and construction activity. In many cases, archaeological sites are already half-destroyed or in danger of imminent total destruction. Thus, archaeologists must not lose time to survey whatever still remains of these records of history. Investigation areas vary in size and in surface conditions. Additionally, in these archaeological landscapes many sites are still hidden in remote places, hardly accessible to motor vehicles.

Geophysical prospection projects under these preconditions also require versatile measuring equipment and case-by-case approaches. The geophysical investigations in the Kaikos valley (Bakırçay), the archaeologically very rich landscape between the ancient Greek city of Pergamon in Aeolis and its port Elaea, are textbook examples.

Between 2009 and 2011 a number of Classical sites were investigated within the frame of the DFG-funded SPP (priority program) "The Hellenistic polis as a manner of life". The fieldwork was directed by Dr. Albrecht Matthaei from LMU Munich University (Zimmermann 2012; Mattthaei 2014). Parallel to it, a survey program of prehistoric sites in the environs of Pergamon started in 2010. In this case, six prehistoric sites, partly recorded earlier (Driehaus 1957) and partly newly discovered, were surveyed with geophysical methods. The main objective of the survey was to study

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Fig. 1. The LEA MAX magnetic gradiometer array in the olive groves at Yeni Yeldeğirmentepe

Fig. 2. Results of the magnetic survey at the site of Teuthrania 114

the settlement patterns and lifestyles of the late 4th and 3rd millennium BC in a region that may have served as a link between the Troas in the north and the central parts of western Anatolia. This project was initiated and directed by Dr. Barbara Horejs from the Institute of Oriental and European Archaeology of the Austrian Academy of Sciences in Vienna (Horejs 2010; 2013).

Magnetic prospection was the main survey method. A LEA MAX gradiometer array, an in-house development, was applied in all the investigations. The positioning of the data was supplied by both a DGPS RTK system and an odometer. Arrays of three to six sensors were used, both on wheels and carried by hand, corresponding to specific site conditions (Fig. 1).

Constraints were set not only by the general conditions on the ground. Since the area of investigation is located in a region of intensive agriculture today, complete sites or parts of them were covered by crops or plantations of olive or pomegranate trees. Postponement of the surveys was not possible, as government license for archaeological fieldwork in the region of Pergamon is usually restricted to the months of August to October, that is, at the height of the harvest season and, in any case, the time flexibility of survey teams and equipment is limited to a short time window of a few weeks due to economic considerations. These additional constraints can be compensated for to some extent by resourcefulness.

Additionally, all datasets are characterised by very high magnetic anomalies complicating the archaeological interpretation. The reason for that is the high magnetisation of andesitic rock, a Miocene volcanic rock forming the landscape of the Kaikos plains, a Pliocene rift valley. A further peculiarity is that the residual soil over andesitic rock shows very high electrical conductivity values, which means that the conditions for both electrical resistivity methods and GPR are highly unfavourable.

THE CHORA OF PERGAMON

Three classical sites are presented in the poster. First is the fortified settlement of Atarneus, a Greek settlement that was inhabited from the 6th century BC to the 1st century AD and is characterised by settlement structures on mostly narrow terraces surrounded by steep slopes conditioning special measures to conduct the geophysical prospection. The next site is Teuthrania 114, located about 1.5 km to the northeast of Kalerga Tepe, in the plain of the Kaikos river. To trace the architectural remains in an area of intensive agricultural use, it was necessary to investigate several fields, including a pomegranate plantation (Schneider *et al.* 2014). The third site, Taşlari Tepe, containing the remains of a rural site of Roman date, like a villa or hamlet, was covered with sunflowers at the time of the survey. To map all three sites magnetically, the gradiometer array had to be converted to ensure optimal coverage and data of sufficient density and quality. The magnetic data revealed evidence of monumental structures, as at the site of Teuthrania 114 (Fig. 2), or settlement patterns, as was the case at Atarneus and Taşlari Tepe.

PREHISTORIC SURVEY IN THE ENVIRONS OF PERGAMON

The same variability of measuring conditions characterized the sites of prehistoric date in the Kaikos plain. The geophysical survey started at the site of Yeni Yeldeğirmentepe, a late Chalcolithic and early Bronze Age settlement. Surface finds indicated a relatively large perimeter, which magnetic measurements and additional electrical resistivity tomography (ERT) were supposed to trace. A small part of the site was located on an outcrop of andesitic rock in the river plain. The main area, however, is buried under intensively used croplands. It must be assumed that archaeologically interesting layers have already been levelled out of existence.

The second site, Bağlı Tepe, was located on the left riverbank of a tributary of the Kaikos river in the Gümüşova valley. The site was covered by dense olive groves and brushwood, so that even the more easily accessible areas were challenging to say the least. Magnetic surveys were carried out both with a wheeled and a carried array. Together with additional GPR data, the geophysical results gave numerous indications of preserved archaeological structures in the ground.

One of the most spectacular prehistoric sites in the region is the settlement at Çiftlik Höyük. Parts of a tell are still preserved, today forming the base of a modern farmstead. The fields surrounding the farm offered a number of prehistoric finds, advising the implementation of an extensive magnetic survey. Farmland levelling in the past few decades does not seem to have been particularly destructive, leaving open the chance for recording the deepest and hence potentially the oldest layers of the prehistoric settlement. The magnetic data give reason to assume that early stages of settlement development can be discerned at this site.

ACKNOWLEDGEMENTS

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The Tibiscum project: non-destructive research in Romania

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KEY-WORDS: Romania, Roman fort, archaeological prospection, UAV photography, thermography, magnetometry

INTRODUCTION

In 2011, a non-destructive survey was initiated in Crimea, in the suburbs of Sevastopol, on remains of ancient Roman farms that were part of the *chora* of the Tauric Chersonesos. Non-invasive methods, like earth resistance and kite aerial photography, were applied. Four sites were photographed from the air and two of these sites additionally investigated with geophysics. In 2014, the project received funding from the Ministry of Science and Higher Education of Poland within the frame of "The Diamond Grant" program (grant for 2014–2016). The project was meant as a continuation of the research started in 2011, but on a much bigger scale permitted by the grant. The political situation in Crimea ruled out any action there, however, and the survey had to be carried out in another location (by permission of the grantor).

THE ROMAN FORT AT TIBISCUM

Tibiscum near the modern village of Jupa (Caras-Severin county, Romania) is considered to be one of the best known and investigated archaeological sites in the Banat province. Nevertheless, archaeological excavations have uncovered only approximately 5% of the surface of ancient Tibiscum. The total area supposed to be related directly with this settlement is considered to be about 27 ha. The history of the settlement began after Trajan's Dacian War, when a detachment from a Roman legion established a garrison on the left bank of the Timis (Tibiscus) river.

RESEARCH

The aim of the study was to locate, examine and document Roman settlements, both the known ones and those as yet undiscovered. Non-destructive methods were chosen, such as geophysics (magnetic and earth resistance survey), aerial photography (UAV), and aerial thermography, coupled with traditional field walking surveys, including mapping of the finds. Fieldwork was carried out in October 2014, aiming at locating with the use of GPS coordinates all the known Roman archaeological sites in the Tibiscum area. Some of these have been investigated to some extent, but their wider context is unknown, while many sites are located, but have not been examined. Selected sites were subjected to magnetic prospection in March and April 2015.

No extensive fieldwalking had ever been done in the environs of the Roman fort in Tibiscum, hence the importance of the present survey (Fig. 1). A team of 12 investigators covered a total area

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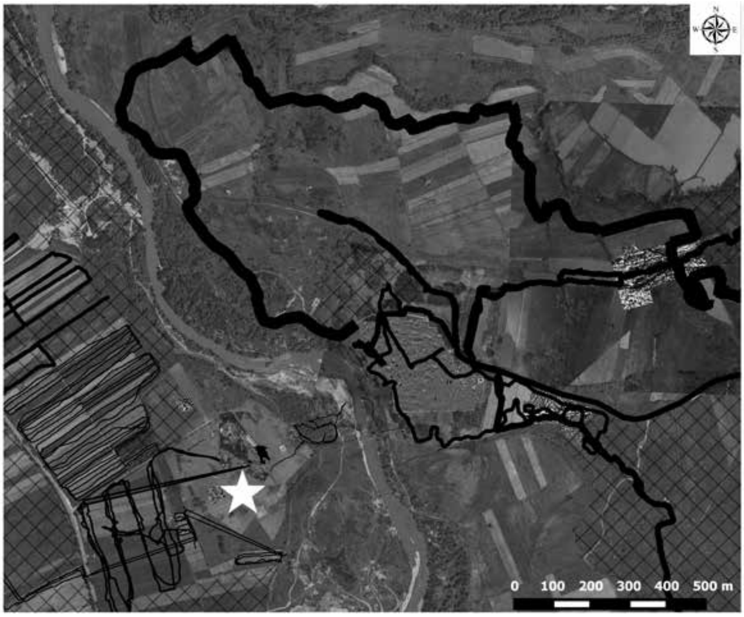

Fig. 1. Area of research. The fort is marked with a star. Results of the magnetic survey, thermography, GPS fieldwalking tracks and orthophotomaps overlaid on a satellite image. GPS tracks reflect actual research spread, the hatched areas being unavailable for prospection

of not less than 5 km² and found dozens of archaeological features, including 10 sites or bigger clusters and numerous surface finds. These were registered with handheld GPS devices and put into a GIS database for further analysis. The impressive results of surveys of this kind should encourage standard use of this prospection method by Grad601-2 researchers.

A magnetic survey followed, carried out on both already known sites (*municipium*) and in new locations tracked by the fieldwalking. A fluxgate gradiometer (Bartington Grad601-2) was used, data being collected in parallel mode with a sampling interval of 0.25 m along transects spaced 0.5 m and 1 m. Data processing was performed using Geoplot 3 software. The results revealed many anomalies (linear and orthogonal), especially in areas investigated for the first time. They have been interpreted as induced by necropolis remains (Fig. 2). The negative character of the anomalies may suggest that the structures were constructed of non-magnetic limestone. These ideas need to be verified in the field.

Aerial Thermal Imaging was tested as a method in October 2014, as well as in March and April 2015 (Fig. 3). The method is not widely employed in non-destructive archaeology, apparently due to high equipment costs and the greater popularity of other methods. Promising results have come from experimental application of temperature measurements on the surface of a surveyed area (e.g., Křivánek 2013) and thermal cameras have also been tested in aerial prospection. The best results came from investigations of Roman villas in the territory of Germany, where thermal imaging was performed from a paraglide (Kiesow 2005). The Polish–Romanian Tibiscum Project aims to determine the best conditions for aerial thermal

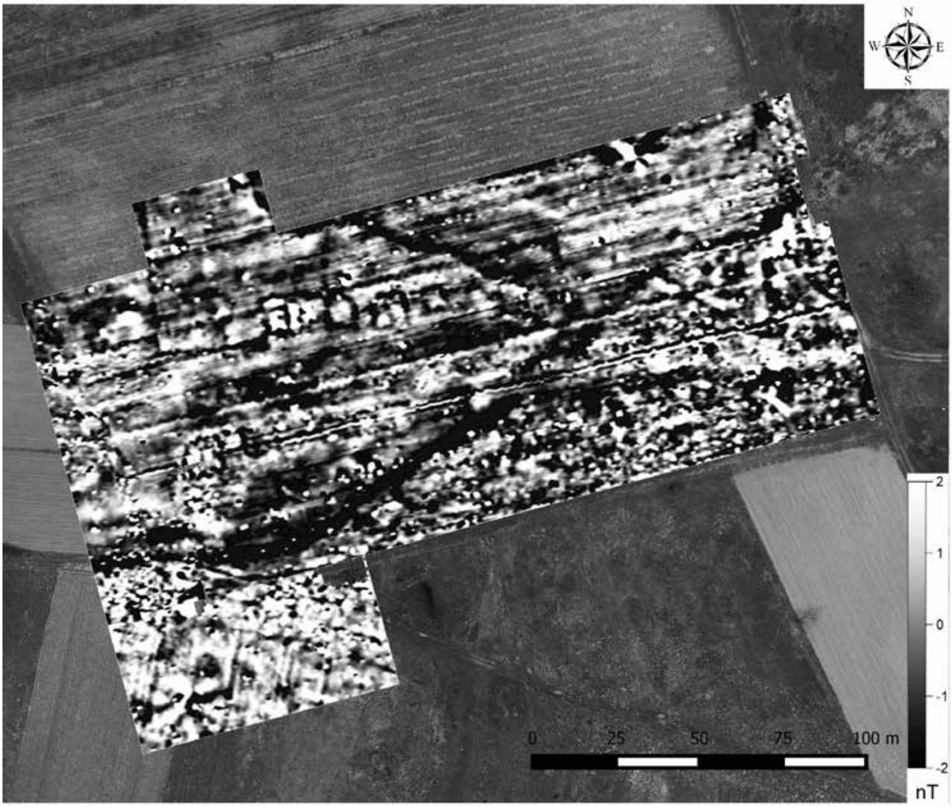

Fig. 2. Magnetic survey. Negative linear anomalies probably correspond to a Roman paved road that is partly visible in the field. The exact nature of the other features needs further verification

prospection and to evaluate the feasibility of this method for revealing features buried at shallow depth. The study takes a holistic approach with research to take place during different calendar seasons, in varying weather conditions and at different hours of the day.

CONCLUSIONS AND PERSPECTIVES

Geophysical prospection is determined by many different environmental factors. Tibiscum appears to be a good site for this type of investigations as conditions there allow all of the planned prospections to be performed, including geophysical survey, fieldwalking, aerial photographical documentation and thermography experiments. At the present stage, the magnetic method can be said to bring positive results, but further verification is needed for the data to be interpreted properly. Earth resistance results depend on the contrasts between the resistivity of investigated objects and its surroundings (Schmidt 2013) and this condition is fulfilled, at least theoretically, at Tibiscum.

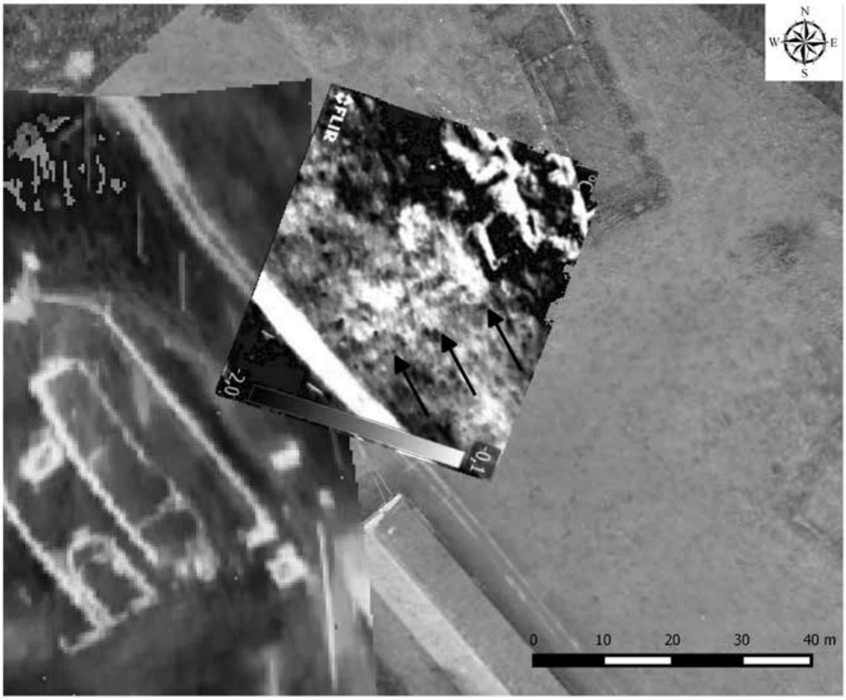

Fig. 3. Oblique aerial thermal pictures, georeferenced and overlaid on an orthophoto image performed from a drone. Arrows point to a positive thermal anomaly visible only on a cold evening after a hot day

The first seasons of field research at Tibiscum have brought important data and convincing results. Many new features and settlement sites from the Roman period were localized during the survey. Indeed, the fieldwalking survey was a significant step in recognizing the landscape around the ancient Roman fort, facilitating the process of merging the results of earlier work done in Tibiscum (see Cîntar 2013) with the results of the new surveys. All the collected data has been put into a GIS database, providing the framework for further analysis. Already (and the project is planned to continue through 2016) our knowledge of the ancient landscape of Tibiscum and its surroundings has been extended considerably.

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Reconstructing the history of the planning of the Medamoud temple: magnetic and electromagnetic prospecting results

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KEY-WORDS: Medamoud temple, magnetic and electromagnetic prospection, magnetic signal

INTRODUCTION

During the pharaonic era, Medamoud was a provincial city of average importance. The god Montou was worshipped in the city, as in the neighbouring cities of Karnak, Ermant and Tod. Archaeological surveys were undertaken by French scientists from the Louvre Museum between 1925 and 1939. They excavated the Greco-Roman great temple, which was founded on top of Middle and New Kingdom remains. A new study started in 2011 in order to summarize and to complete the earlier ones. The geophysical surveys, planned as part of this project, are aimed at completing the topographic survey undertaken to georeference the map drawn in 1925 and at an evaluation of the archaeological potential of the area located south and east of the temple (Fig. 1), which has never previously been investigated in this regard.

MATERIAL AND METHODS

Site

The preserved area around the temple covers about 15.5 ha. Its limits describe a roughly circular kôm. The height difference compared to the surroundings is about 1.5 m with some mounds reaching nearly 3 m. Only the dromos, the temple area and the embarking area have been excavated. Figure 1 shows the whole area as it was excavated in the late 1920s. Considering that the site can be quite complex (various building alterations, several old excavations), the idea was to combine electrical resistivity/conductivity measurements with magnetometry in areas defined as being of maximum archaeological interest.

Geophysical methods

A G858 caesium magnetometer (Geometrics) will be used for mapping magnetic anomalies. These surveys will be combined with electromagnetic induction (EMI) prospecting using a CMD-MiniExplorer (GF Instruments), which will give values of apparent electrical conductivity and magnetic susceptibility. Finally, detailed studies will be done using a MS2B and D susceptibility meter (Bartington) and a prototype resistivity meter (UMR 7619 METIS).

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Fig. 1. Aerial image taken in the late 1920s showing the excavated areas and the anticipated geophysical surveys

Archaeological potential of the surrounding area

As the excavations have concerned mainly the temple itself and its entrances, the protected area of nearly 15.5 ha around it has never been explored, except for a Byzantine pottery workshop discovered in 1928, but never published. The excavations in the temple area proved that a Coptic settlement had been located there, giving reason to believe that it extended probably over the entire area of the kôm. The Greco-Roman and pharaonic settlements may have been located there as well. The hatched areas on the plan show where the survey will be carried out (Fig. 1).

Area of the temples

Excavation reports describing work by the French Institute for Oriental Archaeology (IFAO) in 1922–39 are the main source of information (Bisson de la Roque 1946). Although the kôm of the ancient city of Madou was known from the 18th century (Pococke 1743: 96), no excavations were undertaken until 1925, when the Louvre Museum initiated its project. The excavations yielded significant results and many artifacts from the Greco-Roman temple and the Coptic settlements, but the accuracy of the descriptions (annual reports concerned the seasons between 1925 and 1933, while the last campaigns were published only in part, see Robichon, Varille 1940) leaves much to be desired and information is missing. A new study of the archeological archives, in particular with regard to the so-called "Temple Primitif", will accompany the survey (Relats Montserrat 2014).

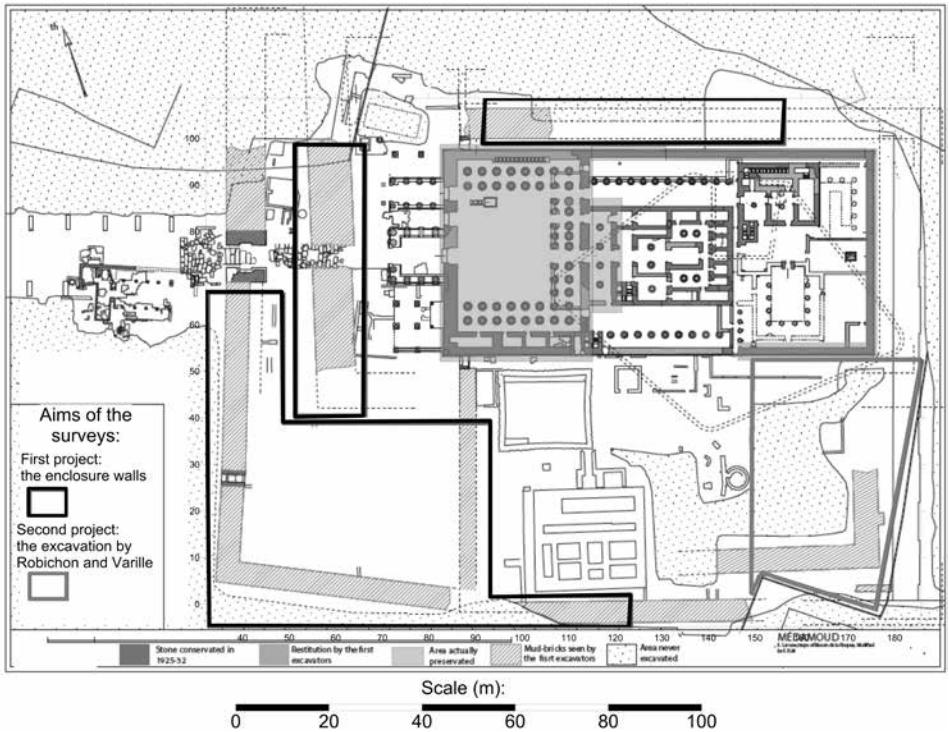

Fig. 2. Map of the structures known from earlier excavations to be confirmed by the survey

The enclosure walls are of particular interest. A separate set of walls existed for each temple stage, but during the excavations finds were not associated with the different stages. Consequently, various plans were proposed by archaeologists without an accurate match. The synthetic plan (Fig. 2) indicates that the layout of the surrounding walls needs to be confirmed. The areas in blue will be covered by a geophysical survey and excavations will be carried out to determine the date of the features found.

RESULTS

The surveys are part of a project funded by the ComUE Sorbonnes Universités to be conducted in May 2015. The results will be presented at the conference.

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Geophysical survey - archaeological excavation - micromorphological analysis. What do magnetic anomalies show? An example from Hedeby

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KEY-WORDS: 2D-geomagnetic survey versus 3D-archaeological structures, magnetic susceptibility, micromorphological analysis

In 2002, a magnetic survey was carried out in the Viking-Age trading settlement of Hedeby, Northern Germany (von Carnap-Bornheim, Hilberg 2007; Hilberg 2003, 2007, 2009; Neubauer *et al.* 2003). The aim of the magnetic survey was to redirect the perception that up to then had been concentrated on the excavated areas to the historic site as a whole. The magnetic survey yielded great results. For the first time something similar to a map of the proto-urban town of Hedeby could be glimpsed. But the closer one looks, the more the question poses itself of what is actually shown by the magnetic survey. How does the two-dimensional magnetic survey relate to the three-dimensional reality of nearly three centuries of occupation and the up to two-metre thick, highly stratified archaeological layers, shown by the excavations?

In a case study this issue of correlation of geomagnetic anomalies and archaeological excavation is pursued using the example of extremely strong magnetic anomalies on both sides of one of Hedeby's most important high streets and comparing it to the settlement development as it is highlighted by excavation (Schultze 2008: 235-243). To take the study even further, cores were drilled on the spots of the magnetic anomalies and measurements of magnetic susceptibility and micromorphological analysis were carried out on these to explain the layers of extremely high magnetism.

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Fig. 1. Hedeby's main road running parallel to the waterfront seen in the geomagnetic survey (strong anomalies regularly spaced on both sides of the road) and the excavation (excavation results shown in a simplified way)

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Interpretation and presentation of prospection results

Exploring the past Carpathian landscape: the application of LiDAR and archival cadastral maps

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KEY-WORDS: microtopographic relief, deserted villages, airborne laser scanning, Austrian cadastral maps, Polish Eastern Carpathians

INTRODUCTION

The project uses non-invasive methods for gaining a better understanding of the past Carpathian landscape through the detection and interpretation of earthworks created before World War II.

Landscape in general is a dynamic feature that is in the process of continuous change. Most of the Carpathian landscape has been shaped by man, who has added new features often distorting or destroying older forms (palimpsest landscape, see, e.g., Mlekuž 2013) To grasp today the shape of a cultural landscape from the past one needs an area where human activity has ceased and the forms of landscape have somehow been conserved. It is what happened apparently in the Polish Eastern Carpathians, from where Ukrainians were displaced *en bloc* in the late 1940s and the abandoned land became afforested.

STUDY AREA

The research concentrated in the central part of the Wiar River basin in the Przemyskie foothills and the Sanok–Turka Mountains, close to the contemporary Polish–Ukrainian border (Fig. 1). The investigated area covered around 65 km^2 the altitude being from 290 m to 670 m a.s.l. It was inhabited since the 15th century by Ruthenian highlanders of Vallachian origin, displaced in the 1940s in the name of the communist mono-national policy (Wolski 1956). Five deserted villages are found in the area of research. More than 75% of the area is currently forested, this being twice as much as before WWII (Affek 2011a).

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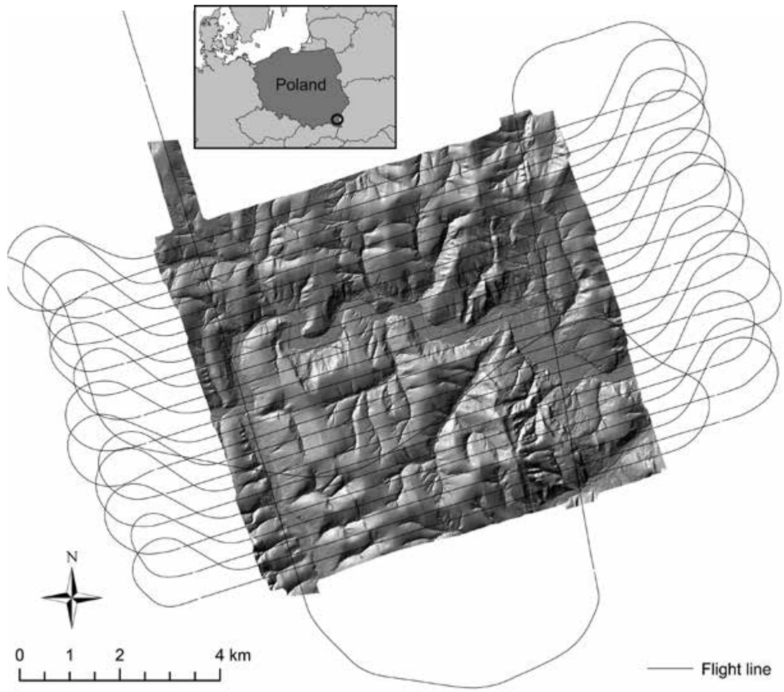

Fig. 1. Shaded LiDAR-derived DEM of the study area (part of the Wiar River basin) with marked flight lines

METHODS

An integrated approach to detection and interpretation of past landscape features was applied. Three groups of complementary research methods were used:

- remote sensing
  - airborne laser scanning (ALS): 3D point cloud, Digital Elevation Model (DEM),
  - aerial photographs taken simultaneously with laser scanning,
- analysis of current and archival cartographic and descriptive materials, such as cadastral maps from 1852, 1965 and 2008, Polish Archaeological Record (Polish acronym AZP), other topographic and thematic maps,
- field survey
  - LiDAR data verification of the detected earthworks,
  - gathering additional information regarding the time and cause of creation of earthworks (e.g., interviews with residents and Forest Office workers),
  - photographic documentation.

All the ALS parameters (data collection and processing) were selected so as to obtain the most accurate picture of the earth's surface for archaeological purposes. Airborne laser scanning was conducted by MGGP Aero in April 2013, after the retreat of the snow and before trees started to green. The mean effective ground point density was close to 12 points/m^2.

Two main visualization techniques of LiDAR-derived DEM for the detection of features were applied: analytical hillshading with elevation differentiation (colour shading) and Sky-View Factor, a geophysical parameter that measures the portion of the sky visible from a certain point (Kokalj *et al.* 2013). These techniques proved to provide maximum benefits in hilly terrain. 3D visualization of point cloud and cross-sections served as additional sources of information.

Interpretation of the detected features was carried out by means of several parallel methods. The key issue was to extract prewar earthworks from all other microtopographic features, namely modern earthworks and forms of relief created by nature, such as former riverbeds, landslides, ravines, fallen tree pits, etc. To do this properly, all types of detected features needed to be recognized. The identification of earthworks created after forced displacement (e.g., by forestry and collective farming) was primarily based on the analysis of RGB orthophoto, LiDAR intensity data, postwar cadastres, field survey and interviews with foresters and local people. Prewar features were identified with the help of Austrian cadastral maps, other historical maps and archival sources, the documentation of the Polish Archaeological Record project, literature, field survey and, last but not least, interviews with senior local community members. Despite strenuous efforts a number of microtopographic features remained unrecognized.

RESULTS

The analysis of LiDAR-derived DEM showed that under the tree canopy there were numerous, well preserved earthworks created before WWII, corresponding to a great extent with the spatial pattern of land use presented on cadastral maps from the mid-19th century (Fig. 2). Although 70 years have passed since they lost their dedicated function, earthworks such as rural roads, agricultural terraces and field boundaries continue in the landscape in almost unchanged shape. The remnants of settlements (cellars, stone wells, foundations) are also reflected on DEM. Most of them did not match exactly the location shown on mid-19th century cadastral maps. Still, they did not change location among parcels, only within the boundaries of a given parcel. That is because wooden buildings were short-lived and were usually built again in a new spot. Specific ruderal vegetation found in the forest additionally indicates the location of former buildings.

The initial fief structure of land ownership dating from the period the village location in the 15th century is clearly visible. Former arable land can be distinguished from permanent forest on the basis of ploughing traces. Some fields have well preserved evidence of medieval ridge and furrow patterns of ploughing with non-reversible ploughs (ridges approx. 4.5 m wide and 0.5 m high) (see Sittler 2004).

Village boundaries are usually marked by embankments or ditches. Often boundary corners are marked by small mounds, while tripoints are marked by three middle-sized mounds. No burial mounds were detected in the study area. Some mounds visible on DEM turned out to be piles of decomposing branches formed as a result of forest maintenance. The existence of one medieval stronghold was confirmed (Zoll-Adamik 1958). A thorough analysis of the collected data revealed many locations of potential archaeological sites to be verified by excavation.

Fig. 2. Village Borysławka abandoned and afforested after forced displacement in the 1940s. Top: orthophoto taken simultaneously with ALS (pixel size: 10 cm); center: Sky-View Factor from ALS data (DEM resolution: 0.5 m); bottom: Austrian cadastral map from 1852, original scale: 1:2880 (source: author, Austrian cadastral map from the State Archive in Przemyśl, sygn. 56/126/0/129M)

CONCLUSIONS

Earthworks generally survive in better condition under the tree canopy than in open space. In villages with continuity of settlement, it is hard to distinguish and extract prewar landscape patterns.

Airborne laser scanning gave a unique possibility to reveal a historic Carpathian landscape in areas abandoned after WWII and afforested directly afterwards. Prewar earthworks appeared to be very well preserved under the canopy of trees planted after the war that have not been felled since then. It is also quite easy to distinguish prewar features from modern ones, which are rather sparse and of different shape.

Nevertheless, a total and immediate afforestation of the deserted villages was not a common occurrence. Fields in most of these villages were cultivated and managed by postwar collective farming at least for some time. The prewar field mosaic and settlements were wiped out by planned levelling and mechanised agriculture. Only in a few former villages (e.g., Borysławka in the study area, see Affek 2011b) the historic Carpathian landscape is clearly readable and may serve as a site of cultural heritage of great value.

Therefore, there is need to protect the prewar landscape pattern hidden today under the forest canopy. Threat comes from modern forestry and high levels of mechanization. Monstrous trucks heavily deform the existing microtopographic relief. Multiple parallel logging roads leading along the ridges and streams have often ruts deeper than 1.5 m. Also the application of new methods of forest planting involving deep ploughing results in the destruction of prewar earthworks. Nowadays, there is not much left to protect and a very urgent need of conservation emerged.

The work confirmed the usefulness of archival cadastral maps in verifying findings from ALS and field survey. The high consistency between data sources proved the good quality of the maps and the durability of earthworks.

ACKNOWLEDGEMENTS

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Georadar study of early structures under the Hagia Sofia, Istanbul, Turkey

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KEY-WORDS: urban archaeology, architecture, laser scanner, georadar, Hagia Sofia, Istanbul

INTRODUCTION

As part of an international project for the examination of the Hagia Sofia monument, carried out by an interdisciplinary team from the University of Calabria and the University of Mexico, varied techniques were applied, including 3D laser scan, thermography, mortar analysis and georadar (Cura *et al.* 2014).

The monument has a very long building history. It seems that the first church, built close to the current location, was completely destroyed by fire in AD 404 (Mainstone 2009). The second church, built in AD 415, was also destroyed by a fire in AD 532, during the Nika revolt. A new building started to be constructed immediately by the Emperor Justinian I and was opened in AD 537. Therefore, it is possible that the remains of the second church were preserved under the present floor. For this reason, it was decided to carry out a georadar survey of the central area of the building to see whether the underground structures could be responsible for the deformation of the building. Our measurements and observations confirmed the deformation of the entire structure (van Nice 1965; Mainstone 2009). The present paper discusses the results of the georadar survey of the southern part of the nave of the Hagia Sofia, the northern part being out of bounds owing to the scaffolding raised there for the purpose of restoration works.

METHODOLOGY

The georadar study was carried out employing the GSSI SIR 3000 instrument with 400 MHz antenna and survey wheel on lines every 0.5 m from south to north, penetrating to a depth of over 4 m.

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[c] Restructura – Surveys for Cultural Heritage, Cosenza, Italy
[d] SISTEM A.S., Leica Geosystems AG., Turkey Distributor

Earlier experience with the same methodology in other places, obtained by the Archaeological Prospection Laboratory, revealed the suitability of georadar measurements for providing information on the substructure below the prospected floors.

RESULTS

The marble surface of the floor in the nave of the Hagia Sophia is quite homogeneous. Nevertheless, there are some areas with different characteristics. Some changes were caused by archaeological excavations from the 1950s in the western part of the nave (van Nice 1965).

Other broad reflections probably related to the presence of earlier architectural structures below the floor were also traced (Fig. 1). These reflections show a high contrast in properties between the aligned stones and the earthen matrix. Earlier archaeological excavations near the main entrance of the building discovered two thick parallel walls running east–west, equidistant from the central axis. The 1.5 m depth slice (Fig. 1) reveals the said walls. The wall closing the structure by the eastern side is clearly visible at a depth between 1.2 m and 1.6 m, while the wall on the southern side reaches almost 2 m in depth.

Taking into consideration these data a hypothetical reconstruction of the plan of an ancient building underlying the present floor can be proposed. Duplicating the half of the structure identified in the georadar study with a symmetrical reflection of the surviving remains, it is possible to suggest the presence of a whole building.

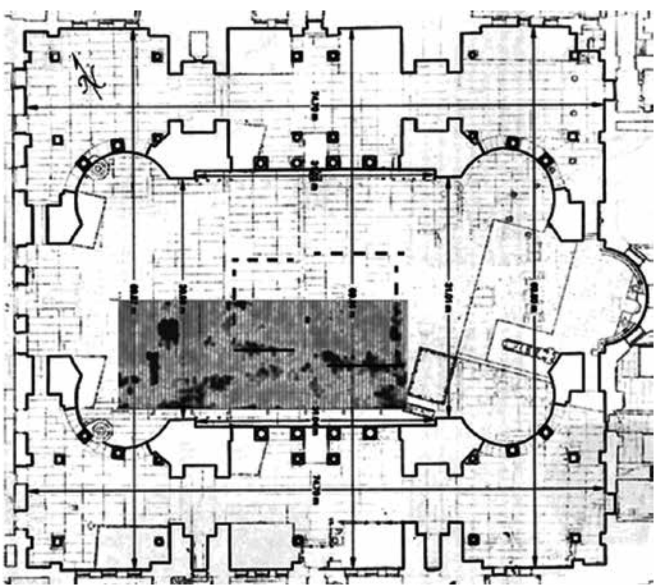

Fig. 1. Plan of the ground floor of the Hagia Sofia (modified after van Nice 1965), showing 1.5 m depth slice and the most feasible interpretation of the shape of a substructure, obtained by mirroring the wall traces detected in the southern part of the area

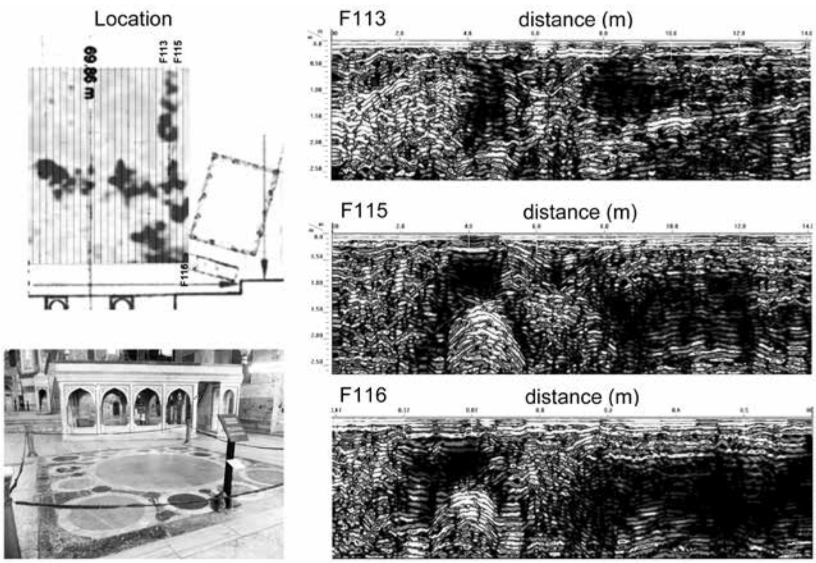

Fig. 2. Radargrams of three lines that show important reflections below the marble mosaic

In the individual radargrams F115 and F116, at 2 m depth and 4.5 m distance, there is a clear hyperbolic reflection (Fig. 2). Taking into consideration six parallel radargrams, they show an important reflection (at least 3 m long and 2 m wide) that seems to connect a point below the surface close to the center of the mosaic to some point under the muezzin's gallery to the east. In radargram F116, two walls are visible bordering the hyperbolic reflection in the center.

FINAL REMARKS

The interpreted building looks rather small, 22 m E–W and 16 m N–S, and should be located at less than 2 m depth. Its true dimensions and the symmetry of the building will be verified as soon as the scaffolding is removed, which will make it possible to carry out the georadar survey of the northern part.

The interpretation of the georadar results of the southern part of the floor in the nave of the Hagia Sofia indicates many architectural remains buried at apparently different levels, suggesting the presence of earlier structures. Moreover, the identification of a structure under the marble mosaic suggests that an unexpected relationship exists between them and seems to indicate that the mosaic was placed there to mark the presence of an important feature below.

Nevertheless, the topographic map from the laser scanning of the building reveals no deformations or topographic changes in the nave floor surface (Fig. 3). It means that although there are at least two levels of important architectural remains under the current floor of the Hagia Sofia, the central part of the floor is stable, with almost no deformations. Therefore, the results have not confirmed the idea that the visible deformations of the Hagia Sophia structure are caused

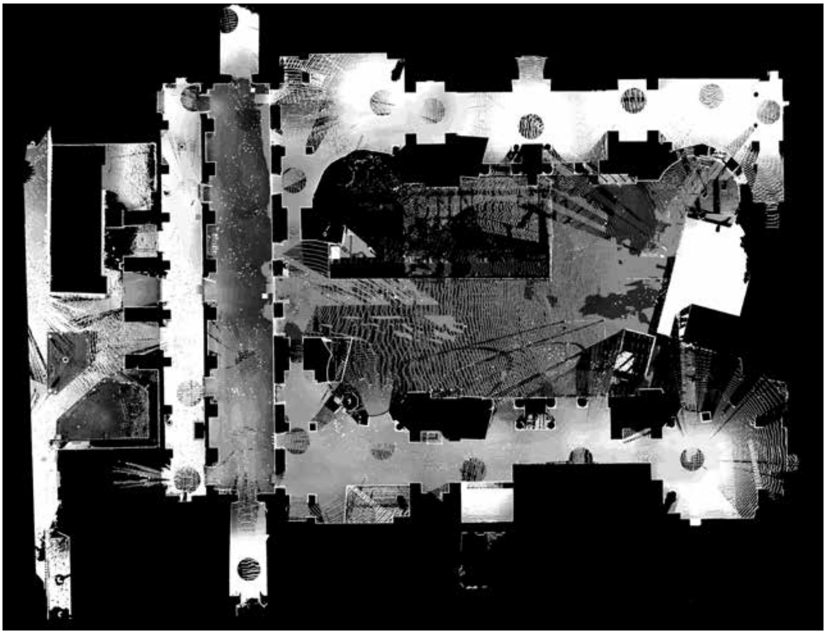

Fig. 3. Topographic map of the ground level of Hagia Sofia obtained by Leica Geosystems' Scan Station 2. There is a uniform flat grey area in the nave. Whitish areas are the higher levels in the east corner of the gallery, the dark grey area in the west corner is the deepest. The interval between two extreme points is 0.5 m

by earlier architectural remains below the central part of the building. These deformations must be caused by other factors and it is clear that the earlier structures were carefully covered, using suitable materials and proper compacting.

ACKNOWLEDGMENTS

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Community prospection: archaeological ground-penetrating radar analyses performed for and by the Healy Lake Village community, Interior Alaska

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KEY-WORDS: Interior Alaska, Healy Lake village, community, ground penetrating radar

INTRODUCTION

In 2014, a ground penetrating radar (GPR) survey was conducted in the Healy Lake Village of Interior Alaska, a location that has played a pivotal role in shaping concepts in interior Alaskan archaeology and with an extensive record of North American human occupation (Cook 1969; 1996; Holmes 2001; Potter 2008). Prior to beginning field data collection, an open dialog was established in order to provide the community with an opportunity to become more familiar with the operation of GPR technologies, field data collection methodology, post-processing training, and interpretation on questions individuals had about the archaeology in their village.

From these initial conversations a threefold research approach was established and conducted the aim being: (1) to determine whether GPR technologies can record radar imagery of potential archaeologi-cally-related anomalies from underwater contexts in Healy Lake, which is a seasonally freezing lake consisting of lacustrine and alluvial deposits ranging from 1 m to a known 3 m depth, (2) to establish the placement of unmarked graves based on ethnographic data, as well as detect marked graves accurately in signal reducing media, such as the local Fairbanks schist bedrock; and (3) to detect other anomalies in loess that could be associated with unexcavated areas near the Old Village Site, which was the first site to be excavated regularly in the interior of Alaska. During the examination favorable results were reached for all three approaches.

METHODOLOGY

In order to gather data appropriately, collection protocols had to be tailored to each research approach independently. As a result slight differences exist in the data collection procedures for each survey location. Device settings reported in Table 1 describe overall GPR protocols and settings for each research location.

GPR data collected during these examinations came from four locations: Healy Lake itself, the Upper and Lower Cemeteries, and the Old Healy Lake Village Site (Fig. 1). Data collected in order to assess the potential for underwater prehistoric archaeological material in Healy Lake was conducted in the center of the lake as a preliminary test in order to determine, if vegetation levels, ice, water, and sediments at Healy Lake presented an acceptable candidate for further underwater research. In order to collect data on the quantity and placement of burials, as well as loss of signal

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Table 1. Device settings for Healy Lake surveys

Survey location	Antenna (mHZ)	Recording method	Dielectric constant	Scans/ meter	Gain points
Healy lake Bathymetric Analysis	200	Distance	3	30	5 (-14, -14, 27, 36, 36)
Ethnohistoric Grave Location and Bedrock Signal Loss (Lower Cemetery)	400	Distance	5.3	50	3 (-20, 36, 52 [corrected to match the Upper Cemetery])
Ethnohistoric Grave Location and Bedrock Signal Loss (Upper Cemetery)	400	Time	5.3	N/A	3 (-20, 36, 52)
Old Healy Lake Village Site	400	Distance	5.3	50	3 (-20, 38, 55)

from within the local bedrock, two locations were selected for evaluation. These two locations, referred to as the Lower and Upper Cemeteries, are relatively close to one another, but separated by a great deal of elevation. The Lower Cemetery lacks standing fences and superficial/surface grave features. For this area, data was collected using a survey wheel attachment and a distance setting in a grid pattern to maximize our potential for locating unmarked grave-related anomalies. Alternatively, within the Upper Cemetery, where grave fences and monuments were still standing and present for all graves, a timed pulse setting was necessary to gather data. As a result, a distance test had to be conducted at the Upper Cemetery in order to determine accurately, which signal of the time-collected data represented a given burial. Gain points were corrected between cemeteries to ensure comparability of received signals.

At the Old Healy Lake Village Site, the northeast portion of the site was selected for survey. This approach was taken because this part of the site constituted one of the only locations where earlier archaeological testing had not disturbed the natural stratigraphy. Grid data were collected utilizing a one meter interval and a directionally alternating pattern in order to be combined into a plan view map of anomalies located within the survey grid area.

All data collected during these examinations were processed primarily using Radan 7 GSSI software. For plan view mapping Golden Software's Surfer 10 and Voxler 3 were used to generate spatial maps. ESRI ArcGIS 10.2 was then used to generate point locations for discovered anomalies and to provide a spatial context with regard to areas outside the current GPR survey boundary.

RESULTS

Preliminary data gathered on the potential for locating paleo-shore lines of Healy Lake, as well as underwater prehistoric archaeological material, showed the approach to be successful. During our examination we were able to differentiate easily the locations of all aspects of the lake surface and bottom, including the depth of surface snow and ice, water, the presence of lake bottom, and

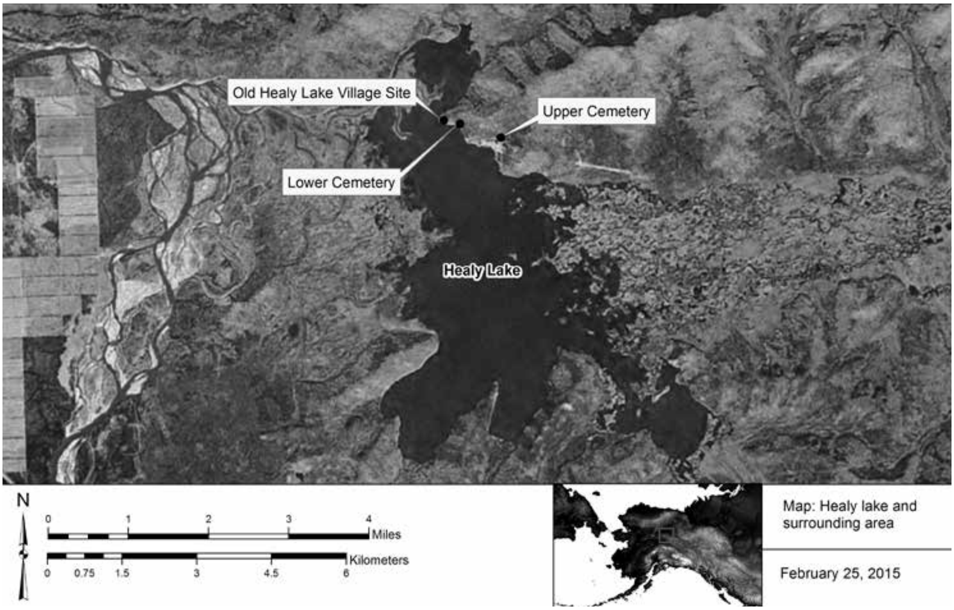

Fig. 1. Healy Lake and surrounding terrain, survey locations represented by black points

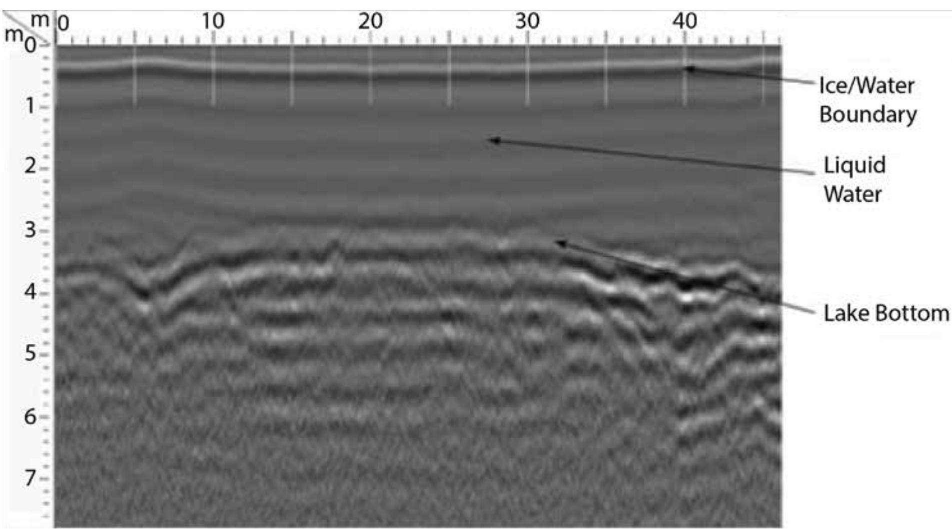

Fig.2. GPR reflection profile of Healy Lake, 200 mHZ antenna

potentially related vegetation (Fig. 2). This leads us to believe that Healy Lake will be a good candidate for upcoming GPR surveys, attempting to locate underwater cultural materials and paleo-shorelines.

During our examination of the Lower Cemetery potential unmarked burial locations were confirmed. Unmarked grave-related anomalies were located at the edges of the Lower Cemetery and may have been added without markers, or markers may have disintegrated or had been removed over time. During our examination of the Upper Cemetery signals associated with burial directly in the upper layers of the local bedrock displayed approximately 36% signal loss proportionally when compared to marked burials located at the Lower Cemetery buried in aeolian silt (Fig. 3).

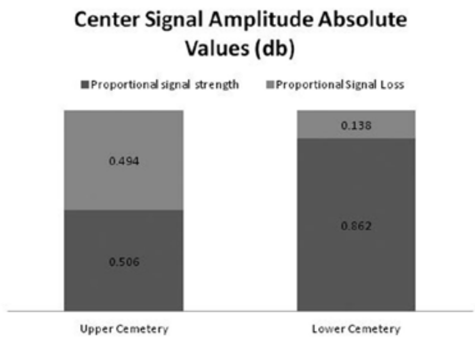

Fig. 3. Proportional differences in electromagnetic signal amplitude (in decibels) between the Upper and Lower Cemeteries

Examination of the Healy Lake Village Site revealed more than 20 anomalies associated with cultural remains ranging in age from the end of the Pleistocene into the historic period. As this examination was performed to provide preliminary data for potential future testing endeavors, a more detailed electromagnetic survey will need to be undertaken in order to make detailed statements about individual anomaly interpretations at this survey location.

CONCLUSIONS

Throughout the course of our investigation, positive results were achieved for each of our three research questions. A preliminary analysis of the potential for locating underwater cultural materials and paleo-shorelines for Healy Lake was established. Regarding the placement of marked and unmarked graves in the Lower Cemetery, GPR survey results suggest that larger numbers of burials exist within the cemetery boundary than indicated by surface markers, depressions, and features. This data helped to confirm information provided by local residents and the ethnographic record that more people were likely buried at this location than displayed currently. Together with the presented data from the Lower Cemetery, this research was able to determine that the local bedrock does act as a significant signal reducer. Burial features placed in this medium (coffins dug into and placed in the bedrock) at the Upper Cemetery displayed approximately 36% more signal loss when compared proportionally to burial signals from coffins located in aeolian silts in the Lower Cemetery. More than twenty anomalies were located on the Old Healy Lake Village Site, corresponding to archaeological material ranging in temporality from the end of the Pleistocene to Euro-American contact. Based on these conclusions, continued work will be performed in the Healy Lake village to assess these questions in more detail as well as to refine datasets presented here, and continue to answer questions asked by the residents of Healy Lake and train them in the operation, methodology, and interpretation of geophysical equipment.

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Lightning strikes in archaeological magnetometry data. A case study from the High Bank Works site, Ohio, USA

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KEY-WORDS: lightning strike, magnetometer, Ohio, earthworks, interpretation

INTRODUCTION

Determining whether a magnetic anomaly detected at an archaeological site has a natural or a cultural source can be quite challenging in some regions of the world because of magnetic variability related to soil development and differing rock/parent material types. Though not consistently recognized, lightning is one major source of magnetic anomalies on archaeology sites that has been consistently overlooked and misinterpreted. A case study from the High Bank Works in south-central Ohio, USA shows the range of strike anomaly sizes, shapes, and intensities.

HISTORY AND GLOBAL OCCURRENCE

The effects of lightning strikes throughout the world are well known. Except for lightning-damaged trees, the most common visual evidence of strikes are fulgurites, which are fragile, tube-like geological features created by sand that has been fused by the strike's intense heat (Pye 1982; Appel *et al.* 2006). Fulgurites are only formed in sandy soils (Veimeister 1972); in other soils there might be no visual evidence of a strike event. Strikes can be apparent, however, in magnetometer data.

One of the first occurrences of lightning anomalies in archaeological data was detected in 1988 during a gradiometer survey in Wales (see Crew 2008). At the time, these anomalies were not interpreted as lightning strikes. Seven years later, a short article on lightning anomalies in magnetometer data was published by Bevan (1995), followed by an article about a probable lightning strike from an archaeological site in Japan (Sakai *et al.* 1998). Since the mid 1990s, other observations of lightning strikes have been published from, for example, the United States of America

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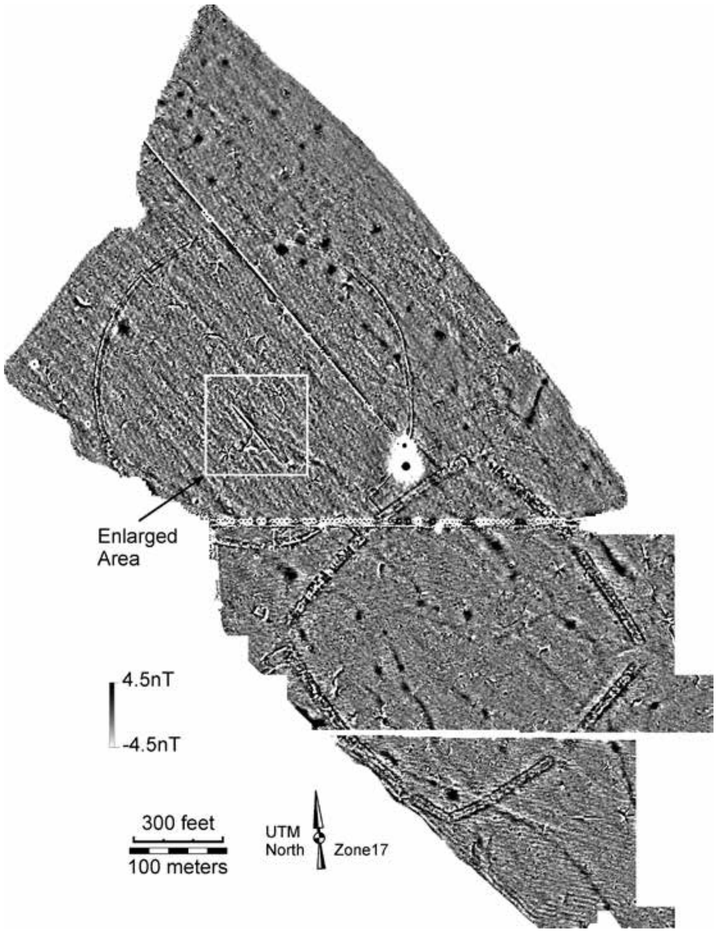

Fig. 1. Gradiometer results from the High Bank earthworks site, Ohio, USA: observed over 60 lightning anomalies in the magnetic data (data images provided by J. Burks)

(Jones and Maki 2005; Maki 2005; Beard *et al.* 2009; Cook and Burks 2010; Burks 2014), Sweden (Biwall *et al.* 2011; Trinks and Biwall 2011), Wales (Crew 2008; Bevan 2009), Austria (Walach *et al.* 2008), India (Bevan, personal communication) and Peru (Fassbinder and Górka 2009).

ATTRIBUTES

The most distinctive character of lightning strikes on magnetic maps are the positive and negative rays that extend out from a central point. The radiating arms are often about 10 m long (sometimes shorter), but examples from the United States show that they may extend for many dozens of meters. The amplitude of the magnetic anomaly decreases with distance from the strike point and

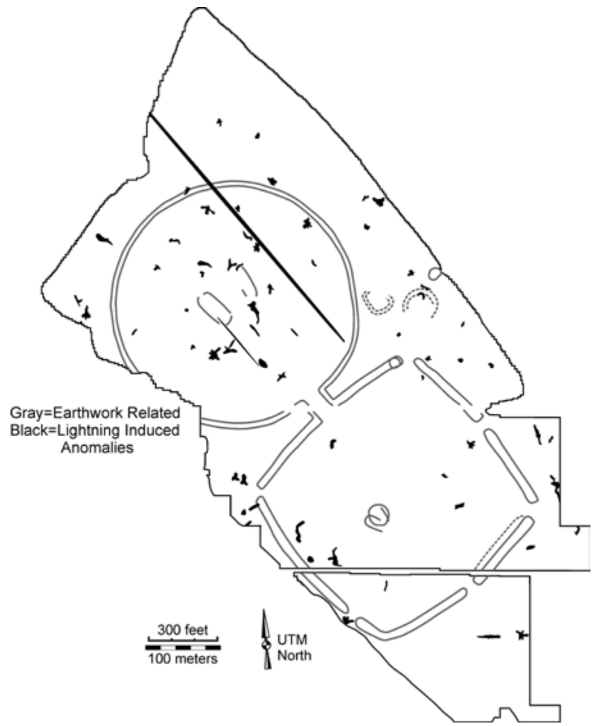

Fig. 2. Interpretation of gradiometer results

the anomalies may taper to indistinguishable at the end, rather than ending abruptly. Each radial arm is bipolar, with a magnetic low paralleling a magnetic high. The magnitude of the high will be about equal to the low, independent of the direction of the ray. This approximate equality will be true where the inclination of the Earth's magnetic field is rather steep, for example, 70 degrees or more. At locations where the strike is found closer to the Earth's equator, the magnetic high and low will become less equal, and the amplitudes of the rays will change much with direction (north–south rays will become invisible). Along each ray of a single lightning strike, the magnetic high will be clockwise from the magnetic low, relative to the strike point. Alternatively, along each of the rays, all of the magnetic highs will be counterclockwise from their matching lows. In the former case, with the magnetic highs clockwise from the lows, the magnetizing current (the strongest or final current) flowed outward from the strike point. Otherwise, with lows clockwise from highs, this current flowed inward toward the strike point (see Rakov and Uman 2007: 4 ff. for definition of different kinds of lightning discharges). The magnetic anomalies of lightning strikes will be found only where the current flow is primarily horizontal, at a shallow depth of perhaps less than 1 m. The horizontal flow of current probably requires that shallow soil has a greater conductivity than deeper soil. The low conductivity may result from an increased fraction of clay, silt, or other conductive materials at a shallow depth, compared to deeper underground.

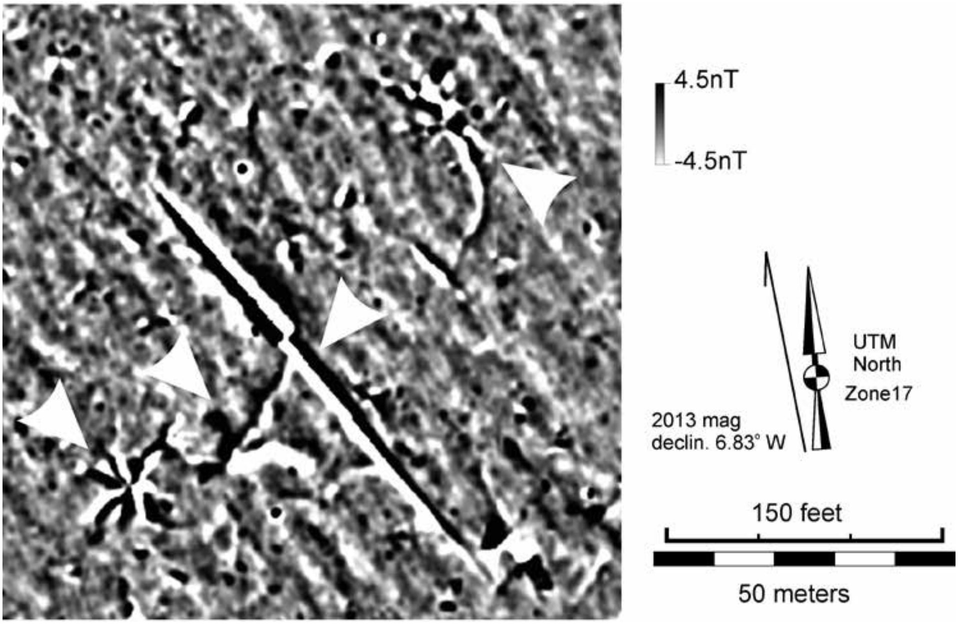

Fig. 3. Enlarged area showing a variety of lightning induced anomalies (indicated by white arrows)

THE OHIO CASE STUDY

Between 2011 and 2013, just over 30 ha was surveyed at the High Bank Works in Ross County, Ohio (USA) using a Foerster Instruments Ferex system (Burks 2013). High Bank is a large Hopewell earthwork complex constructed approximately 1700 years ago. The embankments, which are still slightly visible in the topography, where clearly detected in the magnetic survey (Fig. 1), as were dozens of lightning-induced bipolar anomalies (Fig. 2). It would appear that there are two kinds of strike anomalies at High Bank, those that are long and narrow with only two radiating arms, and those that are more amorphous, with more rays (Fig. 3). Many of the linear anomalies are parallel to plow marks, suggesting that these occur very close to or at the surface. While High Bank has not been plowed in perhaps a decade, over 150 years of plowing, prior to the site becoming a park, has left many fragments of lightning strikes that complicate attempts at interpreting the magnetic survey. However, the broader view provided by the large survey area makes it easier to identify definite and probable lightning-induced anomalies.

CONCLUSION

Lighting-related anomalies can be quite common in magnetic data. With large survey areas it is relatively easy to spot lightning anomalies. But in small surveys or thoroughly plowed ground, lighting anomalies may only appear as fragments of the more typical anomalies. As the

High Bank example shows, lightning anomalies can be abundant in magnetometer data. The correct identification of lightning strikes in magnetometry data is therefore an essential part of understanding magnetic maps and ensures the avoidance of unnecessary interpretational errors and misunderstandings.

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Extensive multi-channel GPR mapping over the site of the ancient Archiepiscopal Palace of Alcalá de Henares (Spain)

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KEY-WORDS: GPR, multi-channel, archaeology, Archiepiscopal Palace, Alcalá de Henares

INTRODUCTION

A case history concerning an extensive multi-channel GPR survey (IDS Stream-X 200 MHz, 16 channels) carried out over the site of the ancient Archiepiscopal Palace of Alcalá de Henares (16th century AD) (Madrid, Spain) is presented in this paper. The palace was built over a *mudejar* hillfort (13th century AD), in 1858 it became the Historical Central Archive of the Spanish Kingdom and in 1939 was largely destroyed by an accidental fire (Sánchez España 2012).

The objectives of the work include identification of the remains of the palace and the investigation of undocumented underground structures, like old tunnels and rooms, where, according to oral tradition, documents and precious materials were buried after the fire.

DATA ACQUISITION AND POST-PROCESSING

The survey investigated about 25,000 m^2 (Fig. 1) with 3195 radargrams organised into 213 swaths. Each swath is composed of 15 radargrams acquired simultaneously at fixed spacing (cross-line resolution*)* of 12 cm (Novo *et al.* 2011). The data positioning was performed by an RTK GNNS system (Topcon GR5) including base and rover, working with GPS and Glonass constellations. The GPR and GPS equipment were synchronized with the UTC clock pulse by ppsync link.

GPR data post-processing was carried out using GRED HD (IDS spa) and GPR-Slice (Geophysical Archeometry Laboratory, California, USA). Radagram filtering included static correction (first pulse realigning and synchronizing), gaining curve, spectral whitening, spectral deconvolution, background filtering and Hilbert transform. The estimation of the velocity was performed by the hyperbola fitting method, giving values ranging between 0.09 and 0.075 m/ns. Due to the high variability of the parameter, data were not migrated.

RESULTS

A set of GPR time slices, each one representing a soil thickness of about 10 cm, was processed for the four areas covered by the survey, employing and comparing both techniques based on volume pulsing and classical slicing/gridding method (Goodman *et al.* 1995).

High quality GPR results were obtained despite the electrically conductive lithological context, mostly in the sector occupied, in ancient times, by the "Patio de Fonseca" and "de la Fuente", around

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[b] G3A, Guadalajara, Spain

Fig. 1. Area covered by the GPR survey (marked with straight lines)

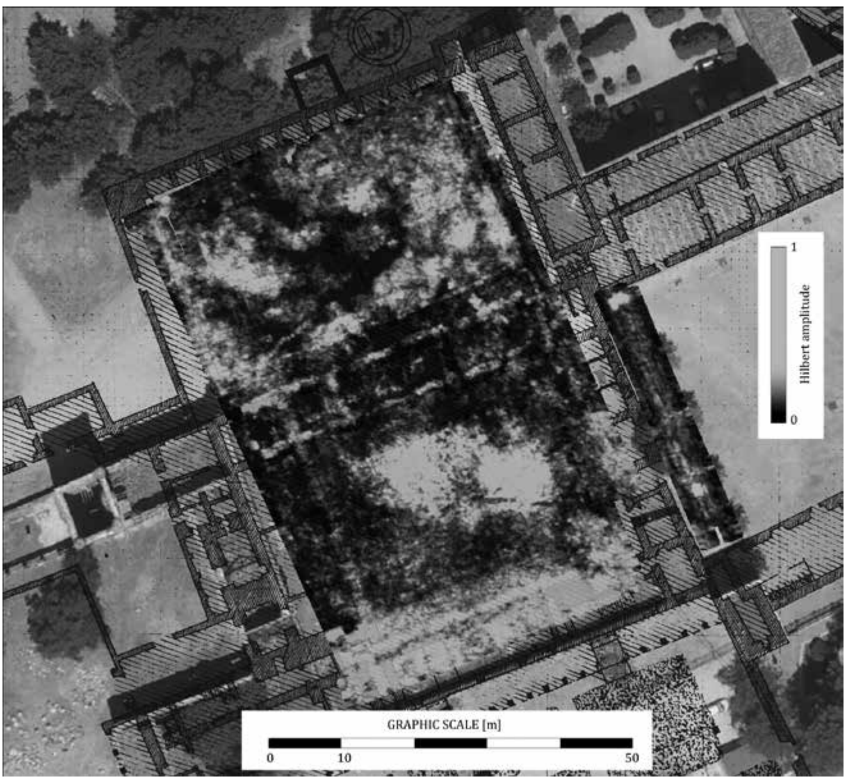

Fig. 2. GPR time-slice at about 0.7 m depth, overlapping documentation from AD 1862. The northern area (north is up) corresponds to the ancient "Patio de la Fuente", the southern to the "Patio de Fonseca". White corresponds to strong GPR reflections, dark to weak reflections

which most of the buildings were erected. The GPR imagery clearly showed the layout of the ancient building, matching almost perfectly the historical records from the beginning of the 19th century.

Moreover, several undocumented structures were discovered lying below the "Patio de la Fuente". They could represent the remains of a partly preserved underground tunnel, documenting an important stratigraphic discontinuity in the "Patio de la Fuente" and providing interesting archaeological information about the origin of the Palace. An example of the GPR results from the above sectors is shown in Figure 2 (time slice at 0.7 m depth). The results of an archaeological verification of a selection of GPR anomalies, carried out in the spring of 2015, will also be presented.

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Reading an ancient *vicus* with non-invasive techniques: integrated terrestrial, aerial and geophysical surveys at Aequum Tuticum (Ariano Irpino-Av)

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KEY-WORDS: ancient road, landscape archaeology, magnetic prospecting, aerial photography

Archaeological investigations by the Laboratorio di Topografia Antica e Fotogrammetria (LabTAF) of the University of Salento have been carried out in recent years within the frame of the Via Traiana Project. The main goal of the project is a complete topographical reconstruction of the ancient route by means of a multidisciplinary approach including traditional landscape archaeology methodology and other methods, such as geophysical prospecting. The Via Traiana was built by the Emperor Trajan in AD 109 to link Beneventum and Brundisium over a distance of some 320 km (Fig. 1). Much of its route has now been identified thanks to a large number of surveys conducted in the territories of Apulia and Campania (Ceraudo 2008: 9–23).

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[c] ATS Archeo Tech & Survey, Siena, Italy

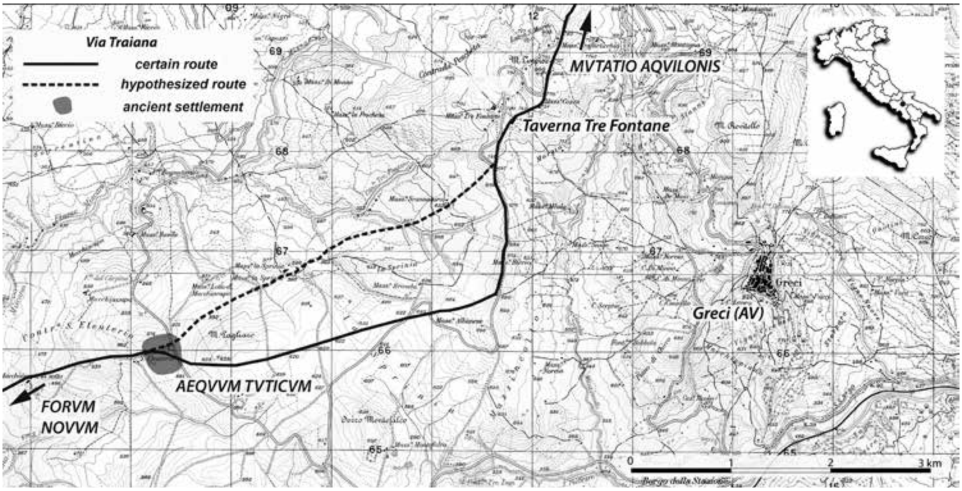

Fig. 1. Route of the Via Traiana crossing Aequum Tuticum, between Forum Novum and mutatio Aquilonis

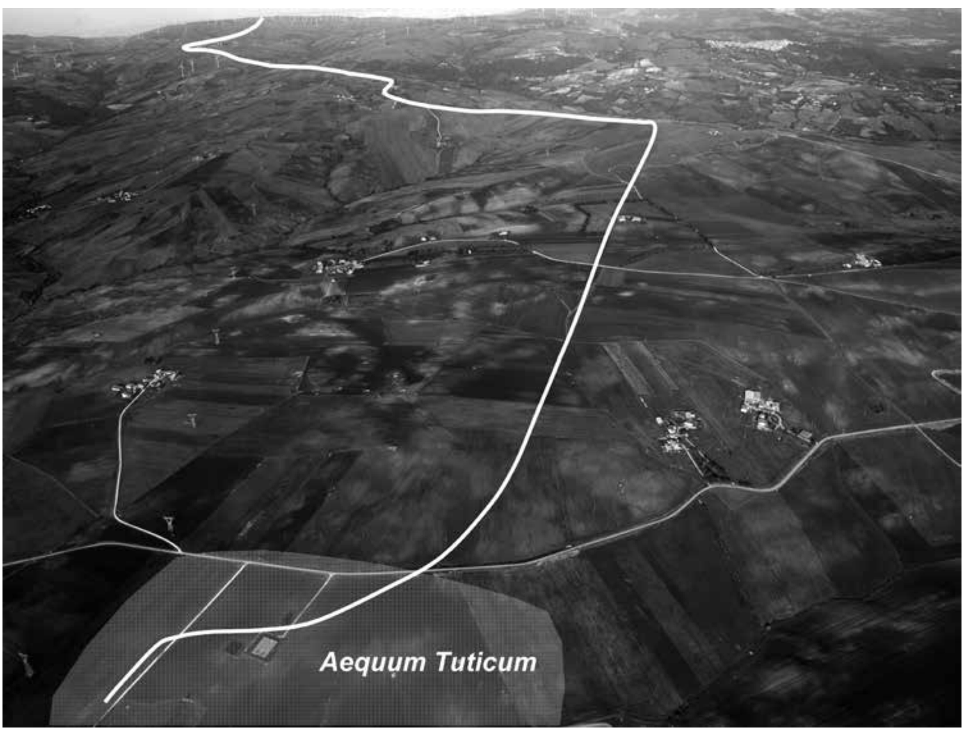

Fig. 2. Oblique aerial image of Aequum Tuticum: highlighted route of the Via Traiana coming in from the east

The project employed systematic field walking and aerial survey as well as the analysis of multi-temporal and multi-scale aerial photographs. In addition to reconstructing the Roman road, the study has led to the discovery of numerous ancient settlements, ranging in date from prehistory to the Middle Ages. Moreover, the thousands of flights over the territory crossed by the road have enabled the reconstruction of important elements in the organization of the ancient landscape, such as land divisions and minor roads. Also of importance was an analytical study, including 3D reconstruction of all the key bridges along the route and the study of inscriptions relating to it (Ceraudo 2012: 255–256).

Of considerable importance are recent investigations focused on the *vicus* of Aequum Tuticum (modern Sant'Eleuterio countryside, in the Ariano Irpino municipality), conducted in cooperation with the Superintendence of Archaeological Heritage of Salerno, Avellino, Benevento and Caserta Province and the ATS company (Fig. 2). Roman itineraries place Aequum Tuticum along the via Traiana between the *stationes* of Forum Novum and mutatio Aquilonis, but the site is still not well known (Ferrari 2013: 67). Only two small-scale archaeological excavations, carried out in the 1980s and 1990s, have unearthed a small part of the settlement with attested stratification from the 1st to mid-15th century AD, although literary sources record the existence of a more ancient Samnite settlement in this location (Gennarelli 2011: 42).

The site of Aequum Tuticum was an articulated junction of roads. In fact, since the prehistoric time the area was crossed by the so-called *Pescasseroli–Candela* cattle track. Later, in Roman times the settlement was reached by via Aemilia, a consular road (2nd century BC) that linked Aeclanum to Aequum Tuticum, via Traiana (AD 109), and via Herculia, which starting from the end of 3rd century AD connected southern Samnium to the Lucania region.

Systematic fieldwalking was performed with the aim of defining the site extent and the urban layout system, which appears to have consisted of small and middle-sized residential buildings. The exact location of the necropolises was also important, their presence being documented so far only by occasional finds of funerary inscriptions. In the southern part of the site, about 500 m from the excavation area, numerous fragments of scattered surface pottery attested to the presence of tomb structures, positioned on the side of the via Herculia, already identified in an aerial photo. A similar situation occurred in the northern part, about 250 m north of the excavation area, where, moreover, numerous fragments of pottery and other materials led us to suppose the presence of a furnace (some graves attributed to the medieval phase of the town were attested in the excavations). Along the roads, near the urban site and in the environs of the city there are also attested several small- and middle-sized rural settlements, characterized by occupation phases ranging from the Republican to the late Imperial age, confirmed by finds of some bronze coins. Furthermore, about 200 m west of the excavation area, in the courtyard of a private house, several funerary inscriptions from the area of Aequum Tuticum can be seen, chronologically referred to the Imperial age.

Aerial photographs, whether vertical or oblique, can provide an objective and intelligible record of large parts of an archaeological site or landscape, but the results become vastly more informative when combined with other sources of archaeological information, such as excavation, ground-based survey and topographical analysis, and the newer forms of remote sensing. A precise interpretation of all the photo frames has been carried out to extract all the visible archeological data. Of particular significance for the present study are two flights. The first one was in 1953, performed by the Istituto Geografico Militare; it is possible to reconstruct a long section of the road running from Aequum Tuticum to Aecae. The second was part of a regular

Fig. 3. Results of a geophysical magnetic survey performed in the area of Aequum Tuticum

aerial survey carried out between 2010 and 2011, where cropmarks can be recognized as traces of minor roads and there is a long section of the via Herculia approaching from the southeast and a section of an urban road that runs east–west, both flanked by buildings. Traces of buildings are also visible to the south of the ancient settlement.

A fundamental contribution came from high-resolution magnetic prospection performed over an area of about 7.5 ha, using a Foerster fluxgate magnetometer equipped with four sensors spaced 0.5 m apart. The instrument was interfaced in real time with a GPS system. Moreover, ground control points were collected by centimetric GPS for better georeferencing. The results from the magnetic survey highlighted anomalies related to ancient roads, main and secondary, and many different structures (Fig. 3). Of interest among these was a large trapezoidal area, probably the Forum square, where two main roadways (maybe via Traiana and via Herculia) appear to have converged. The magnetic map shows clearly the trace identified with via Herculia, oriented NW–SE, which is extraordinarily clear in the southern sector of the map; it is due to its width (about 9 m) and to the presence of many funerary monuments that lie along its route, confirming the location of the necropolis close to the urban area. Moreover, it is possible to observe in the entire investigated area how the buildings have a different orientation in relation to the road network; this opens the way to a number of hypotheses with respect to the diachronic development of the urban center, heavily affected by the crossing of important roads. The magnetic results also indicated the presence of minor roads, from 3 m to 4.5 m wide, separating the blocks in the *vicus* layout.

In many cases magnetic data are clearly in good correspondence with traces identified in the aerial images and the results of archaeological fieldwalking, proving the huge potential lying in an integration of the outcomes of different methods. Nevertheless, it is important to emphasize that the results coming from each survey can find final validation only in archaeological excavation.

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Landscape with enclosures. Magnetic prospection and surface survey of the Dobużek Scarp microregion, Eastern Poland

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KEY-WORDS: magnetic prospection, landscape, Eneolithic, enclosures

Current knowledge of the Lublin–Volhynia Culture settlement (4300–3600 BC) is mostly based on the results of large-scale excavations conducted before the II World War at Złota and occasional fieldwork carried out in later times (e.g., Kruk, Milisauskas 1985; Kowalewska-Marszałek 2007). Some more or less enigmatic features, which can be interpreted as ditches, were also discovered during archaeological research at several other sites. In 2012, magnetic prospection was undertaken to verify the character of some of these features. At Moroczyn (site 5, Hrubieszów commune) the survey did not deliver any conclusive results. The outcome of the non-invasive investigations was much more interesting at Las Stocki (site 7, Końskowola commune; Zakościelna 1986), where a chain of elongated, irregular pits was identified around the part of the site of paramount importance.

The most intriguing results were achieved in the Mikulin region (Tyszowce commune) where the research was conducted in the exceptional landscape and environmental setting

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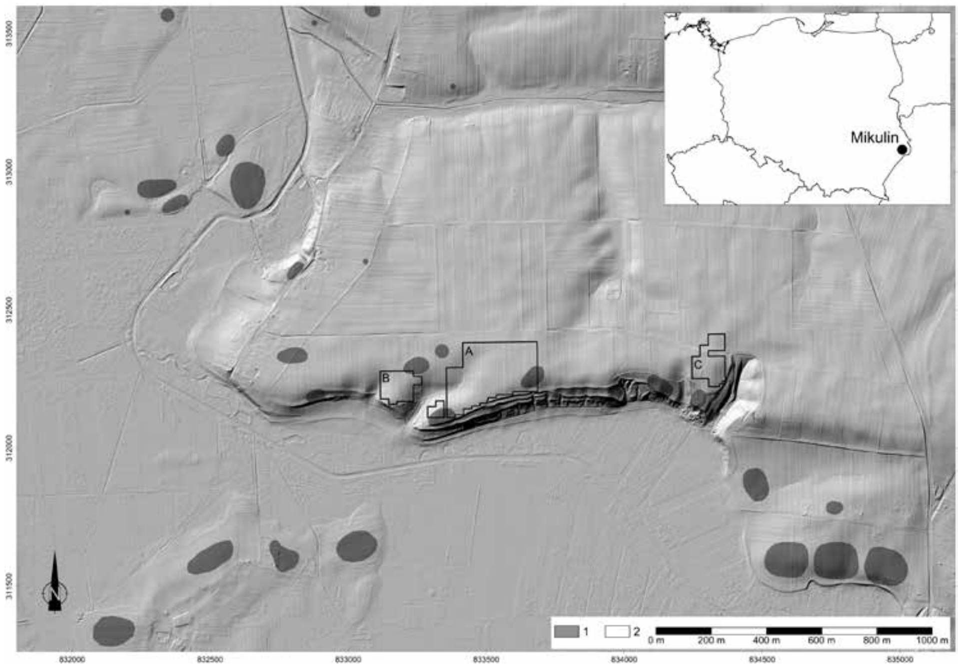

Fig. 1. Dobużańska scarp, Poland. Areas of magnetic prospection: 1 – archaeological sites according to the Polish Archaeological Record project (AZP), 2 – areas of magnetic prospection: A – Mikulin, site 8, B – Mikulin, site 10, C – Dobużek-Kolonia, site 1

of the Dobużańska scarp, on the steep loess and limestone slopes of the Huczwa River valley (Fig. 1). In 2012, studies were focused on one of the promontories of the Scarp (Mikulin, site 8), where the presence of a Lublin–Volhynia Culture ditch had been noted during fieldwork in 1986. The magnetic prospection in 2012 covered an area of 1.68 ha. It was resumed in 2014, broadening the investigated surface to 6.77 ha at the Mikulin 8 site. Additional surveys were undertaken at two neighbouring sites (Mikulin, site 10, 1.41 ha and Dobużek-Kolonia, site 1, 1.59 ha). A Bartington Grad601-2 System was used for taking measurements.

Two enclosures were identified within the limits of the Mikulin 8 site (Fig. 2). The first one consists of two parallel ditches (A1 and A2), which separate the eastern part of the distinct promontory from the loess high ground that stretches westwards and a ravine located to the north. A third ditch (A3), wider than the previous two, was recognized in the northern part of the promontory; together with another one of similar width (A4), it forms a vast enclosure adjacent to the first one from the east and north-east. Apart from the ditches there was a significant number of positive point anomalies, which can be interpreted as the remains of settlement features (pits). They form a belt, several dozens of meters wide, running along the inner part of ditch A3 and the natural ravine, as well as through the inner maidan, which is nearly devoid of features. This arrangement may suggest a chronological relationship between most of these pits and the enclosure formed by ditches A3 and

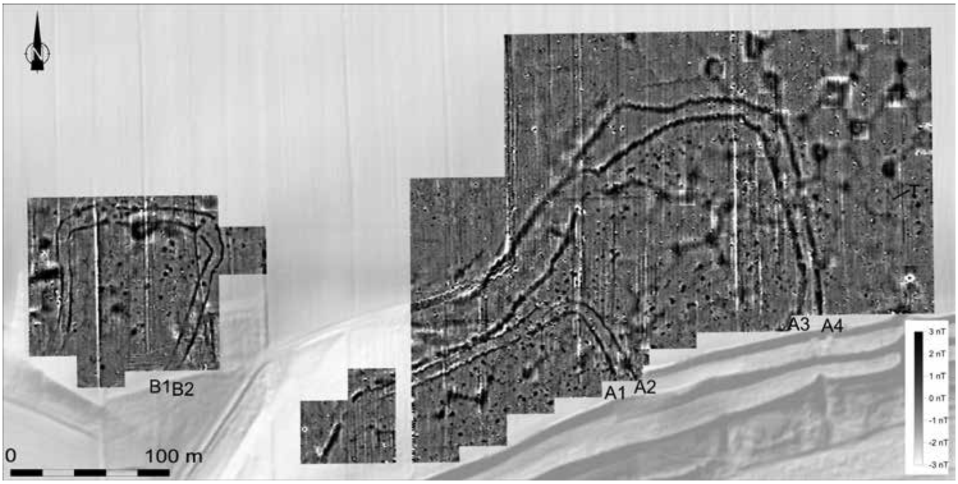

Fig. 2. Dobużańska scarp, Poland. Results of magnetic prospection (left, Mikulin, site 10; right, Mikulin, site 8)

A4. The relics of a tumulus, namely a circular ditch 18–20 m in diameter and a central rectangular pit aligned SE–NW, were identified west of the enclosure (Fig. 2: T).

It can be confirmed based on the results of surface surveys and excavations conducted between 2012 and 2014 that the smaller enclosure formed by ditches A1 and A2 was associated with Lublin–Volhynia Culture occupation. The V-shaped ditch sections typical of the Neolithic and Eneolithic, the collection of specific artifacts and radiocarbon dating support this chronology. Additionally, two richly equipped Lublin–Volhynia Culture burials were discovered in 2012 in an excavation trench located between ditches A1 and A2.

At present there are no conclusive premises for dating the enclosure formed by ditches A3 and A4. The excavations conducted in 2013 revealed a trough-like cross-section of ditch A3, suggesting a younger chronology related probably to Funnel Beaker Culture or early Bronze Age communities.

Detailed research was also conducted at a second site located on a promontory immediately adjacent to the Mikulin 8 site. During a surface survey at this landform (designated Mikulin, site 10) 50 clusters and single finds of human bones were recorded. A test trench excavation revealed that the skeletal material came from ploughed-up graves, which formed a cemetery from the Early Bronze Age. Artifacts collected during the survey could be attributed to communities of the Lublin–Volhynia, Funnel Beaker and Early Bronze Age and Lusatian cultures.

The magnetic prospection (Figs 1 and 2) showed the presence of various anomalies, including two parallel linear anomalies that can be interpreted as ditches forming a hoof-like (trapezoidal) enclosure. In the northern part of the enclosure, two gaps that could be gateways were identified in the line of the ditches. Despite the fact that there is no definite chronological data currently available for this enclosure, certain features, such as the arrangement of the ditches and their width, bear resemblance to the smaller enclosure discovered at the neighbouring Mikulin 8 site, suggesting a relation with the Lublin–Volhynia Culture.

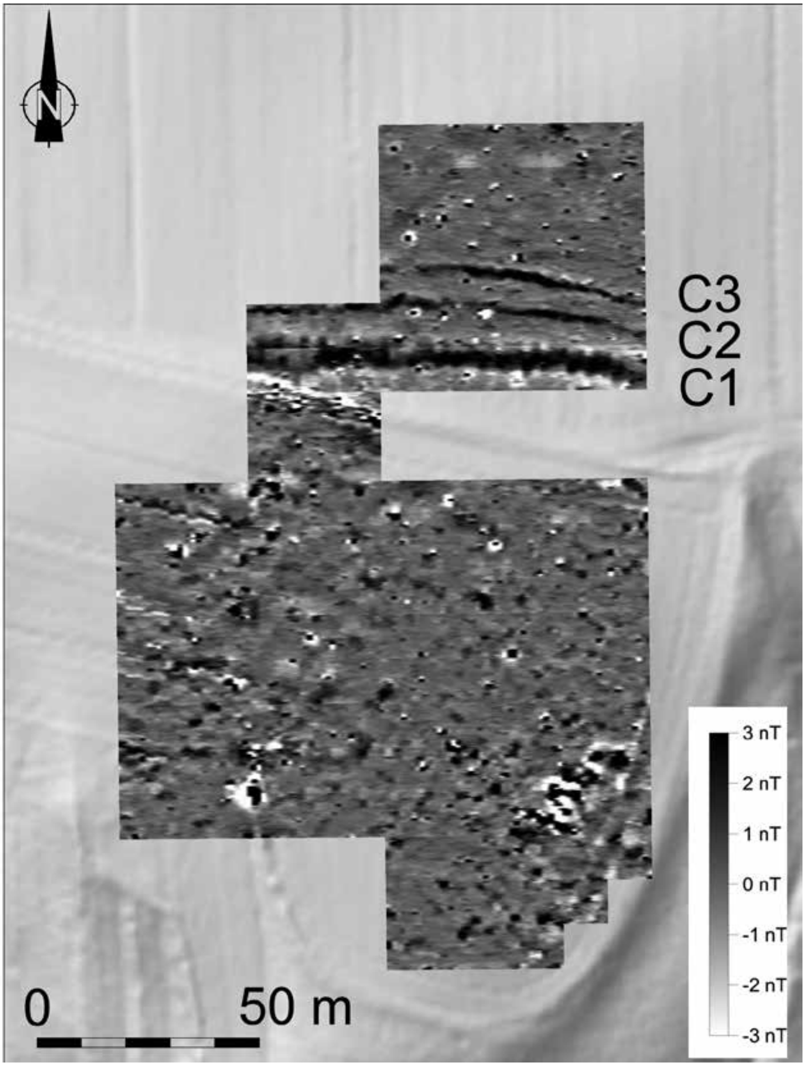

Fig. 3. Dobużańska scarp, Poland. Results of magnetic prospection (Dobużek-Kolonia, site 1)

Other anomalies can be considered as archaeological features forming a number of clusters. The largest one is located within the enclosure, while two more were found between the ditches and outside their perimeter in the northern and northwestern parts of the investigated area. Their chronology is unclear; it seems, however, that they do not have any chronological connection with the enclosure. No spatial relationship was noted between them and the scatters of human bones and other artifacts discovered during the surface survey.

The last investigated part of the Dobużańska Scarp was its eastern periphery where the surface survey resulted in the identification of a new site, Dobużek-Kolonia 1, characterized by an abundance of surface finds (e.g., pottery, flint artifacts, spindle whorls) associated with the Funnel Beaker Culture (including numerous Tripolye Culture pottery), the younger Danubian, Corded Ware as well as early Bronze and Iron Age cultural occupation episodes (Figs 1 and 3).

Surprisingly, the magnetic prospection results seem to suggest the existence of another enclosure. Its form cannot be fully reconstructed due to the limited extent of the magnetometry, however the course of the ditches in the western part of the site can be traced on the basis of poorly visible vegetation marks. Fragments of three ditches were recorded in the northern part of the studied area. The two outer ditches (C2, C3) are visibly narrower than the inner one, reassembling the ditches of the smaller enclosure at the Mikulin 8 and 10 sites. This difference in size may suggest two developmental phases of the enclosure. The rest of the anomalies represent the relics of prehistoric occupational features and some of them are related to the existence of a POW camp at that location.

Artifacts of Funnel Beaker Culture were concentrated within a wide belt located inside the ditch perimeter, with the central part of the enclosure almost devoid of finds. This coincidence is an important chronological and functional premise, suggesting that the enclosure functioned in the Funnel Beaker Culture period, but an older phase associated with the Lublin–Volhynia Culture cannot be ruled out.

Intensive non-invasive research conducted in the Dobużańska Scarp region revealed an outstanding picture of various forms of spatial and cultural landscape management by prehistoric communities. Particularly intriguing is the concentration of enclosures in this area, which regardless of their interpretation, whether in practical, utilitarian terms or symbolic and ritual ones, manifests the uniqueness of the place.

ACKNOWLEDGMENTS

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Ground-penetrating radar data analysis for more complete archaeological interpretations

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KEY-WORDS: ground-penetrating radar, reflection profiles, reflection traces, GPR interpretation

GPR DATA PROCESSING TODAY

The use of GPR for archaeological mapping and interpretation has changed from its roots as a purely-exploratory technique into one that uses sophisticated three-dimensional mapping and computer generated visualization programs to understand much larger areas of the subsurface (Conyers 2013). The standard visualization techniques today commonly produce amplitude slice-maps from two-dimensional reflection profiles or three-dimensional antenna arrays, generate isosurface renderings from those complex three-dimensional datasets, and generate a number of other three-dimensional outputs (Conyers and Leckebusch 2010; Novo *et al.* 2008; Trinks *et al.* 2010). These now common collection and processing techniques are the result of robust and easily accessible hardware and software advances that collect and process large datasets quickly and efficiently. While these advances are now common, it is still important to understand and interpret the basic GPR data, that is, reflection traces and individual profiles. Only when all GPR information is interpreted together can the complex three-dimensional aspects of the method be understood. A few examples are presented here to illustrate how a visualization of uncorrected profiles used in slice-mapping can often produce erroneous images of layered ground. Buried features of interest also may not reflect radar energy and only an analysis of what is not reflecting waves will identify units of interest. In addition, an analysis of individual reflection traces, which are the most basic of datasets in GPR, will allow a determination of the types of materials in the ground that produce the reflection.

SOME GPR EXAMPLES OF HOLISTIC INTERPRETATIONS FROM BASIC DATASETS

If the geological materials in the ground are complexly bedded, the computer sampling methods for amplitude mapping will display reflection amplitudes from one continuous horizon, as if it was a series of aerially restricted "anomalies" at various depths within each slice. As the layers in the ground are dipping, most GPR processing software used to generate three-dimensional images will generate extraordinarily busy "anomaly" maps that are mostly irrelevant to the final interpretation because slices cut across horizons at various depths. Then the amplitude maps image only bedding horizons that may be located in any one slice (Fig. 1). Any archaeological features within this package of bedded material will be effectively hidden within the final images. In this case, only an understanding of the basic reflection information, from which the images are produced within a geological context (Conyers 2015a), will allow an accurate final product.

Another basic question with GPR interpretation (Conyers 2012) is what may be producing the reflections in a dataset. Often this can be determined only from viewing reflections in profiles and

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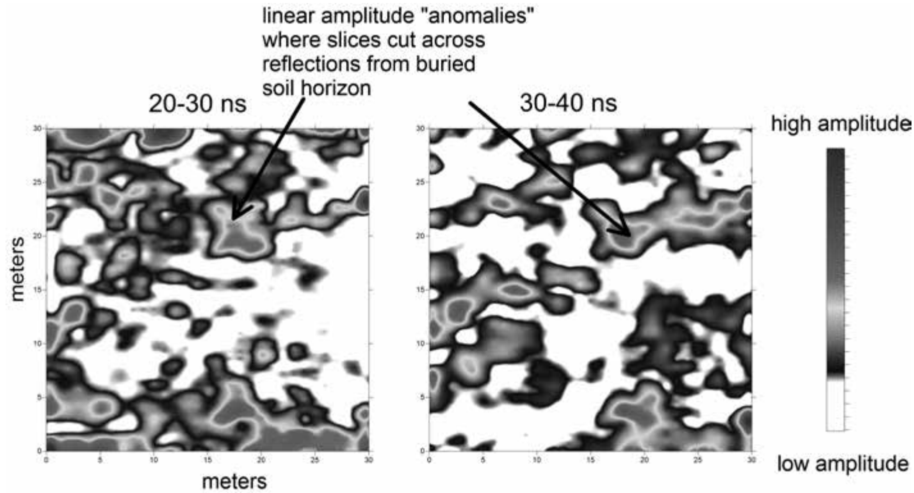

Fig. 1. Results of amplitude slice-mapping from 61 reflection profiles in a grid of depth slices, where amplitudes that appear to be aerially discrete reflections from that one horizon are plotted

understanding what produces radar reflections and then correlating those directly to the excavations or other information about the ground (Conyers 2015b). These basic interpretations make sense, only when the interfaces between archaeological materials and surrounding sediments and soils that produce high amplitude reflections are understood. In an area with buried homogeneous clay walls and floors, only the horizontal floors are visible in GPR profiles with the walls being non- reflective as they are composed of clay and other fine-grained materials with no interior bedding planes or other interfaces from which to reflect energy (Fig. 2). Any vertical interfaces between the walls and surrounding materials are also not reflective, as radar waves transmitted from the surface move parallel to these vertical boundaries; also if they intersect the interfaces, they are reflected away from the surface recording antenna and not recorded. When viewed in reflection profiles, the vertical clay walls appear as areas of no reflection and unless an interpreter understands the nature of the materials in the ground, these features will often go unnoticed.

Only after the houses are abandoned and the walls eroded will the stratigraphy adjacent to the walls, composed of eroded walls, be visible. In this case, an understanding of the ground materials and what produces reflections will allow for an interpretation of the generated amplitude slice-maps. In these maps, it is the non-reflective areas that are denoting the buried walls, which are often not visible to the human eye without first integrating profile interpretations with amplitude maps.

The basic dataset from which all GPR images are produced are the individual wave traces (Fig. 3). These are most often stacked along antenna transect lines to produce reflection profiles, and are seldom analyzed individually. For some applications the individual traces can be of great use in the interpretation to determine the physical properties of materials in the ground (Conyers 2012). When oscillating radar waves encounter buried interfaces, the waves change velocity and reflection occurs. In most contexts, as radar energy moves deeper into the ground, moisture retention increases and radar travel

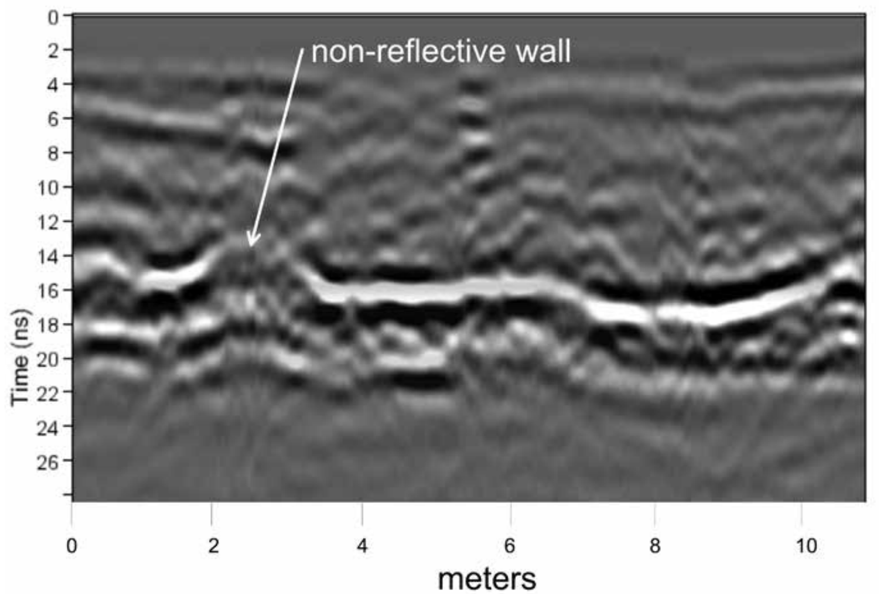

Fig. 2. Reflection profile perpendicular to an adobe wall that is non-reflective, with highly reflective adjacent "adobe melt" layers deposited on a buried living surface

velocity will decrease. When radar energy is reflected from a buried interface where the wave velocity decreases in the lower unit along the boundary, the polarity of the reflected wave will be the same as the direct-wave generated from the transmitting antenna (Fig. 3). This is termed normal polarity. However, if there is an increase in velocity along a boundary, such as an underground void space, the reflection generated will display a reversed polarity sine wave (Damiata *et al.* 2013). These types of polarity changes will occur not only when void spaces are encountered, but also when any buried material in the ground allows energy to increase in velocity rather than decrease. One very important, but often neglected aspect of GPR interpretation is this study of the polarity of individual waves generated from different materials. Usually amplitude slice-maps do not plot the polarity of the waves, but only their amplitude, and therefore an analysis of individual traces is necessary.

CONCLUSIONS

While amplitude slice-maps and isosurface renderings have revolutionized the way GPR data are presented, an accurate interpretation of those images often necessitates integration with more standard data analysis derived from reflection profiles and individual traces. The complexity of stratigraphic interfaces in the ground and changes in topography and surface materials can produce amplitude "anomalies" in the ground that are a function of the way data are resampled during processing. Only when profiles can be adjusted for these common variations, will the amplitude images be interpretable. While the common GPR processing steps move through

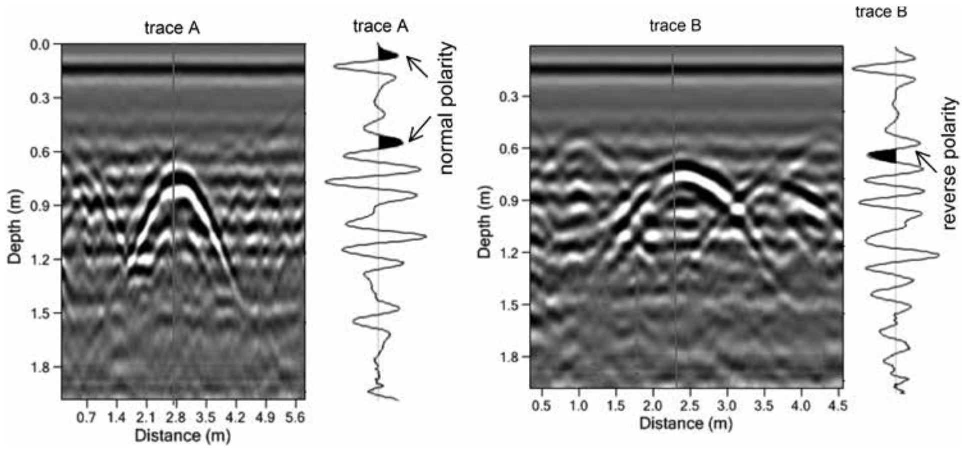

Fig. 3. Comparison of reflection traces from waves reflected from two graves. In burials that retain void spaces within caskets, reflections are reversed polarity (trace B). The usual case for most buried materials is to produce reflections that are normal polarity (trace A)

a series of computing steps to the final products, users should often step back to the raw data, or the simplest images of reflections as a way to interpret the slice-maps and isosurfaces. Some may consider this integrative interpretation method "old fashioned", as this is the way most GPR reflections were processed prior to the now-common amplitude images, an understanding of intuitively generated reflection profiles and traces can produce important clues during interpretation tasks.

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The Hellenistic settlement of Tuna el-Gebel

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KEY-WORDS: magnetic prospecting, Tuna el-Gebel, Egypt, Graeco-Roman period, Hellenistic settlement, tower houses

INTRODUCTION

Tuna el-Gebel is situated about 300 km south of Cairo, in Middle Egypt, on the western side of the Nile. It is the necropolis of Hermopolis Magna, ancient capital of the 15th nome and cult centre of Thot, god of writing and sciences. The archaeological site of Tuna el-Gebel is particularly known for its Greco-Roman necropolis and the *ibiotapheion*, one of the largest animal cemeteries of pharaonic Egypt. In the course of almost a millennium, millions of ibises and baboons, representing the god Thot, were buried in the vast catacombs. Since 1989, the Institute for Egyptology and Coptology of the Ludwig Maximilian University Munich, and the Faculty of Archaeology of Cairo University, have cooperated on the Tuna el-Gebel Project aimed at exploring the architectural development of the animal cemetery and related religious and administrative buildings.

Since 2002 the principal investigations have been concentrated on the site to the east of the underground galleries. A processional way lead once from the animal necropolis to the remains of the ancient town, on Kom el-Loli, where priests and craftsmen of the religious association of the animal cemetery had lived. The geophysical prospection of this area, conducted by the University of Kiel, to the north and south of the processional way, huge mud-brick building complexes lying side by side under sand mounds. Five of these complexes, two of the northern and three of the southern row, were excavated in the past years (Figs 2, 3). All these building complexes — only foundations, sometimes basements, and rarely ground floors have been preserved — consist of one to three tower houses, surrounded by smaller annex houses as well as numerous production facilities, like bakeries, siloses and animal stables. The earliest buildings date to the reign of Ptolemy I, an important phase for the architectural and cultic development of the animal cemetery. Several cult places, almost identical to the ritual places of the animal cemetery, were discovered in some of the houses. A second construction phase of the tower houses dates to the reign of Ptolemy VI. Some buildings were in use until Roman times. The square-plan tower houses of Tuna el-Gebel probably had five floors and were constructed with undulating walls and vaulted ceilings. Although most of the building complexes were either excavated or looted at the end of the 19th century, plenty of ceramics, organic and botanical materials, artifacts of daily life and religious objects were discovered in the course of the excavations (Arnold 2000). Domestic courtyards consisted of production and kitchen areas equipped with siloses, ovens, mills and bread moulds.

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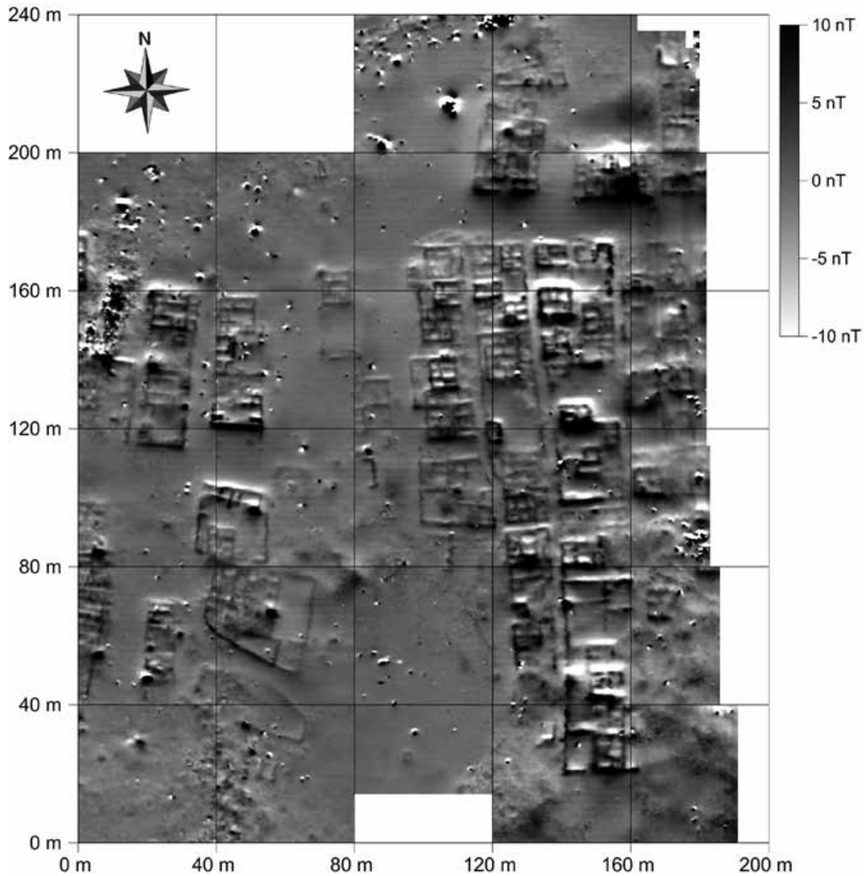

Fig. 1. Settlement on Kom el Loli,. Magnetic map of survey area I. Caesium total field magnetometer Scintrex, SM4G-Special in duo-sensor configuration, total Earth's magnetic field at Tuna el-Gebel 4/2013, 42.360 ±12 nT, sensitivity ± 10 pT, sampling density 25 x 50 cm interpolated to 25 x 25 cm, dynamics in 256 grey scales, 40 x 40 m grid

RESULTS OF MAGNETOMETER PROSPECTION

During the spring campaign of 2013 the ancient settlement at Kom el-Loli, where the processional way and its building complexes merged into the urban area of the kom, was surveyed by magnetometer prospection (Fig. 1).

A Scintrex SM4G-Special Caesium magnetometer was applied in a duo-sensor configuration with sensitivity of ±10 pT and sampling rate of 25 x 50 cm interpolated to 25 x 25 cm. The total Earth's magnetic field in Tuna el-Gebel (4/2013) was 42,370 ± 20 nT. As far as magnetic properties and the contrast of mud-brick structures with Nile sediment and the adjacent quartz sand are concerned, Egypt can be regarded as the "promised land" for magnetometer prospection (Fassbinder

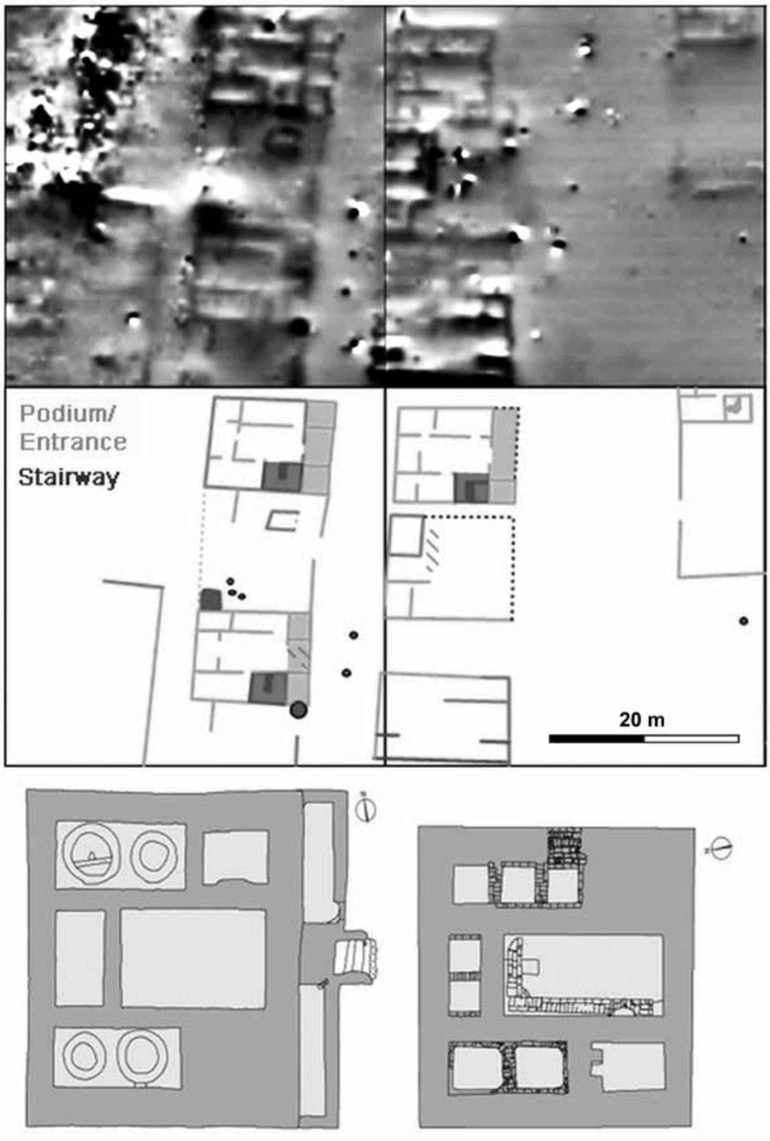

Fig. 2. Detail of the magnetic map and interpretation of the north-western area of the prospection with assigned room functions (© Bavarian State Department for Monuments and Sites). By comparing these with ground plans of the tower houses in Tuna el-Gebel excavated in earlier campaigns (TG2002.K2 North tower, TG2010.K5), the structure of the tower building is obvious: the podium to the first floor with steps to the entrance is mainly in the east; next to this, in the corner, the inner stairway to the upper stores is located, marked by the foundation of the lowest step (© Institute for Egyptology and Coptology, LMU Munich)

Fig. 3. Excavated North tower with staircase, TG2002.K2 (©Institute for Egyptology and Coptology, LMU Munich)

2015). The magnetic susceptibility of volume mud bricks was comparatively low (values range from 0.3–0.7 x 10^{-3} SI), but the adjacent sand consisted of diamagnetic quartz and revealed even negative kappa values. Such conditions deliver an ideal background for magnetometer surveying in Egypt (e.g., Forstner-Müller *et al.* 2010).

The processional way narrowed to a street of 16 m width, dividing the settlement into two parts: two huge buildings, probably temple structures, are situated in the north, while the southern part of the kom consisted entirely of numerous tower houses and annexes. As we know the composition and setting of typical Hellenistic tower houses, we can recognize the entrance plans with stairs on a podium to the first floor in front of the buildings, the stairway inside the building, identifiable by one thick wall inside a room, and the typical three rows of rooms (Fig. 2). The kitchen was normally located in one of the long rooms. The ground map, the architecture and even the detailed utilization of the houses can be derived from the measurement by comparing them to excavation reports (Flossmann-Schütze 2011; 2014).

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Early Iron Age kurgans from the North Caucasus

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KEY-WORDS: magnetic prospection, Iron Age, kurgan periphery, North Caucasus

INTRODUCTION

The steppe regions of the northern Caucasus, which cover the areas of the Stavropol district in Russia, contain thousands of large burial mounds, the so-called kurgans of the Iron Age period. They were constructed by the Scythian nomads and constitute a visible legacy of this culture. A few hundreds of these kurgans are defined, simply because of their sheer monumentality, as "great kurgans" and are ascribed to the elite of the horse-riding nomads (Gass 2011). Generally, these great kurgans dominate large burial grounds and form visible landmarks in the steppe. In the western part of the Stavropol region, very few kurgans have been investigated archaeologically in detail. Within the frame of a Russian–German cooperation and with the support of the "Exzellenz Cluster Topoi (Berlin), Program B-2-4" and the Geophysics Department of the Ludwig-Maximilians University in Munich, we started in 2012 with a geophysical mapping project on selected sites.

The eastern part of this large region of Stavropol (which covers about 66,000 km^2 in total) has not been explored yet. Historical reports describe the northern foreland of the Great Caucasus Mountains as the starting point of the "heroic history" of the Scythians, from where these horse-riding nomads started their raids to the Middle East (Herodotus I, 103–106). Hence, it can be assumed that the northern forelands of the Caucasus played an outstanding strategic role in the organization of these raids. Since little is known about the origin and development of Scythian culture, this region was selected for our research project.

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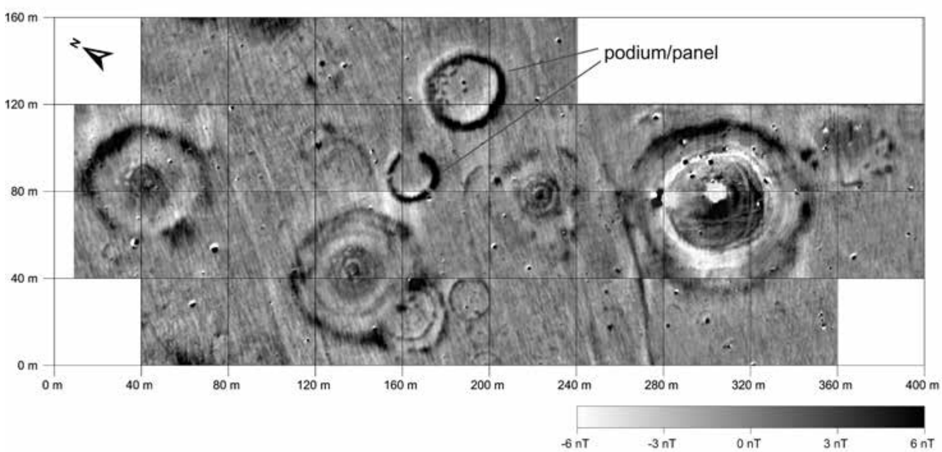

Fig. 1. Vinogradova. Magnetic map of the early Iron Age necropolis and its environs. Smartmag SM4G-Special caesium-magnetometer, sensitivity ±10 pT, variometer (duo-sensor) configuration, sampling rate 25 x 50 cm

ARCHAEOLOGICAL RESEARCH QUESTIONS

Were the Scythian nomads of the eastern part of the Caucasian forelands involved in the warlike operations of the horse-riding nomads of the Eurasian steppe, who were acting from southern Siberia in the east to the upper Danube river in the west? And what was the role of these nomads in this region? What was the burial ritual of these Scythian people, where were their burial mounds and graveyards with all the accompanying features and structures and what did they look like?

Valuable information can be found not only beneath the great kurgans, but also in a thorough survey of their environs, the periphery of these large kurgans. Basically, we would expect to find evidence of the complex rituals that took place before, during and after a burial ceremony. In the periphery of a kurgan, we can also expect to find further burials, architectural structures, secondary burials, grave goods, offering places, as well as evidence of ceremonial acts and feasts. Finds of this kind have been reported from many sites of the Eurasian steppe belt in South Siberia, e.g., Kurgan Aržan 2 in South Siberia, and the necropolis Žoan Tobe and Tört Oba in Southeast and West Kazakhstan (Fassbinder *et al.* 2009; Gorka and Fassbinder 2011). Structures like these have been found with magnetometer surveys at the necropolis in Vinogradnyj 1 in the northern Caucasus (Fig. 1) as well as on the kurgan of Alexandropol in Ukraine.

PROSPECTION RESULTS

A cesium total field magnetometer in a duo-sensor configuration was used for the survey. It allowed us to reduce the diurnal variations of the Earth's magnetic field and thus apply the instrument in its full range of sensitivity. The crucial factor for the application of this type of

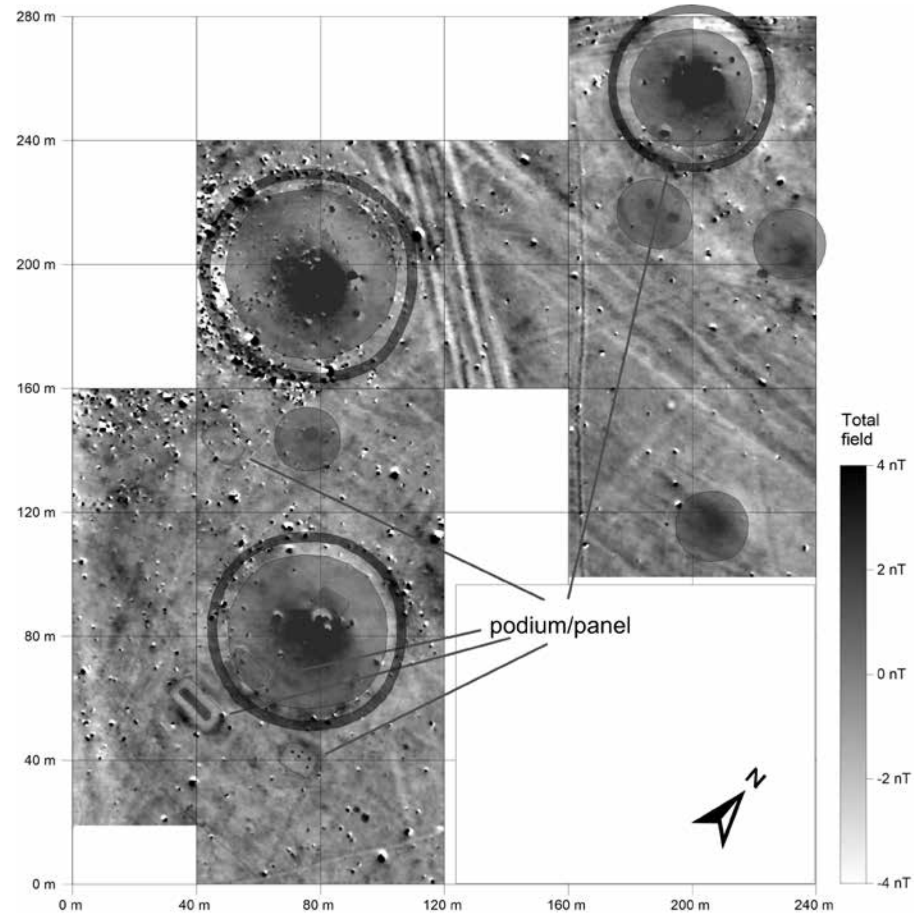

Fig. 2. Zunkar 2. Magnetic map of the early Iron Age necropolis and its environs with the interpretation map as overlay. Smartmag SM4G-Special caesium-magnetometer, sensitivity ±10 pT, variometer (duo-sensor) configuration, sampling rate 25 x 50 cm

instrument, however, is its tilt tolerance, which is invaluable when prospecting uneven and rough terrain like a kurgan field with monuments of considerable size and steep slopes.

The Zunkar 2 necropolis is composed of three kurgan rows that are aligned and directed north–south. Every row or chain of kurgans consists of at least five mounds. The largest kurgans have heights of 2.5 m to 7.0 m; they are found in the middle row, and the highest of them is at the north. All these great kurgans have a typical form with flattened dome, three steep slopes and a dip slope on the south side.

The magnetic map reveals first of all ring ditches around the kurgans, some further little kurgans and single irregular-sized pits (Fig. 2). The most interesting, however, was the finding

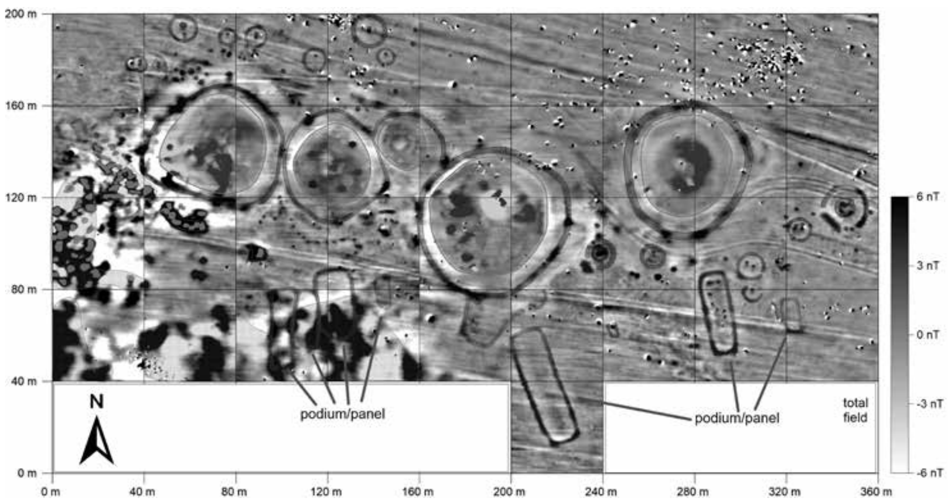

Fig. 3. Tört Oba. Magnetic map of the necropolis and its environs. Smartmag SM4G-Special caesium-magnetometer, sensitivity ±10 pT, variometer (duo-sensor) configuration, sampling rate 25 x 50 cm

of rectangular features in the south of the two great kurgans. Oriented northwest–southeast and about 10 m x 15 m and 10 m x 20 m in size, they resemble similar structures that were found in west Kazakhstan on the kurgan field of Tört Oba and Besoba (Fig. 3).

The rounded and square-shaped structures from Tört Oba and Besoba varied a great deal in size, but in orientation they pointed with the narrow side towards the kurgan, while at the Zunkar site they were all oriented broadside to the kurgan. Without exception, however, they were all to the south of the kurgans.

The excavation in Tört Oba demonstrated that the features are ritual places, were some feasting ceremonies and offerings took place. The excavated rectangular feature was 39 m x 13 m in size and can be seen in the field as a slight elevation (10–20 cm). The surrounding ditch has a depth of 1.0–1.8 m and was 1 m wide at the base. Animal bones were found in some parts. After short usage the ditch was obviously refilled with black earth. The fact that no potsherds or waste were found and that the feature was in use only for a short time points strongly to its interpretation as an offering place. The object dates to the same archaeological period as the great kurgans and radiocarbon dates provided by the Poznań laboratory point to the 7th–5th century BC (early Iron Age, early Sakes period).

Our archaeological considerations support the thesis of archaeologists, who claimed that the Scythian–Sakian culture spread from east to west.

As a result of the geophysical survey and on the basis of similarities with the layout and orientation of features from western Kazakhstan and northern Caucasus, we propose that these structures followed similar rituals and traditions representing the same culture. Our measurements in the northern Caucasus have uncovered a case of similar ritual conventions occurring independently in both regions. Further research, test excavations and case histories with similar results may clarify, confirm, or reject this ideas.

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Geophysical prospecting of the Yamnaya barrows (3rd millennium BC) from Ciorani de Jos, Prahova county, Romania

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KEY-WORDS: barrows (tumuli), Bronze Age, magnetic and electrical measurements, Cioranii de Jos

INTRODUCTION

The Titu-Sărata divagation plain, located in the east-central part of the Romanian Plain, is part of the Ialomița plain and lies between the Argeș and Sărata. It is a plain with altitudes not exceeding 20–25 m (Sandu 2011: 95), continuing to the south, the piedmont plain of the Prahova. Lithologically, fluviolacustrine deposits attributed to the Pleistocene prevail, over which Holocene alluvial and loessoid formations are deposited in sediment continuity. The microrelief comprises alluvial terraces, meadows of the alluvial lowland type, holms, alluvium banks.

In this geographic area are a number of archaeological features and standing out among them are the burial mounds (tumuli) characteristic of the Yamnaya communities, populations originating from Eurasia, occupying a vast area of 3,000 km from the Pannonian Plain to the Ural Mountains in the direction of the Caspian Sea coast and the Caucasus, dated from the late 4th to the first half of the 3rd millennium BC. In the territory of Romania, 150 tumuli have been archaeologically investigated over the years, with 13 of them located in the Piedmont plain of the Prahova (Frînculeasa *et al.* 2013a; 2013b).

Geophysically analysed tumuli lie on the left versant of the Cricovul Sărat, 2 km north of its confluence with the Ialomița, in the Cioranii de Jos village, Prahova. The first (northern) tumulus is a mound of isometric shape, 0.85 m high. The second tumulus is located 250 m south of the first, on the western edge of an erosion batter made by the Cricovul Sărat, with an uneven height of 4 m, topped by two partly deteriorated concrete topographic bollards.

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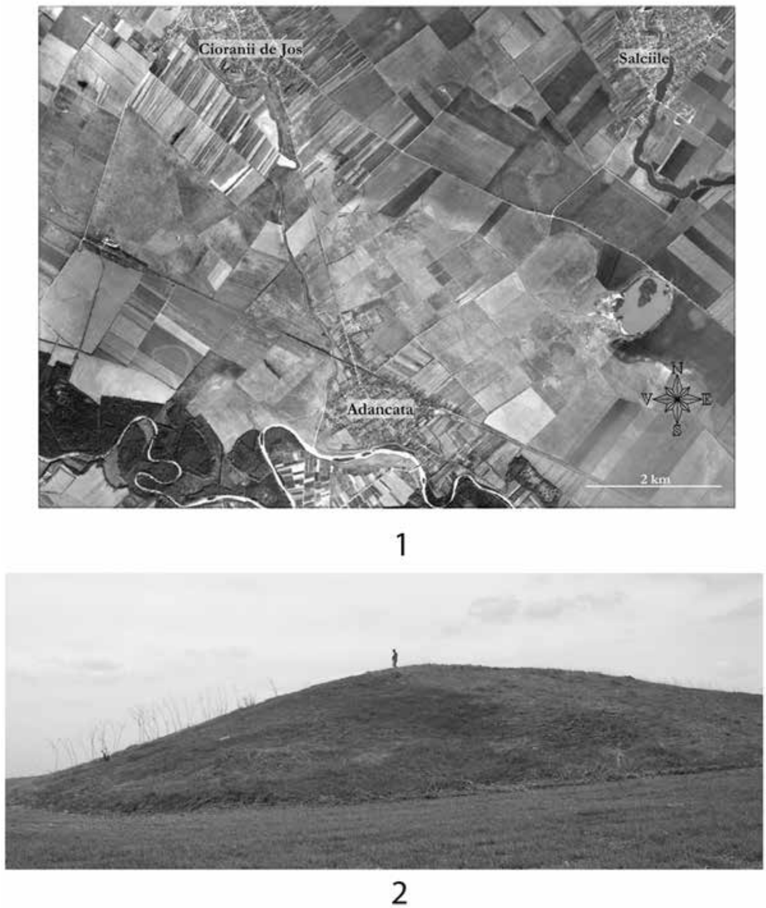

Fig. 1. Cioranii de Jos. 1 – position of the area under geophysical investigation (in circle); 2 - southern tumulus

Both tumuli are made mainly of clay loam with rounded stones. The entire area around the perimeter revealed fragmented pottery, indicating intense habitation (Fig. 1).

METHODOLOGY

Geophysical investigations consisted of magnetic measurements of the total magnetic field and Vertical Electrical Soundings (VES). Magnetic measurements were performed along NE–SW oriented profiles, consistent with the direction of furrows present only on the northern tumulus. The distance between profiles was 0.5 m, and measurements were carried out on a continuous basis, with a sampling rate of 0.5 s (4–5 samples per meter in parallel mode). GSM19W

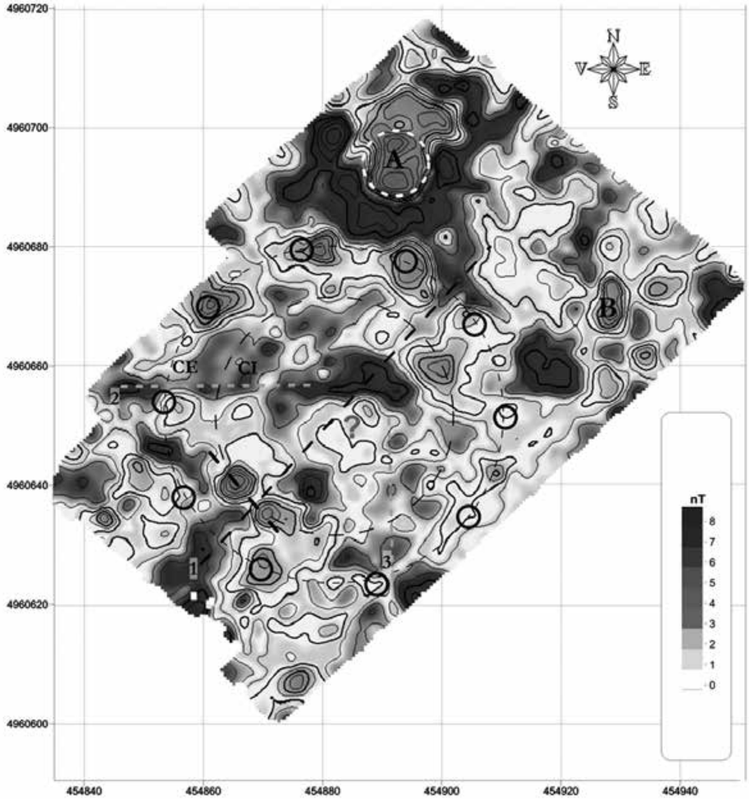

Fig. 2. Magnetic map of the northern tumulus; CE, CI – concentric circular structures identified as archaeological features, possibly remains of tumuli

Overhauser magnetometers with GPS, in base-rover system, were employed. The location of the northern tumulus was investigated in two stages as data interpretation required. First, the researched area was enlarged in order to fully investigate the perimetrical circular structure and, subsequently, to determine the intense anomaly in the northern part of the perimeter.

Diurnal variation and local anomalies were eliminated from the primary data. Low pass filters were applied to remove the effects of superficial sources and of those produced by elements of small size and reduction-to-pole calculations; calculation of the horizontal and vertical derivatives of the magnetic field and polynomial interpolations were performed.

RESULTS AND INTERPRETATIONS

The results obtained are presented as isoline maps, 3D surfaces, shaded relief maps and resistivity crossections. Magnetic investigations have revealed, in the analysis of the northern tumulus, two concentric circular structures (the outer being 55 m in diameter and the inner 40 m), marked by magnetic

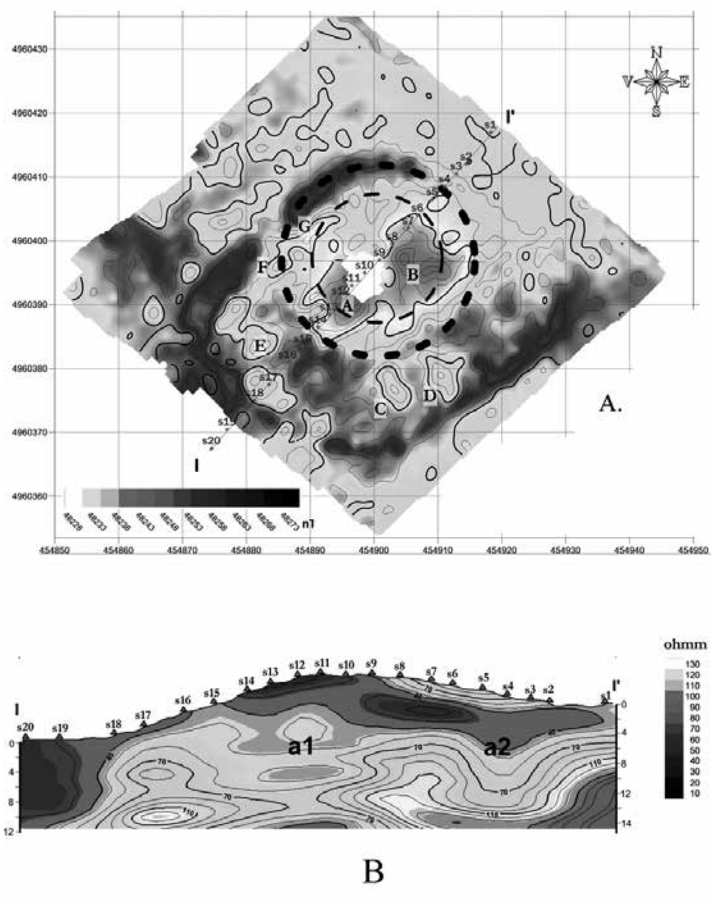

Fig. 3. Southern tumulus: A – magnetic map; B – resitivity pseudosection

anomalies of the highest values (Fig. 2). The interpretation of images present in the magnetic maps leads to establishing their symmetry with respect to a NE–SW oriented axis, 45°, and to outlining two linear areas of lowest values with E–W and N–S orientation. The latter may be ditches or access paths to the centre of the tumular structure. On the outside there are several local anomalies: in the north, an important anomaly considering the intensity and shape, which could reflect an earthen structure, 6–7 m in diameter; in the east, a group of anomalies with complex structure, implyimg the existence of several objects as a source. To the northeastern and southwestern extremity of the inner concentric structure, two pairs of anomaly maxima with a regular shape can be distinguished. Reduced intensity and shape of magnetic anomalies (interpreted as holes for fixing poles) lead to the assumption that the initial structure of the tumulus was delimited by a sun-dried wattle-and-daub structure. South of the centre of the concentric structures there is a bipolar magnetic anomaly with the positive part to the south and the negative one to the north and 18 nT intensity. It is considered to be the result of an artificial feature, the interpretation of which requires archaeological feedback.

With the southern tumulus, the magnetic map indicates, through reduced field anomalies shaped like a parallelogram, a false structure resulting from furrows made systematically in these directions around the tumulus (Fig. 3A). This structure is inscribed in a circle 30 m in diameter and is distinguished by two magnetic anomalies with amplitudes exceeding 40 nT. A second concentric structure is not well defined and is outlined based on several amplitudes of higher values. It may be interpreted as a surrounding ditch. For this tumulus, a VES profile was carried out, applying a Schlumbereger array (Fig. 3B). The profile line, running through the central part of the mound, does not correspond to its axis of symmetry. A few main characteristics can be distinguished in the cross-section: in the lower part, anomaly maxima with values exceeding 70 ohm-m, corresponding to levels of sand and gravel at the base of the natural slope; southeastward, an area of minimum of resistivity due to water-saturated meadow deposits; the presence of a resistive horizon at the top of the section, on the northeastern slope, 1.0–1.5 m thick, the result of a predominantly argillaceous impermeable layer, settled in this perimeter, and of a conductive level, with values below 30 ohm-m, which subsides from the southwest toward the northeast, located 3–4 m deep, corresponding to a sandy water-saturated level. Furthermore, electrical investigations indicated two areas where the stratigraphic sequence is interrupted, corresponding possibly in part with the magnetic anomalies; this could be in archaeological terms the burial pits of this mound.

CONCLUSIONS

Geophysical measurements of the two tumuli have revealed the presence of structures that can be identified as funerary complexes of archaeological value. This emphasises, therefore, the importance of geophysical research as a form of non-invasive investigation preliminary to archaeological excavation.

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New evidence for a Roman military camp at Virunum (Noricum)

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KEY-WORDS: GPR, MIRA, Roman camp, Virunum

The epigraphic evidence for the presence of the Roman military at the site of Roman Virunum north of Klagenfurt in Austria was known for a long time. Confirmation came during a balloon flight in the summer of 2001: distinct crop marks were discovered on the ridge to the east of the ancient town center and were interpreted as traces of a military camp, including a civilian suburb, *vicus*, to the south. The presence of a Roman military camp was further substantiated by an aerial photograph taken in 2010 and topographic data derived from Airborne Laser Scanning (ALS) (Gugl and Jernej 2013; Doneus *et al.* 2003).

The interpretation of the aerials did not answer all the questions vital to the interpretation of the facility, regarding the construction of the enclosing wall and the nature of the buildings inside it. Therefore, the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro) conducted a geophysical prospection survey in 2013. An area of about 2.56 ha was examined with a motorized high-resolution ground penetrating radar system MIRA from MALÅ Geoscience. The surveyed area was scanned at very high resolution of 10 x 5 cm within approximately three hours, focusing on the location of the military camp.

GPR data collected in the northern part of the surveyed area revealed numerous Roman buildings situated within a walled area (Fig. 1). The survey data clearly indicates that the south-eastern corner of the enclosing wall formed a sharp, right-angle and was not rounded, which is unusual for military installations of the Principate. In contrast, the corresponding south-western corner of the wall was rounded. At the same time, this preserved corner proves that the complex followed the edge of the terrace towards the north, confirming the extent of the enclosure reconstructed from ALS data, measuring 165 m by 141 m. No towers could be observed along the entire length of the enclosing wall. The only disruption is the south gate (Figs 2, 3) consisting of a simple gated passage formed by two approximately 5 m long side walls extending into the interior. An eastern gate could not be located and likely never existed. The remnants of a threshold in line with the enclosing wall and two massive foundations at the ends of the side walls were traced.

Several buildings in the south-eastern part of the enclosure support its interpretation as a military complex (Figs 2, 3), as they can be identified easily as military barracks. The building (Fig. 1: 2) that was most clearly visible in the aerials from 2010 is also the one that is the most distinct in the GPR data. The outer walls are more massive than the interior dividing walls. The total length of the building is 56.50 m; the width is 11.50 m, including a portico along the northern side. The officer's accommodation, clearly divided into several rooms, is situated on the eastern side and measures roughly 11 m by 9 m. The accommodations for the soldiers are attached on the west and comprise a 2.50 m wide portico

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Fig. 1. Interpretation of high-resolution GPR measurements conducted in 2013: 1–3 – barracks with end buildings for officers; 4–5 – barracks without end buildings; 7 – central building (?); 6, 9, 13–14 – building of unknown function; 8 – cliff with quarry; 10 – south gate; 11 – latrine; 12 – baths; 15 – channel; 16–19 – streets (© LBI ArchPro)

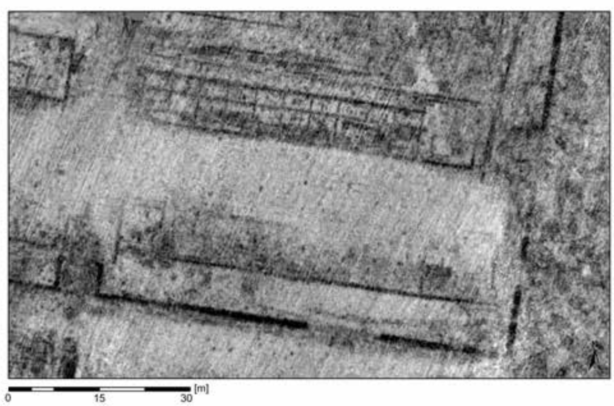

Fig. 2. Ground penetrating radar measurements of 2013, in the south-east of the walled area. Accumulated GPR depth-slices from 50 cm to 100 cm below surface level (© LBI ArchPro)

at the front, small anterooms measuring 4.30 m by 2.40 m outside and larger main rooms, approximately 4.30 m by 4.90 m on the inside. Ten *contubernia* could be reconstructed, each composed of an anteroom and a main room. Inside three of the main rooms were stone structures visible alongside the center of the dividing wall; they are interpreted as hearths or fire pits. Notably five of the anterooms show longitudinal central pits arranged parallel to the side walls. In two cases, the pits appear in pairs. These are most likely cesspits that excavations in barracks have often attributed to the cavalry.

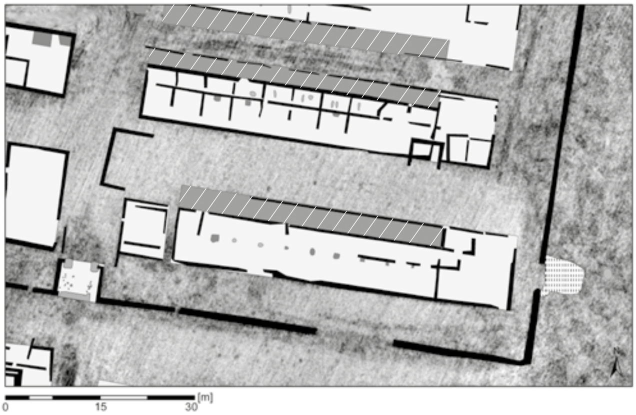

Fig. 3. Interpretation of the measurement data in the south-east of the walled area showing barracks, an earlier building, the south gate and the south-east corner (© LBI ArchPro)

Another barrack in the northern part (Fig. 1: 3) is located opposite the first one and is of the same size. It is separated from it by a 4.5–5.0 m wide courtyard, which gives access to both buildings. A third barrack of roughly the same size as the other barracks (approx. 54.50 m by 11.50 m) was identified next to the south-eastern corner of the camp enclosure (Fig. 1: 1). It is set 5.50 m further to the east, probably owing to an adjoining separate building of unknown function at the western end. The officer's dwelling is subdivided into several compartments. It was assumed that this barrack was constructed more or less in the same way as the northern barracks. Two rectangular buildings (Fig. 1: 4–5) are located north of and parallel to the three 10-*contubernia* barracks (Fig. 1: 1–3). The GPR depth-slice images indicate for the southern building (Fig. 1: 4) a similar subdivision into anterooms and main rooms. With a length of 37 m, these two barracks without evidence of porticoes are significantly shorter owing to the missing officer's billet. The south-western corner of a large central building (Fig. 1: 7) with massive walls or foundation platform is located within the survey area. The road, which ran northward from the southern camp gate, may have reached the southern front of this building. Assuming that the road reached the central building in its center, then its width could be reconstructed as 44–45 m. The continuation to the north in the forest could not be measured, but the terrain further north with its prominent rock formation (Fig. 1: 8) would have restricted the area available for construction.

Three buildings are visible in the south-western part of the enclosed area (Fig. 1: 12–14). The largest of these three is a tripartite complex measuring roughly 40 m by 16 m. A sewer runs from this building to the exterior of the enclosure wall via the supposed latrine. Because of the building layout, connection to the sewage system and close proximity to a possible latrine, it may have been a bath complex (Fig. 1: 12). A north–south oriented rectangular building (Fig. 1: 14) of unknown function and no apparent internal structures, measuring roughly 16 m by 9.5 m, is situated between the tripartite building and the road. To the north lies another east–west oriented building (Fig. 1: 13) of undetermined function, measuring roughly 18 m by 10 m. Within the enclosure, some remains of roads were detected together with evidence indicating earlier use of the site (Fig. 3).

The GPR survey also provided new evidence regarding the residential structures located outside the enclosure, starting at a distance of 8.5 m south of the enclosing wall (Fig. 1). A densely occupied residential area flanks both sides of the main road. The prospected and here described walled facility located on the eastern edge of Virunum is not a conventional imperial-era military camp. It has been suggested therefore that the military unit stationed here was attached to the governor of Noricum. *Singulares* and other military personnel assigned to the procurator, who had no strictly military duties, such as policing and surveillance, would have been billeted here.

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Magnetic prospecting on basaltic geology: the lower city of Erebuni (Armenia)

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KEY-WORDS: Urartian culture, Erebuni fortress, magnetic prospecting, basalt geology, Armenia

INTRODUCTION

The Kingdom of Urartu (about 900–650 BC) covered the geographical area of the modern countries of Turkey, Iran and Armenia and represented a mighty rival to Assyria, the realm which stretched then across almost the entire Near East, from the Mediterranean coast to Mesopotamia.

Extensive work has rendered a comprehensive picture of the monumental architecture of Urartu, above all with respect to palaces and temples. Little is known, however, of the way of life of the people of Urartu, whose houses are to be found outside of the fortified areas (Stone and Zimansky 2009). This is above all due to the fact that for this cultural area almost no landscape archaeology has ever been undertaken. Surveys and prospection were not carried out before the late 1990s and even then only sporadically. Therefore, only a few settlements have been excavated so far, e.g., Ayanis in Eastern Turkey and Bastam in Northwestern Iran. In the territory of today's Armenia, there is evidence of the remains of settlements in Argištihinili, Karmir Blur, Oshakan and Erebuni. The well-known settlements of Ayanis, Karmir Blur and Bastam date back to the reign of Rusa II at

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Fig. 1. Georeferenced satellite image (Google Earth) of Erebuni fortress, overlaid with the contour map and the magnetic map (grid size 40 m x 40 m, technical data see Fig. 3, north is at the top)

the beginning of the 7th century BC and thus to the late phase of Urartian hegemony (Stone and Zimansky 2009). In a building inscription from Ayanis, Rusa II reported that he had a fortress and a settlement built there (Salvini 2008). The settlement structures in the southern part of the fortress appear to have been professionally planned and erected. Some of the buildings are exceptionally big, which suggests that they might have been public assembly rooms (Stone and Zimansky 2001).

The town complexes of Argištihinili in the Ararat-plain and Erebuni were built somewhat earlier; the latter is situated on a hill in the southeastern urban area of today's capital Yerevan. Both towns were founded by Argišti I at the beginning of the 8th century BC, when he invaded and conquered the Ararat plain in the fourth year of his reign. While it is certain that Argištihinili remained populated until the decline of the Urartian empire, at least the administrative center of Erebuni was abandoned in the 7th century BC in favor of the newly-founded city of Karmir Blur, which was erected only 7 km to the west of Erebuni.

Argišti I had the entire town complex of Erebuni built to secure the newly-conquered area. In one of his inscriptions, it is reported that the emperor had 6600 people resettled to the new town (Salvini 2008). According to the report, the population consisted of both prisoners-of-war and of people who had been deported from the countries of Hatti and Supani in the western part of the empire to its eastern zone of influence. In the course of Soviet excavations carried out at the fortress of Erebuni from 1947, Boris B. Piotrovskij discovered (but apparently never published) corresponding remains of settlements on the eastern, southern and western hillsides. Short excavation reports describe the residential buildings as consisting of multiple rectangular units, each of which opened towards a yard paved with little pebbles (Hodjasch 1982). The

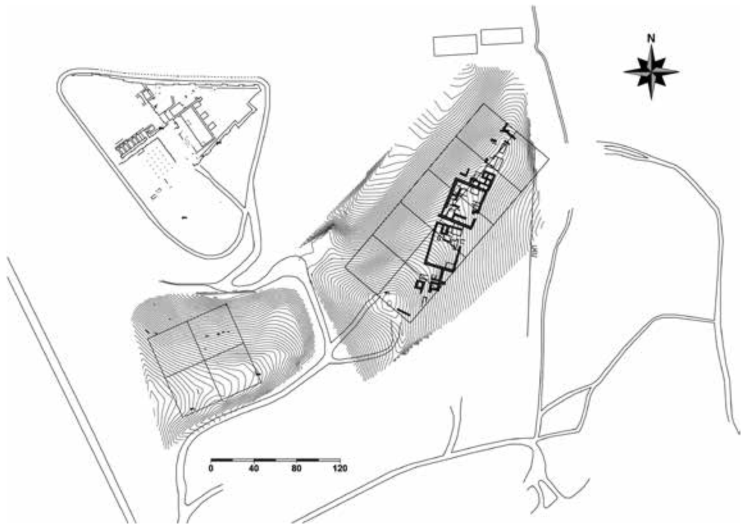

Fig. 2. Erebuni. Topographical map of the site with archaeological interpretation of the magnetic results

population at that time is thought to have been heterogeneous, since it is presumed that apart from the deported prisoners-of-war it also comprised local building workers and craftsmen. Small finds from the settlement of Erebuni provide evidence that it continued to be populated beyond the decline of Urartu until the Achaemenid era (531–330 BC).

RESULTS OF MAGNETIC PROSPECTION

Excavations on the southeastern hillside outside the fortress were carried out in 2007 within the frame of more recent campaigns at Erebuni (Stronach *et al.* 2009). With respect to the results of early trench excavations in the eastern part of the fortress by Boris Piotrovskij and surface finds on the eastern slope of the Erbuni fortress, we chose two test areas, 40 m x 80 m and 160 m x 80 m for the first magnetometer survey (Figs 1, 3). For the magnetic survey a Scintrex SM4G-Special cesium magnetometer was applied in a duo-sensor configuration with sensitivity of ±10 pT and sampling rate of 25 cm by 50 cm interpolated to 25 cm x 25 cm. The Earth's total magnetic field in Erebuni (9/2009) was 48,720 ±300 nT. The measurements on the eastern slope of the fortress revealed only some smooth geological features and almost no traces of stone architecture; however, the magnetic map on the adjacent hill, 200 m east of the fortress, exposed clearly the features of monumental house foundations, similar in size to the buildings in the fortress itself (Fig. 1). The groundwork becomes visible due to the high remanent magnetization of basalt rocks (dynamics ±300 nT), which show up the erratic directions of the remanent magnetization of the basalts (Fig. 3). The adjacent soils may contain further features, such as mud-brick walls, which, if they exist, cannot be traced beside the high magnetic anomalies of the basalts. The topsoil by contrast provides a perfectly smooth background for the stone foundations and enables a clear map to be drawn, interpreting the stone architecture (Fig. 2). The magnetic map

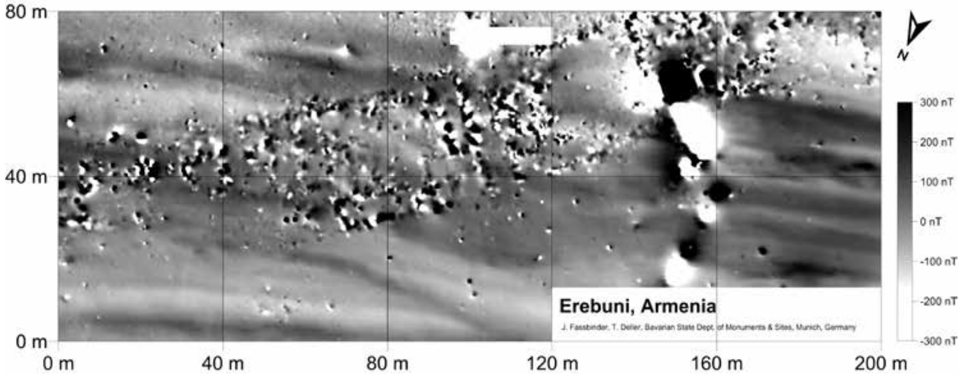

Fig. 3. Erebuni. Magnetic map of the site. Scintrex, Smartmag SM4G-Special caesium-magnetometer, dynamics ± 300 nT in 256 greyscale, sampling rate 50 cm x 25 cm, interpolated to 25 cm x 25 cm, 40 m grid, total Earth's magnetic field at Erebuni (9/2009): 48,720 ±300 nT

confirmed and complemented the results of earlier test excavations at the site. The measurements uncovered two big structures of up to 40 m lateral length, separated by an 8 m-wide corridor, which probably used to be a road. The entrances of the two buildings are on the eastern side and lead to a big yard. The ground plan is suggestive of an official building, like those in Ayanis.

CONCLUSION

The fortress of Erebuni is among the most important Urartian sites; however, archaeological excavation and research have concentrated so far mainly on the fortress itself. Very little attention has been paid to the urban hinterland of the site. Today many areas east of the fortress are still used as waste land and parts even as a waste dump. The results on basaltic geology, however, show that it is still worthwhile to undertake magnetic prospection on such complex terrain. The results can not only kickstart further research and surveys in similar conditions, but also show encouraging results that were simply not to be expected on basaltic geology. It should, moreover, encourage archaeological geophysicists to undertake magnetic surveying in similar geological circumstances.

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Automatic detection, outlining and classification of magnetic anomalies in large-scale archaeological magnetic prospection data

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KEY-WORDS: magnetic prospection, magnetic anomaly, automatic classification, automatic outlining

IDENTIFYING ANOMALIES

A process consisting of several steps has been developed for the purpose of identifying anomalies. The first step is the identification of magnetic anomalies (Fig. 1). Therefore, we detect local magnetic maxima on a spatial magnetic map. The magnetic maximum under consideration has to be greater than an interactively set threshold value (usually 1 nT) and has to be the largest value with a certain distance (usually within a circle of 1 m radius). Then the corresponding minimum of the anomaly is detected. If both a local maximum and a local minimum are found, we assign these two points to a magnetic anomaly. Then we calculate some physical and geometrical properties of the anomaly for classification purposes. These properties are the maximum and minimum magnetic values, the difference between the maximum and minimum magnetic values (magnetic strength) and the spatial distance between the position of the maximum and minimum magnetic values.

ROUGH CLASSIFICATION

Using these properties the detected magnetic anomalies are assigned to two classes. The first class comprises anomalies that presumably originate from individual objects in the very shallow subsurface. These are called "iron litter" anomalies (Fig. 2). The second class of anomalies is assumed to originate from objects located in deeper soil layers and these are classified as "pits" (Fig. 3). These two classes are not exclusive. Some of the anomalies are assigned to both classes, when the selection criterion is close to the threshold value of the classes. The

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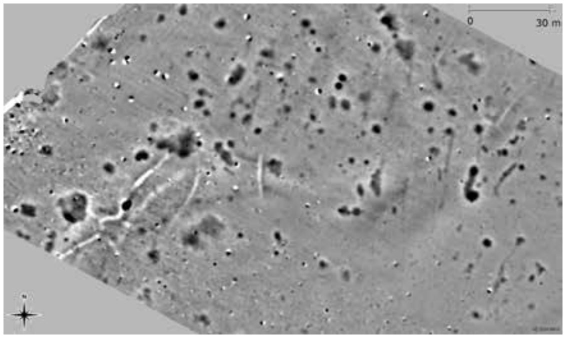

Fig. 1. Detail of a magnetic anomaly map with probably Neolithtic structures from the LBI-ArchPro case studies area Kreutal. Gray scale range, white/black: -4/6 nT

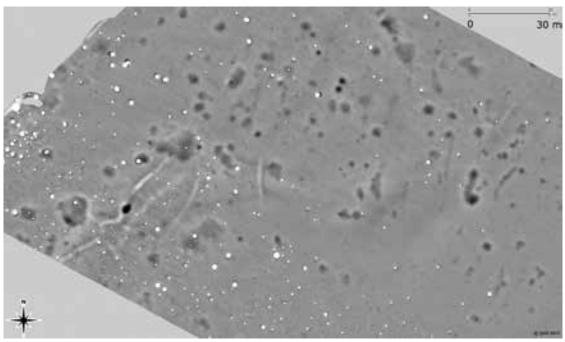

Fig. 2. Detected iron litter in white superposing the magnetic anomalies. Gray scale range magnetic map, white/black: -16/24 nT

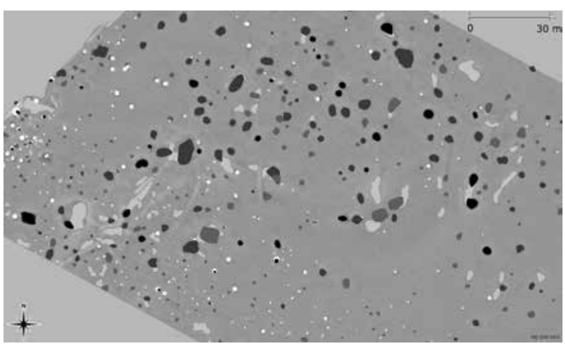

Fig. 3. Detected iron litter in white and detected pits in gray superposing the magnetic anomalies. Four classes of pits according to maximum magnetic anomaly are visualized. Gray scale range magnetic map, white/black: -16/24 nT

final classification is done in GIS using a combination of more properties than used in this first, rough classification step. The later criterion used for classification is the quotient of the strength of the magnetic anomaly and the spatial distance between the location of the maximum and minimum. If this relationship is high, the probability that the anomaly originates from iron litter is high as well. Likewise, if this quotient is small, the probability that the anomaly originates from a pit is high.

OUTLINING OF THE ANOMALIES

The detected and roughly classified anomalies are then visualized by drawing the outline of the anomaly. Therefore, a polygon consisting of 32 points is calculated, representing a virtual line of a certain magnetic value (a magnetic contour), usually drawn at 30% of the magnetic maximum. This polygon describes the location, size and shape of the detected magnetic anomaly. For each polygon further physical and geometrical properties are calculated and the polygon and its properties are written into a GIS shape-file, to be included into GIS for further classification in support of the archaeological interpretation.

The physical and geometrical properties calculated for each polygon are the maximum and minimum magnetic values, their difference, the orientation of the magnetic anomaly with respect to geomagnetic north (declination), the spatial distance between the position of the maximum and minimum magnetic values, the probability to be classified as "iron litter", the size of the area defined by the polygon, the perimeter of the polygon, the maximum length and width of the polygon, the relation between length and width, the orientation of the length axes and a value that describes the circularity of the polygon. Additionally some statistical properties of the magnetic values within the polygon are calculated. These properties are the difference between the highest and lowest magnetic value within the polygon, the mean value and the stan-dard deviation of all magnetic values within the polygon, the relative number of values higher than the half-value of the maximum value and the number of local maxima within the polygon.

INTERPRETATION WITHIN A GEOGRAPHICAL INFORMATION SYSTEM

The generated shapes and computed properties of the automatically detected magnetic anomalies are subsequently analysed, classified and interpreted in the GIS framework. The intelligent combination of selected properties can be used for a comfortable and efficient detailed classification of the anomalies in GIS. For instance, a refilled posthole on the one hand usually has a small corresponding magnetic anomaly, a circular polygon with a small diameter, a magnetic orientation to the north and a homogeneous magnetic anomaly (a small standard deviation of the anomalies within the polygon). A *Grubenhaus* on the other hand generally displays stronger, inhomogeneous magnetic values, a larger, rectangular shaped polygon of a certain (often known) size, (often) a known ratio of length to width, often a certain orientation and a low degree of circularity. All these properties can be parameterized in GIS and therefore used an automatic anomaly classification.

The described approach considerably speeds up the archaeological interpretation process when dealing with large quantities of high-resolution prospection data. The drawing of the outline of the anomalies and the calculation of all the corresponding properties is a fully automated, very fast process. By using an intelligent selection and combination of ranges of appropriate properties, it is possible to generate a detailed data classification. The number of anomalies to be interpreted is not important anymore; it is almost as much work applying this classification approach to 100 as to 1 million anomalies. Furthermore, this automated classification approach is objective and comprehensible.

The interpreting archaeologist is not only unburdened from very time-consuming drawing tasks, but he or she is also automatically provided with a large amount of additional, objectively derived information and classified anomalies with meaningful properties, aside from mere data images and visualizations of magnetic anomalies. By relieving the interpreter through the here described approach, more valuable time and effort can be spent on the actual understanding and archaeological interpretation of the underlying structures that express themselves through the prospected magnetic anomalies.

Archaeological prospection of kiln sites in the Samurai era

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KEY-WORDS: kiln, magnetometry, ground penetrating radar, electric resistivity, electromagnetic method

INTRODUCTION

The purpose of this study is to examine the possibility and effectiveness of archaeological prospection for detecting ceramic kiln sites from the Samurai era using geophysical remote-sensing equipment. The Samurai was a class of military nobility that ruled Japan during the medieval and early modern periods.

In the Samurai era, there were significant developments in ceramic production and technology. These developments had a global influence, particularly in Europe, where Japanese pottery was highly appreciated.

The authors have studied pottery production and distribution from diverse archaeological perspectives, including excavation and pottery reconstructions. However, acquiring data to assist in reconstructing the design of archaeological kiln sites is difficult. A great many kiln sites have been demolished, and the type and structure of the kilns cannot be identified by simple surface observation. The authors believe that employment of geophysical prospection methods is proving to be an effective method to help discover and reconstruct the details of historical kiln sites (Kaneda and Nishimura 2007; Nishiguchi 2012: 16–20).

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Fig. 1. Location of the Naeshirogawa and Ookaya kiln sites where geophysical surveys were conducted

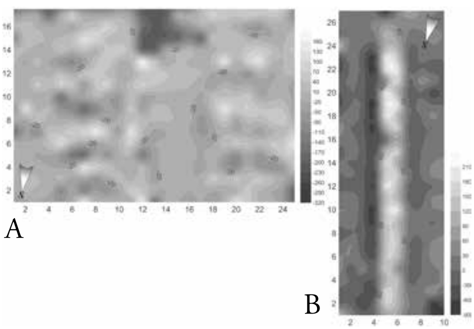

Fig. 2. Magnetometry survey results of the Naeshirogawa kiln sites (sites: A – Nankin Sarayama; B – location of B-2 kiln)

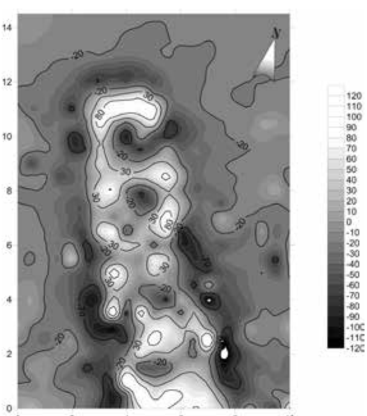

Fig. 3. Magnetometry survey result of the Yashichida kiln site

SURVEY AND RESULTS

This article introduces results from two well-known archaeological kiln sites in Japan (Fig. 1), the Miyama Naeshirogawa kiln sites (Kagoshima prefecture, southern Japan) and the Ookaya kiln sites (Gifu prefecture, central Japan).

Naeshirogawa kiln sites

Satsuma pottery was produced at the Naeshirogawa kiln sites in the Kagoshima region from the 17th century AD and was known for its raised enamel design on the vessel surface. The Archaeological Laboratory at Kagoshima University conducted a ground survey of the area in 2006. They collected various data about the sites in addition to detailed topographic maps indicating the presence of anomalous elevations at certain locations. Many of these elevation changes are thought to have been caused by human activity related to kiln sites that had been demolished, eroded and buried over the years. Kagoshima University and the Nara National Research Institute for Cultural Properties undertook joint archaeological prospection and excavation in 2008–2009 (Watanabe 2012). These studies incorporated geophysical surveys employing FM-36 fluxgate magnetometers (Geoscan Research). Data were recorded with a spatial resolution of 0.5 m. Two anomalies, one long elliptical shape and one ladder-shaped, were recorded at this site. The authors interpreted these subsurface anomalies as reflecting the remains of magnetised floors from one type of kiln (Fig. 2). The long elliptical anomaly corresponds to a long, single-chamber, inclined kiln called the "Tanshitu Nobori Kama". This specialized kiln does not have a barrier separating the combustion chamber and firing chambers, the two being located together.

A second uniquely designed kiln is interpreted from the ladder-shaped anomaly and this is believed to correspond to a "Renboshiki Nobori Kama" kiln, which is characterized by consecutive chambers built on an incline, having their combustion chambers and several additional firing chambers separated by walls. The magnetometry result suggests that the ladder-like anomaly is related to the thermoremanent alteration of the magnetic field stored in the kiln walls. Based on these considerations, we conducted an archaeological prospection and partial excavation of the Nankin Sarayama kiln, which is representative of the Naeshirogawa kiln sites. The magnetometry data clearly indicated that there were two consecutive-chamber kilns present in the study area (Kaneda and Watanabe 2009).

Ground penetrating radar (GPR) and electrical resistivity were among the other methods employed in the archaeological prospection. A SIR-3000 data acquisition system (GSSI, USA) with a 400 MHz antenna was used for GPR survey. Data were recorded with survey lines at 0.5 m intervals. The GPR survey shows a ladder-shaped reflection similar to that on the magnetic map. The GPR survey strongly suggests the remains of a single-chamber inclined kiln adjacent to the two-consecutive-chamber inclined kiln.

The electrical resistivity method used a Handy-ARM (OYO, Japan) with 32 electrodes. The electrical resistivity survey shows high resistivity anomalies at the same location where the strongest magnetic anomalies were recorded. Targeted archaeological excavations were conducted, using the geophysical prospection results and they confirmed that the ladder-shaped anomaly was in fact due to a consecutive-chamber inclined kiln.

Ookaya kiln sites

Shino ware was a famous Japanese kind of pottery that was highly valued in Samurai society and was made at the Ookaya kiln sites in the 17th and 18th centuries. These ceramics were typified by white glazes made of feldspar and were manufactured in what is known today as the Gifu prefecture. Local government researchers have identified nine production locations; however, their existence and the actual position of the kilns have to be sufficiently established. In 2012–2014, the Nara National Research Institute for cultural properties and the Kani City Board of Education undertook archaeological prospection to find undiscovered kilns (Kaneda *et al.* 2014). A fluxgate magnetometer FM-36 (Geoscan Research, UK) was employed. Data were recorded with a spatial resolution of 0.5 m. The results indicated that there were six kilns in the survey area. The Yashichida kiln, which is located in the northern part of the Ookaya kiln site, was recognized in a ladder-shaped anomaly on the magnetic map (Fig. 3). GPR and electromagnetic (EM) methods were used. GPR used a SIR-3000 with a 400MHz antenna. Data were recorded with survey lines at 0.5 m intervals. The result of the GPR survey showed a ladder-shaped reflection; however, the strong reflections are wider than those found at the Naeshirogawa sites. In addition, pieces of the kiln body were found scattered on the ground surface around the target area. The authors believe that these data show the upper part of the kiln was destroyed and only the floor of the kiln remains buried and intact.

The EM method used a CMD Mini-Explorer (GF Instruments, Czech Republic)(Bonsall *et al.* 2013). Data were recorded with a spatial resolution of 0.5 m. The results of the EM survey show both the quadrature (apparent conductivity) and in-phase (apparent magnetic susceptibility) components of the kiln.

CONCLUSION

The recent accumulation of archaeological prospection results has provided new information about kiln type and condition, in addition to confirming the existence and number of kilns. This information can support not only future archaeological studies, which employ non-destructive methods when investigating historical kiln sites, but also cultural resource management policies.

ACKNOWLEDGEMENTS

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Archaeological excavation and GPR prospection in delineating defensive embankments on Ostrów Tumski (Cathedral Island) in Wrocław (Lower Silesia, Poland)

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KEY-WORDS: Lower Silesia, Wrocław, Tum , Cathedral Island, medieval stronghold, GPR

Several islands existed in the Oder river valley at a point where five small tributaries joined the main river, on the spot of present-day Wrocław. A convenient river crossing at this location fostered settlement on the islands. In modern times, particularly in the 17th and 18th centuries, sophisticated fortification systems were constructed, resulting in the backfilling of the broads. Urban development began in the 19th century. The preferred site for settlement was Ostrów Tumski (Cathedral Island). A stronghold was built there in the first half of the 10th century and within its walls a church and later Cathedral.

Archaeological excavations have been carried out on Tum Cathedral Island for almost 100 years. The data have been used to build a number of models of the architecture and fortifications (timber-and-earth embankments), but researchers are not agreed on the exact location and evolution of these defenses. Excavations between streets Kanonia, Kapitulna, St. Idzi and Katedralna uncovered remains of timber-and-earth defensive embankments in three places (Fig. 1). Beams making up the substructure were reinforced with hooks in the faces (Fig. 1: A, B, C). They were set in pairs, the beams slightly more than 1 m apart, the paired beams spanning a distance of 1.8 m to 2.5 m. Logs 30 cm in diameter, from 3 m to 6 m long, were placed lengthwise, supported on the hooks. Parallel to the outer face of the rampart marked by the logs, at a distance of 2.8 m, a row of wooden battens, rectangular in section and measuring 15 cm by 6–7 cm, were driven into the ground. They formed an openwork wall, possibly plaited together above eyelevel. Cut logs about

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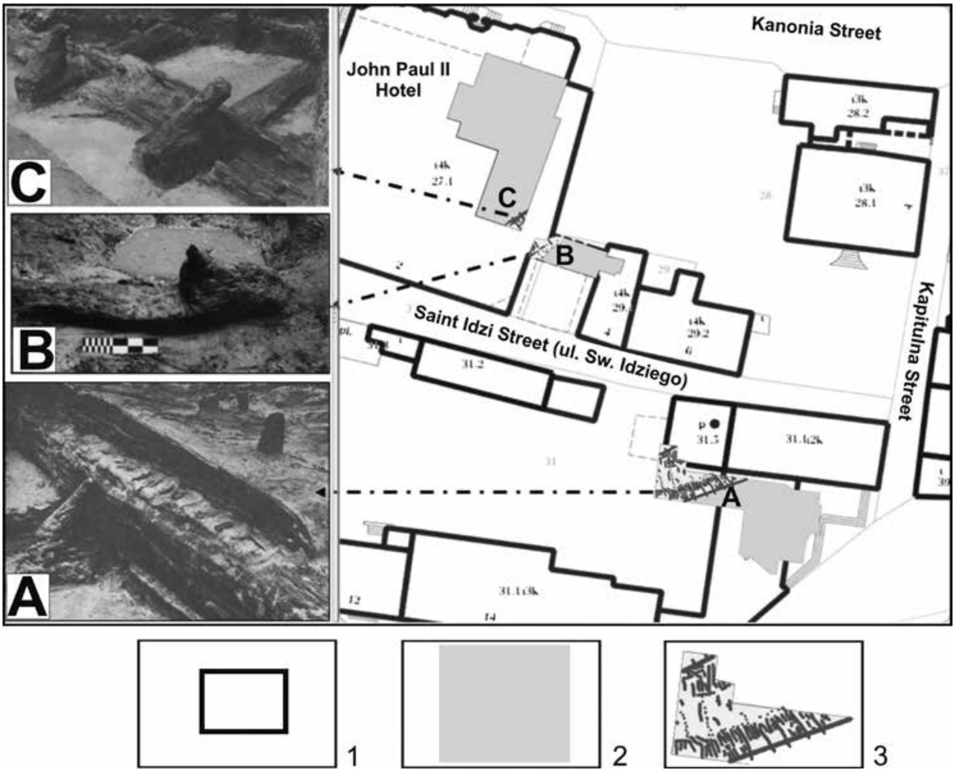

Fig. 1. Ostrów Tumski (Cathedral Island) in Wrocław. Relics of medieval defensive embankments seen in the archaeological trenches. 1) extant buildings; 2) archaeological trenches; 3) medieval defensive embankments in the trenches: A – wooden structures at the base of the southern embankment; B – wooden structures on the inner side of the northern embankment; C – wooden structures on the outside of the northern embankment

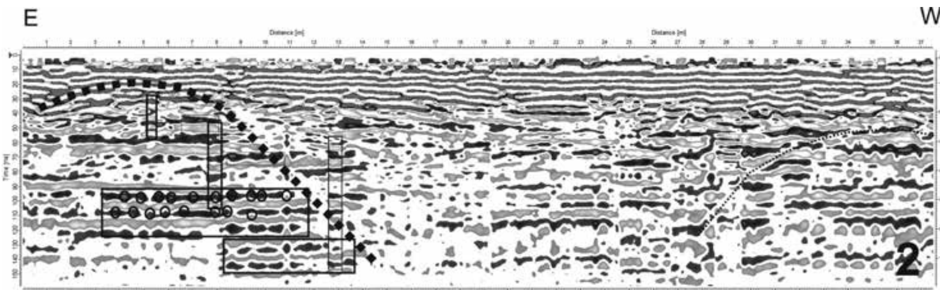

Fig. 2. GPR cross-section through the island: 2. Interpretation: dotted line – embankment, rectangle – wooden structures, circles – echo of wooden beams in the embankment

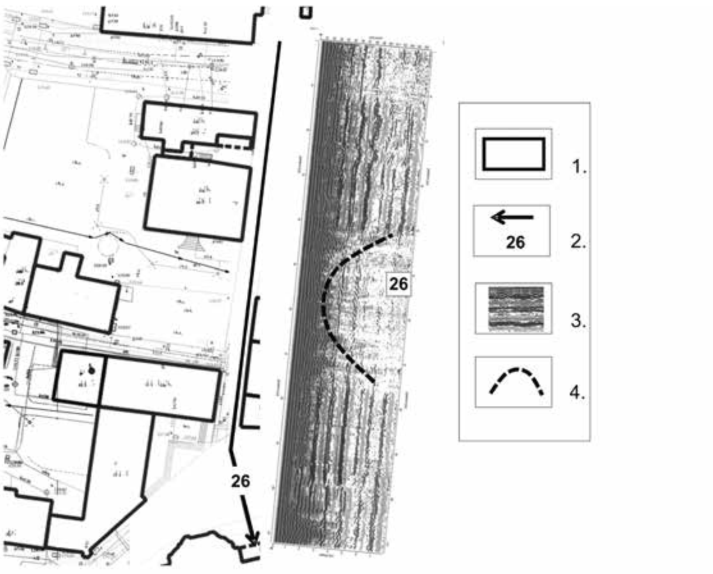

Fig. 3. Example of a GPR section (26), showing the structure of the timber-and-earth embankment. 1) extant buildings outlined on the city map; 2) location of the given GPR cross-section on a map of the city; 3) GPR cross-section; 4) timber-and-earth embankment

Fig. 4. Section of the city map showing Ostrów Tumski (Cathedral Island) in Wrocław. Outline of one of the medieval timber-and-earth embankments from the first half of the tenth century, projected on the basis of archaeological and GPR research. 1) extant buildings; 2) archaeological trenches; 3) relics of medieval defensive embankments in the archaeological trenches; 4) location of individual GPR cross-sections and their numbers; 5) location of timber-and-earth structures on the GPR cross-section; 6) projected outline of timber-and-earth embankment

1.5 m long were placed crosswise in the intervening space, the first layer alongside the openwork wall, the free space to the rampart filled with a layer of sand. In the next layer, the wooden logs were placed over the sand, resting against the long logs in the face of the rampart. This arrangement was repeated, raising the structure. The core of the embankment was filled with sand. Inside, there were vertical logs crosswise and lengthwise, as if framing empty chambers. A flat foreground 4 m wide was formed in front of the embankment; it then dropped almost a meter to the edge of a ditch (moat?) reinforced with pegs and fascine. Dendrochronological analysis of the hook beams from the substructure indicated that the timber came from trees felled not later than in 940.

A GPR survey was carried out between the trenches. The sections were located in the area of the excavated embankments, avoiding relics of prewar architecture and engineering infrastructure, and tree roots wherever possible. A RAMAC/GPR apparatus with 250 MHz shielded antennas was used for the prospection. The data were collected for a depth of 8 m underground, supplying information on the geological structure. The timber-and-earth embankment was recognized in a few places of the GPR sections, including wooden structures and in places also the beams in the rampart core (Figs 2, 3). The GPR results were mapped and analyzed together with the results of the excavations to project the line of the defenses. Since it proved impossible more often than not to connect the parts of the embankment detected in individual GPR sections, it was assumed that the relics represented a number of independent rings of defenses, possibly from different periods in the development of settlement on the island and possibly not interconnected. Indeed, the ramparts could have been superimposed.

The present article concentrates on tracing the line of only one of the embankments (Fig. 4), contributing to a new image of the early defenses surrounding Wrocław's Cathedral Island.

Non-invasive research on medieval strongholds in Silesia. Case studies from Borucin (Silesian province) and Chrzelice (Opole province)

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KEY-WORDS: Silesia, medieval period, stronghold, magnetometry, airborne laser scanning, LiDAR, aerial photography

A non-invasive research project on selected Silesian medieval strongholds commenced in 2013. Its primary objectives were the identification of the sites and an assessment of their current condition. To achieve this goal, data and methods typical of landscape archaeology (Aston 1985: 13–20; Rippon 2004; Chapman 2009: 27–35), such as old analysis of cartographic records, aerial photography, satellite imagery and airborne laser scanning, were used. To a large extent, the research relied on archival data collected for various purposes by different institutions. Fieldwork

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involving surface surveys and geophysical prospection (using a Bartington Grad601-2 gradient magnetometer; data collected in zigzag mode, reading resolution 0.125 m x 1 m: data processing DW Consulting TerraSurveyor 3.0.22.1 software) was also conducted successively.

The project postulated the development of a universal, swift, affordable and effective research methodology, which could be employed in heritage management practice, facilitating the recognition of site extent and degree of preservation.

Since evaluation of the proposed research scenario was a project priority, the selection of study sites followed no special criteria; on the contrary, the diversity of the research sample was seen as an asset. The selected strongholds differ in terms of function, form, size and chronology, implying different models of spatial organization and construction solutions. The research targeted poorly investigated and heavily destroyed sites, where the relief was obliterated almost completely owing to the intensity of agricultural practices.

BORUCIN (SILESIAN PROVINCE, KRZANOWICE COMMUNE), SITE 2

The stronghold is located between the villages of Borucin, Bojanowo and Bieńkowice in the Cyna (Psina) valley, which is over 1 km wide in this area. Nearly the whole width of the marshy valley is cut by palaeochannels; their complex system is clearly visible in LiDAR data (Fig. 1a, b, d). The vast terraces were meliorated in the 19th century and are currently used as arable fields. One of the old channels, used perhaps as a mill race, cuts through the eastern and southern parts of the site, damaging a section of the fortifications.

The maidan was rectangular in plan with rounded corners. It was surrounded by an inner moat, a rampart and an outer moat, circular in shape and measuring approximately 120 m in diameter. An active bend of the watercourse was probably adapted as the southern and western segments of the moat (Fig. 1b–d). The stronghold is dated to the 13th–14th century AD (Hellmich 1930; Fock 1942).

The magnetic prospection covered an area of 2.5 ha limited on the south and west by a modern channel (Fig. 1c, d). The most interesting anomalies were recorded within the central mound area. Two distinct clusters of high-value readings and dipole anomalies were detected in its north-western part, indicating the existence of buried foundations, cobblestones or rubble (Fig. 1d:A). Both clusters have regularly rectangular shapes, the sides roughly 12–15 m long, oriented according to the maidan outline. In the central part of the mound, a square-like contour was also identified (Fig. 1d:B), supposedly pointing to the presence of building foundations (tower?). Linear anomalies identified along the maidan mound (Fig. 1d:C) may be evidence of a strengthening of its edges (e.g., with a retaining wall).

The rampart and moats surrounding the maidan were quite poorly visible in the magnetic map s. The only distinct anomalies were detected in the northern part of the rampart perimeter (Fig. 1d:D). It seems possible that the construction of this segment may have been intentionally strengthened with larger amounts of magnetic susceptible materials or was burnt, which would also result in enhanced magnetic readings.

No anthropogenic features were identified in the partly investigated surrounding area; however, numerous natural structures were recorded (e.g., linear, meandering anomalies tracing the old river network).

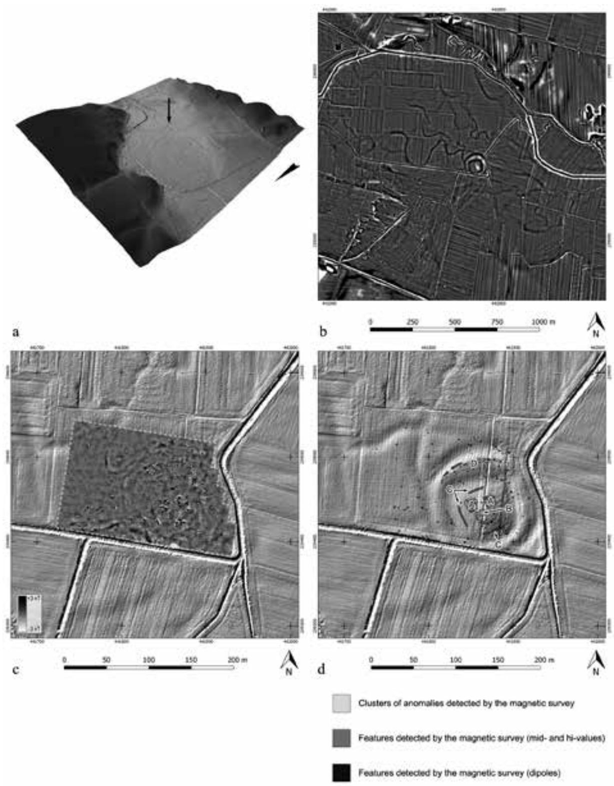


Fig. 1. Borucin (Silesian Province), a - 3D-view of the Cyna (Psina) valley based on ALS data, b - Local Relief Model visualization of the Cyna (Psina) valley, c - results of the magnetic survey, d - interpretation of the magnetic survey results

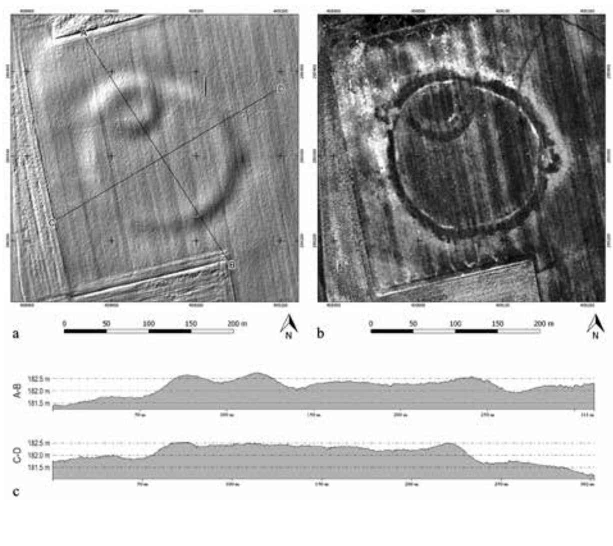
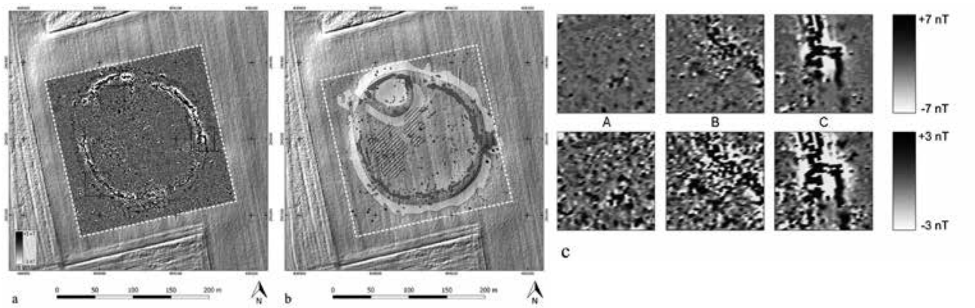


Fig. 2. Chrzelice (Opole Province), a - hillshaded model, b - aerial photograph, c - cross sections of the site



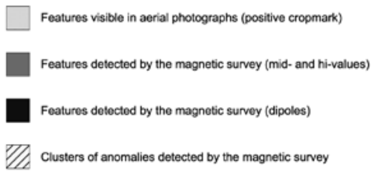


Fig. 3. Chrzelice (Opole Province), a - results of the magnetic survey, b - interpretation of the magnetic survey results, c - results of the magnetic survey (details)

CHRZELICE (OPOLE PROVINCE, BIAŁA COMMUNE), SITE 1

The stronghold is located between the villages of Chrzelice and Pogórze, about 400 m west of a nameless watercourse. Its position in the landscape — on a slight elevation in a wide meltwater valley — is quite typical of early medieval sites of this type. The feature has a ringed form with two segments: a stronghold and an adjacent *suburbium*. The smaller, acropolis segment located in the north-western part of the site was semicircular in plan. A modest, somewhat depressed maidan was surrounded by a rampart and a moat. The diameter of the outer perimeter of these earthworks measured roughly 90 m. Immediately adjacent to its south-eastern part was the *suburbium*, surrounded by a fortification with a semicircular outline and approximately 220 m in diameter. The stronghold is broadly dated to the Tribal and early State periods (8th–11th AD) (Hellmich 1930: 47; Bagniewski 1967: 26; Kaźmierczyk, *et al.* 1977: 359–399; Macewicz 1997; 2000; Gorgolewski and Tomczak 1996: 28–29; Mackiewicz and Myślecki 2014).

At present the site has been heavily destroyed by intensive agriculture and the earthworks are not visible in the field. The differences in elevation between the bottom of the moat and the top of the ramparts do not exceed 50–70 cm as a rule (Fig. 2a, c). The form of the feature is best readable in visualizations of airborne laser scanning data and in aerial photographs (Fig. 2a, b).

The magnetic prospection covered an area of 4.51 ha. A number of anomalies revealing the construction details of the fortification and providing certain information regarding the spatial arrangement of the feature were recorded (Fig. 3a).

The presence of linear anomalies aligned with the ramparts (Fig. 3a, b) indicates the use of construction materials of high magnetic susceptibility (e.g. stone). It is worth noting that stone was used as building material only in the outer (perimeter) part of the fortifications. The segment of the acropolis rampart which was an inner partition was an earthen or a timber-and-earth structure.

Two entrance gates interrupted the course of the earthworks in the eastern and south-western parts of the *suburbium*. They were symmetrically placed in relation to an axis running through the centre of the acropolis and suburbium. The south-western gate belongs to the tunnel type (Fig. 3a:B, 3c:B); it was slightly trapezoidal and narrowing towards the interior of the feature. The eastern entrance extended bay-like outside the perimeter of the rampart, perhaps including a tower (Fig. 3a:C, 3c:C). At present, the ramparts in its vicinity are characterized by the highest elevation in relation to the surrounding terrain, suggesting that they used to be higher and more massive in that part.

The geophysical prospection only vaguely indicated the presence of a moat, the results characterized by a 'magnetic cleanness'. The outline of the feature was revealed based on vegetation marks seen in aerial photographs and LiDAR visualizations. This stresses the necessity of combining different research methods during similar non-invasive studies.

Clusters of small anomalies strewn across large surfaces were detected in the suburb, for example in its south-eastern part (Fig. 3a, b). Their character may indicate the presence of a utility zone associated with activities that left behind significant amounts of material of high magnetic susceptibility. The extent of this zone also corresponds to a concentration of pottery on the surface of the site. Small-scale excavations conducted in 1996 demonstrated the involvement of the *suburbium* residents in metallurgical production (Macewicz 2000: 102). It seems probable that the abovementioned anomalies are related to these activities and the elevated magnetic readings were caused by significant amounts of burnt clay and slag present in the soil.

The geophysical prospection did not clearly indicate the presence of residential, farm or economic structures. Large, rectangular anomalies characteristic of sunken buildings were not detected. However, it seems possible that the constellations of parallel and perpendicular linear readings represent the relics of foundation trenches of aboveground buildings or accompanying structures (Fig. 3a:A, 3c:A).

SUMMARY

By combining spatial data with the results of geophysical prospection it was possible to create a complex picture of the studied sites. New information regarding their extent, form, building materials and spatial organization was acquired.

The proposed procedure turned out to be very cost-effective and efficient, and the methodology quite universal, making it a perfect tool in heritage management practice. It enabled both an assessment of the present condition of the site and the identification of possible hazards, allowing adequate measures to be taken in terms of monument protection.

Geophysical prospection was the main component of the fieldwork. In both presented cases, it was expected that the magnetic method would deliver the most comprehensive results. More information can surely be obtained by integrating additional non-invasive prospection techniques into the procedure. This will also bring a better understanding of the detected magnetic anomalies.

ACKNOWLEDGMENTS

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Distribution of gold and silver in European soils: evidence for a Roman footprint?

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KEY-WORDS: soil geochemistry, MMI, Roman gold and silver

The recently completed low-density soil geochemistry survey of Europe (approximately one sample per 2500 km^2) entitled Geochemical Mapping of Agricultural Soils (GEMAS) has produced distribution patterns for a number of elements by a number of analytical techniques (Reimann *et al.* 2014). These include XRF, aqua regia (AR) digest and Mobile Metal Ion (MMI) geochemistry. MMI is a single-solution, high-resolution, soil-extraction geochemical technique (Mann 2010), which has been employed to detect and define, in exotic overburden, metal anomalies derived from buried mineral deposits for more than a decade. Commercially available, it is widely used in mineral exploration. By preferentially accessing the recently active, mobile form of elements, it also has advantages in delineating anthropogenic soil anomalies (Mann *et al.* 2014). The technique, which utilises Inductively

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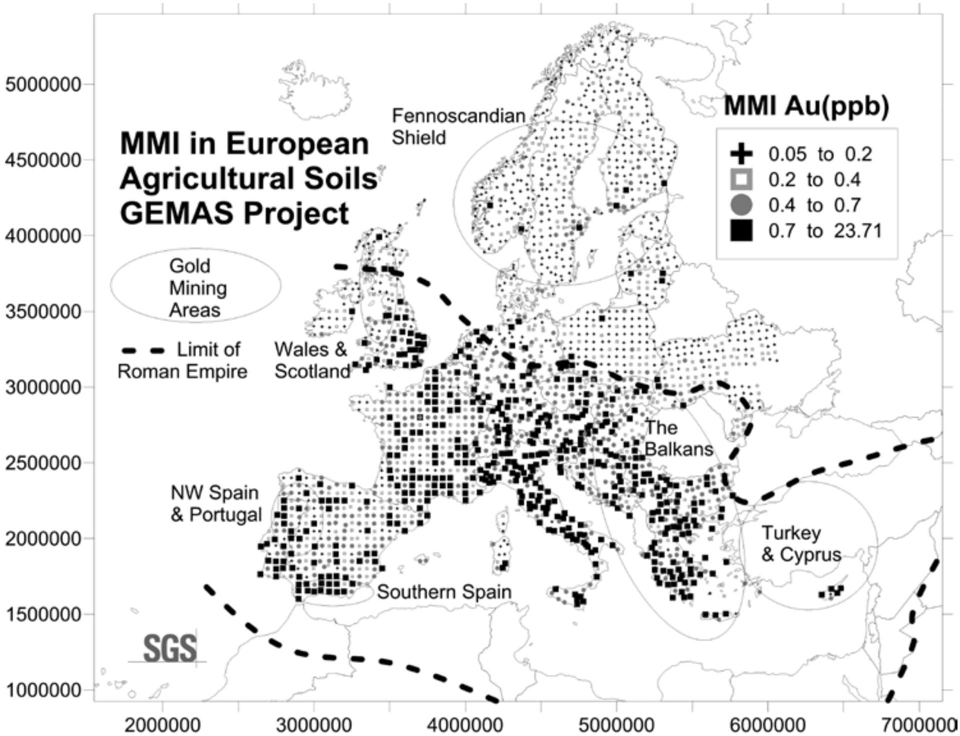

Fig. 1. Distribution of Au in European agricultural soils after MMI analysis and extraction (sample sites are depicted using MMI Au quartile symbols; there are approximately 500 samples in each quartile)

Coupled Plasma Mass Spectrometry (ICPMS) is very sensitive; it has a lower detection limit (LDL) of 0.1 part per billion (ppb) for Au and 1ppb for Ag. Gold values in soil of 0.5ppb and above (>five times LDL) are considered anomalous.

The GEMAS map with MMI Au values arranged in quartiles shows (Fig. 1) a distribution pattern in which most of the upper 25 percent of values (>0.7ppb Au) depicted by large black squares is located in the southern half of Europe. With few exceptions they lie south of the northern limit of the extent of the Roman Empire, shown as a dotted line in Fig. 1. Values to the north of the northern limit of the Roman Empire are predominantly lowest quartile (shown as small crosses). The highest value recorded, 23.7ppb, is from close to the Roman mining district of Mirandela in Portugal, but high values are not confined to the gold-mining districts (shown as ellipses). In southern Italy, which includes Rome and Naples, 34 out of 47 (=72%) of GEMAS soil sites have Au>0.7ppb.

High values of gold occur in areas of highest historical population densities — central Europe including western Germany, the Netherlands, northern and western Italy and central Britain. Northern Germany and Denmark have high population densities, but not high values of gold in soil. Roman occupation of Europe effectively ended at the river Rhine in central Europe and at the Scottish border, although some trading did occur north of these boundaries. Redistribution

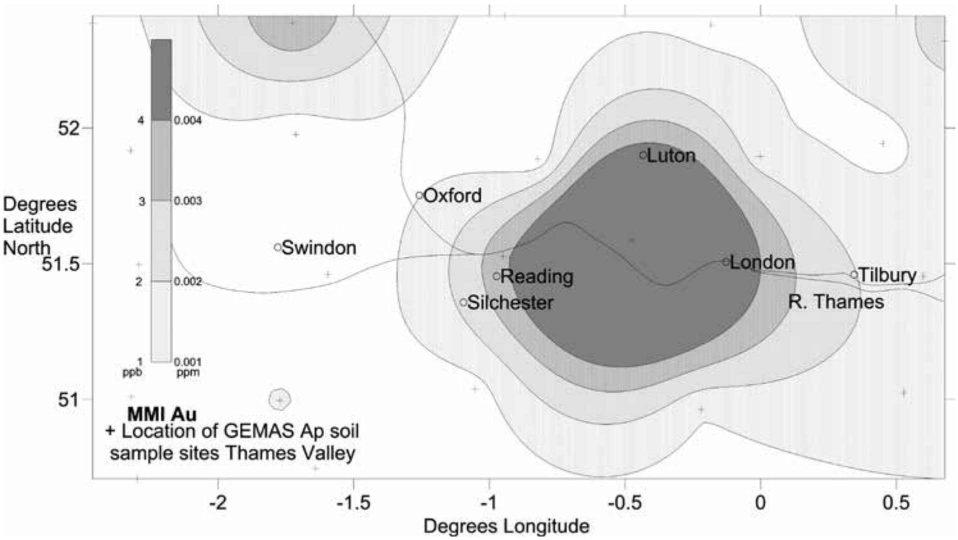

Fig. 2. Contour map of GEMAS MMI Au data in agricultural soils in the vicinity of London

of gold and silver by anthropogenic activity has taken place over at least two millennia, from the time of Roman occupation of Europe (and earlier) to the present day.

It has been estimated that between AD 100 and 300 the Romans mined between five and ten tonnes of gold per annum (see: *www.goldavenue.com*). Were this case, the Romans conservatively mined on the order of five x 200=1000 tonnes Au = one million kg Au in all. The area of the Roman Empire is approximately 2.75 million square kilometres, so this equates to approximately 0.35 kg (=350 g) Au per square kilometre of Empire, or 0.035 g (= 35 mg) Au per square metre (if it were evenly distributed, which of course it was not) — not an insignificant amount.

A 20 cm deep layer (the depth over which the samples were taken for the GEMAS survey) of soil one square metre in area contains approximately 350 kg soil. Given that soil has a density of between 1.5 and 2 (an average of 1.75 gm/ml), 35 mg Au per square metre of soil amounts to a soil concentration of the order of 35/350=0.1 mg/kg = 100 ppb Au, if all Roman mined gold is attributed to this layer. Clearly not all Roman mined gold has returned to the soil; if a 1% attrition and distribution rate is applied, a concentration of one ppb, comparable to the observed MMI upper quartile limit of 0.7 ppb Au is obtained for this layer. This suggests that a significant amount of the gold measured in present day soils could have been derived ultimately from Roman sources.

Silver shows a similar distribution pattern in European soils. The highest value for Ag in soil from the GEMAS study is 1340 ppb from southern Spain, an area which has been extensively mined for silver and gold since at least Roman times. The second, third and fourth highest values, 973 ppb, 664 ppb and 629 ppb are from Italy, London and Paris — all non-mining areas. Silver was used more extensively than gold in Roman coinage.

One of the most interesting outcomes of the GEMAS study with respect to gold is that the third and fourth highest Au values, 12.1 ppb and 11.4 ppb respectively are from the soil samples closest to

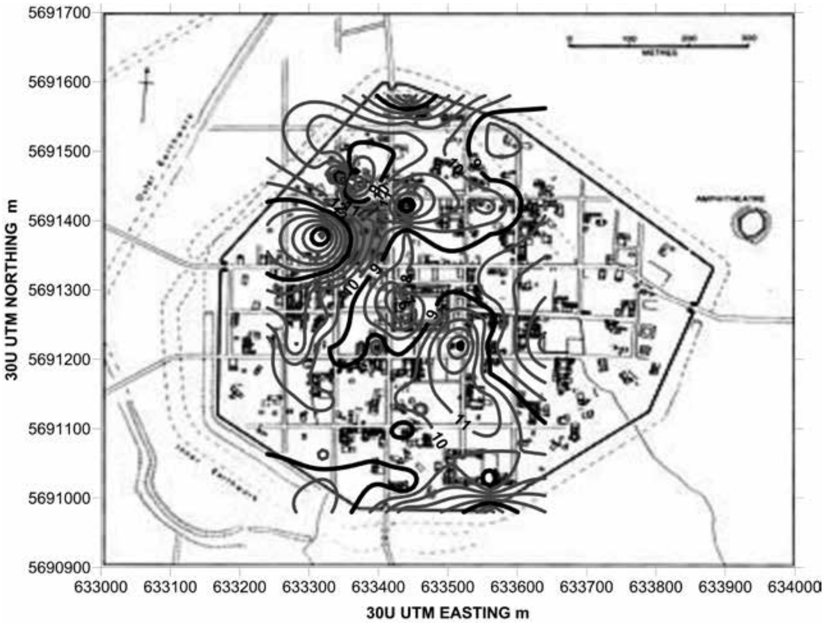

Fig. 3. Contour map of Au values after MMI extraction and analysis of soil samples from the Roman town of Calleva Atrebatum superimposed onto a town plan

Paris and London. These have never been mining towns, but centres of high population, trade and commerce for nearly two millennia. As shown in Fig. 2, the sample closest to (west of) London is anomalous in gold. This site is also anomalous in Ag, Cu, Ni, Pb, Sn and Zn. To the south-west of Londinium, and near Silchester (Fig. 2) was the Roman town of Calleva Atrebatum, the subject of extensive archaeological investigation, and recently some detailed MMI analysis.

A number of high MMI values for Au (up to 21.6 ppb) are evident (Fig. 3) in close proximity to the buried remains of buildings at Calleva Atrebatum. Silver values up to 1740 ppb also occur here. These metals were clearly not mined at this site, but as the Civitas (capitol) of the Atrebatus kingdom, it was a commodity trading centre and new coinage was minted and issued here.

It is concluded that, as a result of coincidence of high values of Au and Ag in soils with dwellings in and around Roman towns and present day cities, and as a result of estimates for the amount of gold mined and the area of the Roman Empire, that anthropic redistribution of Roman gold (and silver) has made a contribution to the distribution patterns observed by high-resolution geochemical techniques in modern-day European soils. It also suggests MMI analysis for Au and Ag in soils could be used in archaeological prospection for identifying and delineating Roman and possibly other habitation sites.

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New data from an urban archaeology project on a medieval town site. High-resolution GPR surveys in Piazza delle Carceri, Prato (Florence, Italy)

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KEY-WORDS: medieval archaeology, urban archaeology, GPR survey, Prato

GEOPHYSICAL SURVEY

GPR surveys were performed, employing the SIR3000 (GSSI) to investigate selected areas in the Piazza delle Carceri. The instrument was equipped with a 400 MHz (GSSI) bistatic antenna with constant offset and a 70 MHz (Subecho Radar) monostatic antenna. The horizontal spacing between parallel profiles at the site was 0.50 m, employing the two antennas. Radar reflections along the transepts were recorded continuously, with different length, across the ground at 60 scan s^{-1} for 400 MHz antenna and at 30 scan s^{-1} for 70 MHz; horizontal stacking was set to 3 scans.

In the investigated area (A-B-C, in Fig. 1), a total of 303 adjacent profiles across the site were collected alternatively in forward and reverse directions, employing the GSSI cart system equipped with odometer. All radar reflections within the 105 ns for 400 MHz antenna and 185 ns for 70 MHz antenna (two-way-travel) time window were recorded digitally in the field as 16 bit data and 512 samples per

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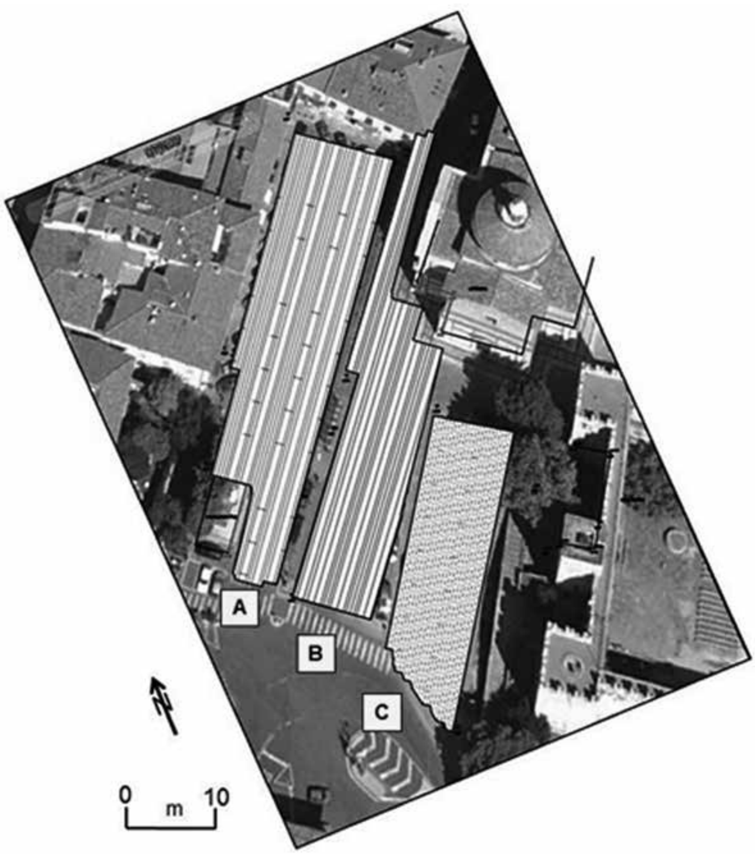

Fig. 1. Prato, Piazza delle Carceri. Location of the A-B-C area, investigated with the GPR system

radar scan. A nominal microwave velocity of about 8 cm/ns was determined from fitting hyperbolas to the raw field data. This was used in estimating a penetration depth for GPR survey.

All the GPR data were processed in GPR-SLICE v7.0 Ground Penetrating Radar Imaging Software (Goodman 2013). The basic radargram signal processing steps included: (i) post processing pulse regaining; (ii) DC drift removal; (iii) data resampling, (iv) band pass filtering, (v) migration and (vi) background filter. With the aim of obtaining a planimetric vision of all possible anomalous bodies, the time-slice representation technique was applied using all processed profiles (Goodman and Piro 2013). The squared amplitudes were averaged horizontally every 0.25 m along the reflection profiles 4 ns (for 400 MHz antenna) and 6 ns (for 70 MHz antenna) time windows (with a 10% overlapping of each slice). The resampled amplitudes were gridded using the inverse distance algorithm with a search radius of 0.75 m.

Time-slices (in depth windows from 0.40 to 0.60 m for the 400 MHz antenna) are shown for the investigated area (Fig. 2). Individualized anomalies on this map are correlated with structures located in the archaeological excavations in sectors D and E.

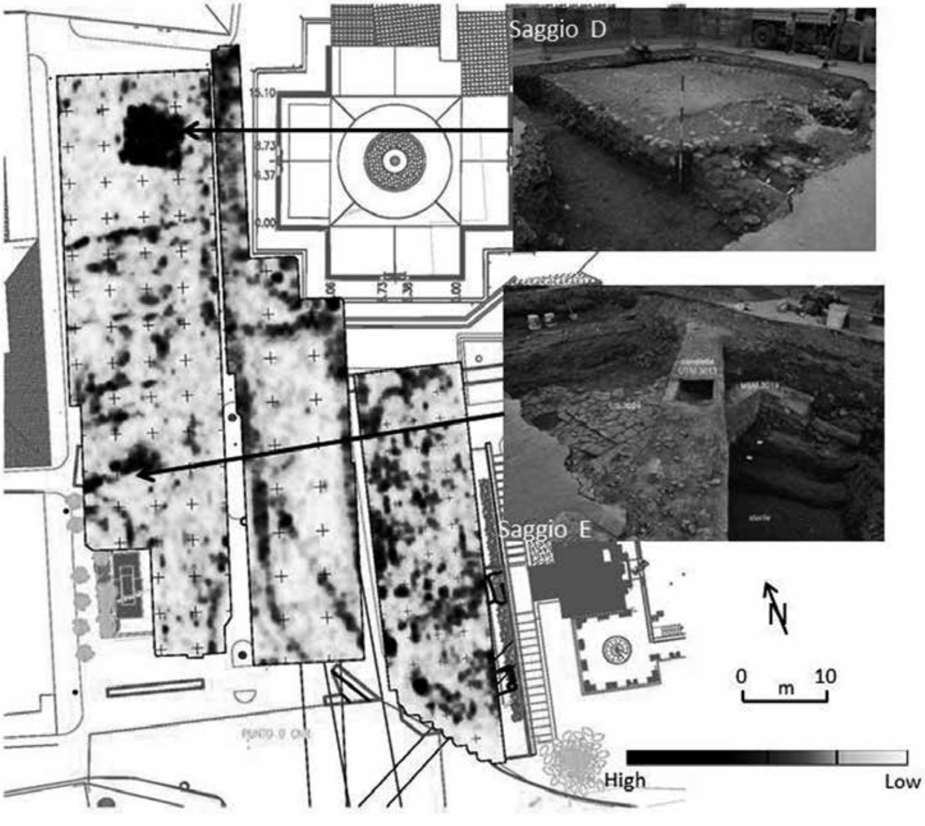

Fig. 2. GPR time-slices, in depth windows from 0.40 to 0.60 m for the 400 MHz antenna. On the right, two views of ongoing archaeological excavations

Fig. 3. Prato, Piazza delle Carceri. Archaeological sondages C-D-E

ARCHAEOLOGICAL RESULTS

To summarize, archaeologists tested three areas of particular interest (Fig. 3). In the first area (sondage D), a quadrangular structure was found, well visible in the geophysical survey. It has been identified as the basement of a big wooden winch, probably used for the construction of the Santa Maria delle Carceri church at the end of the 15th century.

In the second area (sondage E), a stretch of paved road was found, aligned E–W, running to the Palazzo Banci where another paved road and a house were excavated in 2003–2006. The paved road in Piazza delle Carceri was found at a depth of 1.15 m; it measured 3.30 m in width and was only a few centimeters thick. The house near the paved road was a large residential building, probably a former tower transformed into a *domus* and then abandoned in the first half of the 14th century. Archaeologists matched data from the geophysical survey (two walls were recognized) and the excavation, and were able to reconstruct the original dimensions of the *domus*, that is, 7.45 m by 11 m.

In the third area (trench 1 and sondage 2-2b), a second paved road aligned N–S was found. It is of great importance for the history of the medieval town of Prato owing to its construction technique and size (5.30 m wide). This road just a few centimeters thick and located at a depth of 1.50–2.20 m has been recorded for a length of 38 m.

The excavations have been backfilled and data processing is still in progress. The results have been extraordinary with new archaeological evidence of fundamental significance for the pluriannual project of urban archaeology dedicated to Prato. The documentation will help in designing a new museum for the medieval town.

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On the trail of Caesar and Vercingetorix: survey in the Bibracte oppidum, Mont Beuvray (France)

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KEY-WORDS: magnetic survey, GPR, Late Iron Age, oppidum, Bibracte

HISTORY OF THE SITE

Bibracte, a Gaulish oppidum in Burgundy, was the capital center of the Haedui, one of the most important tribes in Late Iron Age Gaul. The oppidum is well known from historical written sources. In 58 BC, Julius Caesar defeated the Helvetii, just few kilometres from Bibracte. In 52 BC Vercingetorix was proclaimed head of the Gaulish coalition here and Caesar, the victor at the battle of Alesia, spent the winter of 52–51 BC here, completing his work entitled *Commentarii de Bello Gallico*.

Bibracte is protected by a fortification of the *murus gallicus* type, enclosing an internal area of 135 ha and an external area of 200 ha respectively. Archaeological excavations at the site have a very long history. The first excavations (1867–1895) were initiated by Jacques Gabriel Bulliot, followed by his nephew Joseph Déchelette (1897–1907). Further research activities were not conducted until 1985 when Bibracte was proclaimed a site of French national interest. Bibracte is currently being excavated by multiple research teams from European universities. The main coordinator and guarantee of archaeological research on the site is the European Archaeological Centre of Mont Beuvray. Excavations on this site yielded evidence of prehistoric settlement, but above all a huge number of features associated with Gallic settlement. The period after the Roman conquest of Gaul is also well represented.

GEOPHYSICAL SURVEY

Preparation and realisation of several independent archaeological excavations at the same site each year demands detailed planning. In 2011, the Masaryk University Brno in cooperation with the European Archaeological Centre of Mont Beuvray initiated a geophysical survey to obtain data on areas where excavations are planned in the near future. Relevant new information on the nature of particular areas of the oppidum greatly benefits planning and archaeological research itself.

The oppidum is located in a mountainous landscape. Most of the site is forested and only a small part consists of meadows. Tourist-related structures (roads, a car park and reconstructed historical buildings) stand in places. A geophysical survey is extremely time-consuming under these conditions. Time is needed to prepare the areas for the survey and continuous prospection is not possible due to the enormous extent of the fortified complex with many steep slopes and densely forested terrain. Therefore, accessibility of the area and the practicality of running a prospection there were important selection criteria.

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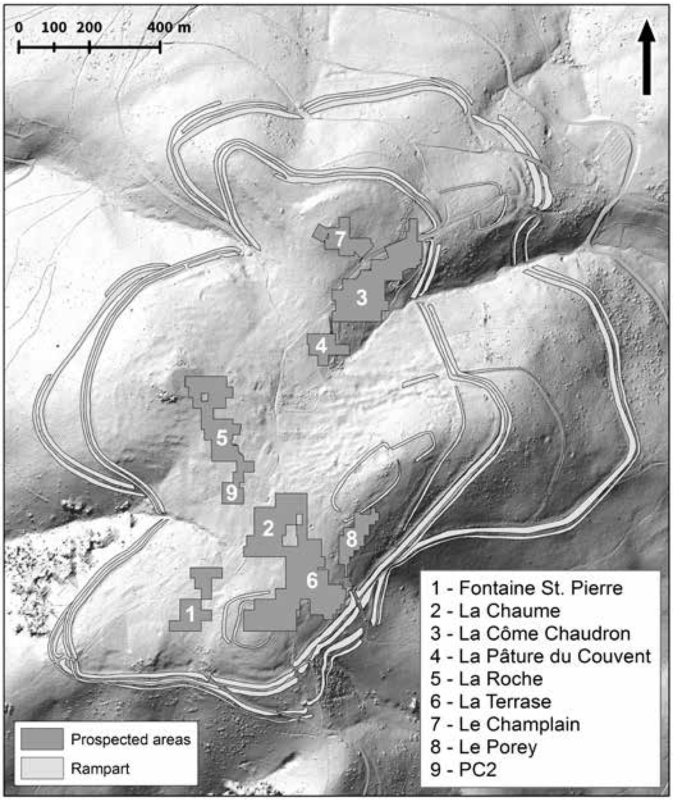

Fig. 1. General plan of oppidum Bibracte with areas covered by geophysical prospection in 2011–2014

Fours seasons of prospection have been carried out by a team of geophysicists from Masaryk University between 2011 and 2014. Two different geophysical methods were employed: magnetic survey (fluxgate magnetometer Foerster Ferex) and GPR survey (ground-penetrating radar RAMAC X3M from Malå Geoscience). Almost 20 ha were surveyed, of which about 80% was a magnetic survey. Hitherto, measurements, which were made in seven individual areas (Fig. 1), have verified knowledge from earlier archaeological excavations and provided new information on settlement at the site.

The most extensive survey was carried out in the area of Côme Chaudron in the northern part of the oppidum (Fig. 2). The 19th and early 20th century excavations revealed numerous houses originally built of wood, including some specific buildings associated with metalworking. However, the general plan of the excavations, is more than 100 years old and therefore not very accurate. The results of the magnetic survey made it possible to verify the position of individual features shown on the archaeological plan and to locate other, still unknown, structures. From the data we now have at our disposal we can draw conclusions on the extent, density and character of settlement in the area. A comparison of the results of geophysical measurements with information from archaeological excavations has given the opportunity to improve the reconstruction of the building sequence in this part of the oppidum.

Fig. 2. Bibracte, Côme Chaudron. Magnetic map (raster 0.25 m/0.50 m, dynamics of measured values –4/+4 nT in 256 shades of grey: black/white) overlaid by the plan of earlier archaeological excavation

Sunken features of various nature, similar to those from the Côme Chaudron, were also found elsewhere, but there were less of them and at other locations they only filled in areas between extensive stone building complexes. Several structures of this type, which are already dated to the time after the integration of Gaul into the Roman Empire, were discovered at the location of Le Parc aux Chevaux. Most of the masonry features were detected with the help of GPR. However, some of these structures, were already revealed by magnetic survey. An ideal example for research into Roman architecture is villa PC2 (Fig. 3). The building was already partly explored and surveyed during excavations by J. G. Bulliot. For the purpose of the geophysical survey, we had at our disposal the original plan of the archaeological excavations, including the measured spatial dimensions of the building. In the data from magnetic survey, individual walls of the villa show slightly negative values (approx. –1 to –3 nT). Particularly well visible are the external and internal perimeter walls. The partition walls inside the villa, on the other hand, are only partly visible. Especially important is the perimeter wall of the internal courtyard of the building, which exhibits distinct deviations towards positive and negative magnetic values (approx. –10 to +15 nT). It can be assumed that this part of

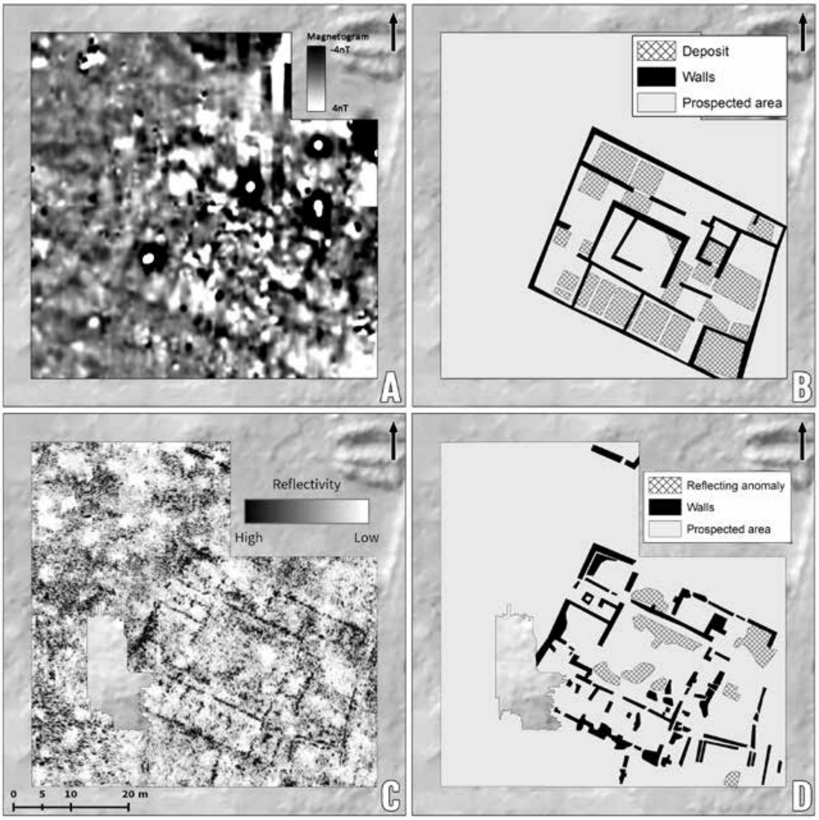

Fig. 3. Bibracte, PC2. Comparison between the results of magnetic (A, B) and GPR (C, D) surveys

the villa was built of magnetic material, most probably bricks. The remaining part of the building, however, was built of local stone. Relatively large differences in the intensity of the magnetic signal can also be observed with regard to individual rooms of the building, whereupon we can suppose differences in the backfill. For the time being, it is not yet clear whether it is a phenomenon associated with earlier excavations or a display of some preserved archaeological context. Answers to these questions will come from planned archaeological excavation. Even so, we aready have a much more detailed picture of the condition of the villa based on GPR measurements. These confirm that the archaeologically documented layout of the building corresponds to reality and that spatial deviations in the geodetic survey of individual walls do not exceed 0.5 m. In addition, walls were detected that had not been identified by archaeological excavations.

Among interesting discoveries we also can count evidence of ore extraction right in the area of the oppidum, represented as spatially extensive and magnetically distinct anomalies. Also interesting are enclosed compounds, which appear toexhibit only minimal, if any, evidence of settlement. Among the most important to be detected is an interconnection between fortifications at La Terrasse and

Le Porrey. Still unsolved is the interpretation of linear structures at La Chaume. The magnetic map shows numerous anomalies of various nature, but most notably, a system of lines from 1.5 m to 3 m wide, oriented east–west (four structures) and north–south (one structure). Thejr length cannot be determined since they continue beyond the prospected area. These structures are interpreted primarily as possible deserted roads. Their dating, however, is unknown. They may have been built in medieval up to early modern times, but their contemporaneousness with the oppidum cannot be excluded.

CONCLUSIONS

Further surveys are planned despite the difficult conditions of prospection, because of the need for long-term research. The evidence from this study has already answered some questions concerning the extent of the settlement area, building density, nature of features in individual parts of the oppidum, and building development structure in individual periods. More detailed information on previous results of the geophysical survey at Bibracte can be found in relevant literature (e.g., Milo 2013; Milo and Goláňová 2012).

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Late Neolithic circular enclosures: never entirely uncovered

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KEY-WORDS: Late Neolithic, enclosures, magnetic survey

Late Neolithic circular enclosures count among prehistoric structures that have left distinct traces in the landscape. Due to their considerable dimensions and a typical round shape they are easy to identify by aerial survey as well as on orthographic survey images of the landscape (Kuzma 2013). This was also the case with three circular enclosures presented in this paper. These enclosures located in Bíňovce (Slovakia), Milovice and Nové Bránice (Moravia, Czech Republic) are new additions to the list of similar sites in the region already investigated geophysically by other teams (e.g., Melichar and Neubauer 2010). Considering the typical shape of

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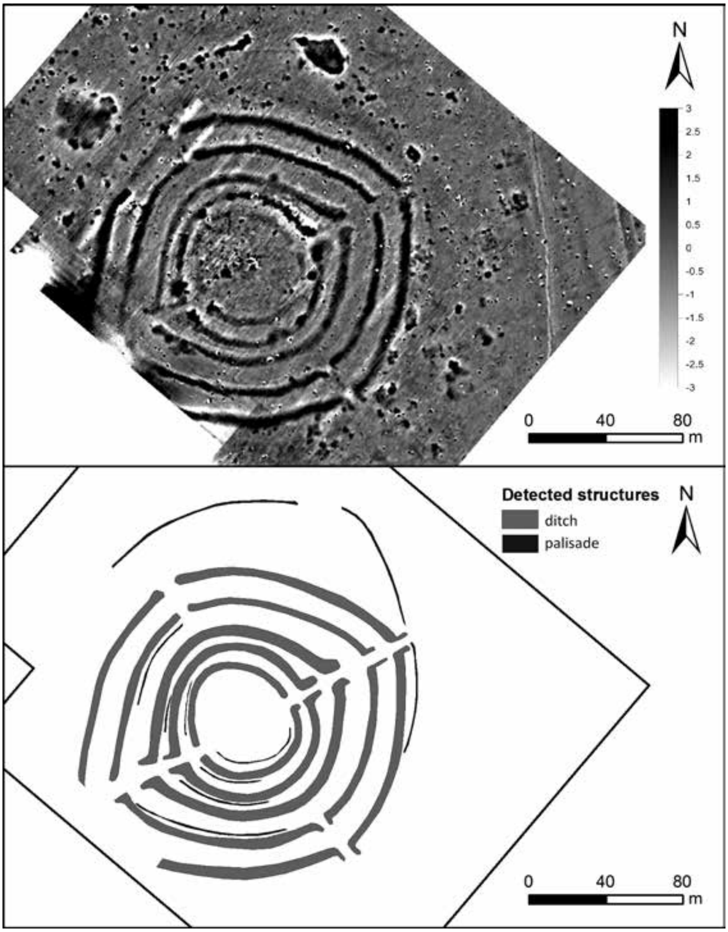

Fig. 1. Bíňovce. Magnetic map and interpretation of archaeological structures

these structures and the potsherds collected from the surface at individual sites, the enclosures under review can be dated without doubt to an early phase of the Lengyel Culture.

BÍŇOVCE

The circular enclosure, irregularly circular in plan, consists of five ditches and several palisade trenches, which in some places are only fragmentarily reflected in the geophysical data (Fig. 1). The western edge of the magnetic map is distinctly disturbed by a gas pipeline, which also partly overlaps with the roundel. However, with respect to the structure as a whole, a detailed picture can be given. The ditches are 4.0 m to 6.7 m wide. The circle inscribed by the internal edge of the central ditch has a diameter of 49 m to 53 m. The circle inscribed by the external edge of the outermost fifth ditch has a diameter of 167 m to 187 m. Counting from the centre to the outside, ditches 1 to 3 exhibit two gaps each; these are the northeast and the southwest entrances. Ditches 4 and 5 have four entrances each. Besides the northeast and the southwest entrance, which parallel the straight line leading through the entrances from the three internal ditches, there are also two diametrically opposed entrances on the northwest and southeast of the circular enclosure. Palisade trenches can clearly be evidenced on the outside of the first and the second ditch and on the inside of the fourth ditch. To the north and east of the circular enclosure, we can follow the course of a palisade trench, which is also related to the circular enclosure. Its preserved length is about 230 m.

The disproportion in the number of entrances in individual ditches might indicate chronological discontinuity of the structure under review as a whole. Why is it that the external ditches have two additional entrances each when they did not lead to the centre of the roundel? A possible answer is that ditches 4 and 5 represent a second or even third building phase. Chronological differences between the ditches may also be indicated by their magnetic fills, which are entirely different. Ditch 1 exhibits very low magnetic values (0.3 to 2.0 nT). The values with ditches 2 and 3 are higher (mostly 1.5 to 4.0 nT). Ditch 2 shows in some places, mainly in the area of the gates, very high values (25 nT). The highest average data are given by ditches 4 and 5 (2.5 to 5.0 nT). The fills of individual ditches and their magnetic properties are attributable to their backfilling, which often took place very long after the roundels ceased to serve their purpose. Therefore, we suppose that the backfilling process in ditches at Bíňovce may have differed in individual cases. Ditch 1, for example, which was only indistinctly visible in the data obtained, may have been filled intentionally by the builders of the roundel. The low-magnetic subsoil material was probably obtained by extending the circular enclosure and digging ditches 2 and 3. More details on this question may come from archaeological excavation.

Many anomalies were detected inside and around the circular enclosure. They can be interpreted as settlement features. Considering the fact that they do not overlap spatially with the roundel, they are most probably contemporaneous with it or a little younger. At least four house plans were identified east of the roundel. The other features can be classified as settlement pits of various nature. The area to the north of the roundel is dominated by two large anomalies (750 m^2 and 330 m^2). The eastern feature is still visible on the surface as a moderate depression.

MILOVICE

The enclosure is nearly circular in shape and consists of an internal palisade trench and two parallel ditches 4 m to 5 m wide (Fig. 2). The distance between ditches is 10 m. The circle pf the external ditch has a diameter of about 120 m. The ditches are interrupted at regular distances by four opposite gaps. The entrances are flanked by pairs of shorter connecting ditches about 3 m wide. The palisade trench inside the roundel runs at a distance of 5 m to 8 m from the internal perimeter ditch of the roundel and forms an approximately circular area of 66 m in diameter. The entrances in the palisade are oriented in the same directions as the gaps in perimeter ditches.

The changes in magnetic values in the area inside the palisade are curious compared to the area immediately around the ditches. Higher magnetic values inside the roundel might indicate a preserved occupation layer. The palisade trench forms a distinct border at the perimeter of this

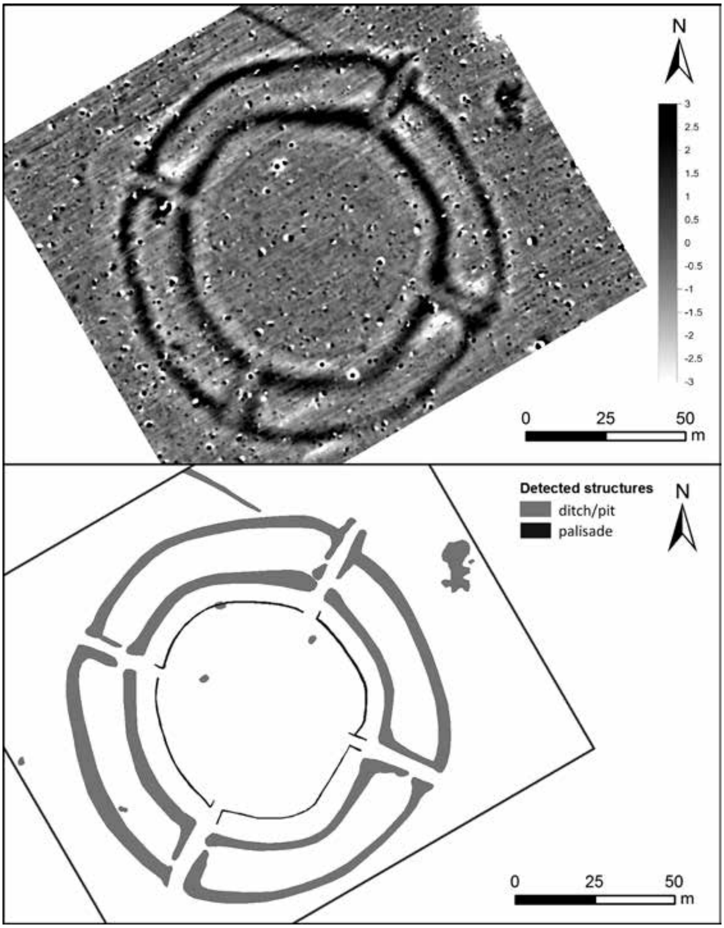

Fig. 2. Milovice. Magnetic map and interpretation of archaeological structures

area. However, it may also be supposed that low magnetic values around the ditches resulted from piled up low-magnetic or non-magnetic subsoil earth, which was obtained by digging the perimeter ditches. If so, then the Milovice roundel can be imagined as a system of not only ditches and palisades, but also massive perimeter ramparts.

NOVÉ BRÁNICE

The irregularly circular linear enclosure consists of two internal palisade trenches, which are only fragmentarily preserved in the geophysical data, and an external ditch (Fig. 3). The circle inscribed by the internal palisade trench has a diameter of roughly 60 m to 70 m. The circle inscribed by a ditch about 2.0 m to 4.0 m wide has a diameter of roughly 108 m. The ditch exhibits

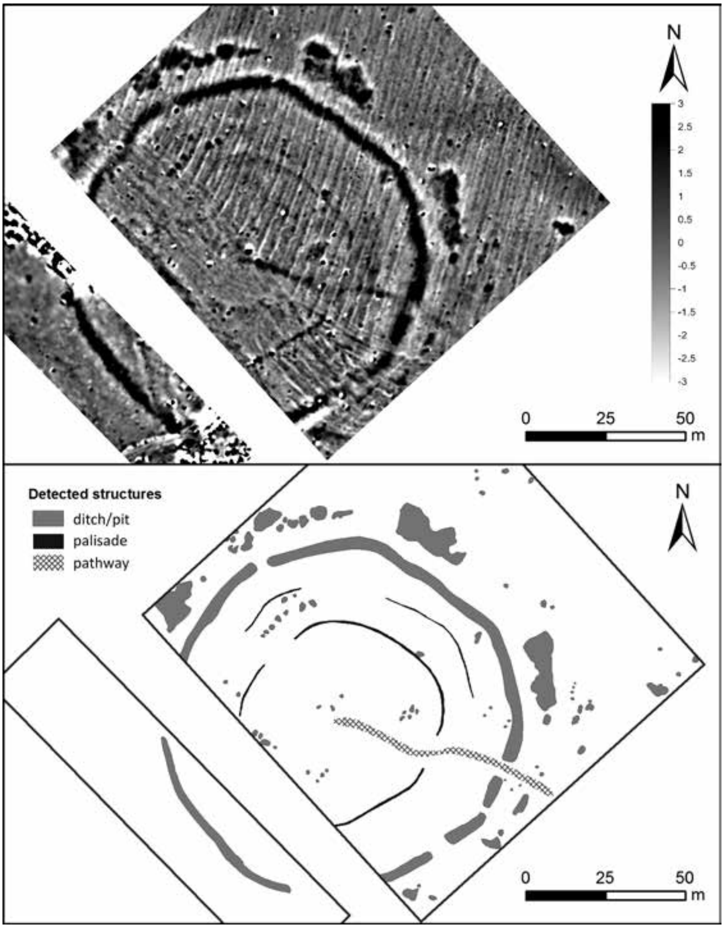

Fig. 3. Nové Bránice. Magnetic map and interpretation of archaeological structures

four gaps, but only the one in the north–northwest part can unequivocally be identified as an entrance. An entrance is also supposed with the easternmost of the three gaps in the southeastern part of the enclosure ditch. Through this gap runs a narrow linear anomaly leading directly to the centre of the enclosure. This feature was most probably connected with the functional purpose of the circular enclosure. It might be a trench-like structure, but also a shallow depression, a pathway, for instance. Naeither can a pedological origin of this structure be excluded.

Several extensive anomalies, which are accumulated outside and around the circular enclosure, deserve special attention. These features are situated at regular distances of 5 m or 6 m from the external edge of the circular ditch. The only reason for such arrangement can be an aboveground obstacle, which has not been reflected in the geophysical data. It may have been a light fence or a shallowly sunken palisade. A road running around the roundel is also possible, but the most likely interpretation is apparently an earthen rampart piled up in these places. The whole archaeological context of the circular enclosure at Nové Bránice, the ditch of which seems to have been enclosed from outside by a rampart, is thus a further valuable contribution to this discussion.

ACKNOWLEDGEMENTS

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Results of a magnetic survey at the Bronze Age site of Shahr-e Sukhteh, Sistan, Iran

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KEY-WORDS: Iran, Sistan, Shahr-e Sukhteh, magnetic survey, Bronze Age

INTRODUCTION

Shahr-e Sukhteh (Burnt City) is located to the east of Sistan and Baluchestan (Iran), some 50 km southwest of Zabol (Fig. 1). The site was first recognized by Maurizio Tosi, who conducted field surveys and undertook excavations in the area between 1967 and 1978 (Tosi 1983). Between 1995 and 2010 and later in 2014, the area was reinvestigated by S.M.S Sajjadi, in cooperation with a team from ICHHTO and an international team (Sajjadi 2003; 2005; 2006a; 2006b; 2008). Shahr-e Sukhteh is one of the most important sites of the Bronze Age in the east of Iran and was occupied from 3200 until 1900 BC. According to Iranian and Italian studies, Shahr-e Sukhteh had extensive business relationships with other contemporary civilizations in Central Asia, the Indus plains and the western part of the Iranian plateau.

The site covers an estimated surface of 151 hectares and surface pottery is spread over an area of more than 120 hectares. There are three main areas: the residential central part divided into two sub-sectors (central residential area and monumental area); the northwestern part corresponding to the industrial area, and the southern part occupied by the necropolis. The buildings are constructed of mud brick, rammed earth and wood. Each building was divided

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Fig. 1. Map of Iran, showing the location of Shahr-e Sukhteh (map © *www.mapyahoo.com*)

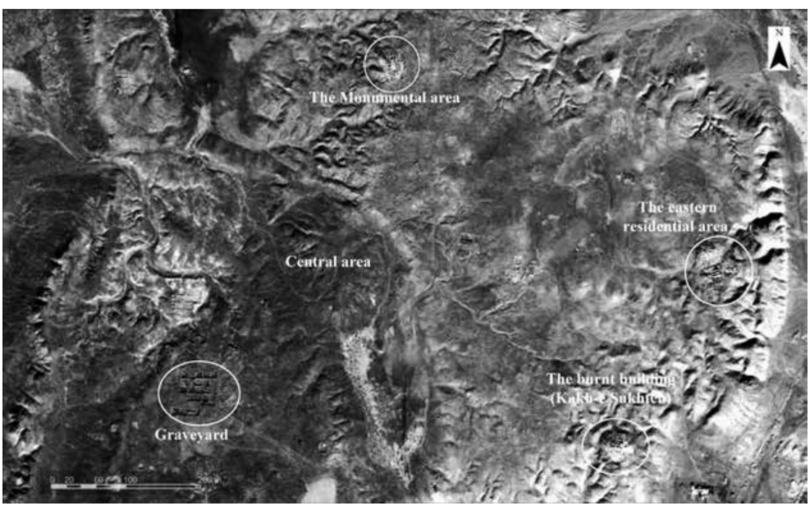

Fig. 2. Satellite image of Shahr-e Sukhteh, showing the location of archaeological structures (© Google Earth 2015)

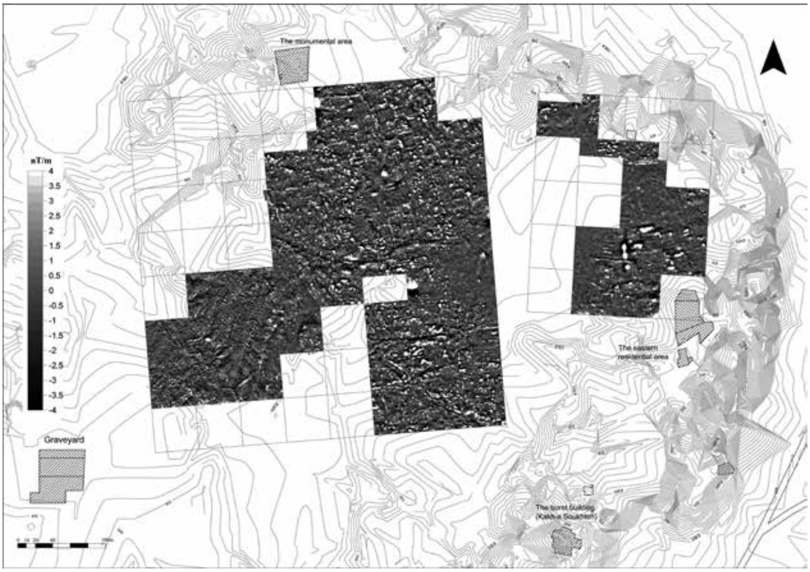

Fig. 3. Map of magnetic surveys results at Shahr-e Sukhteh (Iran)

into six to ten rooms at various levels, considering the remains of stairs, ceilings and floors that were found. Each structure had a kiln. There are also some faint traces of architectural remains on the surface. The site was abandoned between 2100 and 1900 BC. According to Sajjadi, the main reason for this was the change in the course of the Helmand River (Sajjadi 2006b: 465).

Large-scale high-resolution magnetometry has been carried out in the area between the excavated parts to complete a plan of the settlement layout. This campaign was organized in cooperation between the Iranian center for Archaeology Research (ICAR) and the Iranian center of Heritage, Handcraft and Tourism Organization (ICHTO) in Zahedan.

RESULTS OF MAGNETIC PROSPECTION

The area selected for the first campaign was divided into two sectors, one located to the west of the eastern residential area and the other in the central part of the site, between the monumental area and the graveyard (Fig. 2). The survey, which covered 13 hectares, was completed with a caesium gradiometer (G-858 by Geometrics).

The resulting magnetic map shows very concentrated sectors with dense and planned organization to the south of the central area and a more isolated monumental building in the eastern sector (Fig. 3). This building of 38 m by 31 m was composed of a central courtyard surrounded by rectangular rooms to the north and to the east. The western part had a slightly different orientation, which might be interpreted as a later extension. In the central area, the urban layout is mostly orthogonal and composed of buildings and streets following an almost exactly north–south orientation. There are some local variations in this orientation, particularly to the west, where a very dense settlement composed of small cells was recorded, possibly linked to the graveyard area identified in the excavations 100 m to the west. A huge building (at least 60 m to the side) was also identified in the southern part of the central area, apparently "disconnected" from the main sector.

Whereas urban planning from the Bronze Age is well known in other geographical areas (Syria and Turkey, for instance) (Creekmore 2010; Gondet and Castel 2004), this is the first time that such a planned organization has been revealed in Iran over an extended surface by means of a geophysical survey. This first campaign revealed some major finds, including domestic and monumental areas, and a presumed part of a necropolis.

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The archaeological prospection project Rheinau (Switzerland)/Jestetten, Altenburg (Germany)

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KEY-WORDS: interdisciplinary prospection project, aerial archaeology, geophysics, subaquatic survey, field walking, history of settlement, Celtic oppidum

The survey area is situated in the northern part of the Canton of Zürich, just 2 km south of the famous "Rhine Falls", where the river flows round two big peninsulas, the Rheinau "Au" (Switzerland) and Jestetten, Altenburg "Schwaben" (Germany) (Fig. 1). Between these two peninsulas with their well preserved embankments there is a little island with a Benedictine monastery, founded in the 9th century AD. The two peninsulas were described historically for the first time in the 16th century. The fortifications were then connected with battles between Allemanic tribes and the Roman army in late Roman times, as is known from ancient sources. Today, we know that the fortification at Rheinau was first built in the late Bronze Age (Frascoli 1991: 7 and 20). Together

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Fig. 1. Aerial view of the research area at Rheinau (Switzerland) / Jestetten (Germany) with the two peninsulas. Photo Kantonsarchäologie Zürich

with the embankment on the Schwaben peninsula, they protected a huge Helvetic *oppidum* in the late Iron Age (2nd/1st century BC). Since the second half of the 19th century archaeological and historical research has proceeded with varying intensity and focus, and has revealed a great deal of information concerning the occupation history of the two peninsulas and the surrounding region (Nagy, Schreyer and Tiziani 2003).

Intensive archaeological research work in the area of the Celtic *oppidum* was carried out between 1971 and 1985 on the German Schwaben peninsula, while on the Swiss peninsula different rescue excavations took place between 1991 und 2005 (Schreyer 1994; Bräuning and Nagy 2012). Traces of house structures, pits with different functions (cellars, wells, shafts), stone layers and even the remains of a blacksmith's workshop provide important information about the settlement structure. The archaeological finds from Altenburg and Rheinau can be dated to the late Iron Age phases LT D1 and 2. Differences in the wide range of finds from both peninsulas are interpreted chronologically. The settlement of Altenburg seems to begin half a century earlier than that at Rheinau, but both settlements seem to end at the beginning of the second half of the 1st century BC. Abundant finds document trade contacts with different areas in the Celtic world as well as with the Mediterranean, and even with the Germans. In the time of the Celts, the *oppidum* of Rheinau/Altenburg seems to have been an important commercial centre on the route from the Mediterranean regions along the river Rhône to the north and those from Gaul to eastern areas, such as the territories of the Vindelicians and Noricans.

A detailed aerial survey of the area and its surroundings began in 1988. In the last 20 years over 2000 photographs were taken and many archaeological sites, mostly visible as crop marks, were discovered. The visible structures are predominantly pits and ditches, traces of agricultural works, historic harbour facilities and refilled riverbeds. The remains can be dated from the late Ice Age until the present (Nagy 2005).

In 2006, a special research project was carried out together to test in detail with the Swiss Federal Office of Topography (swisstopo). The goal of this research was to test the potential of ADS40 data for archaeological prospection (Kellenberger and Nagy 2008). In a first flight campaign in July 2006, the ADS40 data from a first generation SH40 camera head was used. A second flight campaign in September was carried out with the ADS40 sensor, operated by the manufacturer (Leica), with a new, second-generation SH52 head. Spectral signatures of several ground targets were taken parallel with a field spectrometer and a field survey was carried out. The ADS40 data sets were geometrically corrected with respect to national map sheets. A radiometric calibration of the spectral bands was applied with the empirical line approach, including the ground spectra. Archaeological interpretations of both ADS40 datasets and the oblique aerial images were then compared. The visibility of archaeological structures in ADS40 data and oblique photos was compared. It was demonstrated that, thanks to the higher radiometric performance of ADS40, additional geological and archaeological elements were detectable. ADS40 data are shown to be a good choice for archaeological prospection. Every three years, a complete nationwide coverage of Switzerland with 25 cm ground sampling distance will be flown operationally by swisstopo, a perfect alternative to, or even substitute for, archaeological prospection using traditional aerial imaging surveys.

To obtain a better understanding of the entire cultural landscape, the Kantonsarchäologie Zürich decided in 2006 to start a binational, interdisciplinary archaeological research project in cooperation with the Landesdenkmalamt Baden-Württemberg and many other institutions (University of Zurich, Swiss Federal Institute of Technology, Zurich). The aim of this research project was to get a comprehensive inventory of archaeological remains within the project area and to research all aspects of the history of settlement and economy (Nagy and Schäppi 2007; Nagy 2010). Between 2004 and 2014 a whole range of archaeological prospection methods was used (aerial prospection, airborne scanning, geophysics, fieldwalking, metal detecting, subaquatic survey, test trenches and archival studies) (Figs 2 and 3).

The first geophysical prospection was made between 1996 and 2004 by Jürg Leckebusch (Kantonsarchäologie Zürich) in some small areas of the Celtic and medieval settlement prompted by building activities (Nagy 2008), and also in the church of the former monastery, in connection with a research project (Leckebusch 2007). In late 2006, an extensive magnetic survey was started by GGH Solutions in Geosciences GmbH (Freiburg i. Br., Germany), first in Altenburg, then also in Rheinau. Up to 2014, an area of 55 ha was surveyed with a high-resolution multisensor caesium magnetometer. The digital image (Fig. 2) of the magnetic data shows the remains of hundreds of pits, postholes, “Grubenhäuser”, outlines of dwellings, ditches and other archaeological remains.

In the areas of the monastery and the fortification of Rheinau, ground penetrating radar and geoelectric tomography were used by GGH Solutions in Geosciences GmbH and also by the Institute of Geophysics of the Swiss Federal Institute of Technology, Zurich, Department of Earth Sciences.

In 2014, by order of the Baudirektion Kanton Zürich, Amt für Raumentwicklung a high-resolution airborne LiDAR survey was achieved for the whole area of the Canton of Zurich (1868 km^2). The laser scanning was done by bsf swissphoto (Regensdorf-Watt, Switzerland) with a Trimble AX60 laser scanner. The required data specification (point density: 8 point per m^2; height accuracy: 0.1 m; positional accuracy: 0.2 m) was reached and the digital terrain model is currently being analysed in an archaeological research subproject.

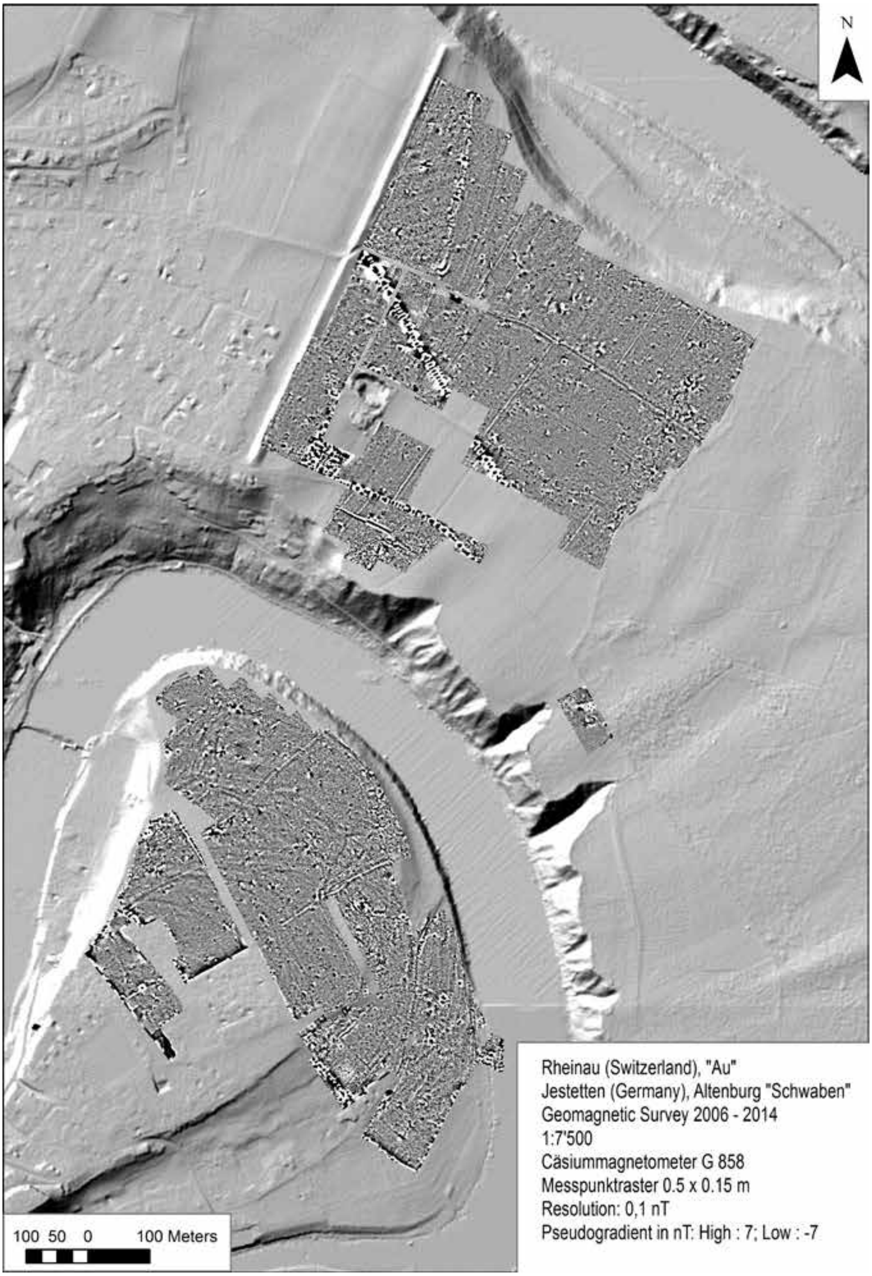

Fig. 2. Magnetic measurements in the Celtic *oppidum*. Geomagnetic survey 2006–2014 with caesium magnetometer G 858 (Ch. Hübner, GGH Solutions in Geosciences GmbH, Freiburg im Br., Germany). Measuring point grid: 0.5 m x 0.15 m; resolution: 0.1nT; pseudogradient in nT: ±7

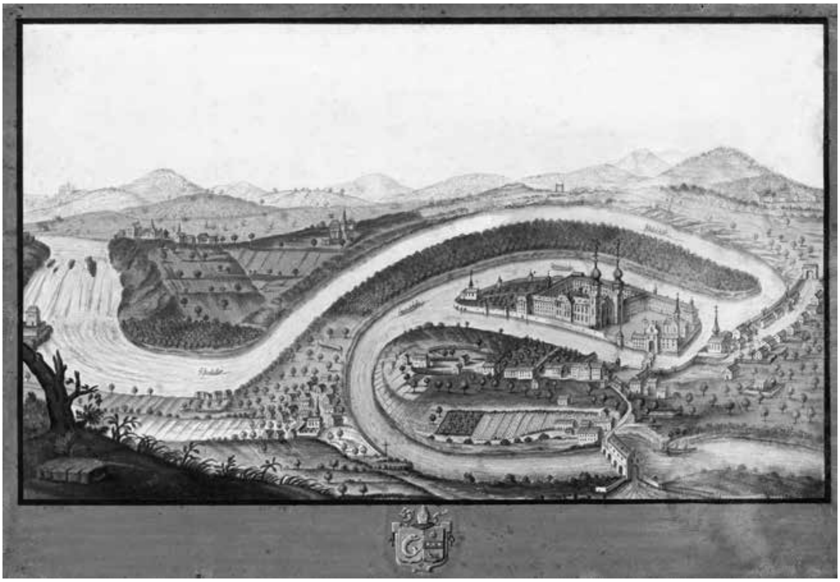

Fig. 3. Historical view of Rheinau (Switzerland) with the Benedictine monastery. (Zentralbibliothek Zürich, Graphische Sammlung, Rheinau I, 15)

In 2007 and 2014, test pits were dug at different places on the Swiss side of the river Rhine and also on the small island to calibrate all the data from the non-destructive surveys.

The field and archival work of the past ten years provided important evidence of landscape use from the Mesolithic until recent times, e.g., a Bronze Age hoard, settlement remains of a late Iron Age *oppidum*, traces of Roman settlement activities from the 1st–4th century AD, a deserted early medieval village, pit houses of the 14th century AD, abandoned buildings of the Benedictine monastery, a wooden structure in the river dendrodated around 1600 and over 2500 single finds. At the moment the analysis of all the data is underway, so that the results can be published within two years.

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French experience using sub-bottom profiler combined with sonar multi-beam as a preventive archaeological diagnostic before dredging

Philippe Pelgas[a] **and Bruno Wirtz**[b]

KEY-WORDS: sub-bottom profiler, bathymetric digital terrain model, preventive archaeology

INTRODUCTION

Underwater archaeological diagnosis of several tens or even hundreds of hectares can be conducted nowadays using geophysical surveys. The use of acoustic tools is emerging as a fundamental step in the diagnosis before sending divers to do visual surveillance or excavation.

METHODS AND INSTRUMENTS

There are three types of systems: those that visualise the seabed (side-scan or multi-beam sonar), those that measure the intensity of the magnetic field (magnetometer) and those which enter the sediment at depth (sediment echo-sounder or sub-bottom profiling). We will look at a combination of two of these systems. Faced with a lack of authoritative guidance using industrial protocols for on the use of these tools, Inrap decided in July 2014 to develop preventive archaeology protocols using geophysical data acquisition (Mesuris) and protocols from SHOM (Service Hydrographique et Océanographique de la Marine). A committee of acoustic tool experts considered how these systems and software could be used to explore the data, using "filter measurement" and other mathematical treatments to analyze the signal.

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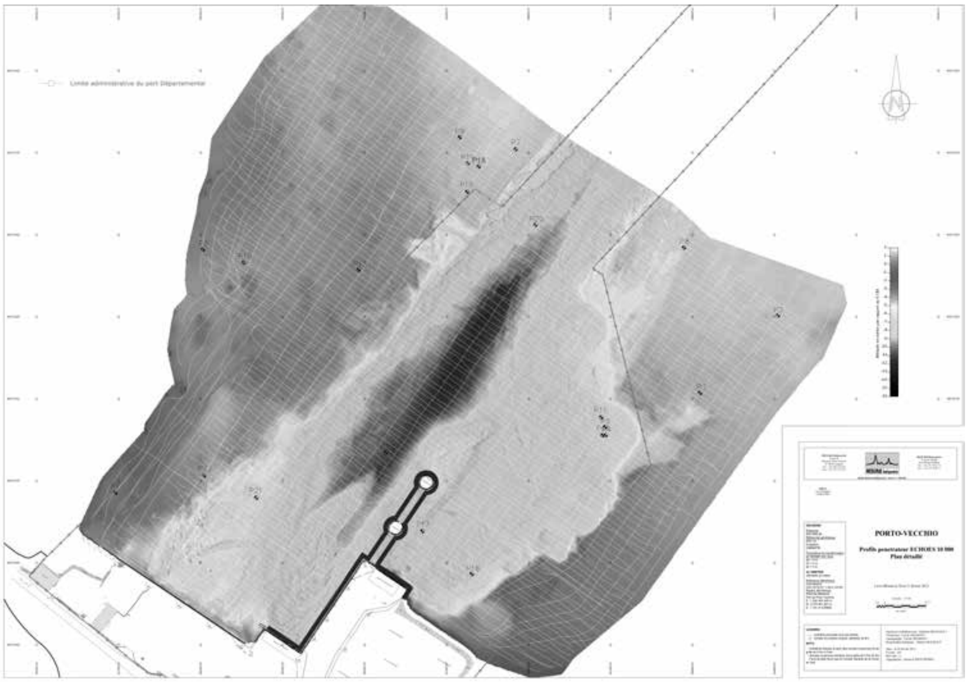

Fig. 1. Bathymetry DTM made with multi-beam sonars and sub-bottom profiles in Porto Vecchio (Mesuris)

Expert recommendations led to coupling the sub-bottom sediment echo-sounder with a multi-beam sounder (Fig. 1). Thus, Inrap collaborated with Mesuris to implement an underwater survey using multi-beam sonar (type Reson 8101) and a sub-bottom profiler (Echoes 10,000; XBLUE Company).

The use of a multi-beam echo sounder has the advantage of reliable positioning between one and ten centimetres or less. Another advantage is that even should the anomaly be covered with sediment after the survey, the reliability of the positioning will increase the likelihood of relocating the anomaly. In recent years, in Europe, multi-beam has been used in various locations for performing high-precision readings (Caiti 2009). According to Fuertes (2009: 126), from a methodological point of view, prospecting or diagnosis must be based on sea-bed mapping. As for the sub-bottom profiler surveys, they are recommended for non-intrusive diagnosis to understand sediment over the first few meters or tens of meters.

SURVEY OF PORTO VECCHIO

The Inrap Bureau of Subaquatic Activities was commissioned in February 2013 to do an underwater archaeological survey of the commercial port in Porto Vecchio in Corsica

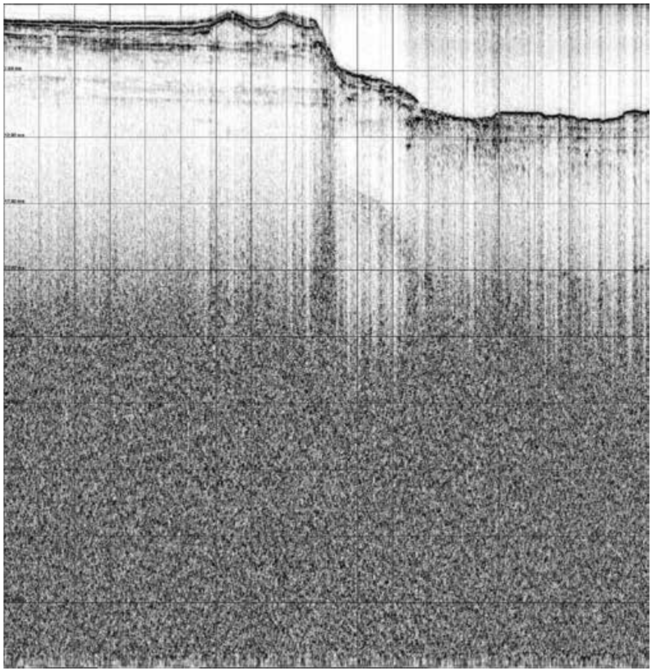

Fig. 2. Sub-bottom profile (SHOM)

(France) prior to conducting dredging work. The objective was to find shipwrecks, as well as port structures and any other manmade features.

Mesuris constructed a bathymetric Digital Terrain Model of the area (Fig. 1). A sub-bottom profile was carried out every 5 m, giving a total of 189 profiles (Fig. 2). The frequency range of the sub-bottom profiler (Echoes 10,000) is between 5 and 15 kHz for a vertical resolution of less than 10 cm and a maximum directivity of 20°. The transducers are electronically controlled by DELPH Seismic Acquisition software and read using DELPH Seismic Interpretation software. The native data to XTF were exported to SEG-Y (unformatted). They are readable with other seismic scoring software (Kogeo, Kingdom Suite, etc.).

Following the survey, SHOM made the following recommendations:

– slowest possible acquisition speed (2 knots),

– positioning paramount to superpose survey on the bathymetric DTM,

– system attached to vessel preferred over towed system,

– redundancy profiles established along different acquisition axes,

– density profiles depending on target size,

– export data processed with proprietary software in accessible and known format; proprietary software should allow export to other software (Hypack).

In addition, while conditioning the use and combination of a particular system and before starting diagnosis, it is essential to understand the geological context, sediment dynamics,

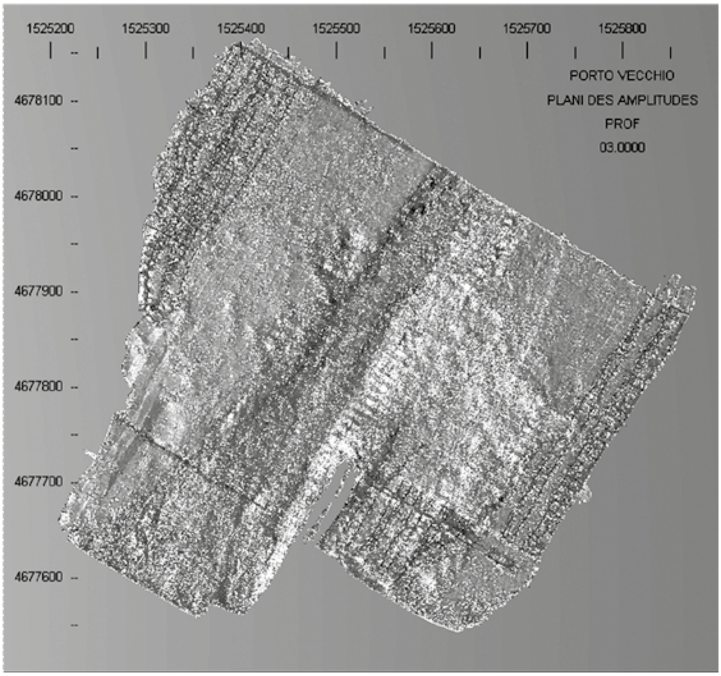

Fig. 3. Synthetic planimetry of acoustic reflectance

nature of the expected relics and their potential size. Not all the recommendations could be used in all contexts.

Seismic data (SEG-Y) were collated and analyzed by the processing chain "SID shom O-V1.11" developed by SHOM. Metadata files incorporate: position of individual seismic emission pings; speed of the ship; name of each acquired profile; ping number. These parameters are used to check the acquired profiles. Geo-referencing of each profile permits a cross-check whether the scores achieved on a profile are consistent with adjacent profiles. All the georeferenced scores are exported and integrated into QGIS (Quantum GIS V2.8).

RESULTS

The features discovered counted 51 in all. The superposition of different data in QGIS permitted an easier classification of the elements found (geological, false hyperbolic echo, anthropogenic, etc.). However, in order to differentiate between abnormalities of a geological or anthropogenic origin, additional geological research on the local area was essential.

At the same time, a mathematical analysis was conducted by B. Wirtz, using Delaunay triangulation and other calculations, including complex function, differential calculus, geometrical and analytical concepts (curvature, gauss curvature, Fourier series). For the bathymetric data, a polynomial orthogonal projection of the initial data was developed using inverse Gram

Matrix, the object being to detect slight changes in acoustic properties of the sediment, which were invisible in the initial formatting of data, but could be highlighted by a complex combination of computations.

The results identified foremost a possible fossil beach. Secondly, 3D cartography of bedrock was produced and, thirdly, several abnormalities were located. These indices are oval shaped, between 10 m and 30 m long, and from 5 m to 10 m wide, resembling potential shipwrecks.

Developments in underwater preventive archaeology and the use of different geophysical techniques will lead to improvements of acoustic tools where essential, such as the use of multi-beam sonars, sub-bottom profilers, magnetometers and side-scan sonars. Further applications will define the extent to which these methods are best suited to finding buried artefacts, depending on the hydro-sedimentary context.

ACKNOWLEDGMENTS

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Seismic refraction tomography in the Texcoco Region, Mexico

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KEY-WORDS: seismic refraction tomography, Texcoco, Mexico, tlatel

Geophysical studies of early human occupation in the Valley of Mexico are limited. Nevertheless, archaeological remains have been found inside and around ancient Lake Texcoco. The presentation concerns the results of seismic refraction tomography (SRT) surveys of two archaeological sites, Chapingo and San Miguel Tocuila, aimed at locating and determining the nature of early human settlements in the Texcoco region. The sites are at an altitude of 2246 m a.s.l., around 30 km northeast of Mexico City and 4 km apart.

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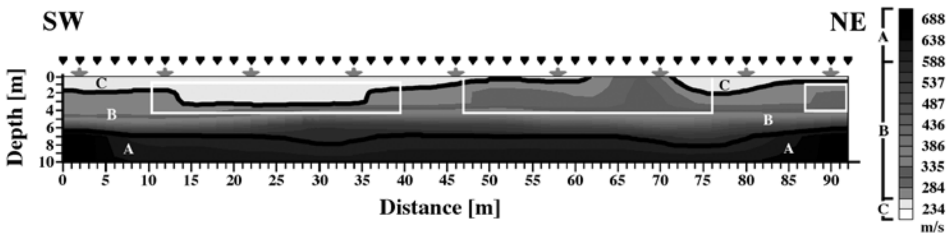

Fig. 1. Example of a seismic refraction tomography profile from the Chapingo site, showing a three-layer lacustrine deposit (A to C), featuring archaeological structures: channel (left), mound (middle) and an undefined structure (right). Asterisks indicate source position and triangles geophone position. Velocity in m/s shown in gray at right

Seismic techniques in archaeological prospection are not very common. However, SRT is a high-resolution and non-destructive geophysical exploration technique that provides data for mapping human settlement and reconstructing the geometry of structures, like walls, mounds, tlatels, pits and ditches, buried in the subsurface (Arciniega-Ceballos *et al.* 2009: 1203–1205; Batayneh 2011: 84–85).

Tlatels, which are widespread in the Valley of Mexico, are pre-Hispanic settlement mounds that are formed of built stonewalls filled inside with rock debris, silty sand and rubble from other structures. The height and size of these mounds were determined most likely by the water-level fluctuations of Lake Texcoco and the use of these sites was either residential, defensive or ceremonial (Arciniega-Ceballos *et al.* 2009: 1200–1201). Applying SRT helped to locate and differentiate between archaeological structures, such as tlatels and channels, and geological structures in the first 10 m below the surface.

SRT is an active non-destructive geophysical method based on recording first-wave arrival, detected with an array of equidistant geophones spread out over a surface at equal increasing distances from the source. In near-surface geophysical studies, impact sources like hammers or bounce weights are commonly used, and the transect length depends on the target depth. In the present survey, an 8 kg sledgehammer and an iron metal plate for better coupling with the soil were used and profile length was varied between 11 m and 46 m. The seismic velocity distribution of the subsurface is obtained from the analysis and modeling of the first-wave arrivals and the travel-times, applying a non-linear regression approach. This analysis takes into account the different layers that the wave travels through and the elastic properties of the earth (Milsom 2003: 207–221; Linford 2006: 2244–2245).

The surveys were carried out using 24 14-Hz vertical OYO Geospace geophones and a 48-channel Geometrics StrataVisor NZ seismometer. To enhance the signal-to-noise ratio three to five traces were stacked at each point source, having a minimum of five point sources per profile.

In the central campus of the Universidad Autónoma Chapingo, two 46 m and four 92 m profiles were made over two adjacent smallholdings, covering an area of 2.9 ha. The SRT results indicated the presence of a variety of transit or irrigation channels (see Fig. 1). The channels were found on all the profiles. Four of these channels could be part of a single channel aligned NE–SW with a width varying from 16 m to 21 m. Structures of irregular shape, interpreted as mounds or dams, were located on three profiles. These structures are 23–29 m wide and 3–4 m high. Trapezoidal structures 1–2 m high and 4–6 m wide were also identified (see examples of

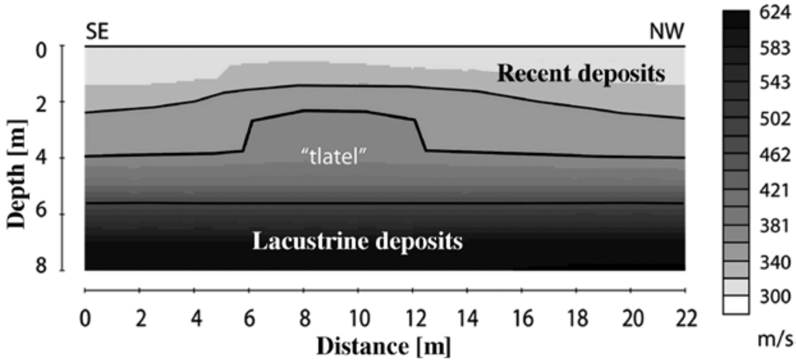

Fig. 2. Example of a seismic refraction tomography profile of a tlatel from the San Miguel Tocuila site. Velocity in m/s is shown in gray at right

both in Fig. 1). The seismic profiles also suggested a series of depressions at a depth of more than 5 m. The depressions are interconnected and are related to an ancient riverbed that ran from east to west (Rosado-Fuentes 2014: 94–102).

In a soccer field at San Miguel Tocuila, four 118 m and one 96 m SRT profiles were performed. A ceremonial tlatel was located in the western part of the field. The width cannot be precised accurately, but the total height was 5 m and there is reason to believe that it was built in three stages (Arciniega-Ceballos *et al.* 2009: 1201–1205). Five profiles, 22 m long and one 11 m long, made in the neighborhood of the Museo Paleontológico de Tocuila located two small tlatels. One was about 6 m long and 2 m high (Fig. 2), the other roughly 4 m long and 1 m high (Vergara-Huerta 2011: 35–48). These sites are characterized by lacustrine sediments and lahar deposits containing paleontological remains (Siebe *et al.* 1999).

Further studies are required and a combination of geophysical exploration methods (e.g., magnetic and ground radar penetration techniques) is recommended. These studies have demonstrated SRT to be a powerful method for locating and differentiating archaeological and geological structures.

ACKNOWLEDGMENTS

We wish to thank Luis Morett Alatorre for granting permission to work in the Texcoco region and Esteban Hernández for his help in the fieldwork. This work was partly supported from the UNAM-PAPIIT-IN106111 project. AR acknowledges CONACyT and the financial support from Posgrado en Ciencias de la Tierra, UNAM to attend the 11th International Conference on Archaeological Prospection.

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Uphill and downhill geophysical challenges in Delphi, Greece

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KEY-WORDS: integrated geophysical survey, ERT, EM, GPR, 3D seismic refraction, magnetics, Delphi, Greece

INTRODUCTION

The first excavations in Delphi started in 1892 with the exploration of the sanctuary of Apollo initiated in 1887 (Luce 2011). Excavations required the old medieval village of Kastri to be moved from the archaeological site to its outskirts, where the modern town of Delphi is located today. A descriptive plan of the site marking the walls of ancient building structures *in situ* was delivered around 1898, whereas a new version of it was made by A. Badie in 1992. The recent archaeological mission had three tasks: topographic mapping of building remains and features from the 19th century trenches after cleaning; re-examination of the original historic documentation; and geophysical mapping of the area, the overall objective being to produce

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a documented study of the urban layout and organization of the city, which had not been the focus of research like the sanctuary of Apollo.

The geophysical survey was carried out within the frame of a broader archaeological campaign aimed at studying the city and its development from the beginning of occupation in the 16th century BC to its abandonment in the 7th century AD. The program studied first (Phase I, 2012) the northwestern sector, then the eastern (Phase II, 2013) and western sectors (Phase III, 2014). The respective areas had not been explored in any greater extent so far, although the 19th century archaeologists had opened in some places a series of about 30 roughly parallel exploratory trenches that had uncovered a number of building remains.

GEOPHYSICAL APPROACHES

Geophysical prospection methods used to record the subsurface information in specific areas of the archaeological site included the magnetic method (Bartington G601), soil resistance (Geoscan Research RM15), ERT (Iris Syscal Pro with dipole-dipole configuration of electrodes), EM (GSSI Profiler EMP-400 and Geophex GEM-2) and GPR (Sensors&Software Noggin Plus with 250MHz antennas). The R-24 StrataView of Geometrics was also used experimentally for the acquisition of 3D seismic refraction data in an area of 50 m (E–W) by 40 m (N–S) to the west of the Delphi theater, using 24 P (12Hz OYO-Products) randomly distributed geophones.

GEOPHYSICAL RESULTS

Despite the challenging conditions: steep slopes (up to railway tracks 30–40%), wooded areas, fire-extinguishing system hoses, metal trash and old excavation railway distributed randomly around the site, and deep older trenches, the manifold methodologies (Sarris 2013) employed in the geophysical campaign produced more than encouraging results. Of all the methods used, GPR and ERT measurements, obtained along transects laid out almost north–south toward the falling slope, produced the best results compared to magnetic, soil resistance and EM surveys. These two particular methods were capable of penetrating through the deeper strata, as it was obvious that in most cases the architectural remains lay 1–2 m below the current surface. The magnetic and EM surveys were successful in areas that were relatively undisturbed by anthropogenic activity.

Various targets were identified, ranging from wells to individual structures and sustaining walls. GPR measurements revealed a number of strong reflectors associated with large retaining walls or collapsed architectural relics, sometimes confirmed by partly exposed remains in the open excavation trenches. The alignment of particular structures seems to follow an iso-elevation layout, looking towards the temple or the lower levels of the site. Ground erosion and landslides bringing down the bulk of soil, stones and other building material from collapsed structures from the upper slopes of the site is obvious in the GPR depth slices. In general, the degree of preservation of the structural remains on the higher slopes seems to be relatively better compared to the lower slopes. This may be justified by the lesser quantities of material that had been deposited on them.

The plateau close to the modern theater facilities and the lapidary of epigraphic stones was scanned with three methodologies: seismic, 3D ERT and GPR methods. The GPR located a few linear reflectors aligned almost E–W, mainly in the upper strata. ATOM-3D (Active tomography

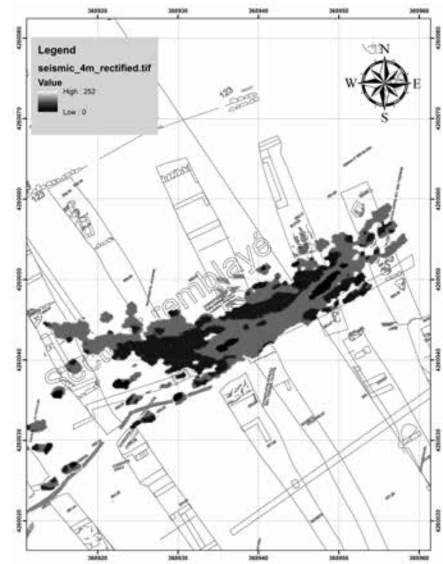

Fig. 1. Seismic depth slice for a depth of 3 m

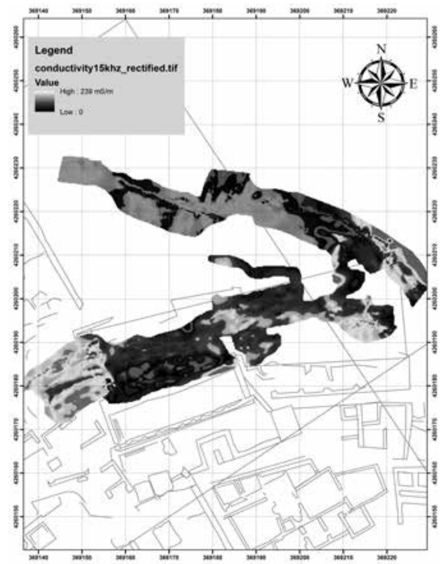

Fig. 2. GSSI EMP-400 EM conductivity measurements for 15kHz

in 3D) was employed for the 3D tomographic inversion of the seismic data (Koulakov 2009; 2011), based on ray-tracing methods and reconstruction of the 3D velocity structure based on travel times of the first-arrival refracted seismic rays from active sources. 73 shots were used to collect about 1752 traveltimes. Horizontal tomograms of velocity (11 depth slices) at various depths (0.5–5.5 m) were produced for the 3D seismic refraction data. In all the tomographic models a linear high-velocity feature was found at 3.0 m to 5.5 m depth; it belongs most likely to a NE–SW oriented structure, in good correlation with the ERT data (Soupios *et al.* 2013) (Fig. 1).

ERT was most successful in cases where deep penetration was needed (such as the mapping of the cistern to the west of the excavation house of the French School at Athens, found to extend within a 2–4 m range below the surface with soil resistivity of more than 2000 ohm-m) and where other methods were impossible to apply owing to difficult terrain and scattered modern metal. Some of the features that were identified with the ERT method were also verified with the GPR, which provided a more precise outline of the underground remains.

The highest frequency (15 kHz) electromagnetic survey that was carried out with the GSSI EMP-400 in the eastern sector indicated areas of low conductivity at shallow depths, and especially to the north of the already excavated monuments, suggesting the continuation of structures in this part of the settlement (Fig. 2).

FINAL REMARKS

Settlement structures clearly extended from the westernmost entrance of the protected archaeological site to the Castalia spring. Sustaining walls followed iso-elevation plateaus and

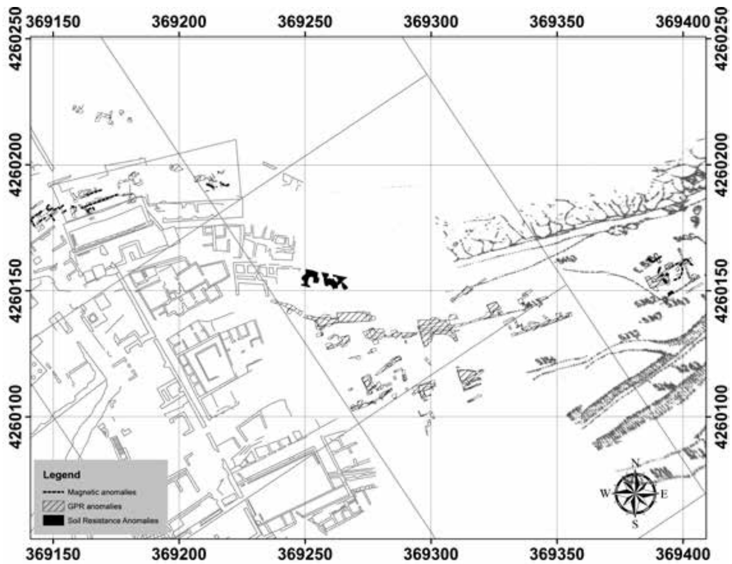

Fig. 3. Integrated image of geophysical features recorded in the eastern sector of the archaeological site at Delphi

structures were built along the slopes, leaving various horizontal and vertical corridors and streets between them (Fig. 3). Deposition depth of architectural features varied considerably on the different levels of the sloping terraces. Combined with test excavations and standing buildings, the geophysical results will contribute to a reconstruction of the settlement plan and fill in the gaps in areas that remain completely unexcavated until today.

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Geophysical prospection in the territory of the Roman town of Aesernia, central southern Italy

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KEY-WORDS: geophysical survey, resistivity, GPR, magnetometry, Aesernia, central southern Italy, Roman period

INTRODUCTION

The geophysical prospection survey at Isernia constitutes a ground-based remote-sensing research module of the Aesernia field survey project (Stek *et al.* in press). This is a subproject of the "Landscapes of Early Roman Colonization project", funded by NWO (Netherlands Organization for Scientific Research) and based at Leiden University and the Royal Netherlands Institute in Rome, which is implemented in Molise in collaboration with the Soprintendenza per i Beni Archeologici del Molise (Stek and Pelgrom 2013). The project investigates the rural settlement organization of the Roman towns of Venusia and Aesernia through conventional surface survey techniques and remote-sensing approaches (aerial imagery and geophysical prospection).

Five different sites in the area of Isernia were prospected using an integrated strategy, namely magnetometry, soil resistance and ground penetrating (GPR) techniques. More than 16,820 m^2 were prospected with a large degree of overlap between different methods.

RESULTS

Of the five sites that were surveyed, three produced significant results. Site A205 is located in the saddle between the valley of Fonte Salomone and the plain of Perete, just north of the Fonte S. Angelo hamlet. The archaeological fieldwalking survey of the site was carried out in October 2011 and resulted in the identification of a dense scatter of pottery (including black gloss, African red slip wares, plain and coarse wares, some recognizably Late Antique in attribution,

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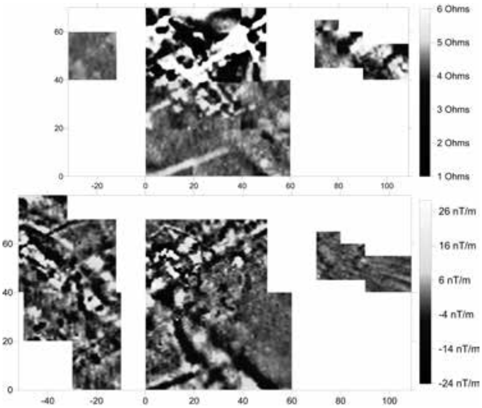

Fig. 1. Site A205. Top: results of the soil resistance survey; bottom: results of the vertical magnetic gradient survey

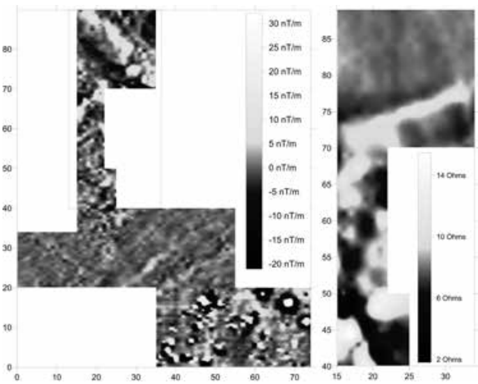

Fig. 2. Site A224. Left: results of the vertical magnetic gradient survey; right: results of the soil resistance survey limited to the upper northern part of the site

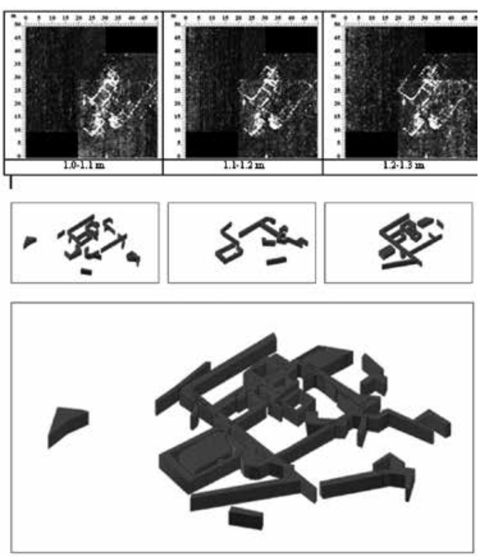

Fig. 3. Site A232. Top: GPR depth slices for depths of 1.0–1.1 m, 1.1–1.2 m and 1.2–1.3 m. The light colours indicate the intensive reflectors as registered by the NOGGIN_PLUS 250MHz GPR unit; middle: 3D reconstruction of the diagrammatic interpretation of geophysical anomalies (from left to right: GPR, magnetic, resistivity); bottom: synthesis of the 3D reconstruction indicates a clear outline of a Roman villa. The reconstruction was made as a primitive prototype, considering not so much the depth of the buried architectural remains, but traces registered by all methods, contributing in this way to a full description of the outline of the complex. The 3D reconstructions were carried out in ArcScene

amphoras and *dolia*, glazed wares) and a large quantity of roof tiles, which are ubiquitous in the field. Surface finds indicated that occupation of the site spanned a period from the Roman Republican to the late Imperial period, with some materials dating to the modern period. The geophysical results provided evidence of a number of features that could be interpreted as a large complex, 50 m (E–W) by 45 m (N–S). The clearest signals were produced by the GPR measurements, which suggested a burial depth of about 80–120 cm below the ground surface. All methods provided comparable results and their interpretation indicated that the antiquities may belong to a large installation apparently in relative good condition.

The fieldwalking surface survey in October 2012 at the cluster of sites A224/A225/A226, which is located on the top of a ridge that extends south from the village of Colle Cioffi, produced fragments of painted plaster, roof tiles, *opus spicatum* bricks and *opus caementicium* rubble. Pottery included a wide range of wares (*impasto*, *bucchero*, black gloss, Italic terra sigillata, African red slip wares, plain and coarse wares, amphoras and *dolia*, glazed wares), reflecting long occupation from the Late Iron Age/Archaic period through modern times, with the bulk of the material dating to the Roman Republican–late Imperial period. Despite the small size of the surveyed grids, geophysical techniques proved that there is substantial evidence for the presence of architectural relics possibly extending further to the central eastern and western sectors of the surveyed area. The subsurface relics seem to be buried within a depth of 1 m below the surface and strong reflectors may have been caused by collapsed building material.

The most striking data, however, were produced at site A232, which is located on the southern slopes of the Colle Facora, with a view to the south over the ridges of Campo Largo and the Cavaliere valley. Personal communication with the field owners indicated that a brick floor and marble fragments had been found in the past. The archaeological fieldwalking survey in September 2013 yielded a high sherd density (about 12 sherds per square meter despite poor ground visibility at the site), consisting mostly of roof tiles, but with some pottery (coarse wares, amphora and *dolia*). Despite the difficulties in dating the site more precisely than generically to the Hellenistic–Roman period, it was interpreted as a structure or multiple structures with possible storage function (as indicated by the *dolium* and amphora fragments).

The results of geophysical surveying verified the finds of the fieldwalking surface prospection. They showed the clear outline of a building complex consisting of multiple rooms. All three of the applied geophysical techniques (magnetometry, resistivity and GPR) resulted in complementary outcomes. GPR signals registered reflectors from 1.0–1.5 m below the surface, with the northern anomalies lying deeper than the southern ones (with respect to current ground elevation). Geophysical measurements outlined an architectural compound, 35 m by 37 m, consisting of various compartments laid out on a plan that resembles a typical Roman villa or large farmstead. At the western end of the complex there is a rectangular building, 9 m by 7 m in size, outlined as an intense reflector (possibly caused by collapsed building blocks), as a high resistance anomaly (for the same reason) and as a high magnetic anomaly (probably due to heating activities occurring inside the building). To the south-east, an aisled building is projected in front of the complex to the west. The outer diameter of it is about 5.5 m. Taking into account the continuity of the western sustaining wall to the north, the possible entrance to the compound is suggested on the southwestern side. The large open space (~18 m by 10 m) to the east of the aisled structure may belong to the inner courtyard of the house. A rectangular anomaly is outlined at the center of this suggested courtyard. To the north side of the courtyard, a long corridor is recognizable. This is not the case for the southern side of the complex, where its limits are not easily distinguished. Three internal divisions (rooms) are identified between the courtyard and the northern corridor, mainly from the GPR and the soil resistance measurements. Another elongated room is suggested on the eastern side of the complex.

FINAL REMARKS

Having a good responce from the surface surveying techniques, geophysical approaches proved extremely efficient in identifying a number of architectural structures most probably related to villas, farmsteads and agricultural installations. The geophysical survey proved a successful addition to the archaeological field survey of the territory of the Roman town of Aesernia to enhance the understanding of surface scatters of archaeological material, and the importance of applying multiple geophysical techniques (manifold approach, Sarris 2013) was clearly demonstrated. In some cases, such as site A232, the complementarity of the various techniques could be exploited in order to produce primitive 3D reconstructions of the various architectural compounds. In the next phase of the "Landscapes of Early Roman Colonization" project, a selection of sites in the research area around Aesernia (including the three examples given here) will be subject to a detailed intra-site study, using a high-resolution, gridded point sampling technique, in order to enhance the chronological and functional interpretation of the sites and to identify possible areas of internal functional zoning.

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Towards an integrated remote-sensing strategy for revealing the urban details of the Hellenistic-Roman city of Demetrias, central Greece

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KEY-WORDS: integrated geophysical survey, EM, GPR, magnetics, Hellenistic–Roman, Demetrias, urban research, Greece

INTRODUCTION

The ancient city of Demetrias is located on a small promontory on the Pagasetic Gulf just south of the modern city of Volos. It was established by the Macedonian king Demetrios in 294 BC and became the royal residence of the Antigonid dynasty of Macedonian kings. The city flourished as a political center and as a stronghold for the Macedonian naval fleet. After the Romans defeated the Macedonians in 168 BC, a prolonged state of decline befell the city, but it continued to be inhabited until the 6th century AD. Organized along the lines of the Macedonian kingdom cities, Demetrias was a major strategic settlement in the region, as attested by its large extent, the expansive fortification walls that enclose a large area in the region, and its monumental architecture. A reconstruction of the city plan of Demetrias has been produced based on past excavations of the 1960s and 1970s by D. Theocharis and a group of German archaeologists (Milojčić 1974; Milojčić and Theocharis 1976; 1978; Milojčić *et al.* 1980; Einwanger 1981; Bakhuizen *et al.* 1987).

GEOPHYSICAL APPROACHES

Previous geophysical work in the area covered the region of the ancient theater which is well preserved (Sarris *et al.* 2013). The aim of our current research involved an expansion of investigation to other sections of the site and the creation of a best-practices approach to geophysical prospection.

High-resolution multispectral satellite images were employed together with excavation plans in order to reconstruct the layout and plan of the city. Based on this, various segments of the city were explored, via magnetic, soil resistance, electromagnetic (EM) and ground penetrating radar (GPR) techniques. In total, about 10 ha of the ancient city were covered, out of which about 5 ha was new coverage without overlap from the different methodologies. Depending on the accessibility of the areas and the vegetation, measurements of the magnetic field were carried out by both Bartington G601 (with sampling of 1 m x 12.5 cm) and a multi-sensor SENSYS Mag-

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Fig. 1. Superposition of the GPR Noggin Plus 250MHz 0.8 m depth slice on the magnetic data acquired from the area to the south of the Hellenistic Palace of Demetrias. Data were overlaid onto a World-View 2 satellite image. The Hellenistic palace is shown in the upper right corner of the image

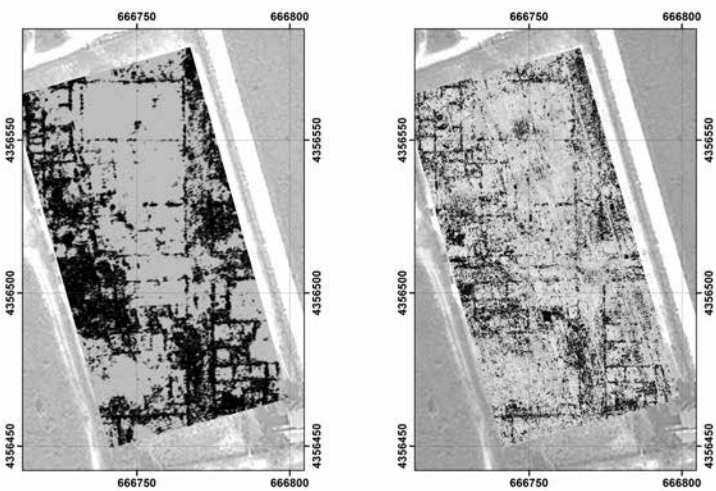

Fig. 2. Demetrias, area of the soccer field. Left: Depth slice of 0.8 m from the Noggin Plus 250MHz GPR unit. Right: Depth slice of 0.8 m from the MALÅ Imaging Radar Array 400MHz GPR unit. Dark colours indicate the most intense reflectors

netometer MX system consisting of eight fluxgate gradiometers (with sampling of about 0.5 m x 10 cm) and a GPS rover unit. A single channel Sensors and Software NOGGIN Plus-Smart Cart system with a 250 MHz antenna and a MALÅ Imaging Radar Array with nine 400MHz antennas were widely employed within a number of flat sections, especially parking lots and soccer fields. Spatial sampling resolution was 0.5 m x 2.5 cm and 10 cm x 8 cm correspondingly for the above GPR units. Soil conductivity and magnetic susceptibility information were acquired via a GEM-2 multi-frequency and a CMD multi-coils spacing electro-magnetometer units (with sampling of 1 m x 1 m). Small sections were also investigated through a twin-probe-array Geoscan RM85 resistivity meter.

MAPPING OF THE URBAN STRUCTURE OF THE ANCIENT CITY

Due to recent activities in the area, deposition of modern debris increased levels of noise for magnetic measurements and vegetation density prevented the implementation of all techniques, especially GPR. Multiple techniques were implemented however in the better preserved areas. The geophysical results through the amalgamation of the various techniques have been extremely revealing in confirming the accuracy of the German city plan, providing evidence for new streets not included on the plan and identifying clusters of subsurface buildings, both large public and smaller private structutres, with great clarity.

Despite the surface distribution of metal and garbage debris, a number of linear anomalies became apparent from both magnetics and GPR to the west and south of the central excavated site, where the Hellenistic palace complex and agora are located (Fig. 1). Most notable is the group of structures located to the south of the palace, which consists of square and rectilinear rooms of various dimensions and long corridors. The western boundary of the complex is clearly defined by a north–south wall identified in GPR and to a lesser extent with magnetics. The structural remains continue further to the west with a similar density, in contrast to any significant features found within the agora itself.

An even higher density of structural remains was found in the region east of the agora and southeast of the Hellenistic palace. Almost all methods (EM, magnetics and GPR) applied in the specific area where a dirt soccer field is presently located produced comparable outcomes with the most clarity and details resulting from the higher-resolution GPR surveys (Fig. 2). The data indicate that the region could have been a dense residential and commercial quarter of the ancient city, where structures were confined in blocks of about 50 m x 100 m and crossed by N–S and E–W streets of about 8.2 m in width. Within the city blocks, structural complexes seem to consist of various clusters of rooms and corridors with or without open yards. This kind of architectural arrangement is typical of Hellenistic and Roman urban houses with courtyards or gardens in the back and shared partition walls between houses (Rumscheid 1998; Zanker 1998).

Moving away (~400 m) from the center of the city and close to the modern shoreline in the northern region of Demetrias, geophysical data discovered the ruins of a large buried structure following the same alignment as the rest of the city plan. The structure consists of a semicircular (20–25 m radius) western half that is connected to a rectilinear (about 45 m in length) complex with individual rooms (Fig. 3). The semicircular exterior of the building has a corresponding semicircular feature 7–8 m inside. The southern end of the rectilinear complex

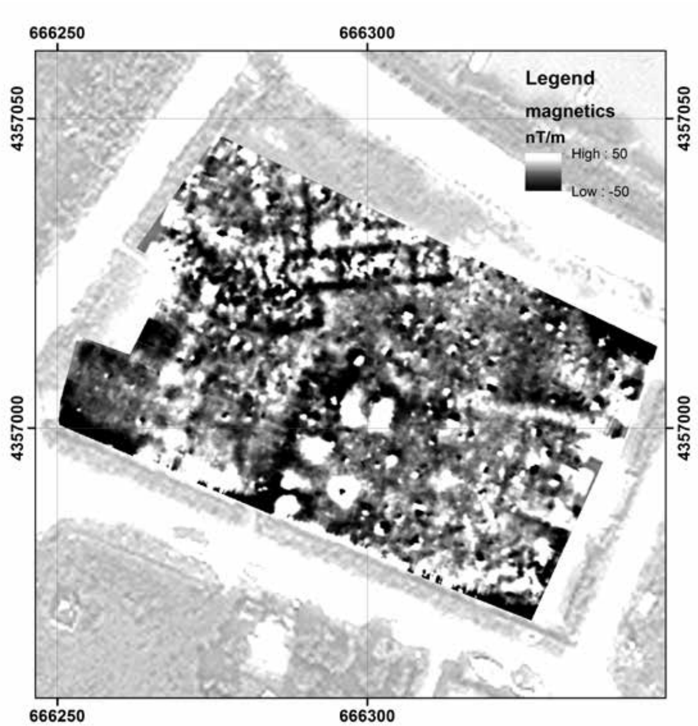

Fig. 3. Results of the SENSYS magnetic prospection from a field close to the shoreline

is subdivided into four rooms. The western room appears to have an apsidal end. North of these rooms, a large square area (courtyard?) appears in the geophysical data. The plan of the particular monument is suggestive either of a small theater with an attached portico or of a covered odeion, although a bath complex cannot be ruled out.

Overall, geophysical survey in Demetrias was more than revealing. It confirmed sections of the older German plan, identified various new features, blocks and roads, provided accurate details of the internal structural planning of the city blocks, and indicated the expansion of the city plan in areas that were completely unexplored. The resulting maps have contributed significantly to an understanding of the usage of the urban space in the Hellenistic and Roman periods, allowing comparisons with other similar cities in the Greek mainland.

ACKNOWLEDGMENTS

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Cultural variations of the Neolithic landscape of Thessaly

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KEY-WORDS: geophysical survey, multisensor magnetic survey, EM, GPR, RM, satellite remote sensing, UAV, magnetic susceptibility

INTRODUCTION

The Neolithic period in Europe (6800–2000 BC) is widely considered a key epoch in the evolving relationship of human beings to their inhabitable environment. Groups of hunters and gatherers gave way to more sedentary agrarian societies dealing with animal husbandry and the cultivation of subsistence crops. Various interdisciplinary studies have focused on settlement

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Fig. 1. Results of the SENSYS MX magnetic gradiometer survey at the Almyros 2 Neolithic tell

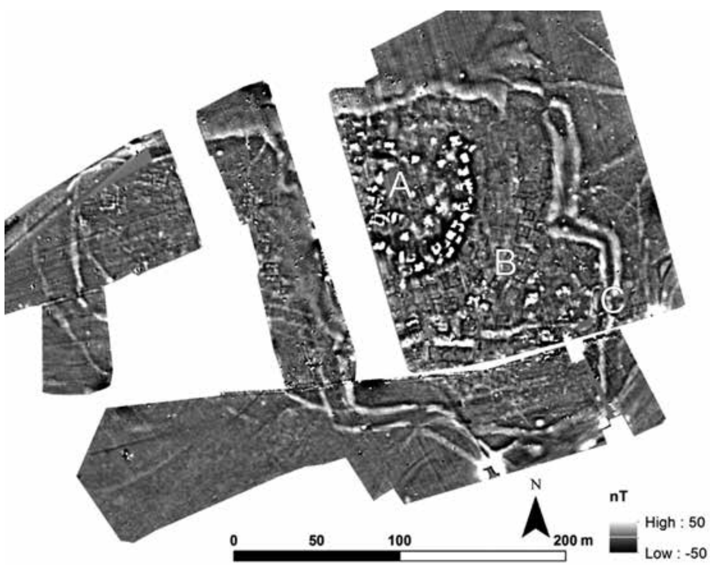

Fig. 2. *Magoula* Almyriotiki. Results of the magnetic survey showing details of the intra-site organization of the settlement: main core of the *magoula* (A) and peripheral structures (B). Traces of flooding episodes are indicated to the north of the *magoula*, where the outer double ditch signature (C) seems to fade away

patterns of the Neolithic period and Greece and Thessaly have been particularly challenging in this respect, being considered one of the first regions in Europe where these new groups developed. Indeed, Thessalian geography and geology make it a closed geographical unit with well-defined natural boundaries and subdivisions. It is therefore a promising region for reconstructing the major habitation models of Neolithic farming groups in Greece and examining the relation over time of the anthropic and natural landscapes.

METHODOLOGICAL APPROACHES

For the past three years the ARISTEIA-IGEAN (Innovative Geophysical Approaches for the Study of Early Agricultural Villages of Neolithic Thessaly) project has been conducting a regular and extensive geophysical investigation of the Neolithic landscape of Thessaly. It has explored specifically a number of Neolithic tells (*magoules*) in coastal Thessaly, designing and implementing for the purpose a geophysical strategy for a rapid, high-resolution assessment of their subsurface. Geophysical surveys made use of multi-component geophysical instruments (single- and multi-sensor magnetic, single- and multi-antenna GPR arrays, multifrequency EM, soil resistance and chemical and magnetic analyses) for broad coverage of the settlements. A Sensys MX compact system with 8 FGM600 fluxgate gradiometer, GEM2 and CMD Mini Explorer conductivity meters were used for wide coverage. The magnetic survey offered high resolution data from all the regions. The EM units offered measurements of soil conductivity and magnetic susceptibility at various depths. In areas covered by trees or in the vicinity of modern structures, the surveys were adapted accordingly, using single-sensor magnetometers (Bartington G601), GPR (Noggin Plus with 250MHz antennas and MALÅ MIRA 8 channel GPR with 400MHz antennas) or resistivity (RM85 Twin probe array) meters. In most cases, however, more than three methods were applied, offering good verification of the suggested targets or complementarity of the different datasets. Sampling was denser for the GPR measurements (0.5 x 0.025 m) compared to the rest of the techniques (0.0125–1 m for G601 and 1 x 1 m for EM85). GPR use was particularly successful in calculating the depth of the cultural layers and estimating the vertical extent of architectural relics. Magnetic susceptibility and phosphate analyses were also applied to provide an index of space limits and usage types.

At the same time, UAV-IR aerial reconnaissance, historical airborne photos and satellite images were used to map both the surface of the sites and their environs, and expose any subtle features related to the environmental setting of the settlements. The satellite data came from WorldView-2, Geoeye-1, and Quickbird-1, and the aerial images went back to 1960. The photo-interpretation of the images relied heavily on the calculation of various vegetation indices and image combinations.

RESULTS

The results of the manifold remote-sensing approaches were extremely illuminating both in terms of identifying numerous details of the settlements and recognizing features that can be related to various past environmental episodes. On most of the surveyed tells, a dense cluster of daub structures was found at the core of the mound, demonstrating signs of burning. On some of the tells, as in the case of Almyros 2 (Floras and Sgouras 2004: 13–14; Wijnen and

Fig. 3. *Magoula* Rizomilos 2. Results of the magnetic survey superimposed on a GeoEye-1 satellite image taken on May 4, 2010. The satellite image is a pansharpened Intensity-Hue-Saturation combination. A second smaller similar tell is suggested to the east of the settlement. To the north, the magnetic signature and the satellite data indicate traces of past flooding activity. According to the locals, the region used to be flooded regularly in historical periods

Rondiri 2004: 24–38), diverse usage was demonstrated on the mound, which was roughly 50 m in diameter. The clustered dwellings were clearly separated by an open/empty zone. In some cases, the nucleus of the tells was surrounded by small enclosures and the limits of the settlements were defined by a larger system of outer multiple ditches, usually of circular shape, all of which bear evidence of multiple entrances. At Almyros 2, an unoccupied area was identified between the nucleus of the tell and the outer ditches to the north, contrasting with the southern part, which seems to have been densely occupied (Fig. 1).

At the Almyriotiki *magoula* (Wijnen and Rondiri 2004: 37), a large settlement consisting of two-to-three room structures built of stone (especially evident in the magnetics and GPR data) extends around the main tell, covering an area of 200 m by 350 m (Fig. 2). The extensive settlement around the tell is surrounded by a double-ditch system with a 10 m gap between the ditches. A similar flat settlement of rectangular shape (~100 x 200 m) seems to have extended also around the nucleus of the Perdika 1 *magoula* (Floras and Sgouras 2004: 16). Mudbrick and stone-built dwellings seem to have coexisted outside the center of the tell, suggesting a diachronic occupation of the settlement. Located on a natural hilltop about 1 km away from Perdika 1, the

Perdika 2 *magoula*, which extends 100 m to 120 m, shows no significant signs of habitation. The few structures that were recognized here seem to be in isolation with respect to the rest of the site, which is partitioned off by a number of internal and external walls.

With respect to the environmental features suggested by the various approaches, the most striking were traces of palaeochannels or of past flooding activities in a number of settlements (i.e. Almyriotiki, Almyros 2, Perdika 1 and Rizomilos 2 (Fig. 3), which was indicated by both the soil signature and the disruptions of the outer ditches. The outer ditches may have also plausibly functioned as a water defensive/management system.

FINAL REMARKS

The multiyear survey of the Neolithic landscape of Thessaly demonstrated the successful application of geophysical, aerial and satellite remote-sensing techniques in the uncovering of the details and dynamics of the Neolithic settlements. The combination of an arsenal of diverse remote-sensing approaches was crucial to this task. It was possible to conceptualize similar and divergent characteristics of the settlements with regard to the planning and building materials, estimate the extent of the settlements and houses, study the intra-site organization of the structures, make a clear discrimination between built and unbuilt areas, understand the way of demarcation of the settlements through the existence of fortifications and ditches, and document the diachronic development of habitation.

The systematic scanning of about 16 *magoules* has made apparent differences in habitation and land use that makes the Neolithic landscape one of variation. Gaining for the first time a thorough understanding of settlement patterns in a small part of the Thessalian plain, it would still be illusive to conclude that we can draw conclusions for the area as a whole. A new frontier of knowledge has been opened evidently, including implications regarding the sustainability of the population, persistency of occupation, spatial and social stratification and exploitation of natural resources.

ACKNOWLEDGEMENTS

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Unfolding the Neolithic wetlands landscape of Szeghalom-Kovácshalom in Hungary

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KEY-WORDS: integrated geophysical survey, magnetics, ERT, multi-frequency EM, GPR, magnetic susceptibility, Neolithic wetlands, Hungary

INTRODUCTION

The archaeological site of Szeghalom-Kovácshalom is located in an agricultural area to the north of the Sebes Körös River and southwest of the modern village of Szeghalom. The site represents a Tisza settlement type with some intrusive Bronze Age finds (Ecsedy *et al.* 1982: 161). The settlement covers nearly 90 ha, comprising a relatively small tell that is surrounded by an extensive flat site with origins in the Szakálhát phase of the Middle Neolithic (5200–5000 BC cal.) and undergoing expansion during the Late Neolithic Tisza phase (5000–4500 BC cal.). The geophysical campaign that continued for five seasons, from 2010 to 2014, was carried out under the auspices of KRAP (The Koros Regional Archaeological Project), which has been investigating various Neolithic and Early Bronze settlements in central-eastern Hungary since 2002. The goal of the geophysical research, which was accompanied by further modules of the KRAP project, such as surface surveying, test excavations, coring for chemical analyses, and topographic mapping, was to contribute to an understanding of tell formation processes and the evolution of farming societies in southeastern Europe (Yerkes 2010).

GEOPHYSICAL METHODS

The geophysical prospection survey around the Szeghalom-Kovácshalom tell made use of the vertical magnetic gradient for extensive mapping of structural settlement remains. Techniques of electrical resistivity tomography (ERT) and mulifrequency EM (operating at five different frequencies: 5010, 10050, 20010, 30030, 40050 Hz) were employed to investigate the stratigraphy of the tell and to confirm the location of the palaeochannels around it. ERT and ground-penetrating radar (GPR) were further used to explore the efficiency of mapping daub-based structural remains.

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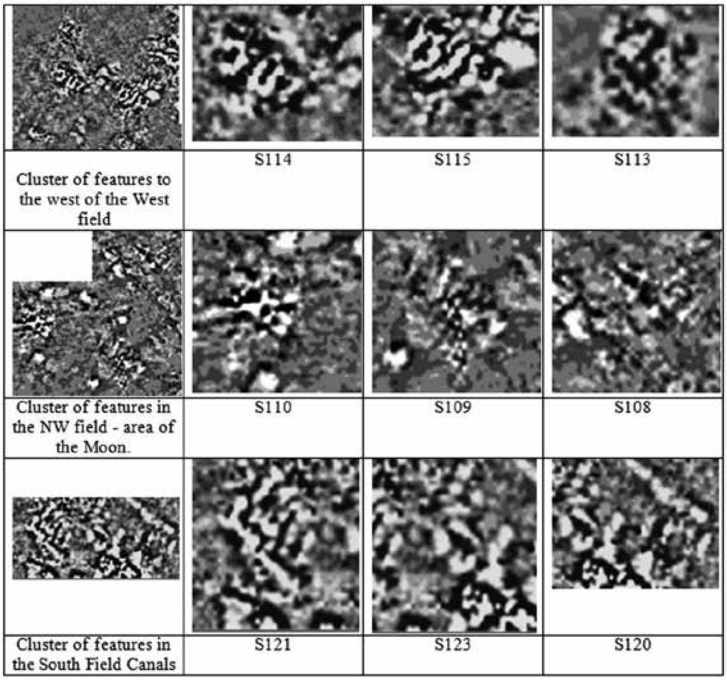

Fig. 1. Typical houses identified by magnetic measurements at Szeghalom-Kovacshalom. Magnetic signature of structures varies depending on their preservation; some are well defined with a very strong magnetic signature, whereas others are diffused, probably as a result of cultivation practices or fluvial erosion

GEOPHYSICAL RESULTS

Geophysical prospection identified numerous elements of the Neolithic settlement, which exhibits a large amount of variation in terms of dwelling distribution and house size and orientation. The magnetic signature of the structures is relatively strong, indicating burning residues (Fig. 1). Some of these features are characterized by a very clear outline, while others exhibit a fuzzy signal that can be attributed to collapsed roofs or overall burning of the houses, or to topsoil disturbance by plowing. Finally, the internal organization of the structures frequently includes inner divisions that partition the structures into three or more compartments. GPR signals above the structural remains were not that informative, probably due to the high conductivity of the clay soils. On the other hand, GPR has given some partial evidence for the location of previous excavation trenches on the tell.

More than 140,000 field data were collected from 28 ERT transects (total length of 5 km) in the area of the tell. The inverted pole-dipole ERT results indicated that the paleomeander around the tell registered with low resistivity values due to the fine clayey material that filled the old river bed and generated a large resistivity contrast with the surrounding material (Fig. 2). The paleomeander is deeper at the east end of the tell, reaching a maximum depth of 2.5 m, while its depth does not exceed 1.7 m at the northern and western parts of the tell. The top soil and

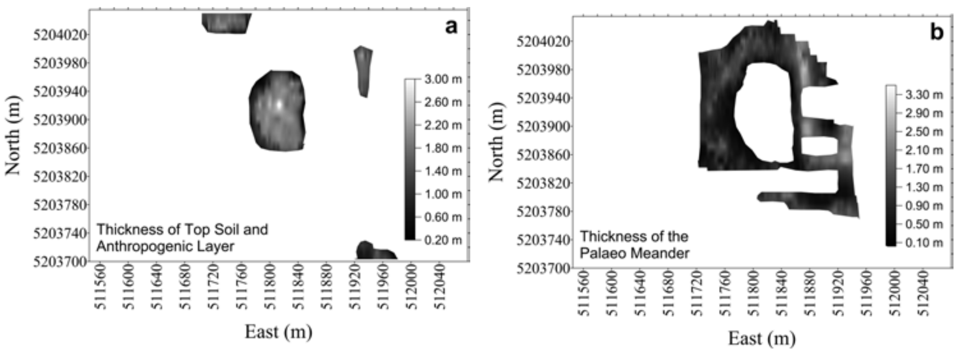

Fig. 2. Spatial variation of: (a) thickness of top soil and anthropogenic layer and (b) thickness of the paleo meander as shown by the combined interpretation of soil horizons mapped with electrical resistivity tomography

anthropogenic layer on the tell have a maximum depth of almost 3.2 m below the summit. The thickness of the cultural layers gradually decreases, reaching about 0.5 m at the edges of the tell. Correlation between the EM and ERT results indicated that the tell is more resistive than the geological banking. Three ranges of resistivity were observed: less than 35 ohm-m around the tell, between 35 and 70 ohm-m close to the elevation and more than 70 ohm-m on the top. Magnetic susceptibility seems to define clearly the outline of the tell. Based on the integrated results of the magnetic, GPR, EM and ERT surveys, the tell can be measured at about 120 m by 75 m, giving a total area of 9,000 m^2. This puts it in the smaller-size category of tells according to the classification by Kalicz and Raczky (1987: 16) for Tisza-period tells.

Magnetic susceptibility samples were collected from a profile of a trench that was opened on the tell. The results indicated that the highest values of induced magnetization of soils were correlated with layers with little or no archaeological material zones, suggesting significant disturbance of the stratigraphy, probably from past excavations. Increased magnetic susceptibility values were registered also where midden layers containing mud plaster floor remnants were found.

FINAL REMARKS

The results of the geophysical campaigns provided a more holistic and detailed picture of the settlement pattern at the archaeological site of Szeghalom-Kovácshalom. Almost 50 ha were covered with the magnetic survey (the largest high-resolution geophysical survey that has ever been conducted in Hungary), bringing to light more than 160 traces of structural remains and many more pits and other features manifesting intensive habitation of the site (Fig. 3). The structures are of oblong shape with similar dimensions around 17–25 m by 8 m and most of them can be considered as thermal features, with intense heating/crafting activities in their interior. They seem to consist of two or three compartments/divisions (representing well the Tisza settlement house type) and in between the houses a number of

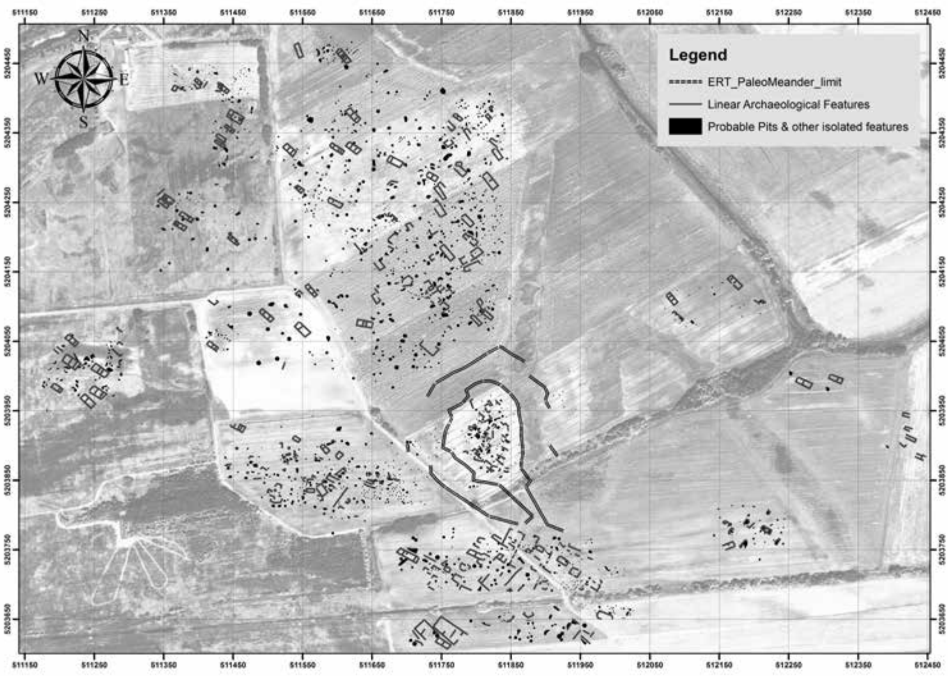

Fig. 3. Part of the integrated image of the results of the magnetic survey at Szeghalom-Kovácshalom. Diagrammatic interpretation of the geophysical anomalies overlaid on the satellite image of the region

pits can be recognized. Excavations on the spot of several structures demonstrated that the magnetic traces were produced by burnt daub.

The built environment of the site seems to have been constructed around a buffer zone of about 100–200 m surrounding the tell. It shows distinct variations differentiating two sectors, one densely settled to the south of the tell and another one with a more dispersed character represented by clusters or neighborhoods of houses. The type of houses in the aggregated flat settlement to the south of the tell deviate from the Tisza type of dispersed farmstead that is found to the north and east of the settlement. This indicates a contemporaneous phase between the tell and the flat settlement, which is also supported by radiocarbon dates. It remains unclear whether the flat settlement sectors were created as a result of gradual population shift in search of exploitable land or temporal landscape changes resulting from the dynamics of river channels in the neighborhood of the settlement. It is likely that the tell was surrounded by paleomeanders that formed a natural defensive ditch.

Having acquired such a wealth of information regarding the spatial distribution of the recognized structural remains of the site, GIS analyses using indices such as average nearest neighbor analysis, Thiessen polygons, and hot spot analysis, allowed us to trace trends and anomalies in community-level organization (Niekamp and Sarris 2014).

ACKNOWLEDGMENTS

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Exposing the Urban Plan of the ancient city of Hyettos, Boeotia, Greece

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KEY-WORDS: geophysical survey, remote sensing, ERT, resistivity, GPR, magnetics, Hyettos, Greece

Both surface surveying and remote-sensing techniques were applied for recording structures and reconstructing the road network of the ancient city of Hyettos in central Boeotia, Greece. A geophysical survey focused on areas of the archaeological site with the highest recorded ceramic density as well as other sections that were hypothesized as the boundaries of the ancient city. The surface survey and the study of the pottery and architecture were carried out previously by the University of Leiden.

Ground penetrating radar (GPR), electrical resistivity tomography (ERT), electrical resistance mapping, magnetic gradiometry and magnetic susceptibility methods were used comple-

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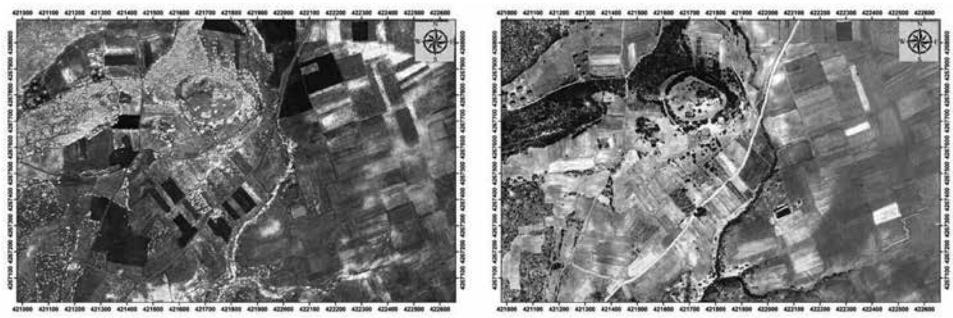

Fig. 1. Results from satellite remote-sensing image processing. Left: Intensity–Hue–Saturation (HIS) filtering; right: Decorrelation Stretch

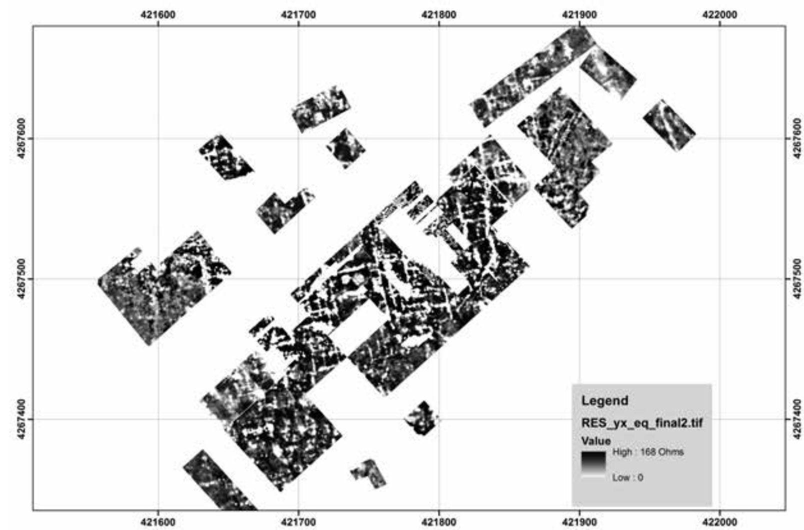

Fig. 2. Combined results of soil resistance mapping and ERT surveying at Hyettos

mentarily for the prospection of various sectors of the archaeological site. Satellite remote-sensing images were also employed in an effort to capture any potential anthropogenic features in the broader landscape of the archaeological site (Fig. 1).

All the resulting maps were rectified to the Greek geodetic topographic system (GGRS 87) and they were overlaid on an aerial photo of the area, together with the rest of the available topographic maps and plans of the area depicting some of the surface architectural remains, like the scattered tombs to the northwest and the agora in the central part of the investigated area. The synthesis of the geophysical results clearly demonstrated the importance of the manifold geophysical strategy

Fig. 3. Integrated diagrammatic interpretation of the geophysical anomalies registered by geophysical surveying methods at Hyettos and reconstruction of the ancient urban street grid based on the results

to survey the area of Hyettos. Each one of the methods applied has been able to suggest specific targets in terms of the physical quantity measured and the properties of the subsurface.

Despite the fact that the GPR provided more details of the stratigraphic extent of some of the architectural buildings, its signals were severely affected by the geological and local environmental setting. High concentrations of iron oxides in the soil similarly affected the magnetic data. Two extensive (6–8 m by 65 m) and outstanding magnetic anomalies were located to the north of the surveyed area, right below the acropolis of the site. These were caused most probably by magnetic ores known to exist in the region and mined in the past. Electrical resistivity and induced polarization tomographic measurements above these anomalies indicated that they were caused by highly magnetized bodies with chargeability of more than 20 mV/V, buried at depths of 0.9–2 m below ground surface.

The enrichment of soils in highly magnetic minerals is obvious also in the magnetic susceptibility values. Magnetic susceptibility variation along the three different transects studied does not indicate any clear fall-off pattern corresponding to the settlement limits. Increased values of magnetic susceptibility were manifested at the centre of the settlement, where architectural relics were revealed by the resistivity, and towards the riverbed to the southeast, suggesting that ancient urban occupation could have extended in this direction.

A number of rectangular buildings were revealed by the GPR survey, mainly in the central area of the settlement. The buildings were of a similar orientation as the rest of the urban street grid and their strong signal indicates satisfactory preservation. Large architectural complexes appear also on the plateau to the south of the acropolis. These appear in good correlation to linear anomalies (possibly ancient streets) found in the same area, extending E–W or N–S and suggesting that the city had reached the acropolis. A few more GPR reflectors were identified above the asphalt road and the area of the churchyard to the south. More specifically, an architectural complex seems to extend to the east and southeast of the church, and it probably runs under the church foundations. The structure has a similar orientation as the rest of the ancient city and measures more than 7 m by 7 m. In general, the GPR signals were relatively strong in cases where preservation of the structures was good and in areas where there was no collapsed building material collected in bulk.

The electrical resistivity method proved to be the most suitable for reconstructing the urban network of Hyettos. A standard twin-probe resistance mapping technique and electrical resistivity tomography (ERT) in a dipole–dipole configuration were jointly applied to map the subsurface resistivity properties of the site within a depth of more than one meter. A total area of more than 40,000 m^2 was covered by the two techniques combined (Fig. 2).

The resistivity map clearly outlined a number of structural remains that extended mainly over the central part of the surveyed region below the acropolis and to the north of the modern road. Most of the architectural remains represented building complexes, consisting either of simple rectangular walls or more complicated divisions. All of them, with very few exceptions, were aligned almost exactly N–S/E–W. Some sectors exhibited a much more complicated plan with interior walls dividing the buildings into smaller compartments.

The N–S roads appear to have been 5.7–6.0 m wide, some of them narrowing at the eastern and western ends of the city. To the south, the N–S streets were about 38 m apart, but they started to deviate as they ran northward, toward the slopes of the acropolis. Some of the long linear street sections were traced for more than 93 m and corresponded to the main pathways leading to the entrances to the acropolis. Traces of about 8 longitudinal roads are evident, and only six E–W streets, which seem to be narrower and harder to reconstruct based on the geophysical signals.

Geophysical techniques facilitated a rough plan of the urban street grid (Fig. 3). It is evident that the city reached the foot of the acropolis and covered an area of at least 300 m by 300 m, whereas the magnetic susceptibility measurements indicated a further expansion of the habitation to the east and south.

The geophysical surveys carried out in the different seasons were accompanied by a hands-on training module for students and theoretical seminars. The workshops on "Geophysics, Remote Sensing Techniques and Ground-Based Digital Recording Methods for Archaeological Sites and Cultural Landscapes" were able to provide a thorough and in-depth training to graduate, PhD and Postdoc students.

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SQUID-based magnetic prospection in interdisciplinary case studies at possible early and high medieval harbour sites in Germany

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KEY-WORDS: geophysics, SQUID, magnetic prospection, inversion, multi-modal analysis, interpretation

For centuries waterways have been very important for the transportation of goods and men, as well as for fast traveling. The boundary areas between land and water have always been a very dynamic system. The reconstruction of the contemporary river bank situation is as important as the analysis of the development of the river and its banks over time. The research on settlement places and production sites with a direct connection to rivers needs a suitable description of possible harbour structures as well as a characterization of the settlement conditions and their changes. The current research project is part of the German Research Foundation (DFG) Priority Program "Harbours from the Roman Period to the Middle Ages" (SPP 1630) and investigates two sites of possible domestic ports in Bavaria (Germany).

These case studies demonstrate the advantages of an interdisciplinary cooperation for the research of archeological sites. In particular, this paper focuses on the potential of an associated analysis of large-scale magnetic prospection and geoarchaeological methods, such as drilling, aerial photo analysis, and field surveys. The prospection was carried out with a SQUID-based gradiometer system, which consists of high-sensitivity magnetometers and gradiometer (Zakosarenko 1996: 112–115), a differential GPS and an inertial unit, respectively. This combination of fast and precise simultaneous acquisition of magnetic gradient components together with the exact localization and orientation of the sensors ensures an effective magnetic anomaly mapping, which is supported by the simultaneously acquired local topography. The spatial coverage efficiency of the presented system is very useful for large-scale archaeological investigations (Linzen 2007: 50–755) and the associated content of information offers possibilities for model-based data inversion (Schneider 2014: #6000704). The applied inversion algorithms directly support the archaeological interpretation. On the one hand, the additional information of the different methods (e.g., coring, digging, aerial photo analyzing) improves the accuracy of

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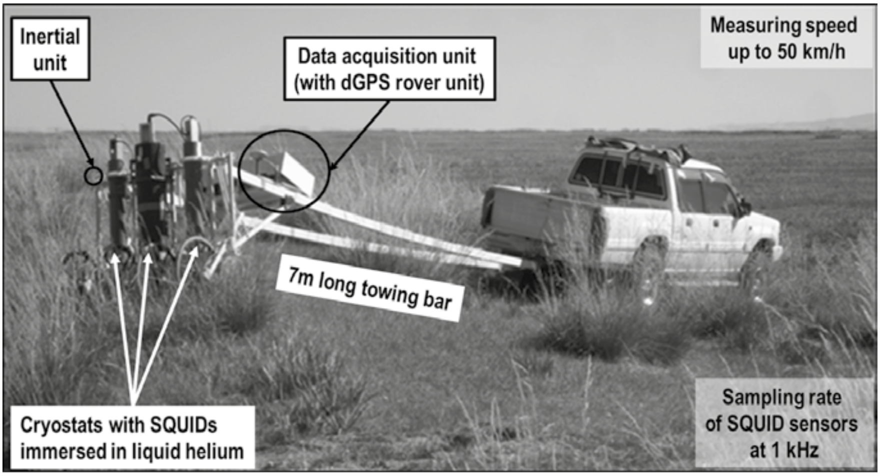

Fig. 1. Overview of the SQUID-based measurement system of IPHT Jena and Supracon AG, which is normally pulled by an all-terrain vehicle. A combination of high-sensitive magnetic sensors, precise localization and orientation reading ensures effective, high-resolution magnetic prospection measurements for archaeological inverstigations with a mapping efficiency of up to 100.000 m² per day

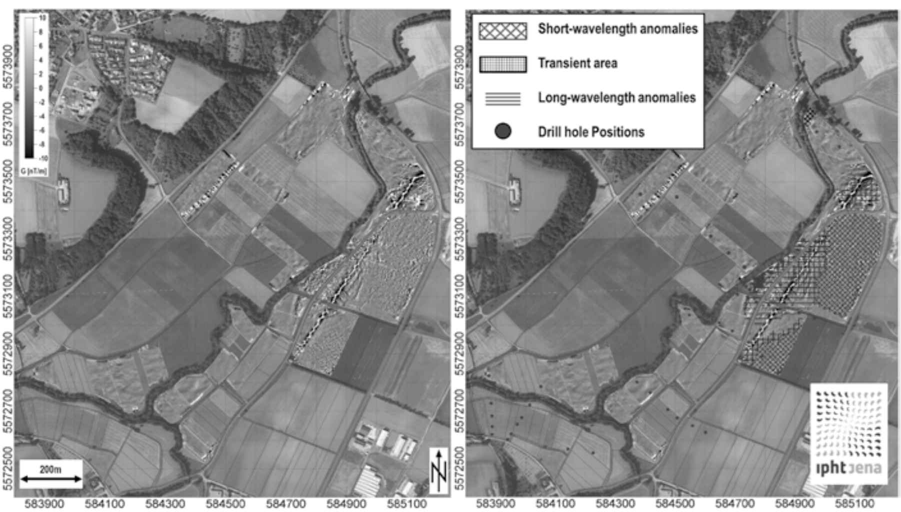

Fig. 2. Integration of georeferenced magnetic maps into an aerial photo (provided by the Bavarian State Department for Monuments and Sites) of the entire site of investigation at Mühlstatt/Bitzenhausen. The grayscale of the magnetic maps represent a vertical gradient in the range of ±10nT/m. Next to the strong anomalies of different supply lines, there are different zones, which vary in their magnetic dynamic. Other point-shaped and linear anomalies could indicate anthropogenic influences. (a) Magnetic map; (b) magnetic maps overlaid with the drilling positions (dot marks), the different zones (hatched marks)

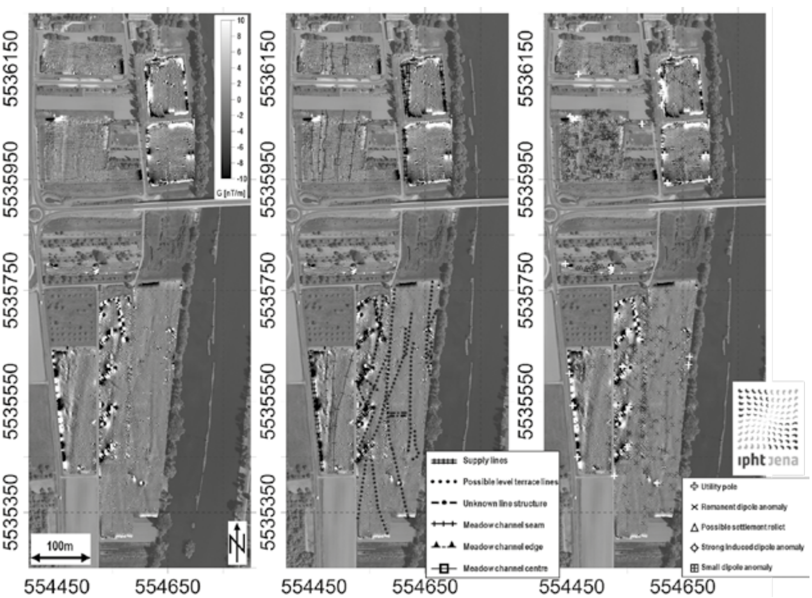

Fig. 3. Integration of georeferenced magnetic maps into an aerial photo (provided by the Bavarian State Department for Monuments and Sites) of a partial site south of Karlburg. The grayscale of the magnetic maps represent a vertical gradient in the range of ±10nT/m. Different point-shaped and linear anomalies appeared next to the strong anomalies left by different supply lines. Linear features could indicate geological developments (meadow and old bank structures), point-shaped anomalies could represent anthropogenic influence. (a) Magnetic maps; (b) magnetic maps overlaid with categorized linear structures (different dotted and continuous line markers); (c) magnetic maps overlaid with a selection of categorized point-shaped features (i.e., remanent magnetized structures, induced magnetized structures with different amplitudes)

the inversion results. On the other hand, the inversion results help to explain different aspects within the results of other applied methods (e.g., geoelectric and georadar measurements).

The settlement site of the first case study is called Wüstung Mühlstatt/Bitzenhausen and is located at the river Fränkische Saale. The Neustädter Becken is connected to the rivers Main and Rhine, which was beneficial for traveling in the past. Hence, it was a suitable location for the establishment of a royal palace in early medieval times. The site was known already from earlier geoarchaeological campaigns, including drilling and excavation (Werther 2012). In this respect, our intent has been to characterize in detail the settlement parallel to the river, to find the location of possible harbour structures, and finally to clarify the settlement conditions during the Early and High Middle Ages. Therefore, our work focused on possible settlement structures, the environmental situation and the development of the river.

Aside from the magnetic prospection and the simultaneously executed point-based geoarchaeological investigations (including surveys, drilling and excavation trenches), which directly supported one another, the applied spectrum of methods included the analysis of aerial photos, geoelectric and near-surface seismic transect lines, as well as small-area electromagnetic measurements at this site. The first results of the magnetic prospection were used in combination with the analysis of the drill-cores to reconstruct the geological near-surface situation of the settlement surroundings. This yielded an estimate of the settlement extension on an alluvial fan, which overlies a rubble body from the Pleistocene. The topographic elevation of this location ensured (in contrast to the present conditions) its protection with regard to flooding. Further results indicate a still ongoing eastward propagation of the recent riverbed, which also required investigation on the western shore of the river. After a comprehensive mapping of the east side of the river, the western exploration was planned as a multi-disciplinary transect, including a magnetic cross-section of the valley, covering the lines of a drilling transect, a geoelectric section, and a near-surface seismic profile. The results of the different and mutually supporting methods were applied then to a reconstruction of the entire settlement environment and its connection to the river. Therefore, the focus was specially on geophysical inversion and reconstruction of the subsurface situation at specific points in order to come to broad conclusions.

The archaeological site handled in the second case study is located in Karlburg directly on the river Main. This site was also already known from earlier excavation (Ettel 2001: 279–301). The modern city of Karlburg corresponded at least in part with the former settlement called Villa Karloburg. Here, the main task was on the one hand to characterize the extension and the development of the settlement and on the other hand to test the hypothesis of a basin as a central harbour structure in the Early and High Medieval Ages. During the measurements and field studies, the nearness of the modern town caused some disturbances associated with modern structures, such as supply lines, concrete buildings, metal objects, and manmade embankments. Therefore, the multidisciplinary approach of combining geophysical and geoarchaeological methods turned out to be very promising.

In this case study, the geological situation, including the localization of the Early and High Medieval river bank, was selectively reconstructed with respect to drilling transects. In order to follow and reconstruct the bank situation along the settlement areas, large-surface methods were essential. Topographical features that through stratigraphic analysis could be connected with the medieval bank structure were tracked for about 2 km across the valley on a high-precision airborne LiDAR image and high-resolution magnetic maps. The magnetic prospection fulfilled another important task by verifying and substantially expanding the spectrum of possible settlement indications, resulting from an analysis of aerial photos and excavations. This required a description and identification of settlement expansion that could hardly be satisfied by point investigations, such as drilling and excavating, or line-based analytics, such as the measurement of geoelectric or seismic profiles.

Nevertheless, our combination of methods illustrates the growing capacity of multi-disciplinary investigations of individual structures or small areas to support extensive reconstructions based on effective large-scale prospection methods, such as SQUID surveys. The results of multi-disciplinary data analysis have been used to verify interpretations mutually and to correlate them to investigation sites, where not all the methods have been applied. Therefore, effective, non-invasive, and high-resolution prospection methods have been shown to be useful for the reconstruction of large-scale scenarios, and the requirements for invasive supporting points of investigation have been minimized. Based on these micro-studies one can review the applicability of the developed methods to other comparable sites.

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Measurement of the dielectric permittivity through multi-frequency EMI for archaeological prospection

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KEY-WORDS: dielectric permittivity, electrical conductivity, complex magnetic susceptibility, multi-frequency EM

INTRODUCTION

Recent developments in EM instruments have opened new opportunities for archaeological surveying. New devices with multi-coil spacing had already allowed investigation of multi-depths for

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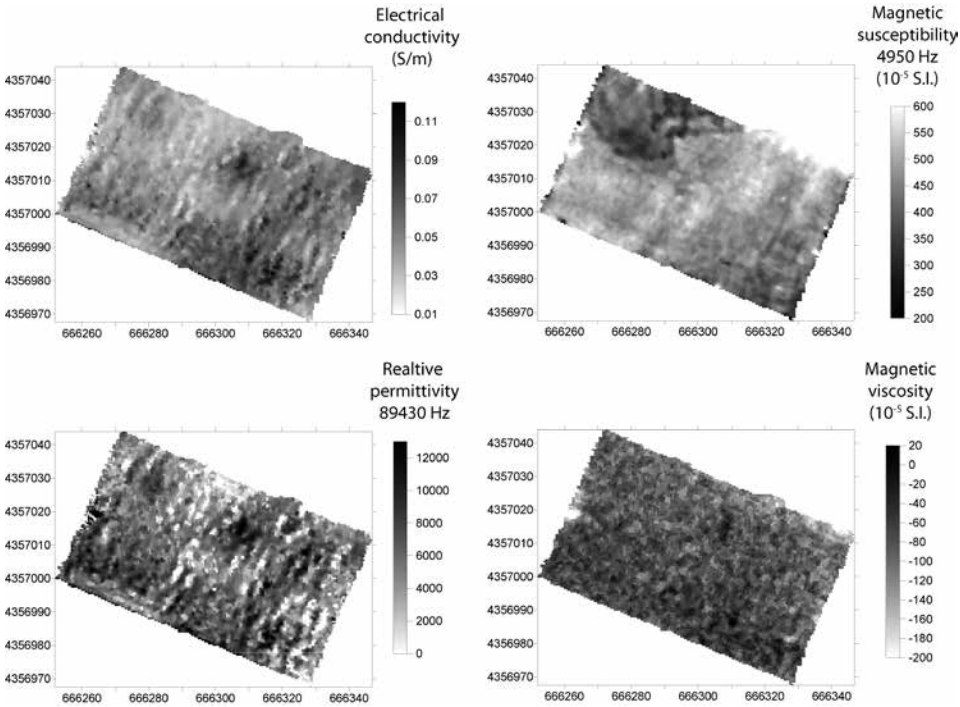

Fig. 1. Result of EM multi-frequency investigation at Demetrias with electrical conductivity (supposed to be independent of frequency) (upper left), magnetic susceptibility at 4950 Hz (upper right), relative permittivity at 89430 Hz (lower left) and magnetic viscosity (lower right). Magnetic viscosity and relative permittivity show an offset that could not be removed despite the application of calibration procedures

characterizing the depth of the remains (Bonsall *et al.* 2013), but also for a better understanding of soil and embankment depth (De Smedt *et al.* 2014). Moreover, EM instruments have also been developed recently for *in situ* measurement of complex magnetic susceptibility (Thiesson *et al.* 2007). Applications of multi-frequency EMI for characterizing magnetic viscosity (together with electrical conductivity and magnetic susceptibility) have demonstrated in turn some effects at the highest frequencies, leading to the present research focused on EMI measurement of dielectric permittivity impact.

STATE OF THE ART

The use of EM theory for geophysical prospection is based on approximations of Maxwell's equation in order to minimize the complexity of the signal and to make a link between the response of the instrument and the physical properties primarily affecting the response. As electrical conductivity mainly affects the response at low frequency, it was an obvious choice to use EM instruments to map it (Mc Neill 1980). It was also proved that for a low induction number, the complex EM signal could be used to map simultaneously both electrical conductivity and magnetic susceptibility (Parchas and Tabbagh 1978).

Since magnetic susceptibility has complex form and since this complex form delivers useful information on magnetic viscosity (Mullins and Tite 1973), the GEM-2 instrument from Geophex Ltd was used to map magnetic viscosity *in situ* (Simon *et al.* 2014). It allows measurement at five different frequencies. Unexpectedly, the results for the highest frequencies were distorted by new effects. As the assumption of the low induction number was not fully justified (we were using a high frequency close to the limits of the assumption <100 kHz), we had expected some effects related to the depth of investigation. For these frequencies, the induction number could be dependent not only on coil geometries, but also on frequency.

But earlier studies and recent experiments seem to follow another track. For twenty years it has been demonstrated that EMI instruments are sensitive to dielectric permittivity, if the frequency is sufficiently high. Authors were firstly interested in the simultaneous mapping of magnetic susceptibility, electrical conductivity and dielectric permittivity (Tabbagh 1994) and for this purpose they explored the middle frequency range of the instruments. It was shown that the EM response is affected by electrical conductivity and dielectric permittivity, but magnetic susceptibility has a negligible effect in this frequency range. This was verified using a new instrument allowing direct measurement of both electrical conductivity and dielectric permittivity at 1.5 MHz frequency (Kessouri 2012). More recently, the effect of dielectric permittivity was used to explain measurements performed at 30 kHz on saline soils (Benech *et al.* 2014), following an approach which is usually applied in mining EM prospection with greater inter-coil spacing instruments (Huang and Fraser 2001).

METHODOLOGY

Our focus was firstly on the electrical conductivity and on the effect of the magnetic viscosity on the quadrature part of the signal. To extract the electrical conductivity we did the subtraction of the measurement at two different frequencies that were as low as possible. As the effect of magnetic viscosity is independent of the frequency, the use of these two frequencies allows for the effect of this parameter to be removed. Then the effect of electrical conductivity on both components of the signal was removed in order to establish the value of magnetic susceptibility using the in-phase part of the signal and magnetic viscosity using the quadrature part. We used these three values (σ, κ_q and κ_p) to do a simulation of the EM response for the highest frequencies, in order to remove this contribution on the raw EM signal and to keep only the effect of dielectric permittivity. The last step aimed at transforming the resulting values into dielectric permittivity.

RESULTS

The above procedure was applied using a GEM-2 instrument from Geophex at two sites in Greece. The first one was the Hellenistic site of Demetrias, close to Volos, and the second one was a Neolithic tell (*magoula*) in Thessaly. Other methods were also used on both sites (magnetic survey, resistivity and GPR) as comparative data for the assessment of the efficiency of our methodology. The results for Demetrias are presented in Fig. 1. It remains difficult to define the zero in-phase values (mechanical drift of the instrument) and thus to affect the observed offset at either magnetic susceptibility or dielectric permittivity. However, the high permittivity values are in agreement with the problems encountered in the GPR survey (but at higher frequencies).

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Using magnetic survey methods to delimit and characterize prehistoric iron production sites in Norway

Arne A. Stamnes[a]

KEY-WORDS: magnetic susceptibility, gradiometer survey, Norway, Iron Age, iron production

"Scanning" is an alternative way of initial assessment of archaeological sites, using a magnetometer in scan mode along a set distance interval of maybe 10 m or similar in advance of detailed systematic surveys, sounding an audio signal when taking readings above a certain threshold in the amplitude. The main purpose of scanning is therefore to narrow down the potential area to be targeted with detailed surveys, and it has been used especially when investigating vast areas (Clark 1996; Gaffney and Gater 2003). The biggest drawback, and the main reason against performing scanning as a way of assessing the potential for a geophysical surveying of sites, is that it does not record the spatial location of readings, resulting in a situation in which the interpretation of the results is biased by the investigator's experience or impression of the response. It is difficult to set an appropriate threshold without having a proper idea of the average response over a site, which is best gained naturally by full-area coverage. An analysis of unrecorded scanning performed on Irish road-building schemes between 2001–2010 illustrates this handicap, as it turned out that 71.2% of archaeological sites were not identified in this way (Bonsall 2014). While the inappropriateness of *unrecorded* scanning may be a relevant conclusion for a wide range of archaeological sites, it might be less relevant for the detection of iron production remains, such as slag and furnaces by *recorded* sampling. Initial tests with GPS-recorded scanning used to locate archaeological features, such as iron production sites and roasting sites for bog iron, have given encouraging results. At Gråfjell in the valley of Østerdalen in Hedmark county in Norway, otherwise elusive roasting sites for bog iron were located by GPS recorded scanning, as well as pits for coal production. This gave new insight into the spatial organization and transport of roasted iron ore compared to the location of iron production sites in this region (Rundberget 2007: 279–308; Larsen 2009: 221–223). Magnetic susceptibility sampling (MS) has also been used to determine the spread of slag over a site in England (Vernon 2004: 19–20). While MS might be preferred for locating areas of activity on cultivated land (Stamnes 2010), it has until now been untested on industrial sites located in mountainous and uncultivated areas in Scandinavia. It was therefore believed that performing recorded volume magnetic susceptibility sampling over iron production sites might yield encouraging results.

In the Trøndelag-region in central Norway, few of the so-called "rosette" iron production sites from the Early Iron Age (500 BC to AD 550) have been completely excavated and none have yet been surveyed in their entirety with geophysical prospection methods. Slag heaps are usually the only visible remnants at iron production sites and the location of roasting sites in relation to the iron production area is considered elusive (Farbregd *et al.* 1985; Stenvik 1987; 1996; 2003). "Rosette" sites take their name from a very specific layout with a reusable oven in the centre, surrounded by

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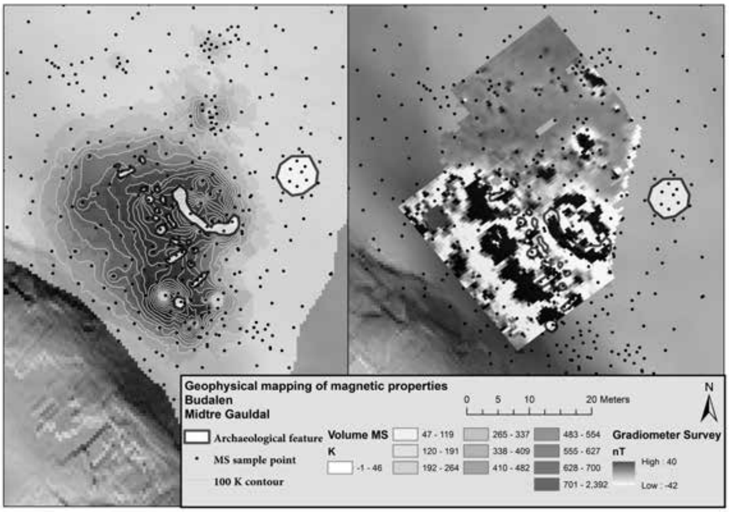

Fig. 1. Budalen: topsoil magnetic susceptibility mapping to the left, gradiometer survey to the right

Fig. 2. Panorama of the Tromsdalen site, view to the southeast

a series of pits of unknown purpose, giving them a characteristic layout reflected in their name. It was therefore decided to survey several iron production sites by recording the topsoil MS and performing detailed fluxgate gradiometer surveys. Special attention was paid to the possibilities of locating, delimiting and characterizing such sites, which have the potential to contribute importantly to knowledge of the spatial organization of prehistoric iron production in the region. The sites were surveyed with a Bartington MS2-D field loop and a handheld Bartington Grad 601-dual fluxgate gradiometer sensor array. The fluxgate gradiometer surveys were conducted with a traverse interval of 0.5 m and an inline sampling interval of 0.125 m. At Budalen, 640 topsoil MS readings were recorded with a RTK GPS over an area of 7567 m^2, an average of 3.4 m between readings. At Tromsdalen, 431 topsoil MS readings were taken over an area of 3865 m^2, an average of 3 m between readings. The susceptibility datasets were interpolated to raster surfaces by ordinary kriging, ensuring both

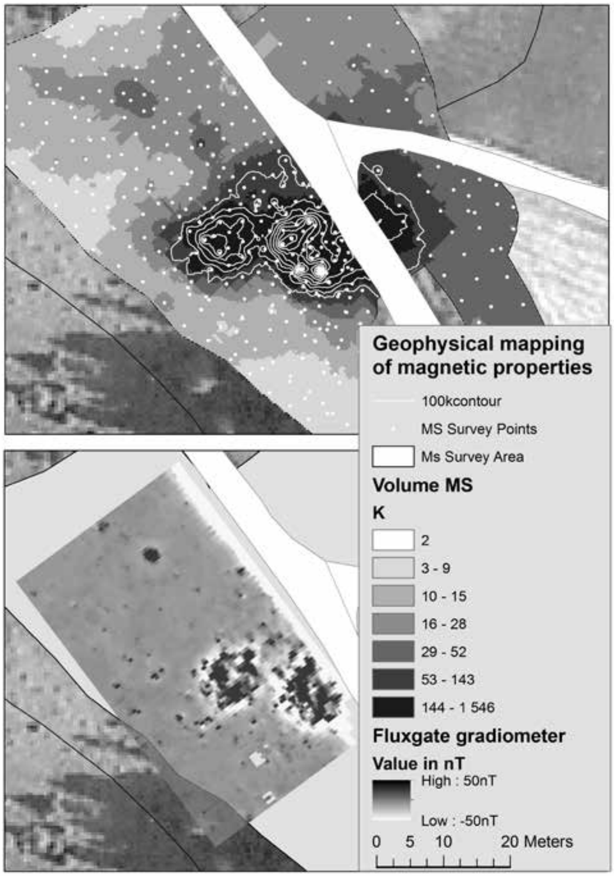

Fig. 3.Tromsdalen: topsoil magnetic susceptibility mapping in the upper part of the image, gradiometer survey in the lower part

a good statistical spatial fit, as well as the additional benefit of providing maps over the prediction standard error; a measure of the quality of the interpolations performed (Isaaks and Srivastava 1989). The properties of ordinary kriging as an interpolation method make a grid-based sampling strategy, when the average distance between each GPS recorded is so low, unnecessary for volume magnetic susceptibility sampling used as a way of locating and delimiting archaeological sites.

Two sites were chosen, the site at Budalen in Midtre Gauldal Municipality and the site of Tromsdalen in the Verdal Municipality, both with known iron production sites.

The site of Budalen (Fig. 1) is located close to a summer farm, which acts as a museum. While the site nowadays is considered to be far away from central settlements, the area is scattered with iron and charcoal production sites, pits for hunting elk or reindeer and tar-production pits, all dating to different periods. The area was surveyed as part of an archaeological field school run by the Norwegian

University of Science and Technology. The topsoil MS (Fig. 1, top) clearly delimited the site and more detailed mapping close to hotspots with increased values allowed smaller areas with high readings to be delimited to the north of the main production area. It is possible that these were roasting sites for bog iron. The semi-oval anomaly in the central part of the image is interpreted as a storage area for roasted iron, which was used subsequently as raw material for iron production. The amorphous gradiometer anomalies seen towards the southwestern part of the image are the slag heaps on sloping ground. The slag heaps typically show readings well above 50 nT, usually in the range of 100–250 nT. The iron production ovens, the potential bog iron roasting site and the assumed storage area for roasted iron show readings of 200 nT and more. The volume magnetic susceptibility of the storage area was in the approximate range of 500–2500 k, while the slag heaps typically were from 30 to 600 k. The potential roasting sites had readings of 20–2000 k, which is in very strong contrast to the surrounding readings observed in natural, non anthropogenic soils ranging only around 3–10 k.

The iron production site at Tromsdalen (Figs 2 and 3) was discovered as part of an archaeological registration scheme in advance of the extension of a larger chalk quarry in 2011, based on information provided by the landowner and test excavations. Apart from the iron production site, there is evidence of more permanent settlement in the area indicated through the presence of burial mounds. The site appears to have been damaged by the construction of a road several decades ago, which, according to the landowner, is how he became aware of the site in the first place. Again, the topsoil MS clearly delimited the site. The readings were higher over the slag heaps, often in the range of 200 k and higher, where the natural soils had readings in the range of 10–40 k. Similarly, the slag heaps at Tromsdalen often had a reading of 50 nT or more. In this survey, the sensor was positioned slightly higher owing to high tree stumps that could damage the equipment.

These two examples show how volume susceptibility mapping and detailed fluxgate gradiometer surveys can help in locating, characterising and delimiting iron production sites and archaeological features associated with such sites. Due to the strong magnetic contrast of iron production sites compared to the natural background, it is assumed that *recorded* fluxgate gradiometer scanning could help in locating such sites, depending on the magnetic properties of local geology. The results from recorded scanning preformed at Gråfjell support this notion. While full-area coverage is to be preferred, the vastness of performed landscape, in addition to topographical difficulties, dense tree coverage and other obstacles, might make GPS recorded scanning procedures a possible way of acquiring new knowledge of the whereabouts of previously unrecorded iron production sites. The cited examples of scanning at Budalen and Tromsdalen show how magnetic susceptibility sampling strategies easily delineated areas of intense iron production and how detailed gradiometer surveys have helped in characterising anomalies of archaeological origin on the sites.

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The application of mobile metal ion (MMI) geochemistry to the definition and delineation of a Roman metal processing site, St. Algar's Farm, Somerset, United Kingdom

Graham C. Sylvester[a], Alan W. Mann[b], Andrew Rate[c] and Clare A. Wilson[d]

KEY-WORDS: soil geochemistry, archaeological prospection, partial extraction, MMI, magnetometer survey, Roman, metal extraction

MMI is a single solution, ligand-based, soil extraction geochemical technique (Mann 2010), which has been employed for more than a decade to detect and define, in exotic overburden, metal anomalies derived from buried mineral deposits. Commercially available, it is widely used in mineral exploration. It is designed to achieve dissolution of adsorbed elements, many of them metals, without significant dissolution of the substrate to which they are attached. It does not involve acid digestion and improves the peak/background ratio.

This paper presents preliminary findings of an investigation of the Roman metal and glass processing site at St. Algar's Farm (SAF) in Somerset. It describes part of a research project to evaluate the potential use of MMI geochemistry in archaeology.

Sixty three soil samples were collected from a depth of 15 cm on a 40 m x 40 m grid in May 2014. They were subjected to MMI ligand extraction and analysed for 53 elements using inductively coupled plasma spectrometry (ICPMS) at SGS laboratories in Perth, Australia.

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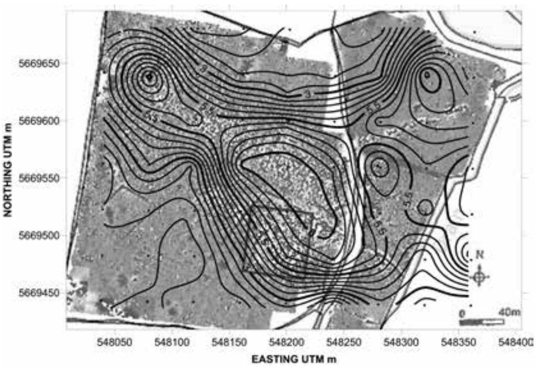

Fig. 1. St. Algar's Farm MMI Tl (ppb)

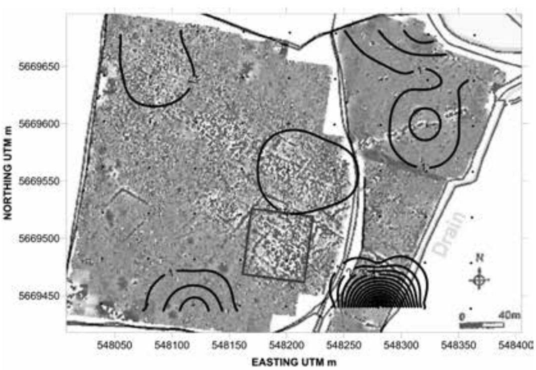

Fig. 2. St. Algar's Farm MMI Sn (ppb)

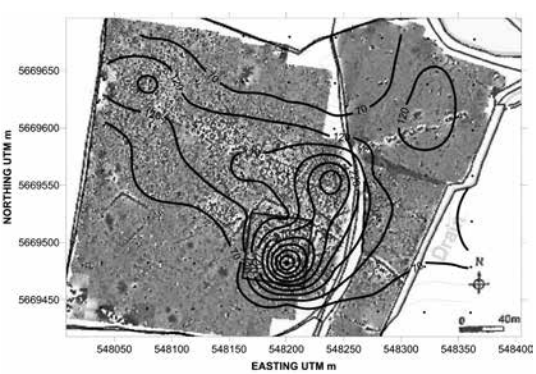

Fig. 3. St. Algar's Farm base and noble metal index

The results are compared with those obtained from a surface portable XRF (pXRF) survey (Dungworth *et al.* 2013), which provided limited data due to the inherently high lower limits of detection (compared with MMI) for very many trace elements. The MMI data are plotted (Figs 1–3) on a magnetometer survey (using a Bartington 601/2 twin fluxgate gradiometer with an automatic data logger on 1 m spaced traverses) base (Lambdin 2011), which provides an interpretation of the underlying archaeology. No surface archaeology is visible on the site, but recent limited excavations (Lambdin and Holley 2011) revealed a 1st–4th century AD winged villa, in which refining of lead and glass manufacture was undertaken. The magnetic image provides support to the excavation findings, indicating the presence of other walled structures and displaying a substantial area of disturbed magnetics around the villa considered indicative of human settlement. An interpreted trackway running from the northwest of the site through the settlement area to the villa has also been identified.

MMI data from the European GEMAS (Geochemical Mapping of Agricultural Soils) survey (Mann *et al.* 2014) are used for comparison and to determine regional elemental baseline concentrations. Statistical analysis in conjunction with visual inspection has been used to determine suites of associated elements: those which display bi- or multi-modal sample distributions and those which display elemental anomalies potentially of anthropogenic origin. Single-element classed post maps (CPM) and/or contour plots of elements of most interest have been constructed. The CPM for Pb shows a widespread distribution across the site for this element; many values are above the upper detection limit for Pb for MMI. The contour plot for Ba indicates that this element is largely coincident with Pb. It is present as gangue in the nearby Mendip Hills lead ore, the probable source of the metals processed here. Thallium (Tl) (Fig. 1) also shows a close affinity with Pb (and Ba) suggesting a common (ore) source. Fig. 2 shows the contour map for Sn. Although the number of soil samples containing anomalous Sn is limited, this element displays a different distribution range of associated elements and indicated source.

A number of elemental suites with common characteristics were identified by statistical analysis. The suite Pb, Tl, Ag, Au, Sb, Ba, (Cu), is associated with and defines the area of lead smelting operations. It overlies a lithological background moderately high in Ca, Ce and other rare earth elements. Another suite, which includes Cs, Rb, Nb, Sn, Th and Zr, occurs in a limited number of samples on the periphery of the SAF site and could be indicative of tin-bearing granite/pegmatite imported for processing.

Multi-element additive and multiplicative indices have been constructed and the distribution of the index scores plotted and contoured. This is beneficial in clearly delineating the zones of interest defined by the elemental suites. One of the most illustrative indices is the Base and Noble Metal Index: an additive index comprised of normalised (to each element's median) values for Ba, Ag, Au, Pb, Sb, Tl and Cu. This plot, shown in Fig. 3, delineates and defines the lead processing area, the human settlement area and the trackway along which the ore (from the Mendip Pb deposits) was brought. It also highlights a number of 'hotspots' particularly relating to soil anomalies for Au and Ag, which appear from the magnetometer data to be in areas of potential archaeological interest and which require further investigation.

In summary, the reconnaissance-style MMI survey has defined and characterized lead processing and other human activities and has provided much greater definition than was possible using the pXRF instrument. In addition, new areas of potential archaeological interest have been located.

ACKNOWLEDGEMENTS

We wish to thank Dr. David Dungworth of English Heritage for his participation in the fieldwork and ongoing discussions, and the SGS Laboratories for kindly providing the analytical services necessary for the fulfilment of this project.

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GPR research around the Hawara pyramid (Fayum, Egypt)

Adam Szynkiewicz[a]

KEY-WORDS: Hawara pyramid, GPR, geology, ground water

Geological and GPR studies around the mud-brick pyramid of the Twelfth Dynasty pharaoh Amenemhat III (19th century BC) at Hawara in the Fayum were performed for the Faculty of Archaeology of the University of Cairo in Egypt, the objective being to identify areas of groundwater inflow into the tomb under the pyramid (for the purposes of a salvage project) and to verify possible links between the pyramid and a structure identified by some archaeologists as the labyrinth of Herodotus. Geological data was obtained from core drilling (in 2002 and 2008) in the vicinity of the pyramid (Figs 1 and 2) through the courtesy of Ain Shams University, Faculty of Engineering, Soil Mechanics and Foundation Laboratory and Mohamed A. Hamdan, Geology Department of Cairo University. GPR research around the pyramid used SIR with multifrequency antennas and RAMAC/GPR with unshielded 100 MHz antennas. Linear profiles were performed down to a depth of 20 m (Figs 3, 4 for two section examples).

The geological data indicates that the tomb and facilities existing beneath the pyramid at Hawara were located in trenches cut into bedrock composed of cohesive schists and mudstones of the Eocene

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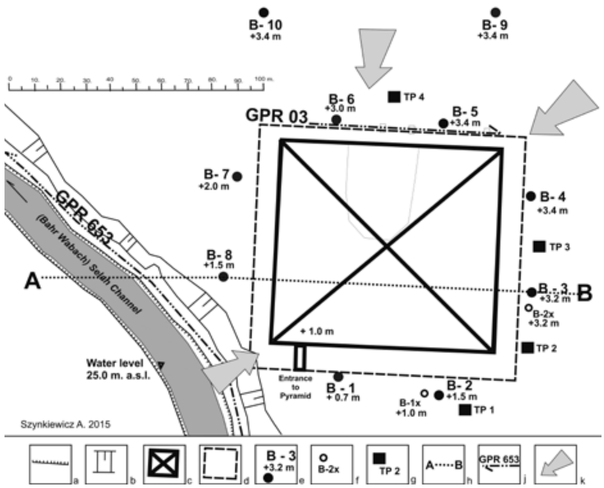

Fig. 1. Hawara pyramid (Fayum). Inflow of groundwater into the tomb: a) Selah canal embankment, b) inclined embankment surface, c) mud-brick pyramid, d) part of mud-brick pyramid covered by sand, gravel and overburden, e) geological borehole (2002), number and ground water level above the water level in the Selah canal, f) geological borehole (2008), g) geological test pit, h) simplified cross-section, j) GPR transect, k) direction of ground water flow

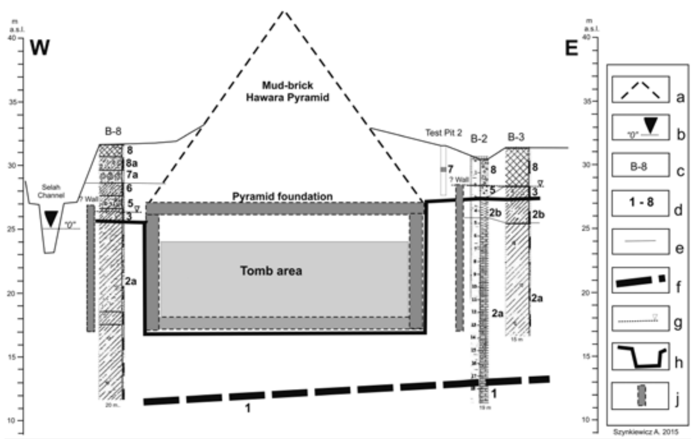

Fig. 2. Hawara pyramid (Fayum). Schematic cross-section: a) mud-brick pyramid, b) water level in the Selah canal, c) number of borehole, d) geological layers: 1 – Eocene limestone, 2a – Eocene mudstone, 2b – Eocene claystone, 3 – mixed layers of calystone, anthropogenic overburden, 4 – Holocene river sand, 5 – sand and gravel, flood period, 6 – clay with rest of flora, 7 – limestone blocks, 7a – fragments of limestone, 8 – mixed layers, anthropogenic overburden; e) boundary of layer, f) top of Eocene limestone, g) ground water level, h) trench for the tomb cut in Eocene rocks, j) presumed wall

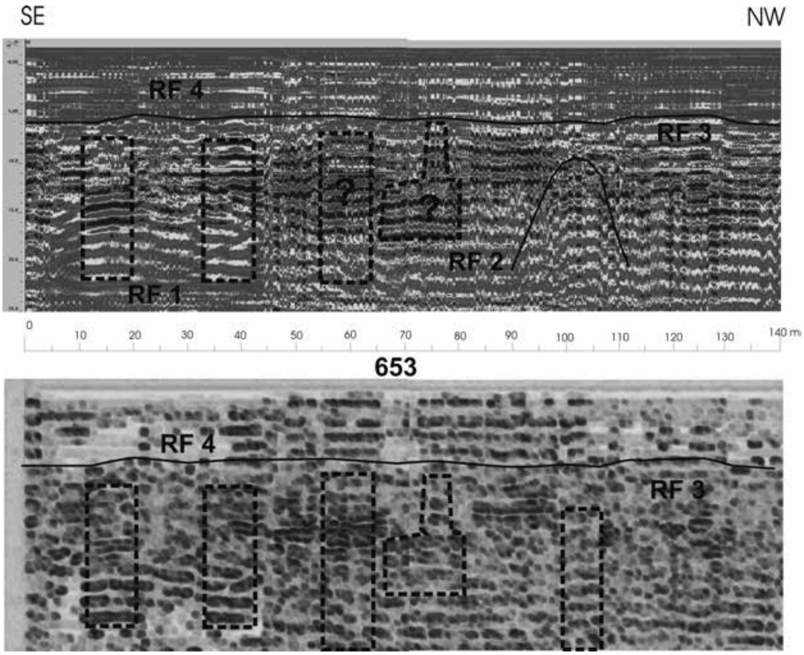

Fig. 3. Hawara pyramid (Fayum). GPR cross-section 653. SIR 2000 with multifrequency antenna. Post-processing using RADAN software. RF – radar facies: 1) claystone, 2) anthropogenic layers with structures, 3) clay with remains of flora and mollusks, 4) sand, gravel and mixed anthropogenic over-burden. Black dotted line indicates possible wall-type structures

age. Eocene limestone is present beneath these rocks, at a depth of approximately 12 m to 15 m. On the western, northern and southern sides of the pyramid, the natural surface of Eocene rocks is about 1–3 m above the water level in the Selah canal (Bahr Wabach). On the southern side of the pyramid, Eocene rock surface is about 0.5 m–1.0 m above the water in the canal (Figs 1 and 2). Holocene gravels and sands covering Eocene rock are approximately 3–5 m thick. They probably also covered the lower part of the mud-brick pyramid.

Groundwater is 3.4 m higher than the water in the Selah canal on the northern and eastern side of the pyramid and about 0.7 m to 1.5 m higher on the southern side. The tomb and rooms under the pyramid are currently flooded with water, and the water level beneath the pyramid is 1 m higher than the water level in the canal (Figs 1 and 2). The water in the tomb and in the rooms beneath the pyramid could come from the Selah canal, which when constructed in the late 19th century AD, presumably destroyed the southwestern corner of walls shielding the pyramid from the inflow of groundwater into the tomb (Fig. 3).

Part of the water in the tomb and rooms beneath the pyramid may also come from groundwater flow from the plateau surrounding the pyramid (Fig. 1). CPR data demonstrated the existence of such channels letting water seep under the pyramid. For example, there is a very strong and clear anomaly on the north side of the pyramid (N1 in Fig. 4). The data from the

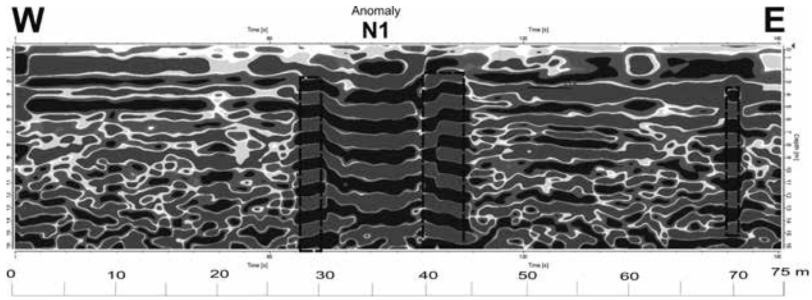

Fig. 4. Hawara pyramid (Fayum). GPR cross-section 03. RAMAC/GPR with antenna 100 MHz. Post-processing using GroundVision software. Anomaly N1 on the north side of the pyramid. Black dotted line indicates possible wall-type structures

survey will be used to prepare a project to protect the pyramid from the disastrous effects of groundwater.

On the eastern and southern side of the pyramid, the survey also traced anomalies that could reflect architectural remains. There is, however, nothing to support the idea that this was Herodotus's labyrinth.

Urban spatial analyses of geophysical archaeological prospection data from the Roman civil town Carnuntum, Austria

Tomáš Tencer[a,b] and Wolfgang Neubauer[a,b]

KEY-WORDS: space syntax, Carnuntum, Roman, interpretation

The archaeological landscape of Roman Carnuntum is situated in the Vienna basin just south of the Danube, on gravel terraces some 45 km to the east of Vienna. As the capital of the Roman province of Pannonia, Carnuntum was an important town during the first four centuries of the first millennium AD. The remains of the Roman town extend over an area of 5 km^2, most of which is used today for agricultural purposes. They consist of the civilian town, a legionary fortress, *canabae*, burial grounds, temples, and two amphitheatres.

Over the past 50 years the Carnuntum landscape has been the focus of aerial archaeology and geophysical prospection (Neubauer *et al.* 2012). Hundreds of aerial photographs have been used for

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Fig. 1. Overview of the reconstructed street network with hypothetical planning grids

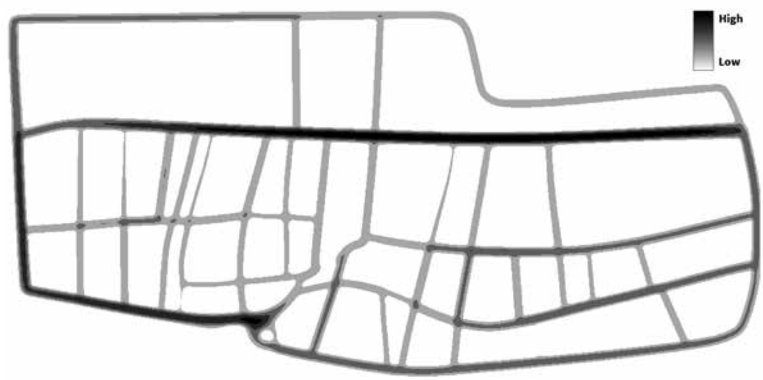

Fig. 2. Results of agent-based simulation of movement; agents were released from different locations within the reconstructed street network. Dark tones indicate areas with the highest intensity of agent movement

systematic archaeological mapping (Doneus *et al.* 2013). Additionally, some 50 ha have been surveyed using various, manually operated geophysical prospection techniques by ZAMG *Archeo Prospections*®. Currently the archaeological landscape of Roman Carnuntum has been surveyed in full using state-of-the-art magnetometry and high-resolution GPR within the frame of a research project implemented by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (Trinks 2011; *http://archpro.lbg.ac.at*). In combination, these prospection projects have gathered wealth of new data on the buried cultural heritage and significantly contributed to a massive expansion of knowledge on the Roman town of Carnuntum. The Carnuntum prospection project aims to generate a preliminary master plan of the town structure and layout.

When archaeological interpretations of prospection data are conducted within a GIS environment, the results are in general compatible with modern excavation plans (Neubauer 2004). The developed GIS project combines all available data and information and permits the study of urban planning as well as the recognition of its practical implementation and the evolution of the town plan.

Despite the different approaches, most archaeological theories agree that the way the people construct and organize their living space is reflected in social, cultural and political, even symbolical structures (Cutting 2003; Stöger 2011). One possibility to investigate this relationship is space syntax analysis. This approach comprises a theoretical and analytical set of techniques used to identify, compare and interpret patterns in the spatial configuration of space. It offers a combination of tools that are able to quantitatively and qualitatively capture the configuration of space, and to visualise important correlations between human movements and their use of space (Hillier and Hanson 1984). The paper focuses on the layout of the street system of the Roman civil town of Carnuntum, demonstrating the application of this innovative approach to analysis of archaeological prospection data.

The organisation of Roman urban space is closely connected with the layout of the street system, which can be regarded as the neural system of each city. The street network carries all movement and communication and facilitates orientation in a town. A regular grid makes orientation in the town easier: basic knowledge of the major roads leading to the town centre is essential for both inhabitants and visitors. The configuration of this network is a determining factor for variations in movement rates (Hillier 2014). The location of these arteries within the town relates to commercial activities, the presence of public entertainment possibilities and meeting places for public interaction or control and the like, which on the one hand can generate high rates of movement, while on the other hand they are a prerequisite to have them in the first place. In contrast, luxury residential areas tend to be placed in rather quiet locations permitting a greater degree of privacy.

The first look at the reconstructed street network of Carnuntum reveals a regular pattern of intersecting, yet not orthogonal streets. The town is organized into more or less rectangular blocks. These blocks have various dimensions that vary across the town. In the eastern part of the civil town, the size of these blocks more or less fits a grid of 600 by 600 pM (*pes monetalis*, Roman unit of length, approximately 0.296 m, thus 600 pM = 177.6 m), while the blocks in the western part of the civil town are more suited to a grid of 600 by 400 pM (Fig. 1). This change may indicate a different planning strategy and is likely to have been caused by an extension of the town area.

Previous studies (Kaiser 2011; Stöger 2011; Benech 2010) have shown that syntactical analysis is well-suited to the investigation of Roman urban environments. This approach can support the localisation of areas related to particular activities within the town. An analysis of street configuration clearly shows a main road running parallel to the Danube bank as the most integrated street within the grid of Carnuntum. It forms the main transit route for movement through the town. The application of agent-based simulation supports this evidence (Fig. 2). This finding indicates the high potential for commercial activities in building plots bordering this main road. The aim of the present study is to understand the organisation of the space and to propose an initial model of land use for the civil town of Carnuntum.

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An UMO landed on the Via Appia. Results of the Minor Centres Project in the Pontine plain, Lazio (Italy)

Burkart Ullrich[a], Gijs Tol[b] and Tymon de Haas[b]

KEY-WORDS: large-scale magnetometer surveys, Pontine plain, Roman archaeology

The presentation will illustrate how large-scale magnetometer surveys can contribute to a better understanding of the scope and function of Roman rural centres in central Italy. Apart from discussing the remarkable results of the surveys linked to the project's main research objectives, it will also focus on a huge complex of magnetic anomalies detected next to the Via Appia, referred to as UMO (Unidentified Magnetic Object) as we have yet to find an explanation for it.

The Minor Centres Project at the Groningen Institute of Archaeology (GIA) aims to investigate the role of minor central places in the economy of Roman Central Italy. The core of the project is formed by field research on three rural central places: the sites of Astura, Forum Appii and Ad Medias (Fig. 1), all situated in the Pontine region (Lazio, Italy). These sites and their respective hinterlands are currently investigated through fieldwalking and magnetometer surveys, while specialist studies of the material evidence, predominantly pottery, help to reconstruct economic interaction and exchange.

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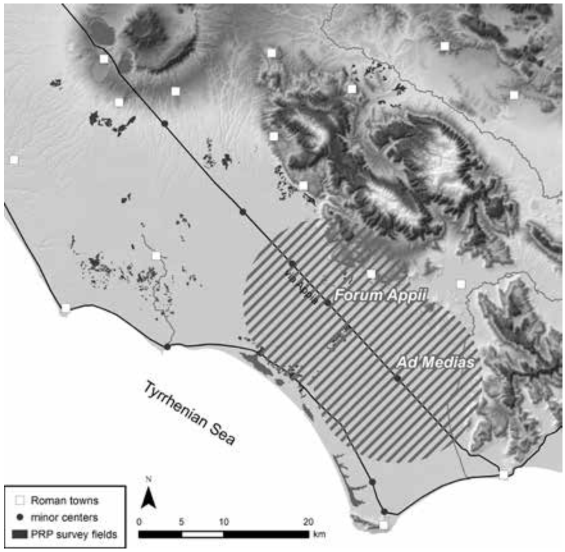

Fig. 1. Location of minor centres along the Via Appia and the investigated areas in the Pontine plain

The magnetometer surveys were aimed at the identification and interpretation of buried archaeological remains associated with the surface material scatters, and at establishing site extent. Different techniques were applied by several investigators, depending on local measuring conditions. Dual gradiometer systems (Bartington, Geonics) were applied to cover small plots in all three areas. To cover large areas on the two sites along the Via Appia, Forum Appii and Ad Medias, a DGPS controlled ten-gradiometer cart system LEA MAX (Eastern Atlas) was used.

The LEA MAX system consists of a light-weight frame carrying several sensors in parallel array, a GPS antenna (rover) and a digitizer LEA-D2 controlled by a mobile PC as a registration unit. For the magnetic survey in the Pontine plain, FEREX (Förster) gradiometer probes were used, measuring the difference between two Fluxgate sensors, the vertical distance between them being 65 cm. In large open areas, ten gradiometers were mounted on the frame in parallel array 0.5 m apart (Fig. 2).

The magnetic data from the gradiometers and the position data from the RTK-GPS are registered simultaneously. Measured data can be visualized immediately in the field to assess the quality and to expand the survey area, if worthwhile magnetic structures are detected. This was the case at the Ad Medias site, where unexpected results came to light. Processing in the field included decoding of data streams from sensors and the GPS, normalisation and drift correction calculated for each channel and a gridding-routine to create a map of the parallel profiles. Drift corrections are made over the full length of a profile, which could be up to several hundreds of meters. This corresponds to the dimension of the targeted fields in the Pontine plain.

Despite not exploiting the full potential of magnetic surveys at Forum Appii, where access to the fields in the available time frames was limited, the large-scale magnetometer surveys at Forum Appii and Ad Medias have shown a large amount of features related to subsurface remains associated with economic functions, such as traces of kilns, possibly associated spoil

Fig. 2. Magnetic survey at Ad Medias using the LEA MAX with 10 gradiometer probes; four individual suspended wheels reduce the effect of the heavily ploughed fields

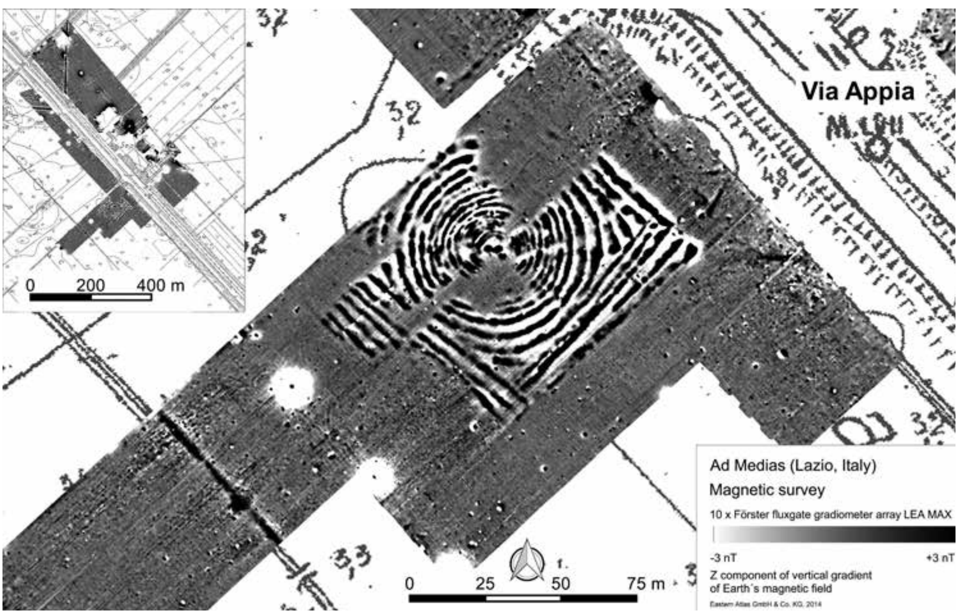

Fig. 3. Results of the magnetometer survey at Ad Medias; map at upper left shows the entire area covered at this site

heaps and clay pits as well as, in Forum Appii, warehouses to be associated with a river port. The results of the magnetic surveys allowed for a hypothetical scenario: Forum Appii was a substantial settlement of approximately 10 ha, involved in the production of metal and ceramics, while bog ore exploitation or loam extraction took place in the lower-lying surroundings. In contrast to Forum Appii, Ad Medias did not have a clear industrial function, based on the magnetic data, but rather seemed to have been a small stopover that could provide a number of important services to the local population and passing travellers.

To the south of Ad Medias, an exceptional structure of 100 m by 80 m was discovered (Fig. 3). The nature of this structure, formed by concentric circular anomalies up to 60 m in diameter and surrounded by linear anomalies, is unclear. This discovery, in an area with only few scattered surface finds, shows the potential of large-scale magnetometer surveys for the prospection and exploration of hidden landscape components beyond already known sites.

The audience is invited to actively contribute towards an interpretation of this UMO.

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Hamadab near Meroe (Sudan): results of multi-technique geophysical surveys

Burkart Ullrich[a] and Pawel Wolf [b]

KEY-WORDS: Meroitic town, multi-technique geophysical survey, archaeometallurgy, settlement

Hamadab is located on the eastern bank of the Nile in present day Sudan, 3 km south of Meroe, the ancient capital of the Kushite Empire (300 BC–AD 400). The archaeological remains are buried below two sandy mounds, the Northern mound and the Southern mound (Fig. 1), rising about 4 m above the fertile plain and forming islands during the annual Nile flood in summer. The northern mound, called Domat al Hamadab (named after the Hamad family who had settled there 300 years ago), contains the remains of the settlement, while the southern mound was used as burial ground. In 1914, a small town temple and two monumental stelae of Queen Aminirenas and prince Akinidad were excavated by John Garstang, director of the University of Liverpool excavations. The stelae are now displayed in the British Museum in London and the Khartoum National Museum.

[a] Eastern Atlas GmbH & Co. KG, Berlin, Germany
[b] German Archaeological Institute, Orient Department / Hamadab Archaeological Project, Berlin, Germany

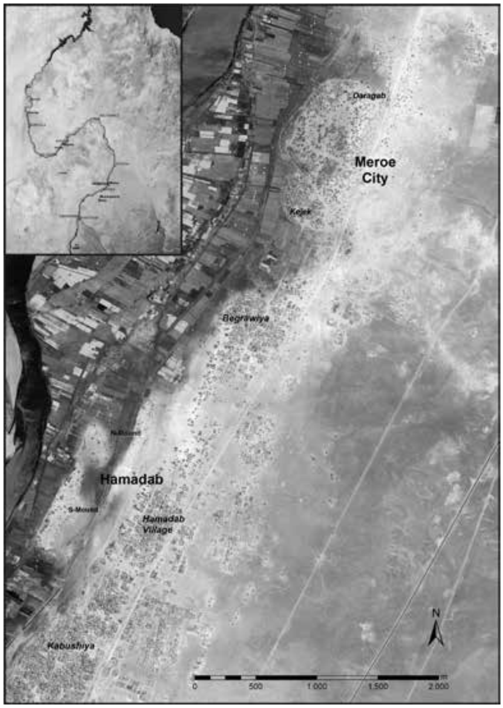

Fig. 1. Map with the archaeological sites of Hamadab and Meroe City

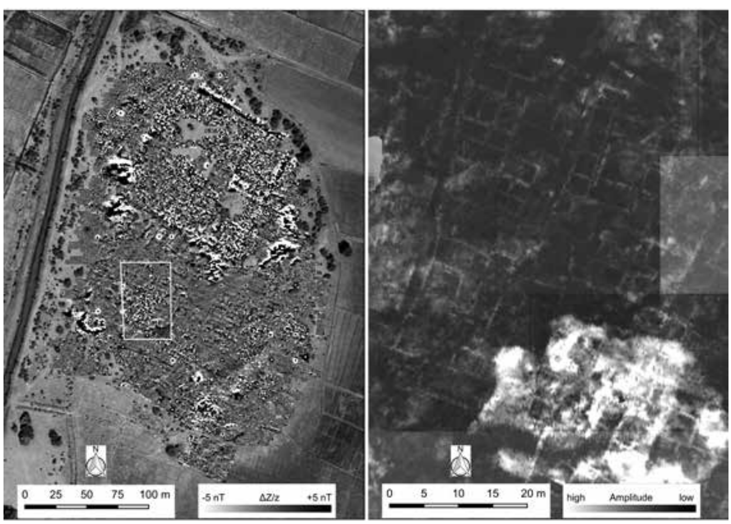

Fig. 2. Results of the magnetometer survey (left) and detail of the results from the GPR survey (right)

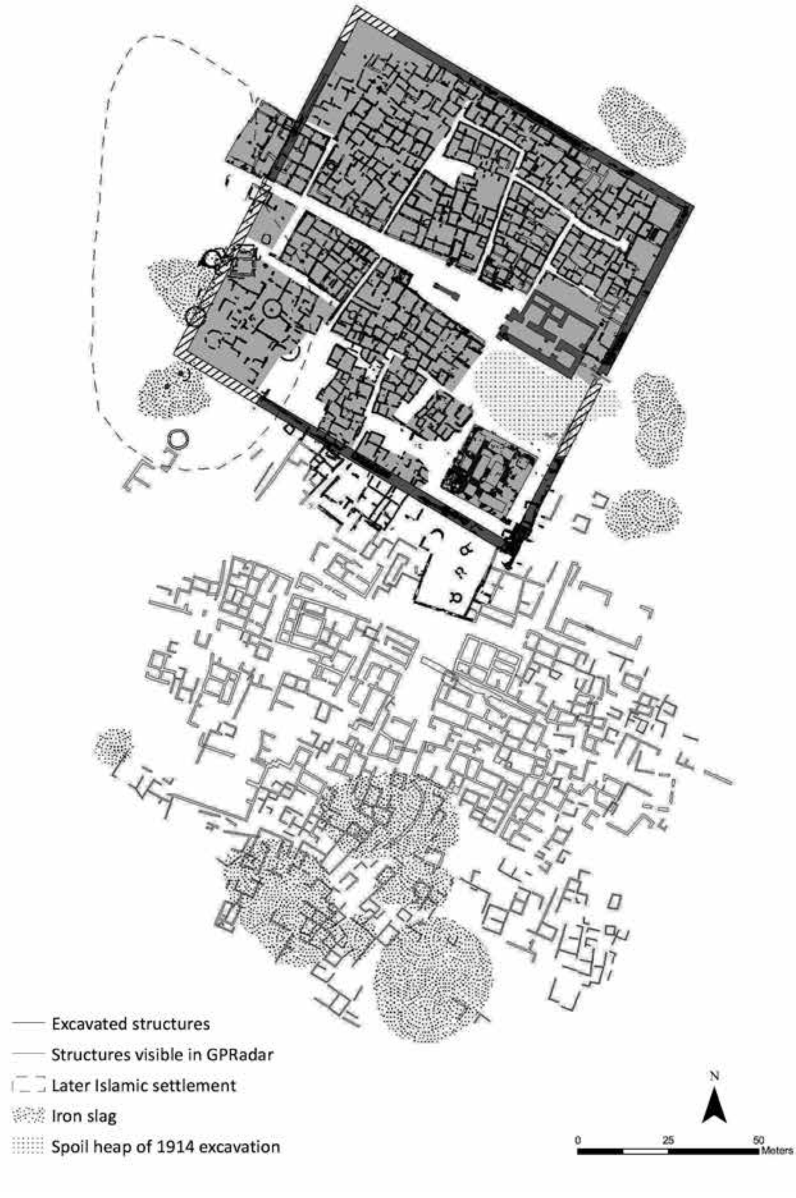

Fig. 3. Meroitic Hamadab with the excavated houses of the fortified Upper Town and structures of the adjacent Lower Town revealed by GPR

In 2000/2001, a joint research project was started by the Humboldt University of Berlin and the National Corporation for Antiquities and Museums, focusing on urban living in ancient Hamadab. Excavations within this project have revealed a densely built Meroitic urban settlement in the so-called Upper Town (Wolf *et al.* 2008). This part of the settlement is enclosed within a massive square town wall of 105 m x 105 m. The substantial wall, made of mud brick and lined with fired bricks, was clearly visible in the results of a magnetometer survey (Goldmann *et al.* 2007).

In 2009, IP-Resistivity and GPR surveys were applied to investigate the archaeometallurgical remains of several slag mounds to the south and east of the Upper Town. The main aim of these surveys was to reconstruct the location of kilns, which were suspected within the iron-slag mounds, but were not visible in the magnetometer data due to the high amplitudes of unstructured fired debris on the surface (Ullrich *et al.* 2015). Recent excavations by a University College London/Qatar team investigating Meroitic iron metallurgy on the Northern mound have confirmed the location of iron-smelting furnaces indicated by the geophysical surveys. A side benefit of the GPR surveys was the discovery of near-surface mud-brick walls next to the edges of the slag mounds, not previously detected by the magnetometer surveys (Fig. 2). In the following years, GPR surveys were extended to all accessible areas of the Northern mound, the combined profiles adding up now to a total length of approximately 50 km. Even under poor survey conditions for GPR due to a high attenuation of the electromagnetic waves, a complete map of the near surface structures of the Lower Town could be reconstructed (Fig. 3).

The presentation will focus on the contribution of geophysics to archaeological reasearch represented by a wide range of methods and survey techniques applied in Hamadab over the last decade. The main results of the geophysical surveys will be discussed, including magnetometer surveys, ERT-surveys (resistivity imaging) and GPR-surveys, in terms of archaeological research questions concerning archaeometallurgy and settlement history.

ACKNOWLEDGEMENTS

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Mobile laser scanning and 360° photography for the documentation of the Iron Age ring fort at Gråborg, Öland, Sweden

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KEY-WORDS: Öland, Iron Age, ring fort, MMS, Sweden, laser scanning, GeoTracker

INTRODUCTION

In May 2014, four prehistoric ring-forts on the island of Öland, namely Gråborg, Vedby borg, Bårby borg and Löts borg, were surveyed using a motorized ground penetrating radar (GPR) system. The surveys were carried out as a part of the project "The Big Five", financed by the Swedish research council and the Royal Academy of Letters, History and Antiquities, and included high-resolution GPR data collection, covering in total approximately 7.5 ha of land inside the forts.

As a complement to the geophysical survey the remaining walls and surroundings of Gråborg and Vedby borg were surveyed with a MMS GeoTracker. MMS systems are currently being used for high-resolution documentation of, for example, railroad tracks, but are also important for road planning and maintenance, asset management and for the generation of 3D city models (see Kutterer 2010: 293 ff.). It has also been tested and evaluated on archaeological sites (e.g., Studnicka *et al.* 2013). The GeoTracker system had not previously been used for the documentation of archaeological remains and the survey was considered a pilot study to evaluate its advantages and disadvantages for archaeological applications.

GRÅBORG

Gråborg is the largest Ölandic ring-fort with a diameter of approximately 200 m and an inner area of about 2.5 ha (Fig. 1; for a map showing the location of Gråborg, see Viberg 2015, 521-525). Based on finds collected during excavations and metal detection, the fort was constructed during the younger Roman Iron Age (AD 200–375) and was used until the Middle Ages (Stenberger 1933: 234; Malm 2003: 5). Several historical records and maps are available and show that the inner area of the fort has been farmed since the beginning of the 17th century at the least (Tegnér 2008: 44). This has seriously affected the preservation of the buried remains within the fort. However, masonry belonging to the outer fort wall is preserved in many places, although in collapsed form. The collapsed sections are as wide as 20 m today, but wherever the wall is in good condition, the original height can be estimated at roughly 6 m and width at 5 m (Swedish registry of ancient monuments, FMIS). The walls are constantly exposed to weathering and other chemical and physical degradation processes and additional sections of the wall are at risk of collapsing in the future. Because of this

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Fig. 1. Aerial photograph of Gråborg (top, photo Jan Norrman 1997, ©Swedish National Heritage Board); the MMS system (bottom: photo Andreas Viberg 2014)

risk, the importance of documenting the masonry structures becomes all the more urgent. Until now traditional archaeological documentation methods, such as photography and field drawing have been used at Gråborg. These methods have produced important results, but they are time consuming and the complete documentation of the entire ring-fort would be a lengthy and tedious process. Therefore, the use of 3D digital documentation methods, such as terrestrial laser scanning or photogrammetry, presents an interesting alternative (see Vosselman and Maas 2010).

THE MMS SYSTEM

The GeoTracker MMS system can connect up to eight laser scanners, standard SLR cameras, 1–4 stereo cameras, a 360° Ladybug5 camera, ground penetration radar systems etc. (Fig. 1). The advanced positioning system consists of a GNSS receiver (Novatel Propak V3), a high-precision wheel speed sensor (Pegasem WSS3) and a 250 Hz inertial navigation system with gyros and accelerometers. All sensor data are post processed to a trajectory (travel path) used for positioning of images and laser data with an accuracy of 2–3 cm. The 360° Ladybug5 camera captures true 12-bit

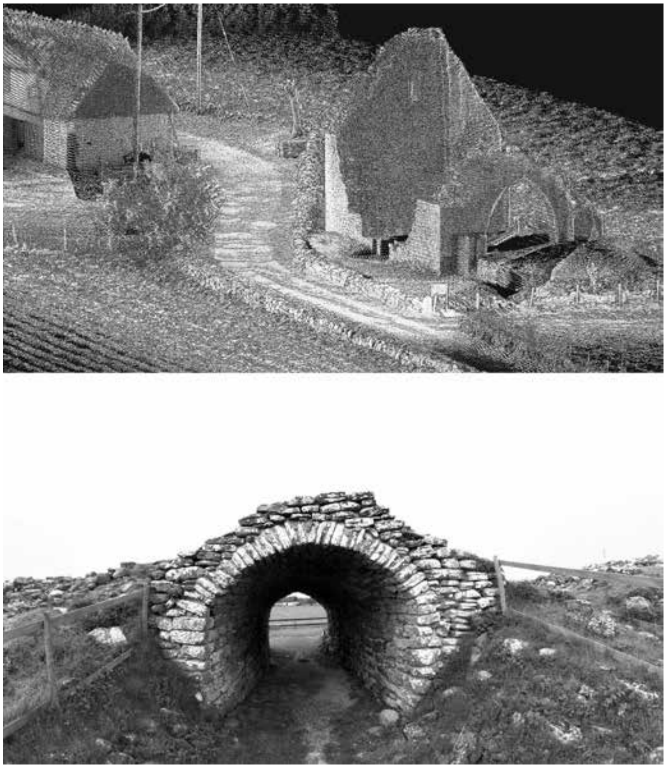

Fig. 2. Laser point cloud showing the chapel of St. Knut near Gråborg (top); still from the 360° photo documentation of Gråborg using a Ladbybug5 camera (bottom) (© Magnus Larson 2015)

images from six highly sensitive CCD sensors with a high dynamic range even in shadows and highlights. During the survey at Gråborg four SICK LMS 511 Pro laser scanners were mounted on the platform. The point density in the laser point cloud is over 120,000 points per second. At a speed of 30 km/h this results in over 1500 points/m^2. It is possible to mount the platform on different kinds of vehicles, e.g., cars, rail vehicles, boats etc.

The GeoTracker software package makes it easy and fast to produce point clouds, stitch panorama images and even produce high quality coloured point clouds. There is also a free image viewer to help the user to evaluate images with online map functionality.

RESULTS AND DISCUSSION

The survey at Gråborg was carried out in the course of two hours and data was collected from the main road to Gråborg, at Borgs by, the chapel of St. Knut and finally inside and around most of the outside of Gråborg. This resulted in 180 million points in LAS 1.2 format with a point density of 3000–7000 points/m^2 around the vehicle. In addition to the laser scanning data, 415 panorama images (18.3 GB of raw data) and 1644 stereo images (5 MP) were collected.

The system provided a valuable high-resolution digital documentation of the Gråborg area (Fig. 2). Even though access to the southern side of the fort was limited, an almost complete documentation of the fort could be accomplished within a matter of hours. The data will be made available to the public and will allow online remote visits to the site. The data is also valuable from an archaeological research perspective as wall construction and condition can be evaluated without visiting the site. The dense point cloud generated by the MMS system also allows for accurate measurement of the perimeter wall, which could form the basis of a very thorough documentation and analysis of the fort. The downside of the MMS system is that it requires that the archaeological site is accessible to the vehicle the system is mounted on. As these kinds of "drive through" ancient monuments are rare, the use of MMS systems will most likely be restricted (see Barber *et al.* 2011). The system could be used, however, for the fast documentation of urban areas, such as the Swedish world heritage sites Örlogsstaden Karlskrona, Hansestaden Visby and Världsarvet Gammelstads Kyrkstad, and similar sites in Sweden and abroad. Another restriction is the density of the point cloud on structures taller than the car. As the system cannot "see" these areas, it needs to be complemented by, for example, aerial photographs, airborne light detection and ranging (LiDAR) surveys or static terrestrial laser scanning (TLS), in order to produce a more complete picture of the surveyed structures.

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ArchPro Carnuntum Project. Large-scale non-invasive archaeological prospection of the Roman town of Carnuntum

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KEY-WORDS: Large-scale non-invasive archaeological prospection, Roman town, Carnuntum

The site of the Roman military camp and civil town of Carnuntum, on the southern bank of the Danube about 40 km southeast of Vienna, constitutes the largest archaeological landscape in Austria. It covers some 650 ha between between the modern-day villages of Petronell-Carnuntum and Bad Deutsch Altenburg. As the capital of the Roman province of Pannonia, Carnuntum was an important town during the first four centuries of the 1st millennium AD.

So far only small parts of this archaeological site and the surrounding landscape have been investigated using traditional archaeological methods. In the 19th century Carnuntum was the "Pompeii at the gates of Vienna" in view of the exceptionally good state of preservation of its ruins, but the situation has changed dramatically. Intensive farming involving deep ploughing, infrastructure development, the construction of new housing estates in the nearby villages and active looting by treasure hunters has increased dangerously irreversible erosion of archaeological layers and destruction of this important cultural heritage site.

The case study presents a long-term interdisciplinary archaeological survey of an entire Roman city. Through the combination of aerial archaeology with high-resolution geophysical subsurface mapping and GIS-based archaeological interpretation and spatial analysis, the archaeological site and hinterland of the ancient town of Carnuntum have been mapped and virtually imaged with blanket coverage and in great detail. The outcome of this integrative prospection approach provides an outstanding wealth of data and new information for future archaeological research.

THE ARCHPRO CARNUNTUM PROJECT

A dedicated project to make use of the great potential of large-scale non-invasive prospection was set up in 2011 by the government of lower Austria, the Central Institute for Geodynamics and Meteorology (ZAMG) and the Ludwig Boltzmann Institute for Archaeological

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Prospection and Virtual Archaeology (LBI ArchPro). The goal was to map the entire landscape surrounding the ancient town of Carnuntum. Within this project, an area covering 10 km^2 was chosen to be explored with all available non-invasive prospection methods.

While large-scale archaeological excavation and trenching was used in the past century for the investigation and reconstruction of the ancient city layout, modern archaeology increasingly makes use of non-invasive means for the exploration and mapping of the buried subsurface. In particular, aerial archaeology and geophysical archaeological prospection methods have proven to be ideally suited survey methods of great value for the mapping and documentation of Roman city sites, as exemplified by the archaeological prospection of the ancient town of Carnuntum.

AERIAL ARCHAEOLOGY

Following the strategy described here, over the past fifteen years considerable areas have been investigated at Carnuntum, using numerous aerial photographs and a large amount of topographical data. One of the basic problems of aerial archaeology is that the visibility of archaeological sites is dependent on many factors. Most of these cannot be controlled and therefore, only a systematic reconnaissance programme over several years can give a more or less complete overview of the archaeological subsurface. The time-consuming process of interpreting several thousands of aerial photos resulted in a very detailed visualization of the buried town-layout. Yet, several areas remained either void of crop- or soil-marks reflecting buried archaeological structures or only a very few interpretable structures were observed, obstructing archaeological analysis and interpretation.

GEOPHYSICAL PROSPECTION

To overcome this problem, it was necessary to combine aerial archaeological evidence with other prospection methods. High-resolution, near-surface geophysical survey methods have already been tested, developed and applied within the last decade, for the prospection of extensive areas within the archaeological park of Carnuntum.

Novel, motorised measurement devices for rapid, high-resolution magnetometer and GPR prospection were designed and developed over the last years within the LBI ArchPro and were extensively used on the Carnuntum project. Together with the integration and application of automated positioning systems as well as adequate, newly designed data processing and visualisation techniques, highly efficient archaeological survey and prospection systems were made available for the detailed survey of truly vast areas.

The motorised GPR-survey using a 16-channel MALÅ Imaging Radar Array with only 0.08 m measurement spacing, both in the direction of the GPR profiles as well as perpendicular to it, has enabled us to detect in several buildings structures that could be interpreted as hypocaust pillars. In case of the area of the civil town of Carnuntum, it has been possible to extract detailed depth-dependent information by moving through the three-dimensional data volumes from top to bottom, and to map the remains of individual structures, such as walls, drains, pavements, corridors, foundations, column bases and other internal architectural details. This novel approach even permitted the identification of staircases and heating systems within some of the buildings.

Fig. 1. Motorised 8-channel fluxgate magnetometer system used for the magnetic survey of Carnuntum

Fig. 2. MALÅ MIRA 16-channel GPR system in adapted version for the prospection of the Roman town of Carnuntum

Fig. 3. Three-dimensional view of the magnetic map s of the survey area from the west

The magnetic prospection conducted with a sample spacing of 25 cm cross-line and 20 cm in-line resulted in relevant and complementary information on magnetised structures, such as brick structures, hearths, filled pits, ditches and water-channels. In case of Roman remains and city sites, the combination of GPR and magnetic prospection proved to be of particular importance and value. Our integrative strategy for the survey of Roman city sites systematically combined large-scale aerial archaeology and ground-based high-resolution geophysical prospection, followed by joint archaeological interpretation of the digital data within a GIS environment.

CONCLUSIONS

The combination of advanced methods of airborne remote sensing and geophysical prospection permits the efficient and highly accurate detection, investigation and documentation of archaeological sites above and below ground, providing a wide range of spatial data in unprecedented quantity and quality for an efficient self-contained archaeological research approach, resulting in valuable and reliable new information on important cultural heritage sites. Until recently archaeology used the great potential offered by these modern prospection techniques only to a limited extent.

The archaeological maps and plans resulting from the archaeological methodology presented here, show individual buildings, streets, graveyards, temporary military camps and Roman infrastructure and thereby allow the virtual reconstruction of the city layout and the development of the ancient land- and townscapes in space and time, providing scholars, planning authorities and the public alike withnew detailed and valuable information on the ancient city of Carnuntum.

ARCTIS – analysing hyperspectral datasets

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KEY-WORDS: airborne imaging spectroscopy, airborne hyperspectral scanning, toolbox, Creative Commons, archaeology, remote sensing

In archaeology, several studies have demonstrated that airborne imaging spectroscopy (AIS), also known as airborne hyperspectral remote sensing, has a huge potential for airborne prospection. AIS overcomes the deficits of conventional and multispectral imagery and therefore holds the potential to enhance the visibility of soil colour differences and plant stress.

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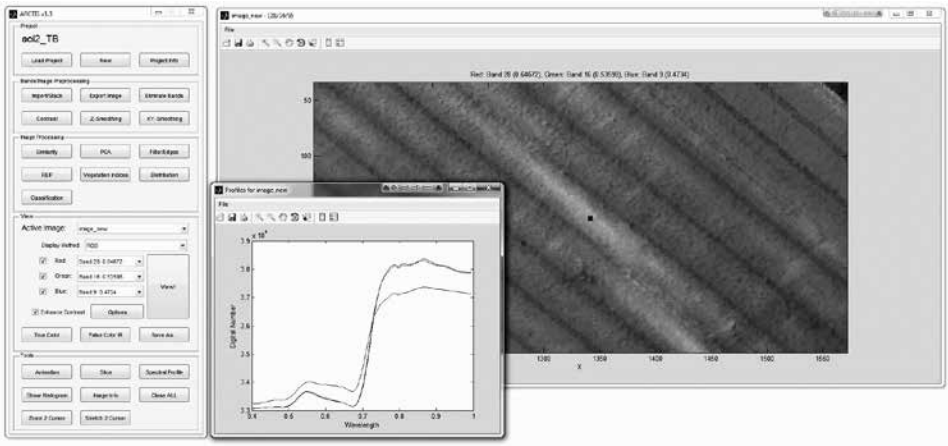

Fig. 1. Display of reflectance curves of user-selected pixels is a standard tool

However, to fully exploit this potential, a number of inherent problems have to be addressed by the image analyst: (1) the large number of spectral bands which need to be inspected; (2) the inherent data redundancy in AIS data sets; (3) the relatively low signal-to-noise-ratio of the imagery, especially when acquiring AIS data with ground-sampling distances (GSD) smaller than one meter; (4) the fact that available software packages do not provide tools specifically aiding data reduction for archaeological feature detection (e.g., red-edge detection and parameterization). Also, the most fruitful ways to visualize the data for a specific scientific investigation have to be explored.

For research in archaeological prospection, suitable software solutions which address these issues are needed. These packages should focus on the overall workflow rather than the technical expertise needed to enhance the visibility of plant and soil spectral differences. Therefore, the toolbox ARCTIS (ARChaeological toolbox for imaging spectroscopy) was programmed in MATLAB® to address the above mentioned problems and requests (Doneus *et al.* 2014; Atzberger *et al.* 2014). ARCTIS was developed in cooperation between the Department of Prehistoric and Historical Archaeology of the University of Vienna and Vienna's University of Natural Resources (BOKU). The main aim of this specific AIS toolbox is to enable users to inspect, visualize and analyse hyperspectral data sets to highlight possibly occurring archaeological visibility marks (of which crop/vegetation marks are the most abundant). It was, therefore, necessary to develop a software for the specific needs of archaeologists.

First of all, a user-friendly GUI had to be designed so that even a non-specialist in remote sensing could work with ARCTIS in a straightforward way. Based on the authors' conviction that only high spatial resolution datasets (GSD < 1 m) will be useful for archaeological prospection, the toolbox includes a Whittaker smoother to reduce the sensor noise which becomes apparent when sampling the earth with small GSDs in very small spectral bands. Despite removing the spectral noise, the Whittaker smoother (Eilers 2003) preserves the complete shape information of the observed spectral signature. Each AIS pixel is smoothed independently

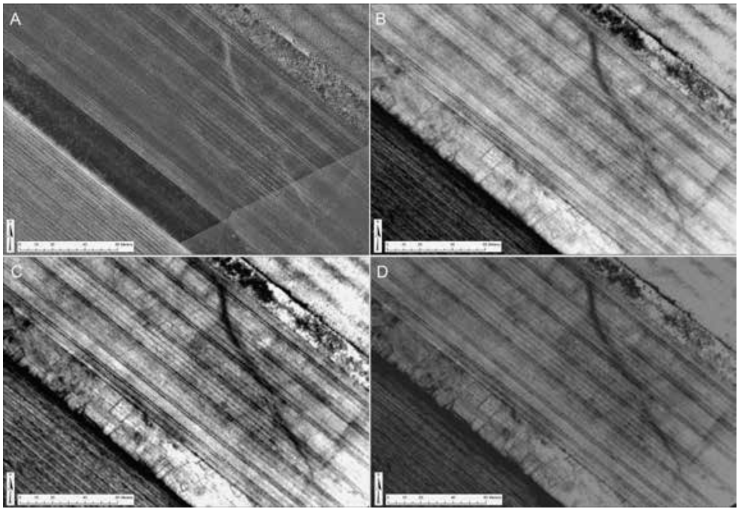

Fig. 2. Data from Carnuntum, Lower Austria, acquired on May 26, 2011. Size of depicted area: 230 x 154 m. (A) Conventional orthorectified aerial image, acquired in the visible spectrum. GSD of 0.1 m; enhanced using contrast limited adaptive histogram equalization (CLAHE); (B) false colour composite created by means of the REIP algorithm (R = band 1 (wavelength), G = band 2 (slope), B = band 3 (reflectance value)); (C) rate parameter b of the gamma distribution fitting; (D) normal distribution fitting (R = NONE, G = band 2 (s), B = band 1 (m)). GSDs of (B), (C) and (D): 0.4 m. Figures B, C, and D were subject to the same histogram stretch by means of standard deviation (from Doneus *et al.* 2014)

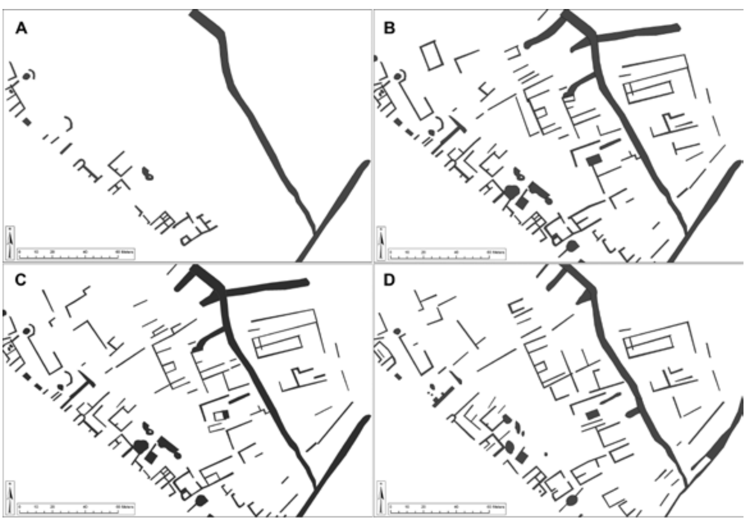

Fig. 3. Mapping of visualizations from Fig. 2: (A) orthophotograph; (B) REIP, (C) gamma distribution fitting, (D) normal distribution fitting (from Doneus *et al.* 2014). Size of depicted area: 230 x 154 m

along the z-axis (i.e., spectral dimension). After this computation, the smoothed values are written into a new image. The latter thus holds all the smoothed spectral signatures. Because the smoother treats all bands as if they were equally spaced in the wavelength range, the number of input bands equals the number of output bands. Moreover, the smoother is easy to parameterize and balances fidelity to the data and the roughness of the smoothed curve.

Furthermore, ARTCIS needed several methods to identify information-rich layers. This task was accomplished through several subtools. First, interactive visualization of the AIS bands is possible and allows the user to mine their hyperspectral data and identify the most useful spectral bands for discriminating soil and vegetation marks. As a standard tool, the reflectance curves of user-selected pixels can be displayed. More importantly, the entire image cube can be visualized along user-selected vertical or horizontal slices. A horizontal slice, for example, corresponds to all data (in column and layer direction) along a fixed row number. If located above a known soil or vegetation mark, this permits the user to detect band numbers (wavelengths) where these marks have their contrast maximised in respect to their surrounding matrix. Because the human visual system is very effective in recognizing structures and movements, a number of animated visualization tools have been added as well. Those permit the layers of the active image to be displayed sequentially (and repeatedly) with a user-specified frequency.

Second, well known image processing techniques are offered in the toolbox. Those vary from vegetation indices, over-edge detectors to data compression techniques such as principal component analysis (PCA). In the case of ARCTIS, PCA is based on selected sample areas with known vegetation marks.

Finally, also a variety of very powerful tools for unique spectral data mining have been developed. One of those is the calculation of inflection points in the red-edge waveband and along the shoulders of other absorption bands. A number of studies have demonstrated the added value of detecting inflection points in the spectral shapes of vegetated pixels (e.g., Darvishzadeh *et al.* 2009). Despite the long-lasting knowledge about the prospects of this indicator, currently no commercial software has implemented suitable algorithms. The inflection point algorithm included in ARCTIS identifies for each AIS pixel the location (in terms of band number) of the highest (absolute) gradient in the spectral profile. In addition to this "inflection point" (first output layer), the algorithm also outputs two additional indicators linked to this point: the value of the gradient itself (second output), and the level of reflectance for the wavelength of maximum gradient (third output).

Additionally, ARCTIS allows the calculation of novel distribution fittings. They can yield new insights into crop vigour and vegetation stress. Their archaeological potential has already been investigated in depth (Doneus *et al.* 2014).

To help the image analyst to remember all individual processing steps, all functions and their parameters that are applied to each image file are logged into an ASCII-based history file. History files inherit their name from the image file to which they correspond and are located in the same folder. When ARCTIS creates a new image from a previously processed dataset, it will extract the original history information and store it, together with new history info, along the new image file. In this way, all functions and parameters that produced a given image are included in its history file. This makes the whole processing chain traceable and repeatable.

Given the fact that many of its residing processing and visualization tools cannot be found elsewhere and commercial software is often costly and less straightforward to use, the authors decided to make the toolbox and its source code freely available under a creative commons license for all interested parties (via download from *http://luftbildarchiv.univie.ac.at*). Together with some test datasets, this open access will enable interested students and remote sensing professionals to become acquainted with AIS, while other scientists can contribute with new algorithms to further expand and even optimize ARCTIS.

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Archaeological revival of memory of the Great War.

The role of LiDAR in tracing the boundaries of the WWI Rawka Battlefield Cultural Park

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KEY-WORDS: Archaeology of Contemporary Conflicts, the Great War Archaeology, non-invasive methods, NMT analysis, pro-social use of archaeological knowledge, LiDAR visualisations

"When I saw it, I was amazed how complex it is". "It should be protected. It has survived for a hundred years". "I was not aware it is so extensive and uncluttered". "It is like a masterpiece, so impressive and so meaningful" — these are just a few of the many reactions noted when presenting a LiDAR visualisation of a World War One battlefield to the general public and to those, in whose power it is to protect it. In Masovia, central Poland, battlefields have not been treated so far — and hence conserved, as legacies of a painful history despite significant social potential (Zalewska 2013). In this context, archaeology can become socially important and causative also within the field of remembrance studies as an institution of cultural memory, forging an important return path from cultural forgetting to cultural memory by retrieving lost objects and defunct

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Fig. 1. Archival photograph of the German trenches close to Bolimów, manned in 1915 by soldiers of the 61 (8 Pommeranian) Infantry Regiment v. d. Marwitz (Copyright by Rodside Lessons Foundation)

information from the past (Assmann 2008: 97–8). A reflection on the crucial role of Airborne Laser Scanning technology for the process of activating warscape memory gives the opportunity to recall the history of the Eastern Front during the Great War (Czarnecki 2014).

DEPOSITIONAL PROCESSES: THE GREAT WAR IN MASOVIA (POLAND)

In the autumn of 1914, the Russian Army established a defensive line in the foreground of Warsaw, based on the Rawka river, where the Russian Army took advantage of the steepness of the eastern bank. However, in the upper reaches of the Rawka this was not possible and in the vicinity of Bolimów the Russians were forced to situate their defensive line at a distance of 2–3 km from the river, turning a series of villages into fortresses. The position was crucial for protecting the road to nearby Warsaw (Fig. 1). For seven months of heavy fighting, the Ninth German Army tried to break through, using the most modern weapons of the time, including chemical warfare. In January 1915, Germans used artillery shells containing tear and irritating agents and then in May, June and July the severe chlorine gas attacks, took place. In mid-July 1915, when the area lost its strategic importance, the two armies retreated leaving behind ruins and ashes.

MATERIAL REMAINS OF A FORGOTTEN GREAT WAR AS SUBJECT OF STUDY

After 100 years the former battlefield became the subject of a transdisciplinary project "Archaeological revival of memory of the Great War. Material remains of life and death in trenches of the Eastern Front and the condition of the ever changing battlescape in the region of the Rawka and Bzura rivers (1914–2014)". The project is implemented by the Institute of Archaeology and Ethnology of the Polish Academy of Sciences and financed by the National

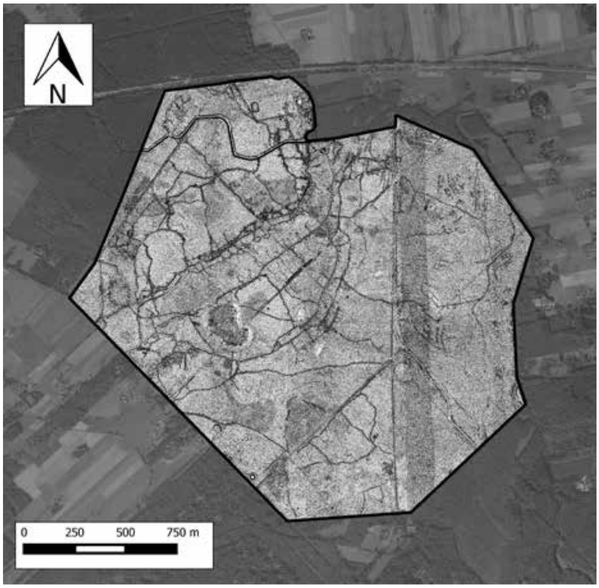

Fig. 2. Zones of WW1 material remains for potential protection in 2014–2018, marked on a visualization of the investigated area. Zone A: area of the best-preserved remains of positional warfare of the Great War, including 'No Man's Land'; zone B: relatively well preserved remains of the former battlefield, including the rear positions; zone C: strongly transformed area of the former WW1 battlefield (archaeological research planned for 2016) (Copyright by APP)

Science Centre in Poland. The scientific team (10 members) has been appointed by Anna Zalewska, the originator and principal investigator of the project. Its objectives of activating the persuasive and causative forces of 'material memory' (landscape memory) are being accomplished by a review of different archival sources on WW1 in Masovia, interviews and discussions, and an archaeological survey of the region.

ARCHAEOLOGICAL STUDIES IN THE PROTECTION OF VESTIGES OF POSITIONAL WARFARE

Non-invasive and invasive archaeological methods have revealed an extraordinary preservation of the ground scarred by war (Fig. 2). By adopting the multidisciplinary approach of "modern conflict archaeology" (after Saunders 2007), a study of written and iconographic sources was combined with fieldwalking, geophysical surveys and test excavation The new concept of the Polish Archaeological Record 2 (AZP2) project proved inspiring (for details, see: Rączkowski 2011: 154; Jakubczak 2014), comprising: a) fieldwalking, b) aerial reconnaissance (here LiDAR) and mapping of archaeological features, c) geophysical surveying and d) test trenches placed wherever current threats to preservation were identified or the cognitive potential for reconstructing life and death in the Great War trenches was recognized. The geophysical prospection is still in progress, GPR

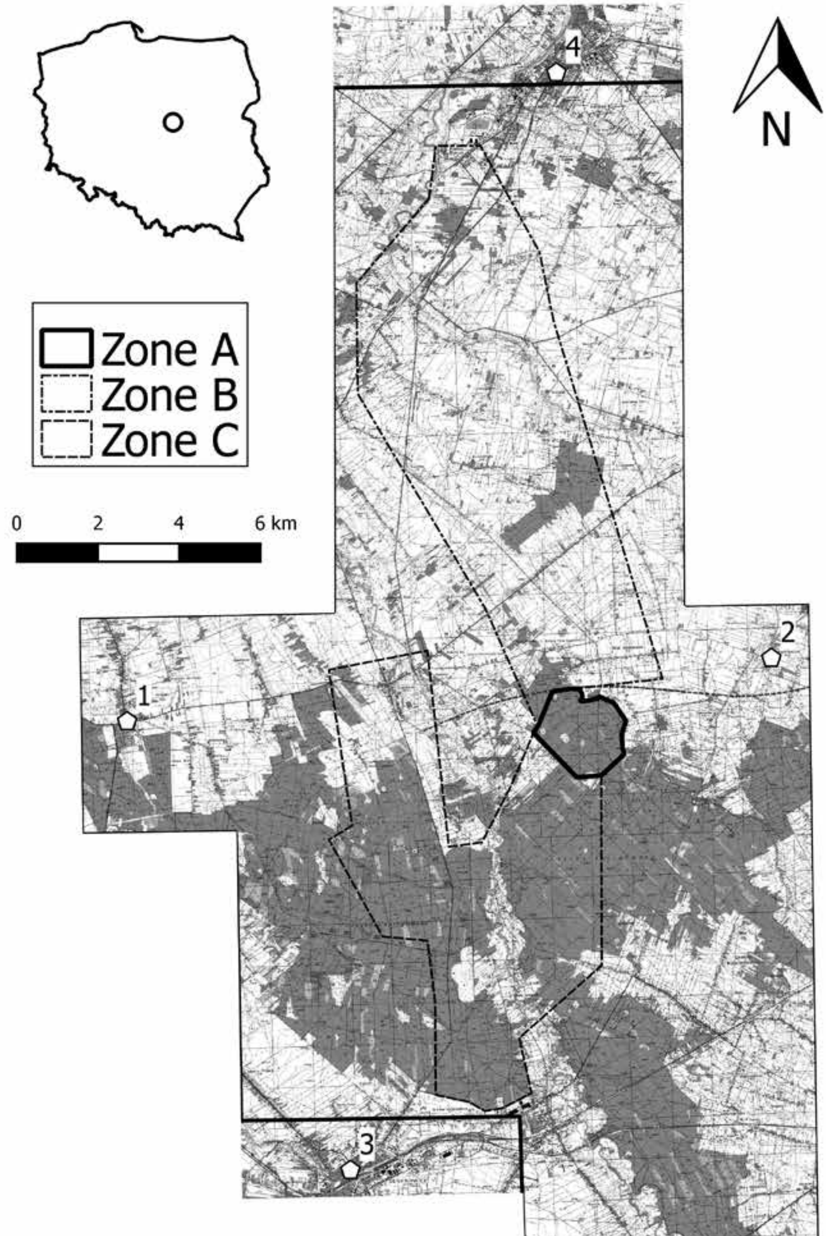

Fig. 3. Zone A as shown with ALS is a piece of the Great War stuck in time: diverse features from 1915, like artillery emplacements, dugouts, weapons stores, field hospitals etc., best preserved in the field but also the most heavily damaged by illicit search for metal finds (Copyright by APP)

proving to be the biggest challenge, electro-resistance and magnetometry already yielding relevant outcomes, and LiDAR turning out to be a crucial tool in recognizing the postwar landscape.

LIDAR TECHNOLOGY IN THE CONTEXT OF SENSITIVE GAS-SCAPES

In the process of activating memory of a place where poisonous gasses were used, airborne laser scanning, which passes also through forest cover, appeared invaluable (Fig. 3). The results of the ISOK Project (IT system of the country's protection against extreme hazards) were employed and clouds of points were reclassified by archaeologists using Lastools software. Visualizations prepared in Global Mapper, RVT and LiVT software were verified for credibility, improving significantly DTM (digital terrain model) quality. The best results were obtained with the use of a SVF (anisotropic sky-view factor), which did not exclude the effectiveness of other visualizations. Analysis of the intensity of laser reflection for plowed fields did not bring the expected results.

Field verification of the LiDAR results augmented the project's QGIS database and facilitated choice of areas for detailed study. These were then implemented to a GPS device as raster images, allowing for very accurate recording in the field of specific landforms. One of the most important results of the archaeological survey was the demarcation of three zones in the studied area: A, 3,5 km^2; B, 55 km^2 and C, 42 km^2.

CONCLUSIONS

The LiDAR visualization was chosen as the core presentation method for the research (Zalewska, Kiarszys 2014) and geophysical methods as a significant element of AZP2 implementation because of a limited range of alternatives (archival aerial photographs from 1915 have still to be found). However, the "more visual approach" to the presentation of the results of archaeological analysis offered by LiDAR, assuming field verification, proved highly persuasive (see Rączkowski 2011: 155). Suffice it to recall the response, mentioned in the opening lines of this abstract, of people living in the neighborhood when they first saw the results and who are responsible for the preservation of these remains for the future.

ACKNOWLEDGMENTS

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Principal component analysis (PCA) of buried archaeological remains by VIS-NIR spectroscopy

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KEY-WORDS: soil spectroscopy, visible-to-near infrared soil spectroscopy, *in situ* measurements

INTRODUCTION

Buried archaeological remains are sometimes visible on the ground surface after ploughing. Such features are detectable to the naked eye, aerial photography or airborne remote-sensing, due to a difference in soil colour between the archaeological remains and the surrounding natural background soil. This work tries to analyse the spectral difference between buried archaeological remains and natural soil in the visible-to-near infrared range using the principal component analysis (PCA) method.

METHODOLOGY

The study was carried out on *in-situ* soil spectra of the excavated sections of six pits from Calabria, Italy. One of the pits contained a red archaeological stratum in the profile, which was clearly distinguishable from the natural soil. For each pit, at least three spectral measurements were taken for every layer using an Analytical Spectral Devices (ASD) spectrometer with artificial halogen light. The instrument has a spectral range of 350–2500 nm, but only wavelengths between 400–2400 nm were applied to minimise the influence of noise. These spectra were normalised by a continuum removal (Clark and Roush 1984) method to emphasise the absorption features and then analysed with the principal component analysis method.

Principal component analysis (PCA) is a multivariate chemometric method. It is a common tech-

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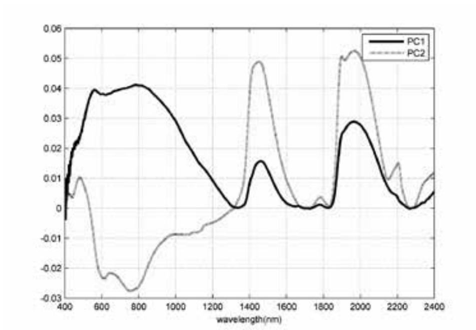

Fig. 1. Intensity of the first (PC1) and second (PC2) principal component

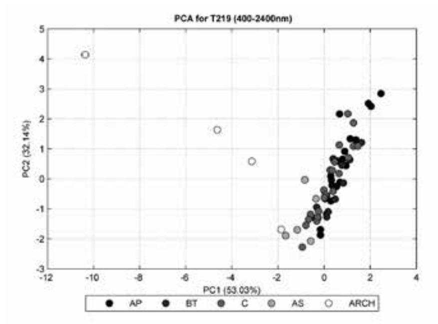

Fig. 2. PC1–PC2 plotting with different soil horizons: AP – distinct topsoil disturbed by ploughing; BT – B horizon (subsoil) enriched with clay; C – underlying unconsolidated material (parent material); AS –archaeological horizon; ARCH – archaeological material (burned soil and ceramics)

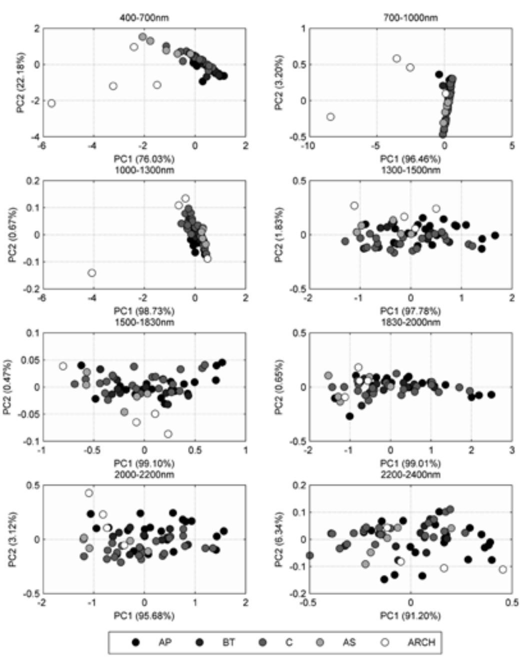

Fig. 3. PC1–PC2 plot at different wavelengths: AP – distinct topsoil disturbed by ploughing; BT – B horizon (subsoil) enriched in clay; C underlying unconsolidated material (parent material); AS – archaeological layer; ARCH – archaeological material (burned soil and potsherds)

nique used to reduce the dimensionality of a dataset (Smith *et al.* 1985) and to discover new variables called principal components (PCs), which account for most of the variability in the data. The first principal component (PC1) represents the most dominant features among the spectra and the second principal component (PC2) represents the second most common features and so on. In soil spectroscopy, PCA is widely used for spectra comparison (Viscarra Rossel *et al.* 2009), mineral determination (Smith *et al.* 1985) and to select the end member spectra for the subsequent application of the linear spectral unmixing model (Galvão *et al.* 2001). In this study, soil reflectance spectra will be analysed using the PCA method to distinguish spectral features related to archaeological remains and natural soil.

RESULTS AND DISCUSSION

The first three principal components accounted for about 53%, 32%, and 10% of the total variation of the measured spectra, respectively, with a cumulative variance of about 95%. Figure 1 shows the first and second principal PC features. Here, the most dominant feature (PC1) is shown as a broadband feature in the 400–1200 nm spectral range. The near infrared region shows common features at the water absorption bands (1400 and 1900 nm). PC2 shows some absorption features in the visible spectral range. The near infrared region of PC2 is dominated by the water absorption bands (1400, 1900, 2200 nm) and small features (e.g., at 1800 nm and 2100 nm) are also included. By looking at the intensity of PC1 and PC2, we can expect that most spectral differences of soil spectra are concentrated below 1200 nm.

Figure 2 shows the scores of PC1 plotted versus those of PC2. We can observe that the archaeological materials (ARCH), which are burned materials and ceramics, are well separated from the "soil cluster" on the right. Although soil spectra of different horizons were not well separated, we can see that archaeological materials (ARCH) and archaeological soil (AS) are gathered together.

To investigate under which conditions we can most clearly distinguish archaeological remains and natural soil, PCA was performed over different wavelengths (Fig. 3). The wavelength ranges were chosen according to various factors which affected the measurement. The separation of wavelength windows was performed at the spectrometer boundaries (ASD spectrometer is comprised of three different spectrometers) and close to strong water absorption bands. Since the archaeological horizon was visually distinguishable, we expected to see a clear separation between archaeological features and natural soil in the visible spectral range (400–700 nm). However, despite the small difference between archaeological materials and natural soil, PC1 did not make a clear separation. Also, the different horizons (which were seen visually) are not very well separated in the visible range. This is probably related to the normalisation procedure applied to the spectra. By looking at the PCA at different wavelengths, we can see that the archaeological materials (ARCH) are separated for wavelength ranges below 1000 nm. Beyond this wavelength, it becomes difficult to find the difference between archaeological material and natural soil.

CONCLUSION

The paper shows preliminary result of PCA application to the reflection spectra of archaeological remains. The result indicates that archaeological materials are well separated from the natural soil through PCA. The PCA result can probably be improved by using a larger dataset (spectra) over a wide range of archaeological sites. This will improve the statistical results and perhaps be used to separate different horizons as well. Currently, more research is going on with the PCA application to archaeological sites to distinguish archaeological remains through spectroscopy.

ACKNOWLEDGEMENTS

We extend our thanks to the University of Groningen and the National Museum of Hungary for their help and support during the fieldwork.

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Integrated prospection approaches

Going over old ground: what can landscape-scale magnetic susceptibility data do for me?

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KEY-WORDS: magnetic susceptibility, scale, landscape, Italy, prehistory

This paper presents work carried out in the "Rural Life in Protohistoric Italy" project (funded by NWO Grant No. 360-61-010), following from pilot magnetic susceptibility (MS) studies conducted in our research area in northern Calabria and published last year (Van Leusen *et al.* 2014). We will explore the integration of magnetic susceptibility data from a variety of methods and scales with other geophysical datasets and with fieldwalking data, and examine how our research has identified gaps in the current understanding of the relationships between soil and site formation processes, magnetic susceptibility changes and the magnetic anomalies these give rise to.

One of the specific goals of the geophysical research within this project has been to develop an effective site detection methodology using MS, to be employed alongside teams engaged in extensive and intensive fieldwalking. This is intended to mitigate against poor visibility conditions that adversely affect protohistoric pottery scatters (and therefore the discovery of sites from that period). We have, as presented elsewhere (Armstrong *et al.* 2012; Armstrong 2013; Armstrong *et al.* 2013), also employed other geophysical techniques in our studies of these small rural prehistoric sites, and this has prompted a new set of questions: What gives rise to the anomalies seen in our gradiometer data? How can seemingly disparate subsurface remains give rise to similar anomaly shapes and intensities? And how can the identification of more amorphous archaeological anomalies be improved in comparison with results issuing from geological or pedological examination? These research issues are being examined within our project using MS measurements at varied scales.

The MS work has been undertaken using EM38 measurements, and measurements using the Bartington MS3 system, with a variety of sensors. This has allowed an exploration of different scales and methodologies, from detailed 1 m or 2 m gridded surveys using the EM38 and the

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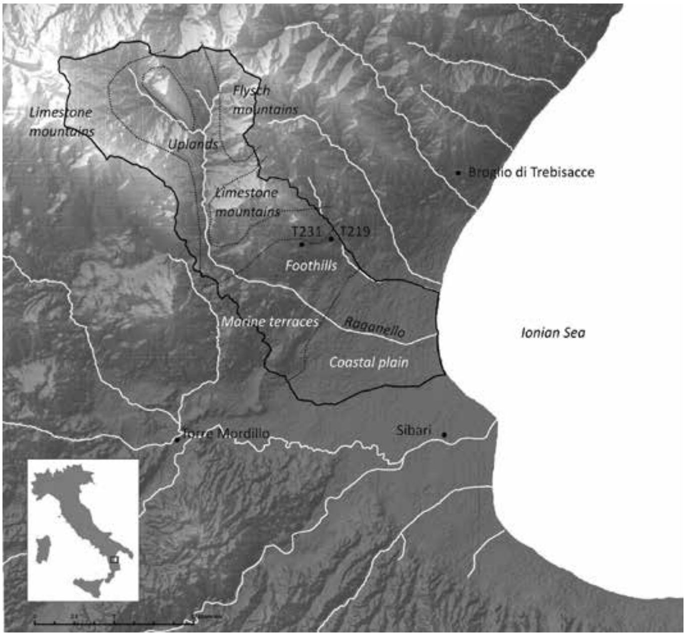

Fig. 1. Research area in northern Calabria showing the major landscape zones mentioned in the text and important local Bronze Age sites

MS3 with D loop, to measurements on sections and samples from contexts, sections and cores, high resolution downhole logs of corings, and in large scale 'transects' of data obtained across landscape units using both the EM38 and the MS3 D loop, with GPS for location.

Measurements made with the MS3 B sensor allowed us to explore the frequency dependency of soil layers and contexts, both from archaeological sites and from 'typical' soil profiles across our varied study region (see Fig. 1). It is of key importance to the presentation that our research involves the investigation of a whole landscape. The nature of that landscape (steep terrain, small fragmented terraces, much of the land not under cultivation) means that a mosaic survey strategy has to be adopted, with multiple small surveys covering available tracts of land. The large number of possible sites (155+) has also necessitated a sampling-based approach, using a site classification scheme, where 'typical' sites of each type are investigated and inferences are made to the rest of the class. This means in turn that geophysical data (primarily using magnetic techniques) come from a large variety of parent geologies and pedologies within the study region. This includes '*terra rossa*'-type soils on the marine terraces, calcareous soils on hard limestone parents and on gravel cones and conglomerates in the foothills, and marls, flysch, mudstones and schists in a dynamic upland valley. The comparative nature of our approach requires that we understand the background magnetic characteristics of these different landscapes in order to be able to make a reasonable judgement about what an 'archaeological anomaly' looks like in each environment, and whether, despite apparent differences in geophysical manifestation, they might represent similar archaeological features and behaviours.

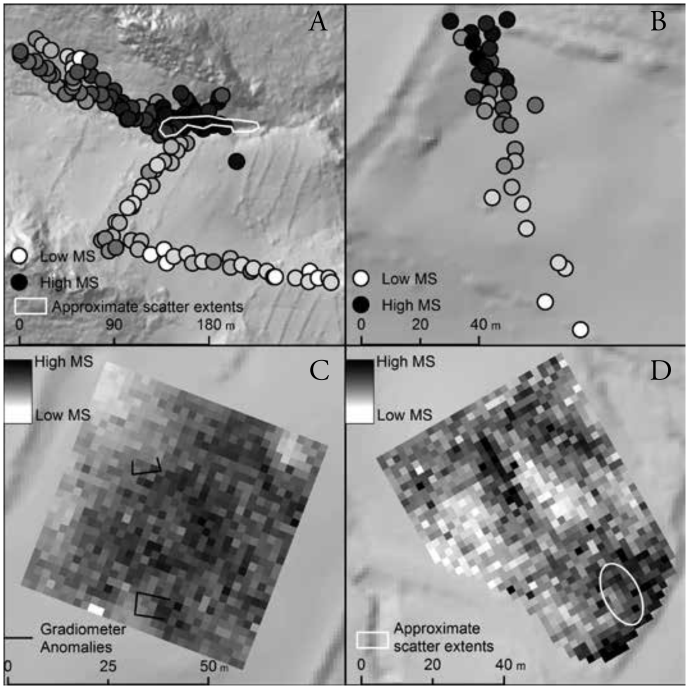

Fig. 2: Top row: 'Dense transect' approach applied on sites with strong 'on site' MS enhancement, A (top left) – Terra Masseta, multi-period site at base of a limestone cliff, showing no associated rectangular structures; B (top right) – Site T50 in the foothils, showing a pottery scatter. Bottom row: C (bottom left) – Site T94, upslope from T50, with pottery scatter but no apparent MS enhancement associated with it, and D (bottom right) – Site T73 in an upland valley, demonstrating clear MS differences not associated with the known pottery scatter; both C and D surveyed using a 2m grid

For example, a 'high MS' result on the marine terraces looks really rather different than on the gravel fans of the undulating foothills. Fractional conversion testing (Crowther 2003) was tested as a way to quantify these different degrees of enhanceability.

In this particular environment, the MS variations that occur due to soil differences were found to occur at similar scales and magnitudes as 'on site' MS enhancements that otherwise might help to verify the results of fieldwalking. When operating at 1 m grid resolutions, we could see some correspondence with gradiometer and total field anomalies, and this has helped to interpret the type and extent of the features giving rise to them. However, this gridded survey method is too time consuming to be undertaken alongside fieldwalking. A 'dense transect' approach, using the MS3 with a D-loop and logging GPS positions, has had some strong results on certain site-types, where strong MS enhancement has been seen in close correspondence with surface pottery and other archaeological material (Figs 2: A, 2: B), but this has not been the case everywhere in the landscape: there are ceramic scatters that occur without any strong local MS signal (2: C) and scatters where any possible signal is lost in 'noise' of a general variation (2: D).

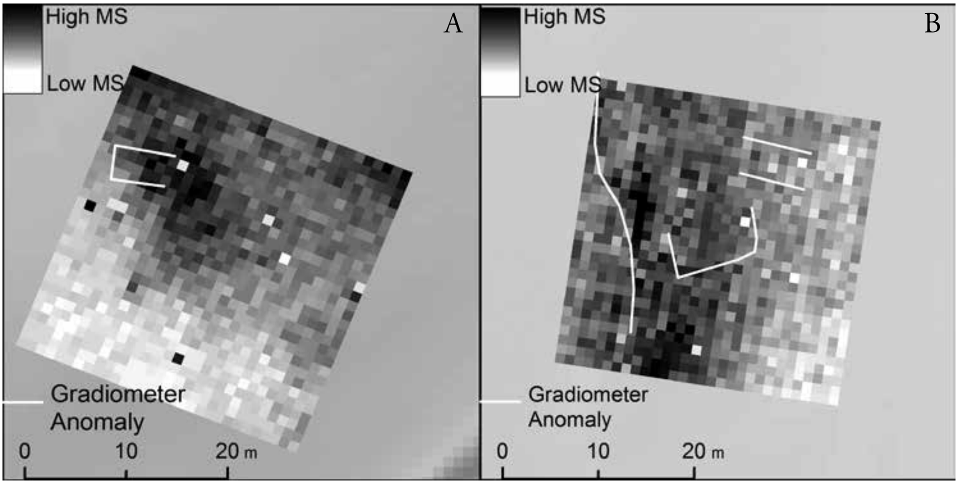

Fig. 3: Left (A), 1 m gridded survey over a gradiometer anomaly later excavated and shown to be an FBA hut, site T231. Right, (B), 1 m gridded survey over three gradiometer anomalies at site T219: a sinuous anomaly at west can be observed in the MS results, but not so the two rectangular anomalies under the northwestern part of the survey

The same mixed picture derives from gradiometer data on our sites. Very strong anomalies of varying rectangular forms have been registered throughout the foothill zone in the study region. These rectangular buildings, dated from the Late Bronze Age, exhibit very strong magnetic gradients, suggesting a thermoremnant component to the signal (Armstrong *et al.* 2012). The 1 m to 2 m resolution detailed MS surface occasionally shows an increase in the immediate location of these buildings (Fig. 3: A), but not always (Fig. 3: B), and furthermore, there is generally no wider 'halo' of magnetic enhancement that can be detected reliably with broader scale measurements (see Fig. 2). Indeed, the sites that the 'dense transect' method succeeded in identifying did not contain these rectangular structures as gradiometer anomalies. Forward modelling work has been implemented in order to examine the relationships between magnetic susceptibilities (of archaeological features and contexts, and surrounding natural soils) and the anomalies that they generate (Schmidt *et al.* 2014) to better understand the processes operating here.

Returning to our research goals, we still do not have a useable site-detection methodology. This is an interesting outcome, because it overturns a widely-held assumption in archaeological geophysics that most archaeological (habitation) sites, on most soils, will produce a detectable MS enhancement. We can, however, place our sites within their landscape context, in magnetic terms, and so make comparisons across different soil types. Our ongoing forward modelling research should help us to understand better the relationship between the MS properties, soils and gradiometer responses, but this is far from straightforward. Our studies suggests that new, fundamental research is needed into MS variations, soil properties and archaeological sites: we have opened Pandora's box, but have shown hopefully that a careful examination of these issues leads to new insights as much as new questions.

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Geophysical studies of Djankent fortress in the eastern Aral sea region (Kazakhstan)

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KEY-WORDS: geophysics, electrical tomography, magnetic survey, burial mounds

INTRODUCTION

The site of Djankent is located about 25 km south-west of the modern town of Kazaly (Russian Kazalinsk). It is one of three known 'marsh towns' in the delta of the ancient Jaxartes (today's Syr-Darya) river east of the Aral Sea. In Kazakhstan, the 'marsh towns' play a key role in research and debate on the origins of the Turkic Oguz state in the 9th/10th centuries AD and the concurrent emergence of a distinct Kazakh ethnos (Rusinova *et al.* 2009).

The 'marsh towns' show differences in layout and appearance, but there are strong similarities in archaeological find categories and their dating (particularly pottery from the upper levels, widely thought to be ethnically diagnostic). Research on these sites since the 1940s has led to a number of partly competing and partly complementary hypotheses on the origin and nature of 'marsh towns'.

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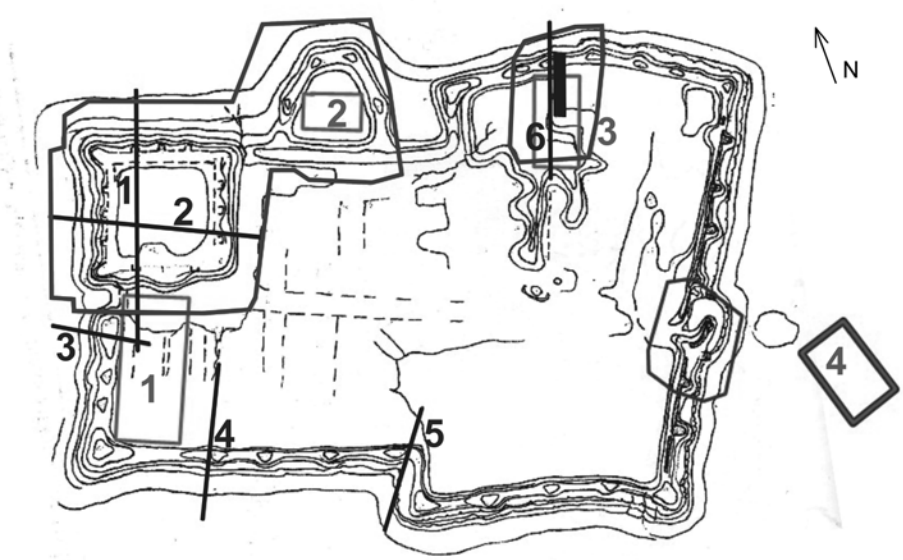

Fig. 1. Topographical map of the Djankent site and areas of geophysical investigations; lines – resistivity imaging profiles, polygons – magnetic survey

Djankent is a deserted site that has not been built over in later medieval and modern times. Its ramparts topped by clay walls rise up to 8 m from the dried-out delta of the Syr Darya, enclosing an area of some 16 ha. Elements of the layout are clearly visible in aerial photographs and on the ground: a broadly rectangular wall circuit given a T-shaped appearance by an eastern 'cross-bar'; a regular layout in the western half of the interior; a gate in the eastern wall; a separately enclosed 'citadel' in the northwestern corner, and a semicircular annex attached to the northern wall.

The study of states, heirs to the Turkic Khaganate of the early Middle Ages, is an important and challenging task with archaeological research playing a key role in the face of an absence of written records. However, sites and fortresses are huge and would require extensive excavation in order to determine effectively the general structure and planning of the given sitesand and reconstruct their paleogegraphy. Moreover, the need to conserve exposed mud-brick walls in conditions of adverse humidity and to assure maintenance care is a deterrent to archaeological excavations. The situation is thus conducive to integrated geophysical surveys in the early medieval Turkic fortresses and the paper examines the possibilities based on experience in the investigation of the Djankent fortress.

GEOPHYSICAL INVESTIGATIONS

Much less than 1% of the total area of the site has been covered by archeological excavations and nowhere has a culturally sterile layer been identified with certainty. The main goals of the Djankent fortress investigation were thus: identifying the structure and origin (natural or

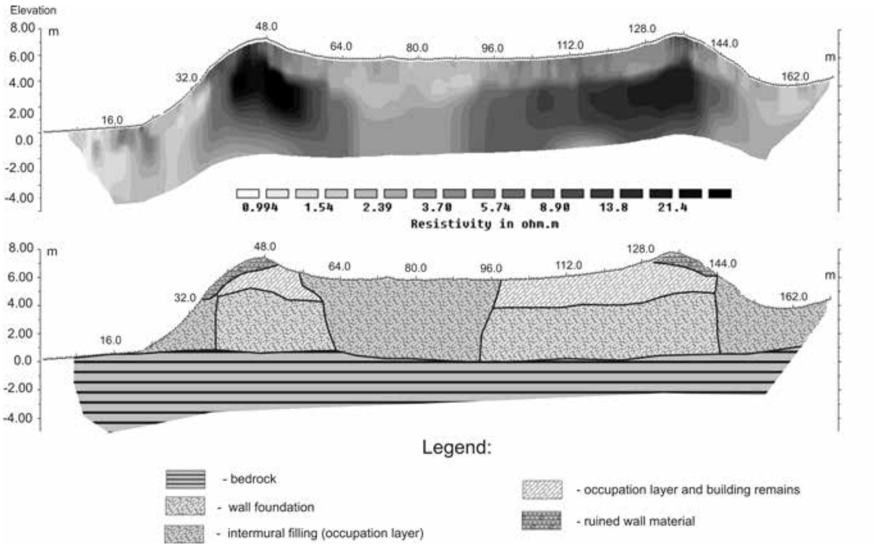

Fig. 2. Profile 2 through the citadel. Geoelectrical cross-section (resistivity imaging as a result of 2D inversion)

anthropic) of the mound, on which the fortress is situated, and the study of several districts of the site, the function of which are not yet clear. Electrical (resistivity imaging) and magnetic surveys were carried out for the purpose.

The results of resistivity imaging enabled several new and important conclusions concerning the Djankent fortress (Fig. 2). Firstly, it can be said with a high level of confidence that the rise, on which the fortress is situated, was anthropic in origin. Huge quantities of soil were transported to the site during the construction of the fortress. From where the soil came from is another question altogether, perhaps for another project in the future, but it was certainly not produced anywhere in the close vicinity because of differences in resistivity. Secondly, it has been established that the fortress walls were raised on built "platforms". This building mode is known from the period, but has been confirmed for Djankent for the first time. Thirdly, further archaeological investigations are necessary to explain the evident difference in resistivity of the soil surrounding the "platforms".

The main result of the magnetic survey was a plan of the structure (Fig. 3); here, a total magnetic field map for one of the investigated blocks has been superimposed on a topographic map of the site made in 1963, when it was still possible to trace some of the streets on the ground. These were now used to facilitate the orientation and interpretation of the magnetic data, because they are reflected on the map with negative magnetic field anomalies characterized by amplitudes of less than 7 nT. Some of them correspond to the structures shown in the topographic map.

On the grounds of the magnetic survey data, it can be said that the investigated area (Fig. 3) was divided into several "blocks" approximately 40 m by 40 m and each block consisted of four yards. This is attested not only by a system of linear negative anomalies, which correspond to the streets, but also by aggregated local anomalies typical of furnaces.

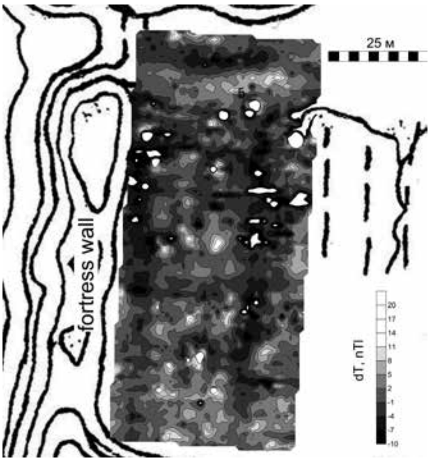

Fig. 3. Area 1: magnetic field and topographical map, tracing streets and furnaces

CONCLUSIONS

The results of geophysical investigation of two large early medieval Turkic fortresses have provided fundamentally new information about their structure. The main conclusion concerns the applicability of geophysical investigation methods for the investigation of sites where mud brick was used as a building material, mud brick having physical properties close to the physical properties of the culturally sterile layer around it. The research has broadened the positive experience of similar investigations, for example, in the territory of the ancient Egyptian capital of Memphis (Belova *et al.* 2005) and at the Uigur fortress Por-Bajin in the Tyva region of Russia (Arzhantseva *et al.* 2009).

At the present time, large-scale excavation of vast sites is impracticable in Turkic archaeology, making geophysical methods of investigation the most optimal way of quickly obtaining reliable information on site plans, thickness of occupation layer and on paleography

ACKNOWLEDGEMENTS

Geophysical investigations of Djankent fortress in 2011 were carried out with financial support from the Wener-Gren Foundation (USA) and the RFBR (Russia) (N° 14-06-00348 "Cultural layer as an information system: an interdisciplinary study of the early medieval settlements of Eurasia", CSRP Irina Arzhantseva). We express special thanks to the organizers of the archaeological investigations, Dr. Heinrich Härke (Tübingen University) and Azilhan Tadjikeev (Kyzyl-Orda University).

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Integrated prospection methods for documenting threatened prehistoric archaeological sites from north-eastern Romania

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KEY-WORDS: archaeological prospection, risk management, prehistoric sites, Cucuteni culture, north-eastern Romania

INTRODUCTION AND OBJECTIVES

Available archaeological registries reveal an extremely high density of (not only) prehistoric sites in the north-eastern part of Romania. In this context, our field investigations conducted in several microzones of this area focused on identifying on the ground and accurately charting the sites (Brigand *et al.* 2012; 2014 a; Brigand *et al.* 2014 b) listed in older or newer archaeological registries, but accompanied only by brief and laconic descriptions, or no longer corresponding to current realities. Another aim was to monitor closely the state of these monuments by means of non-invasive techniques (Romanescu *et al.* 2012; Romanescu and Nicu 2014), and to collect as much information as possible on the most threatened ones (Asăndulesei *et al.* 2012; Asăndulesei 2013; 2014a; 2014b; Caliniuc and Nicu 2015). Most of them, particularly the prehistoric ones, either already known or newly identified, were found to be threatened directly by natural or anthropic factors.

The paper focuses on the integrated use of oblique air photography, cartography, topographic survey, 3D laser scanning, caesium magnetometry, electrical resistance, and GPR methods for the investigation and monitoring of the prehistoric sites Costești–Cier and Filiași–Dealul Mare, and makes a case for generalising such practices in archaeological research, particularly in the north-eastern area of Romania. Apart from elements of archaeological interest, the study takes into account the component of landscape evolution with regards to the identification, evaluation and impact of natural and anthropic risks affecting the two sites.

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RESEARCH AREA AND CASE STUDIES

The microzone containing the two case-study sites comprises the Bahlueț catchment basin, part of the Lower Jijia and Bahlui plain constituting the southern half of the Moldavian Plain.

The first case-study site is Costești–Cier (Iași County), a site on the upper course of the Bahlueț River (approx. 10 km from the source), well known to the Romanian archaeological community. Previous studies, some carried out during the interwar period, unearthed rich material from the Chalcolithic (Cucuteni A_3, $A–B_2/B_1$ phases), transition to the Bronze Age (Horodiștea-Erbiceni II) and early medieval (8th–9th/10th centuries) habitation levels, as well as two necropolises, one Horodiștea-Erbiceni II and the other medieval (Boghian *et al.* 2013).

The second case study is represented by the archaeological site of Filiași–Dealul Mare (Bălțați commune, Iași County). Located on a promontory that dominates its surroundings, this site yielded abundant evidence of Cucuteni A_3 habitation, in the form of pottery, anthropomorphic plastic art and lithic materials. The settlement was investigated in 1935 by fieldwalking and trial pits carried out by O. Tafrali, V. Manoliu and E. Condurachi.

METHODOLOGY

Work consisted of several successive stages, starting with the existing documentation, during which archaeological registries and specialised works treating on the two sites were consulted. Precise information was ascertained: exact location, limits of the areas of interest, and geomorphological characteristics of the areas occupied. An interdisciplinary approach was employed, based on complementary non-destructive prospecting. The most expeditious and convenient methods (in terms of logistics and financial affordability) were surface research (fieldwalking) — which provided the necessary data for a chronological setting — and air photography (Asăndulesei 2014b). Further input came from geophysical surveys and terrestrial 3D laser scanning, which enlarged the body of available information on the buried vestiges (Romanescu *et al.* 2012; Romanescu and Nicu 2014).

RESULTS AND DISCUSSIONS

Costești–Cier archaeological site

The cartographic analysis of several types of topographic maps and orthorectified imagery at various scales/resolutions and from different time periods highlighted the rapid erosion of this site. At the moment of speaking, more than half of the original site has been destroyed.

The detailed topographic survey augmented by the 3D scan (for the inaccessible sectors of the site) generated a digital elevation model at 0.5 m/pixel resolution, on the basis of which several interpretations were drawn concerning the original size of the site and the landform on which the site is located and its hydrogeomorphological characteristics.

The approximate trajectories of Bahlueț's ancient courses in this area were easily traced. Sometime in the past one of these riverbeds bordered the site along its south-western and southern margins; in another period the stream ran along the northern side, aligned NW–SE. The inhabitants made the most of the latter situation, building a fortification system that took advantage

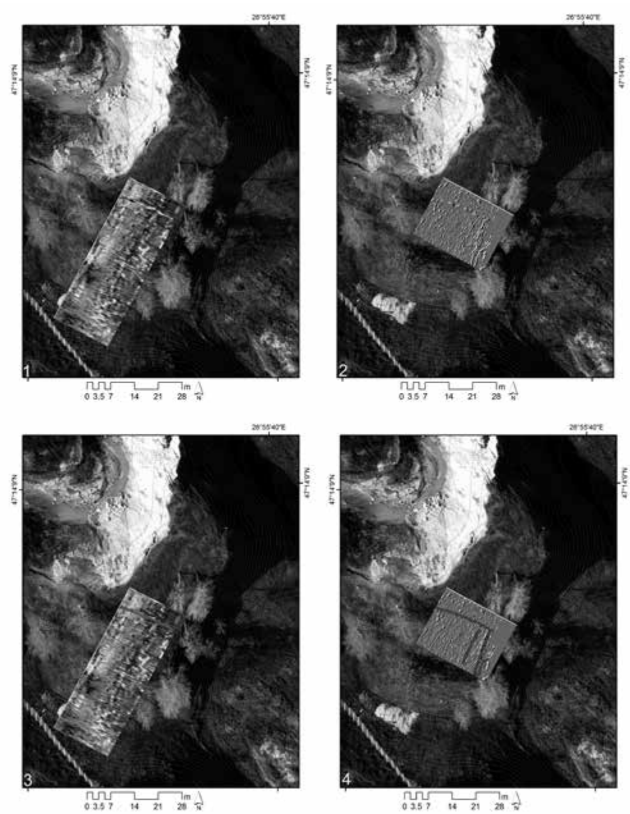

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Fig. 1. GPR interpretation of the archaeological site Costești–Cier

of the ancient riverbed. Moreover, they dug a semicircular defence ditch to protect the entire southern flank of the site. This ditch is observable in both the topographic and GPR surveys, and in the aerial photographs. The advantageous position of the site is also evinced from the steep slopes of the terrain, with values up to 36°.

The analysis of over 30 aerial photographs of the Bahluieț valley revealed several aspects that backed our initiative to prepare an ampler characterisation of the archaeological site at Costești. An analysis of detailed images of the site identified large positive or negative anomalies. Noteworthy is the semicircular defence ditch on the south-western side of the site. Three further linear anomalies were identified in the upper part of the site, two of which formed a right angle, probably stone structures from an old church attested here (Boghian *et al.* 2013).

Georadar surveying was the last non-destructive research method employed at this site. Though the terrain is not ideal for this type of measurements, the results were satisfactory nonetheless. The area was heavily disturbed by tree roots and by sandstone boulders carried by the landslide, visible at the eroded end of the site. Several types of anomalies, of various

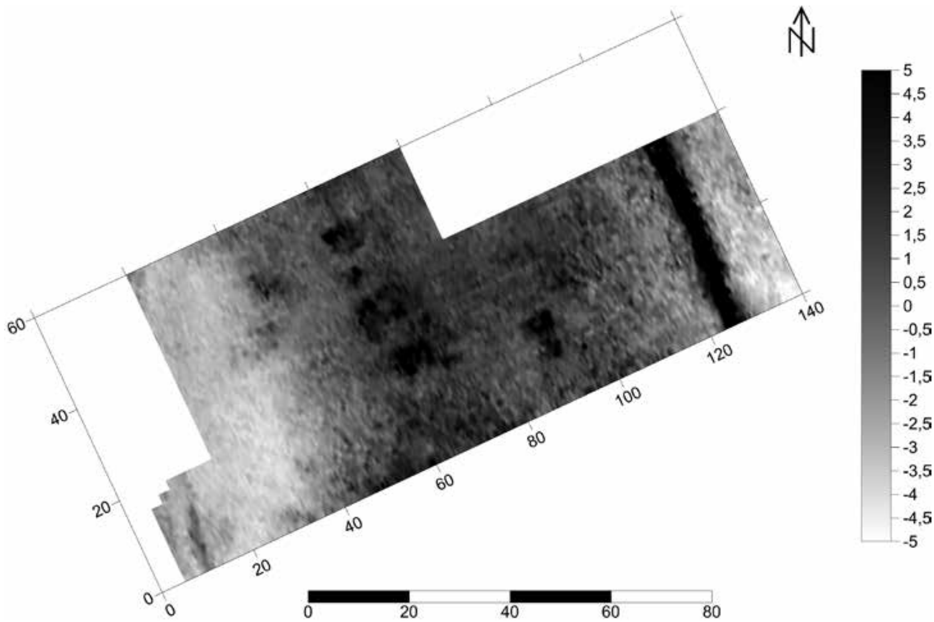

Fig. 2. Resistivity map of the archaeological site of Filiași–Dealul Mare (-5/+5 ohms, white to black)

sizes, were pinpointed after analysing both the vertical GPR profiles and the time slices. The linear or curvilinear anomalies, interpreted conjointly with other results, may be considered archaeologically relevant. The linear structures are probably stone walls and the defence ditch, which should be identified with the marks visible in the aerial images (Fig. 1).

Filiași–Dealul Mare archaeological site

The non-invasive investigation of the second case-study site relied on archaeological topography, aerial photography, soil resistivity measurements, and caesium-vapours magnetometry. The results confirm, on the one hand, the importance of this site, and, on the other, highlight the precarious state in which it is found.

Thus, the Cucutenian settlement Dealul Mare, for which a positive anomaly was identified (a fortification, noteworthy for this period), is threatened by landslides on its northern, eastern and western sides. The site itself has not been affected yet, but immediate intervention is necessary to stop this erosional process from causing more damage. Of greater concern is recent anthropic destruction caused by an open clay quarry inside the perimeters of the site, in the north-eastern corner. The presence of trenches, probably from World War II, fortunately only in the proximity and not crossing the site, contributed to the expansion of the erosion scar.

The soil electrical resistivity measurements revealed the presence of several positive anomalies (Fig. 2), somewhat rectangular, of various sizes. Two linear anomalies with the same polarity can further be observed on the limits of the promontory, connected with a putative fortification system also identified in the air images and magnetometric maps (Fig. 3).

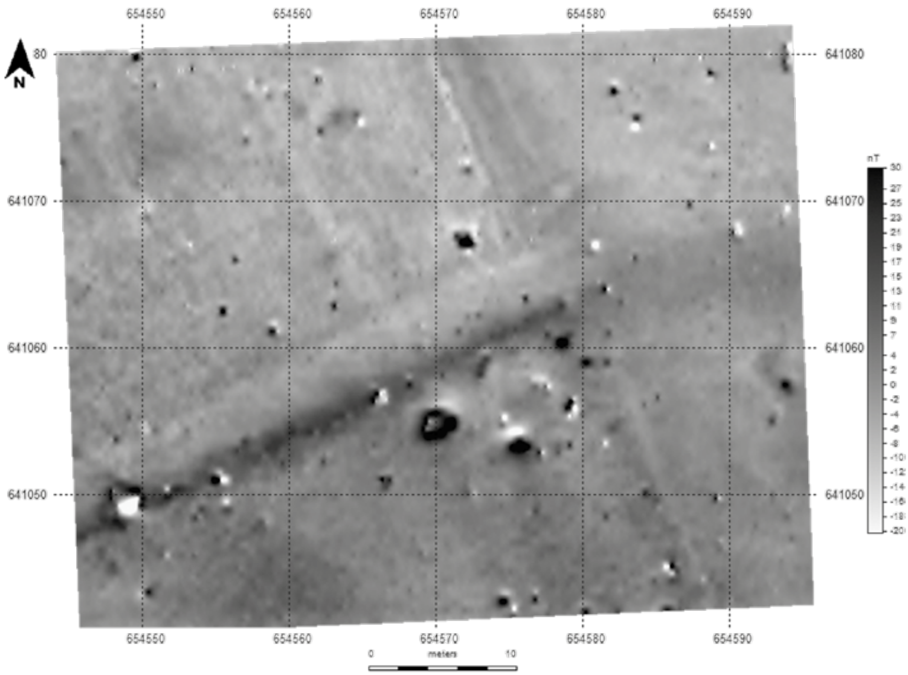

Fig. 3. Magnetic map of the archaeological site of Filiași–Dealul Mare archaeological site (-20/+30 nT, white to black)

CONCLUSIONS

Strict adherence to the methodology imposed at the onset of the research resulted in full achievement of all the set goals, that is, identification and analysis of the archaeological evidence, and assessment of the damage sustained by the sites and the rate of advancement of active hydro-geomorphological processes. The archaeological characteristics identified, foremost regarding planimetry, fortifications and boundaries, will be used to develop coherent plans for mitigating or systematic intervention in the two case-study sites.

ACKNOWLEDGEMENTS

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Geophysical survey at Žitný ostrov, Slovakia, in 2012–2013

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KEY-WORDS: South Slovakia, Žitný ostrov, Arcland Culture 2000, geophysical survey

As part of the Arcland Culture 2000 project focused on mapping of the archaeological landscape of Žitný ostrov, seven archaeological sites were chosen for geophysical research in 2012–13: Dunajská

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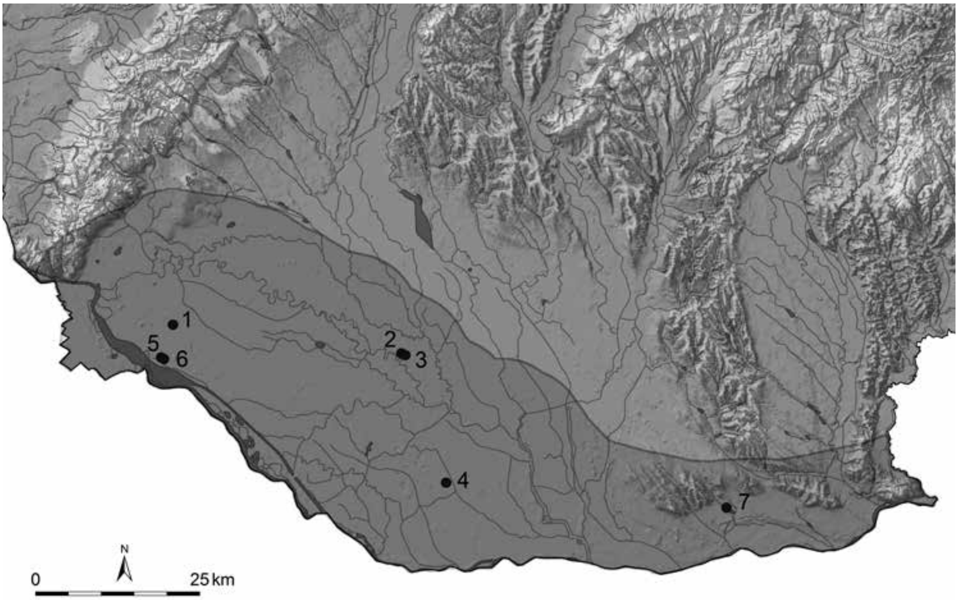

Fig. 1. Žitný ostrov area in the south of Slovakia with marked locations of geophysical surveys: 1. Dunajská Lužná, 2. Jahodná, 3. Tomášokovo, 4. Sokolce, 5. Hamuliakovo, 6. Šamorín, 7. Bátorove Kosihy

Lužná, Jahodná, Tomášikovo, Sokolce, Hamuliakovo, Šamorín and Bátorove Kosihy (Fig. 1). The locations were selected on the basis of an aerial survey of the area conducted by I. Kuzma, J. Rajtár and M. Bartík (Kuzma 2005; 2006). The geophysical prospection was executed with a Sensys fluxgate magnetometer. Five probes, placed 10 cm above the ground and 25 cm from one another, were used for measuring. Free MagPick (Germany) and Surfer 6 software were used for data evaluation.

Within the municipal boundaries of Dunajská Lužná, at the site of Svoradské, a number of circular and square features were recognized. The actual size of the geophysically measured area was 50 m by 150 m. Traces of a modern road and remains of features that could be parts of a settlement can be seen on the map of magnetic anomalies. Roman-age pottery finds were collected from the surface. Within the municipal boundaries of Jahodná, at the site of Družstevné, aerial images showed the outlines of groups of long houses. Aerial and field surveys together with surface artifact collection covered 50 m by 50 m. Outlines of three long houses, identified in the air shots, can also be traced on the magnetic map. Their approximate size is 15 m x 6 m and they resemble Eneolithic structures in type. The deeper-lying bedrock was sandy or pebbly. In Tomášikovo, at the site of Pukliny, groups of long houses identified in aerial images were traced in a magnetic map of an area 50 m by 50 m, which was also fieldwalked. The bedrock here consisted of pebbles.

At the Sokolce Pod záhradami site geophysical measuring and field survey were conducted in an area of 100 m by 100 m. The aerial images revealed a circular feature of unknown function and age. Three types of magnetic anomalies were traced. Firstly, linear magnetic anomalies indi-

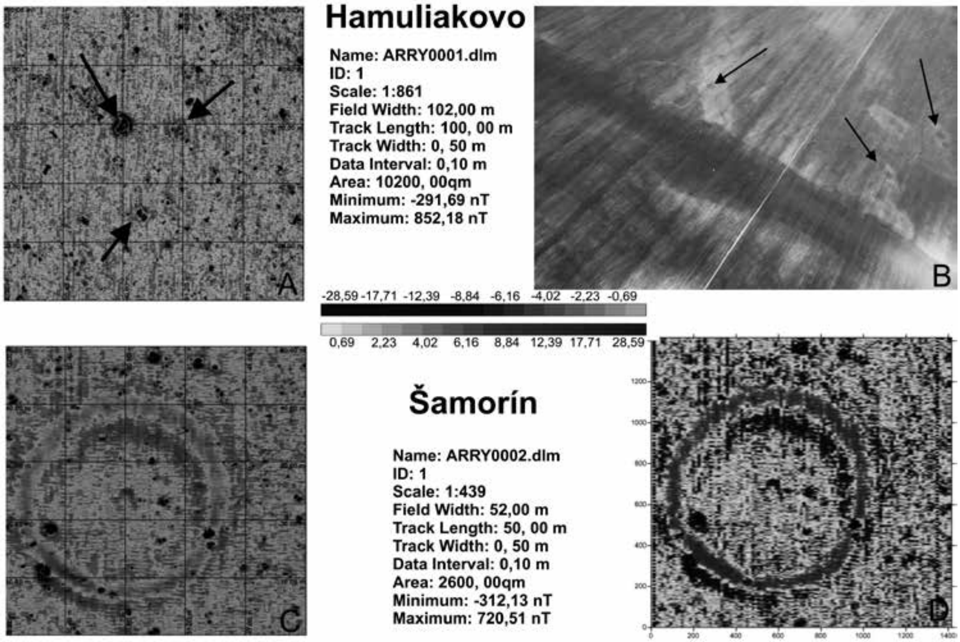

Fig. 2. Magnetic maps: A – late Roman settlement at Hamuliakovo (MagPick software with interpretation); B – Iron Age mound at Šamorín (MagPick and Surfer software)

cating linear archaeological structures, such as ditches and trenches, with values from -2 to 2 nT. Secondly, symmetrical magnetic anomalies most probably indicating archaeological features, reaching values from -4 to 4 nT. Finally, magnetic anomalies indicating recent iron artifacts, reaching values from -679 to -400 nT. Only probable archaeological features were highlighted in the interpretation. The circular feature was presumably a small circular fort (18 m in diameter) with a ditch (40 m in diameter). It might have been one of the towers built in the 16th and 17th century to withstand attacks of the Ottoman Turks.

A geophysical prospection of the site of Dolné in Hamuliakovo was carried out over an area of 100 m x 100 m, selected based on a metal detector survey. Metal finds, but also pottery from the Roman period were concentrated in the area. Anomalies corresponding to remains of settlement features were traced on the magnetic map. They are symmetrical, square or rectangular magnetic anomalies with values from -4 to 4 nT. Another group of anomalies reflected recent iron artifacts with values from -679 to -400 nT (Fig. 2:A). A group of Germanic residential buildings arranged in a circle and farm buildings were identified in the middle of the investigated area, visible also in Google Earth satellite photos. A field survey is needed to identify the actual function of the features. A surface collection of artifacts confirmed a date for the settlement in the Late Roman period (3rd–4th century AD).

At Šamorín, a geophysical survey and field survey were carried out at the site of Hamuliakovské (area of 50 m by 50 m). A circular feature with unclear function was identified in aerial

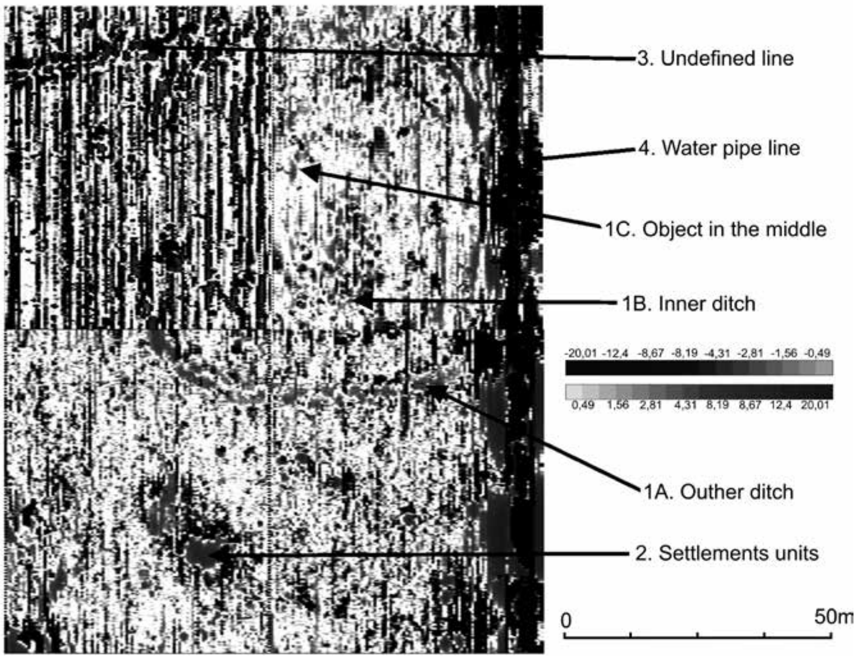

Fig. 3. Magnetic map of a small medieval fortification at Bátorové Kosihy (MagPick software with interpretation)

images. Magnetic anomalies varied from -312 nT to 720 nT. It is presumably a circular mound with a diameter of 30 m and a perimeter ditch (Fig. 2:B). The feature will be dated only once a field archaeological survey is carried out.

The archaeological investigation in Bátorové Kosihy, at the site of Fenyér, was carried out over an area of approximately 1.2 ha (100 m x 120 m). Aerial images were compared with old military maps. A circular feature with several ditches is marked on the first military map. The investigated area featured sandy terrain. Four different types of local magnetic anomalies were observed on the final map: linear anomalies indicating the course of linear archaeological structures, such as ditches and trenches (Fig. 3: anomalies 1A, 1B, 1C) with values from -2 to 4 nT; symmetrical anomalies, most probably indicating archaeological features with values from -4 to 9 nT (Fig. 3: anomaly 2); linear anomalies corresponding to the course of utilities with values from -4 to 7 nT (Fig. 3: anomaly 3); a linear magnetic anomaly with high values (-405 to 575 nT) indicating a high-pressure gas pipeline (Fig. 3: anomaly 4). The potential archaeological site is a small fortified feature with three identifiable lines of defences. The widest line (anomaly 1A) is up to 2 m wide with an overall diameter of 70 m. The second line (anomaly 1B) shows a diameter of 40 m. The third and smallest line (anomaly 1C) is 1.0–1.5 m wide and lines a quadrant with a diameter of 20 m. The surface material is highly fragmented medieval pottery from the high period, that is, from the 12th and 13th centuries.

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Archaeological prospection in Serakhs oasis in Turkmenistan

Miron Bogacki[a], Barbara Kaim[a], Wiesław Małkowski[a] and Krzysztof Misiewicz[a]

KEY-WORDS: Turkmenistan, Serakhs, non-invasive survey

Non-invasive surveys in Serakhs oasis in Turkmenistan were carried out within the frame of the "Landscape of Serakhs oasis settlement during the Sassanid period „project financed from Grant No. 203640 of the National Science Centre of Poland. The project aims to reconstruct the archaeological landscape of the oasis at a time when the area was part of the Sassanid Empire (3rd–7th century AD) and to do this it has envisaged comprehensive studies of settlement patterns and collections of ceramic and building materials, as well as frequent coins in order to determine the chronology of the located sites, isolating those with Sassanid-age relevance. Remains of fortified residences of the local landowners can be assumed to be present at most of the sites. Moreover, one can assume the existence of a relationship between the size of the house and its location (in relation to the main irrigation canals), and the status of the owner, to be confirmed by the results of research on individual sites. This research should be based on settlement studies related to the archaeological landscape.

The non-invasive surveys presented in this paper were the preliminary step to identify different architectural structures at the sites. Site selection was determined by the criterion of no archaeological evidence connecting a site with the Muslim period.

Aerial images were obtained with kites and the geophysical survey was carried out using a G858 Magmapper caesium magnetometer. The magnetometer, with two sensors set horizontally (0.5 or 1 m apart) recorded values of the Earth's total magnetic field at 0.125 m intervals along profiles set 0.5 or 1 m apart (depending on the size of sites and expected dimensions of archaeological remains). The pseudo-gradient of the horizontal component of the total vector of the magnetic field was calculated in order to assist in identifying anomalies caused by modern metal artifacts on the surface or at shallow depths. Fieldwork was carried out on six sites, the total area being more than 5 ha, located in a part of the oasis that had not been surveyed archaeologically before.

Aerial images were the first step in the process of documenting the selected sites (Fig. 1). For this purpose a flow-form kite (self-inflating without rigid reinforcing) with a bearing surface of

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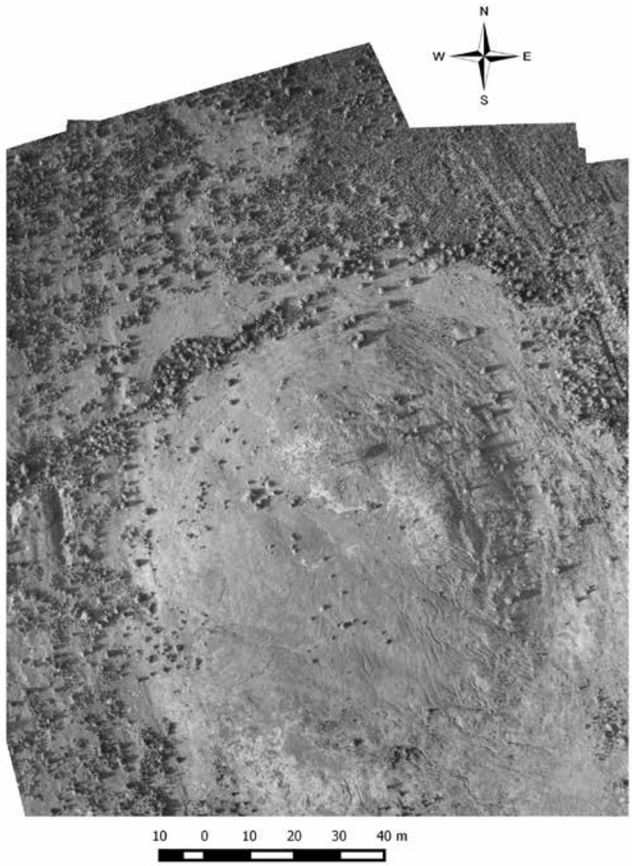

Fig. 1. Orthophotomap of the site Nazar Depe. (scale 1:500)

9-12 m^2 (depending on the strength and direction of wind) was used. These kites allow lifting Canon 5d mk2 camera with 24 mm and f 2.8 lens. The photographer could monitor the camera view via remote control console. Wireless transmission of data to the console also allowed precise control of the geographical location and determination of the altitude of the camera (with an accuracy of 2 m). The mounting of the camera made it possible to take both vertical and oblique photographs. However, defects in optical lenses and perspective deviations do not make the images suitable for obtaining distances directly. Therefore, photographs were processed with photogrammetric software into orthophotomaps and digital terrain models. Models textured with vertical images were recorded in digital form using, among others, standard 3D file format such as VRML or OBJ, but also as an xyz points cloud. Basic orthophotomaps were prepared as standard GeoTiffs, enabling processing and analysis with different compatible GIS software.

Topographic measurements were taken using a RTK GPS system (Fig. 2). Operating RTK (real time kinematic measurements) mode determines the position of the measured points with an accu-

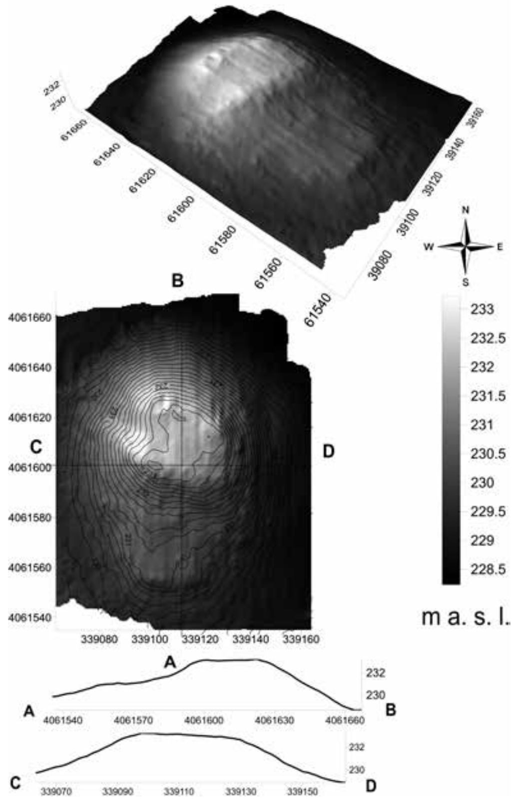

Fig. 2. Site Nazar Depe. Topographical documentation: digital elevation model (top), map of the layers (middle) and cross-sections (bottom)

racy of +/- 3cm (x, y, z). This allows topographic (but also magnetic) surveying without the support of other systems such as orthogonal grids or tape measures when combined with the visualization of the path of travel. The results of topographic measurements were also used for the preparation of orthophotomaps and 3D models of surface microrelief on the surveyed sites. Linking data from magnetic prospection with information about the surface relief not only provided an improved basis for locating archaeological remains, but also allowed a reconstruction of formation leading to a preliminary determination of the depth of features causing the magnetic anomalies.

The recorded total vector value of the magnetic field was in the range of several to tens of nT, the overall range being 49750–49950 nT (Fig. 3). Values depend not only on the state of preservation of the archaeological remains causing anomalies and location of the sites in relation to modern irrigation systems (wells and canals), but also on military installations. The archaeological interpretation could easily discount the latter changes. Remains of outer walls appear to be present on all of the surveyed sites. They are represented by narrow linear anomalies with regular, usually rectangular shapes, identified as internal structural elements. Strong dipolar anomalies on the magnetic maps

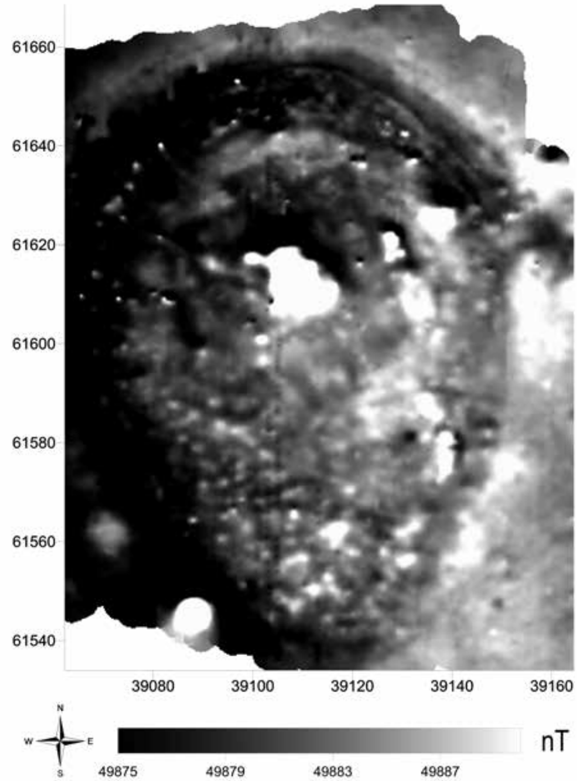

Fig. 3. Nazar Depe. Magnetic survey. Map of changes of intensity of the Earth's magnetic field in the range 49870-49900 nT

are the result of remanence magnetization of heavily burnt features. It is difficult to recognize the sources of such anomalies: they could be caused either by the presence of burnt objects (structures of red brick, furnaces, hearths) or by modern metal artifacts on the surface. Other possible sources include bonfires, usually on the highest points on any given site; it should be kept in mind that goat and sheep herding is a common occupation in Serakhs oasis.

The nature of the anomalies depends also on the state of preservation of the remains. Many features were destroyed already in antiquity and post-depositional processes, such as wind and water erosion on the slopes, would have caused further damages. Wherever Muslim pottery was observed on the surface, one needs to consider a phased stratigraphy as an explanation for the magnetic anomalies.

Naturally, stratigraphy cannot be established based only on the result of non-invasive research and it is even less possible to determine the dating of preserved remains. Potsherds collected from the surface may be helpful in identifying later phases, but the most appropriate solution for a less ambiguous interpretation of data gained through non-invasive methods is to probe selected areas with traditional methods of archaeological excavation.

The Gokstad Viking Age trading site: a voyage of physicochemical prospection

Rebecca Cannell[a], Jan Bill[b], Paul Cheetham[a] and Kate Welham[a]

KEY-WORDS: geophysics, geochemistry, pXRF, Gokstad, Viking Age

Near-surface geophysics can now provide accurate, high resolution, three-dimensional interpretations of archaeological features beneath the topsoil. Rapid, large-scale surveys record complex, interconnecting sites and landscapes, but our interpretation is all too often limited without additional intrusive excavation to confirm the range of past activities, the phasing and dating of the sites, and the evidence of trade and connections to places near and far. To enhance geophysical interpretation, coring and geochemical prospection was combined with high-resolution GPR data on the site of Heimdalsjordet, located just 500 m from the contemporary Viking ship burial at Gokstad, Vestfold, Norway.

The site was recorded in detail using large-scale high-resolution ground penetrating radar (GPR) by ZAMG Archeo-Prospections in collaboration with the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro), the Vienna Institute for Archaeological Science (VIAS) in collaboration with the Norwegian Institute for Cultural Heritage Research (NIKU), with support from Vestfold Municipal County administration. The Gokstad Revitalised Project, a body which initiated the survey, is a research project managed by Prof. Jan Bill at the Museum of Cultural History, University of Oslo, aiming at setting the Gokstad ship burial in a social, cultural and landscape context. This research is part of the project, focused upon the proto-urban trading site of Heimdalsjordet.

The clearest settlement evidence on the site is in the form of parcel ditches, dug for drainage and to divide the land on either side of an east–west orientated thoroughfare. The site was truncated by ploughing, leaving the parcel ditch backfills as the prime source of information, alongside artifacts from a comprehensive topsoil survey. Guided by the GPR results, small scale excavation investigated several of the parcel ditches, as well and one of the several potential burials. Using a 5 cm ø corer, intact cores were taken from parcel ditches during the excavation. In order to expand the understanding of the site beyond the excavation boundaries, cores were taken from unexcavated parcel ditches, the core locations successfully guided by the geophysics data. Thus, the sampling and prospection method is designed to be minimally intrusive.

Geochemistry offers the opportunity to measure directly where an activity took place, and what was the source of the inorganic (and organic) traces in the soil, however the method is not without challenges with regard to interpreting complex and environmentally dependent chemical signatures. The method requires large sampling numbers and detailed understanding of the local soils to improve the quality of geochemical interpretation. Using portable X-ray

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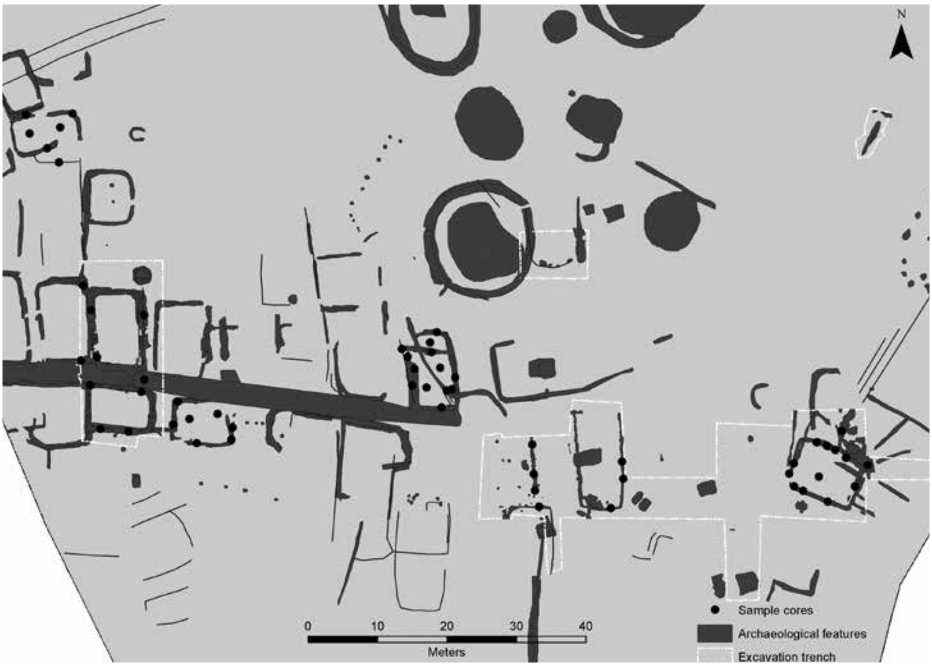

Fig. 1. Map detail of the Viking Age Heimdaljordet site near Gokstad, Vestfold, Norway. The archaeological features are based upon excavation results and interpretations by ZAMG Archeo-Prospections in collaboration with LBI ArchPro and the Gokstad Revitalised Project (MCH, UiO).
Locations of the sample cores for geochemical analysis have been marked

fluorescence (pXRF) for archaeological geochemistry offers an economic, flexible and rapid method for analysing soils, which allows for a reflexive sampling strategy and high sampling volume.

Therefore, after recording, each of the 30 cm long cores were analysed using pXRF at 2 cm intervals. This provided high-resolution geochemical analysis, which was then integrated with micromorphological, environmental, artefact and excavation data where relevant. The result is a better understanding of the potential and limitations of pXRF and geochemistry, and a detailed understanding of the use of space over time in what at first appears to be a highly structured zone within the site.

Applying the geochemical results, in conjunction with the other available data, clearly documents the increasing intensity and expansion of the use of the site over time, giving chronology to prospection data. It is also clear that the plots or parcels of land were used for specialist activities, such as non-ferrous and ferrous metal working, potentially with each plot having a different specialty. The suggestion that possibly contemporary plots were similarly structured, suggests either a degree of site use management or strong cultural and/or practical motives behind the spatial use of the plots. Whilst not all plots have been investigated, the study suggests there is great potential in the method of geophysically informed coring for enhancing geochemical prospection data and understanding better the use of space in past settlements.

Integrated geophysical and in-situ soil geochemical survey at Dromolaxia-Vizakia (Hala Sultan Tekke, Cyprus)

Carmen Cuenca-Garcia[a], Apostolos Sarris[a], Christina Makarona[b], Andreas Charalambos[c], Marina Faka[d], Iosif Hafez[d], Sorin Hermon[d], Vasiliki Kassianidou[c] and Karin Nys[b]

KEY-WORDS: geophysical survey, geochemical survey, in-situ pXRF, archaeological prospection, Cypriot Late Bronze Age

INTRODUCTION

The combination of geophysical and geochemical methods in archaeological prospection has the potential to enhance the information relating to buried archaeological features, as well as to develop a better understanding of how the setting of a site may affect geophysical and geochemical datasets (Cuenca-García *et al.* 2013; Dirix *et al.* 2013). The nuanced data interpretation and technique reappraisal capabilities of this integrated approach are based on the complementary information provided by these two disciplines. In spite of their potential, the requirements of multi-disciplinary teams as well as the lack of established, proven and integrated survey strategies are some of the reasons why these studies are not frequent in archaeological prospection.

This presentation will show the results of a combined survey using non-destructive geophysical methods and minimally-invasive soil chemical survey carried out at the site of Dromolaxia-Vyzakia between 27 October and 7 November 2014. The fieldwork was undertaken by a multi-disciplinary team integrated by researchers from the University of Cyprus, the STARLAB Project (STARC- The Cyprus Institute), GeoSat ReSeArch Lab (IMS-FORTH, Greece) and the Vrije Universiteit Brussel.

The aims of the investigation were twofold. Firstly, to map and characterise possible buried archaeological features and activity areas beyond the excavated areas, as well as to assess the extent of the site in several directions. Secondly, and from a more methodological perspective, to assess the performance of the geophysical and geochemical techniques and strategies used at the site, with particular attention on the use of *in situ* soil chemical analysis.

THE SITE

Dromolaxia-Vyzakia is located immediately west of Hala Sultan Tekke, a mosque situated on the west bank of Larnaca's Salt Lake (Fig. 1). The site was a busy industrial harbour town and is considered one of the major coastal trading centres of Cyprus during the Late Bronze

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Fig.1. Location of the site and the excavated areas

Age. The site has been explored since the late 19th century (British and Swedish archaeological missions, Cypriot rescue excavations and Belgian post-excavation research related to the Swedish 20th century excavation campaigns) (Fig. 1). The remarkable number of finds retrieved is proof of the diverse and long-distance commercial activities developed at the site. The excavations exposed a series of workshop structures and habitation quarters. However, the overall structural organization of the settlement and its full extent remain unknown.

METHODS AND SURVEY STRATEGY

Geophysical survey

Following previous experience at the site (Trinks *et al.* 2013; Cuenca-García *et al.* 2014), the techniques used for the geophysical survey were magnetometry and a ground-penetrating radar using the geophysical equipment pool of the STARLAB Project (Fig. 2). First of all, an extensive magnetometer survey was carried out using a dual Bartington Grad601. In order to clarify some of the magnetic anomalies, targeted GPR surveys were performed in specific areas of the extensive magnetometer survey using a single channel MALÅ ProEx system (250 and 500 MHz antennae).

In situ multi-element measurements and soil sampling

Parallel to the GPR survey, multi-element soil measurements were performed in the same area covered by the magnetometer survey and along two single lines across the main known settlement. The instruments used were two hand-held XRFs (or pXRF): InnovX Delta from the University of Cyprus and Bruker Tracer IV from the Vrije Universiteit Brussel (Fig. 2). The measurements were taken directly on the fresh exposed soil and after removing the first ~20 cm of sandy topsoil. Magnetic anomalies of interest were also targeted for soil analysis using a sand-

Fig. 2. Geophysical and geochemical instruments used during the fieldwork

type Edelman auger with bayonet connection by Eijkelkamp. Further measurements were taken in areas outside of the main settlement and at different depths to act as controls. During the survey, Cu and Fe and a standard sample were used as cross-validation between the instruments.

Lab-based soil analysis

After the *in situ* measurements, small bulk soil samples were taken, dried and measured in the lab using a higher accuracy μ-XRF Bruker ARTAX 200 (STARLAB Project). Some of the samples were also re-analysed in a controlled lab-environment, using the same pXRF instruments. The purpose of these lab measurements was to compare on-the-spot and lab results to assess the use of *in situ* soil pXRF measurements. The soil samples were also analysed for lab-based soil magnetic susceptibility.

RESULTS

The results of the geophysical surveys revealed weak magnetic anomalies possibly associated with the location of structures projecting southeast of the excavated area. A concentration of strong magnetic anomalies (> 100 nT) was also detected around this area (Fig. 3). These may be linked to activities undertaken at the site. The survey also detected undocumented archaeological trenches, showing areas that have already been explored by former archaeological expeditions. The preliminary results of the geochemical survey have identified patterns in the concentration of

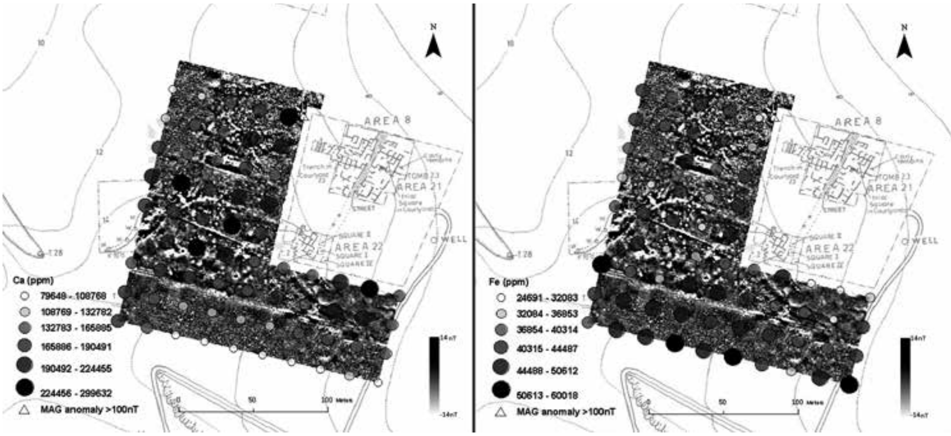

Fig. 3. Some preliminary results of the geophysical and geochemical surveys

some elements (Fig. 3). Some of these enhancements are associated with the location of the site, with particular magnetic anomalies and others suggested to be of geogenic origin. The comparison between the three XRF instruments used in this investigation showed a good correlation. Whilst some elements showed some differences in the total counts, the deviations were within accepted limits and the general concentration patterns matched fairly well.

CONCLUSIONS

As an overall outcome of the fieldwork and ongoing analysis, the combination of routine geophysical techniques and *in situ* pXRF chemical analysis have demonstrated rapid, significant and complementary proxy information relating to the buried archaeology of the area.

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Integrated geophysical investigations at Šapinuva, a Hittite city in central Anatolia, Turkey

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KEY-WORDS: ERT, GPR, integrated approach, MASWT, magnetic gradiometry, SRT, Šapinuva

INTRODUCTION

This paper presents integrated geophysical investigations carried out at the Šapinuva archaeological site, which was one of the important cities in the Hittite Empire. The objective was to explore the buried structures with a multi-method geophysical approach, applying the techniques of magnetic gradiometry, ground penetrating radar (GPR), electrical resistivity tomography (ERT), seismic refraction tomography (SRT) and multichannel analysis of surface waves tomography (MASWT). In the last two decades, integrated geophysical investigations, which maximize information on subsurface features, have been applied in near-surface geophysics increasingly often, especially in archaeological studies (Diamanti *et al.* 2005; Drahor 2006; 2011; Kvamme 2006; Piro *et al.* 2000; Papadopoulos *et al.* 2012; Vafidis *et al.* 2005). The aim of this approach is to obtain more reliable results and interpretations of the subsurface characteristics of areas investigated at archaeological sites, where the soil conditions are often complex. Important archaeological remains have been discovered at the Šapinuva archaeological site using the results of these integrated geophysical surveys.

ŠAPINUVA ARCHAEOLOGICAL SITE

Šapinuva was a religious, military and governmental Hittite city that had a relationship with the capital of the Hittite empire (Hattuşa). Recently, archaeological excavations have been carried out in two different areas: the city itself (Tepelerarası) and the sacred district (Ağılönü) (Süel 1995). However, Šapinuva is a problematic archaeological site for geophysical prospection. The city was affected by major earthquakes during Hittite times, creating a complex soil stratigraphy that would not be without effect on the results of geophysical surveys. Moreover, subsurface structures within the city were affected by an intense and extensive fire that may have left remains giving rise to confusing magnetic anomalies. In addition, the archaeological structures are extremely close to the surface in an area of intensive modern agricultural activity. The archaeological context has been affected by this activity and this may cause spurious and undesirable anomalies to come up in the geophysical surveys.

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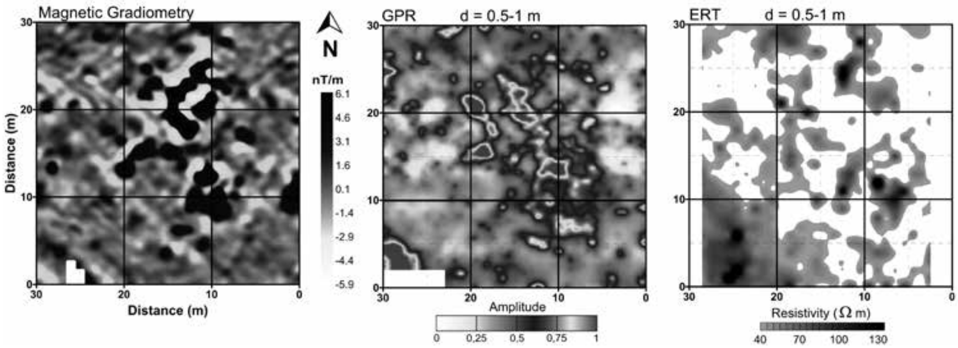

Fig. 1. Comparison of integrated geophysical results from the Tepelerarası area

RESULTS OF INTEGRATED SURVEYS

Ground-based integrated geophysical surveys at the Šapinuva archaeological site were carried out in two stages. Generally, data were processed with well-known data enhancement techniques. Gradiometric data were processed by standard correction and evaluation techniques, GPR data in conventional GPR processing stages; resistivity data were evaluated using a 2D inversion approach and the P wave tomographic velocity models were obtained by an iterative tomographic approach, using SeisImager/2D software. For the MASWT survey results, SeisImager/SW software was used for the processing in similar manner.

Geophysical surveys using magnetic, GPR and ERT techniques were performed in the Tepelerarası area of Šapinuva. Considering the comparative results of these techniques (shown in Fig. 1) one can see that the relationship between the results is very good in terms of anomaly localization. An important burnt archaeological structure is clearly seen in the magnetic image. Dark magnetic anomalies indicate the burnt mud-brick walls, while light anomalies are likely to indicate unfired archaeological structures and limestone material. Medium anomalies describe the soil covering the archaeological ruins. The magnetic image reveals important archaeological structures buried in the near-surface, oriented NE–SW and NW–SE, which is typical of Hittite layers excavated in the area. The GPR and ERT anomalies are of similar character and coincide for the most part with the magnetic anomalies. The high-reflection GPR anomalies in the depth slice between 0.5 and 1 m correlate with dark magnetic anomalies. These structures are likely to indicate shallow archaeological structures affected by agricultural activities. ERT results show that highly resistive anomalies are focused in a similar location. The ERT depth slice from 0.5 to 1 m reveals anomaly groups that are well correlated with the magnetic and GPR anomalies.

The magnetic image from the Ağılönü district was overlain with photographs from archaeological excavations (Fig. 2). It shows structures located at shallow depths, approximately 0.5 m below the surface. Important traces of burning were found in the archaeological context, together with earthquake 'footprints'. It was determined based on the archaeological results that the burnt zones corresponded to highly magnetic anomalies, while the unfired structures did not give distinguishable magnetic anomalies

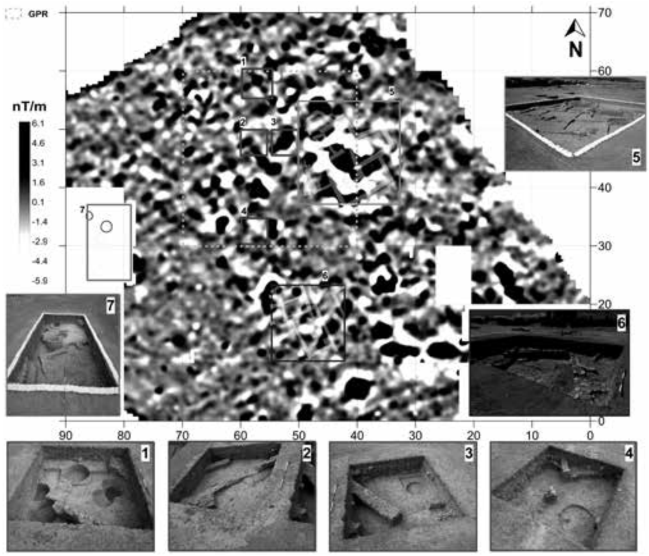

Fig. 2. Archaeological excavation results superimposed on a magnetic image of the Ağılönü area; 1–7 – views of archaeological structures excavated in 2013

Seismic refraction tomography (SRT) and multichannel analysis of surface wave tomography (MASWT) methods were applied alongside GPR, ERT and magnetometry in the Taşdöşem area of the Ağılönü site. In the magnetic data image of the Taşdöşem, three important anomalies are marked with ellipses (Fig. 3): 1 – negative anomalies aligned NW–SE, 2 – distinct anomalous zone oriented almost E–W, 3 – positive-to-negative transition zone due to surface variations, as revealed by recent agricultural activities. Moreover, the GPR, ERT, SRT and MASWT slices between 0.5 and 1.78 m depth, compared with the magnetic image, revealed the anomalies in the first zone to be oriented NW–SE in all cases. The second anomalous zone (2) indicated a loess medium in the GPR depth-slice and a conductive character in the ERT slice. At the same time, this zone demonstrated low Vp and Vs velocity distribution in the SRT and MASWT slices. The third anomaly was arc-shaped and it showed up clearly in the same location in both the magnetic image and the GPR results. Furthermore, the changes were also partly observable in the ERT, SRT and MASWT slices.

CONCLUSIONS

Integrated geophysical investigations carried out at the Šapinuva archaeological site revealed that such an approach based on different geophysical methods will be very useful to interpret the various physical properties, true locations and dimensions of the buried archaeological structures. Magnetic gradiometry provides valuable knowledge about the shallow archaeological remains and the covering soil through the magnetic properties of the deposits. ERT enables

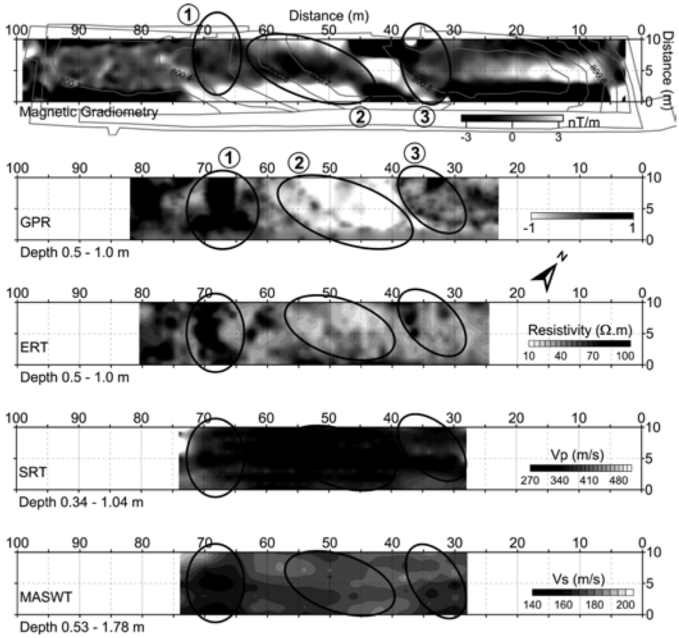

Fig. 3. Combined interpretation results of the near-surface features of the Taşdöşem ditrict of the Ağılönü area

determination of the location, extension, depth, thickness and electrical characteristics of subsurface features including geological units. GPR highlights the overall spatial distribution of archaeological remains and subsoil layers. Seismic refraction tomography supplies additional information about the buried archaeological structures and geological units, particularly with respect to their depths. MASWT detects the lateral Vs velocity changes of any anomalous body and the archaeological context within the geological environment.

This study showed that an integrated approach using different geophysical techniques enabled better definition of position, localisation, depth, thickness, extension and the physical characteristics of buried archaeological structures and their geological context at the archaeological site of Šapinuva. The methods applied provided very useful and informative data on the internal characteristics of this monumental city in the Hittite Empire. The approach provides an important tool for archaeologists to inform their detailed and extensive excavations.

ACKNOWLEDGEMENTS

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3D electrical resistivity imaging and GPR to re-explore ancient mounds near Suzdal in Russia

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KEY-WORDS: geophysics, electrical methods, burial mounds

INTRODUCTION

The investigation site is located 40 km north-west of Suzdal near Shekshovo village in the Ivanovo region. The site lies in a typical plain landscape of central Russia and is comparatively flat. Regular cultivation has ensured that nothing except grass and planted crops grows in the survey area.

Diverse natural and historical factors have conditioned habitation in the Suzdal region since ancient times. One of the most interesting periods is from the end of the first and in the beginning of the second millennium AD, when Vladimir-Suzdalian Russia emerged. Numerous burial mounds of the 10th–11th centuries are among the most important evidence of this period, particularly in conjunction with a study of the corresponding historical processes. The mounds were first investigated archaeologically by A.S. Uvarov in 1851–54. He excavated 7729 burial mounds, 244 of which were located at Shekshovo. But the excavation documentation was neither exhaustive nor informative enough. The excavated sites were poorly located on the maps, classification of the mounds was not precise and the dimen-

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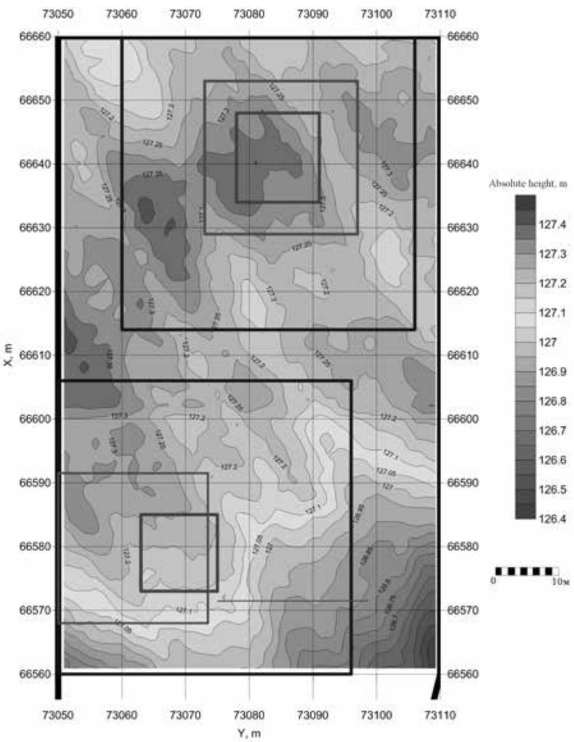

Fig. 1. Microrelief of the area investigated with geophysics in 2013. Solid black lines – areas covered by raw geophysical survey, dashed line – detailed survey areas, dotted line – excavations in 2013

sions specified for only 1% of the features; the collected artifacts were hastily described and no drawings exist. Ten years ago investigations were initiated by the Suzdal Archaeological Expedition of the Archaeological Institute of the Russian Academy of Sciences under the direction of N.A. Makarov. The exploration has focused on the settlement and burial ground near the site of the present Shekshovo village.

One of the main difficulties encountered by modern research is the absence of any sign of buried mounds on the modern surface. Agricultural activity for centuries, Uvarov's excavations and natural processes have deleted all signs of the buried mounds. There is no information about the quantity of burial mounds, their location, the distance between mounds and the morphology of the ground between them. The geophysical survey was designed to guide the excavations by obtaining information about the location of the burial mounds. The geophysical methods applied included magnetic prospection, detailed topographic survey, ground penetrating radar (GPR) and areal electrical resistivity tomography (ERT).

The investigations were conducted in 2013 and 2014. The total area covered by the geophysical survey was approximately 9500 m^2 (Fig. 1). The survey area of 2014 was roughly of the same size as in 2013 and was located slightly to the west of it.

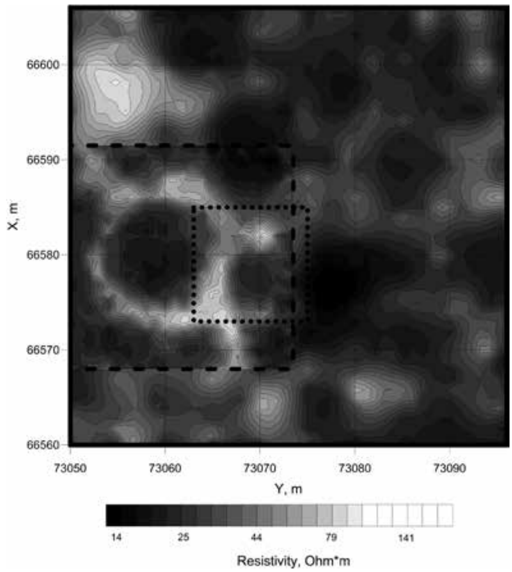

Fig. 2. Resistivity map at 60 cm depth; area of detailed survey (inside the dashed line) integrated into the raw survey map

RESULTS

Resistivity imaging is one of the basic methods in archaeological geophysics (Griffiths, Barker 1994; Erokhin *et al.* 2011). In the current study, ERT was supposed to define the thickness of the cultural layer in the area and to map its spatial structure, including its inhomogeneity. Two ERT survey configurations were used: a raw survey with 1 m spacing between the electrodes and a larger step between the profiles (from 5 m to 1 m), and a detailed survey with 0.5 m electrode spacing and a smaller step between the profiles (from 1 m to 2 m). In both cases, the system with two perpendicular profile directions, as described by Pavlova and Shevnin (2013), was used. Independent 2D inversion for each profile was done in most cases and then the resistivity values for the corresponding depths were extracted from the inversion model. For the detailed survey areas with 0.5 m spacing between the electrodes and 1 m spacing between profiles, both the described technique and the 3D inversion of all data points (for all profiles) were used simultaneously. While ERT supplied the most conclusive results concerning burial mound mapping, the comparison of these two approaches shows that neither can be called the best. Instead, both need to be used as they tend to emphasize small features on resistivity maps in slightly different ways. This observation is important for the interpretation.

The resistivity map at 60 cm depth for the raw survey 1 m × 5 m shows several circle-like structures (Fig. 2); the most distinct of these was chosen for a detailed survey 0.5 m × 2 m (results shown inside the dashed-line square in Fig. 2). The interpretation of the high-resistivity circular zone as the ditch around the burial mound was verified by subsequent excavation in July 2013, covering

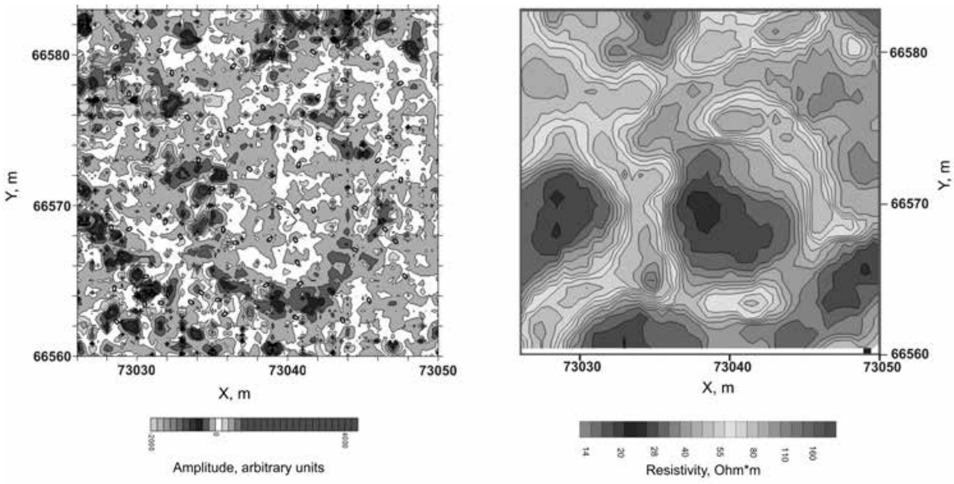

Fig. 3. Detailed survey area in 2014: GPR slice at 25 ns (left) resistivity at 60 cm depth (right)

the western part of the circle. This indicated that ERT technology was capable of reliable burial mound detection in the area of investigation. In 2014, the raw net was made denser: 1 m between the electrodes and 1 m between the profiles, as well as with two profile directions (polarizations).

The GPR prospection was carried out despite the satisfactory ERT result, because the survey time in this case could be decreased substantially. For the GPR investigation, the area was divided into squares 20 m × 20 m, the maximum distance at which the positioning could be done manually, while retaining acceptable accuracy. For improved accuracy, measurements were made with a 1 m step between the profiles and in two perpendicular profile directions. After the individual radar traces were processed, signal amplitude for the needed reflection time was extracted and a map for the area was generated.

A comparison of the GPR map for one square area (Fig. 3 left) with the ERT raw map (1 m × 1 m survey) of the same area (Fig. 3 right) demonstrated that the most distinct circular high resistivity structure on the ERT map could also be seen on the GPR map. This demonstrates the applicability of the GPR to achieving survey objectives, at least, in the small-scale raw surveys. Unfortunately, the magnetic surveys, which have been carried out in the area for many years (Klein *et al.* 2007), have shown less than satisfactory results concerning burial mound detection: the "ditches" surrounding the mounds do not possess anomalous magnetic properties. Two main classes of objects visible on the magnetic map are the relict ice wedges and iron objects, a substantial part of which are artifacts of archaeological interest.

CONCLUSIONS

Circle-like structures, which are interpreted as the remains of "ditches" around the burial mound, were detected with geophysical methods. In 2013, at least nine such structures of different sizes were detected. The diameter of the smallest one is 7–9 m, of the largest 11–13 m. Areal ERT (Pavlova, Shevnin 2013) and GPR were the most informative geophysical technologies applied in this case.

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Geochemical and magnetic prospection of a Neolithic site: case study from Dzielnica (Poland)

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KEY-WORDS: geochemical prospection, magnetic prospection, phosphate analysis, Neolithic, enclosure

An interdisciplinary non-invasive survey project including aerial photography and geophysical, geochemical and surface prospection has been conducted in Dzielnica (Opole province) since 2008. Rescue excavations, which began in 2004, are continuing on the site.

The site is a promontory stretching into the wide Oder river valley. Neolithic, Bronze Age and Iron Age population groups repeatedly occupied the landform. Diverse domestic features, mostly dug-in pits, aboveground houses and graves, are related to these settlement episodes, but the most interesting feature associated with human occupation of the late phase of Lengyel culture is a system of ditches forming an enclosure.

The gradiometry survey was conducted using a Bartington Grad601-2 instrument and covered an area of 6.14 ha. The prospection recorded a great number of anomalies resulting from varied and chronologically diverse human action (Fig. 1), occurring throughout the studied area.

Analysis of some magnetic anomalies led to an interpretation of their function, cultural attribution and chronology. Linear anomalies indicating the presence of ditches are particularly characteristic. As the excavations have shown, these features were not ditches *sensu stricto*, but a system of elongated pits, which had been dug successively one into the other. Two parallel ditches aligned SE–NW were traced and a third ditch was found to connecting them in the middle part. The current state of research does

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Fig. 1. Results of the magnetic survey at Dzielnica, Opole (Poland)

not allow for a full reconstruction of the enclosure (especially in the southern and northern directions) or an estimate of its surface area (surely larger than 3 ha). It cannot be ruled out that the system of ditches was more complicated and that a larger number of anomalies may be interpreted as relics of other ditches.

Elongated anomalies or groups of anomalies concentrated in the southeastern part of the area are equally characteristic; they form rows, dozens of meters long and oriented SE–NW separated by empty spaces between them. Their arrangement seems to suggest that they are the remains of households, typical of the Linear Pottery culture communities; they comprise so-called clay pits located along the walls of post-built longhouses. The remains of post-built structures were recorded sporadically as poorly visible rows of triple anomalies. The neighbouring households formed several rows of buildings laid out regularly along a SE–NW line. Such an arrangement of buildings is also characteristic of Linear Pottery culture settlements. The rest of the anomalies are difficult to interpret unequivocally and represent the relics of settlement features related to all phases of site occupation.

Large-scale geochemical analyses were also conducted with the objective of determining the phosphate content in samples from a series of drill-cores and bulk samples collected during the excavations. In total, 900 drillings were made during the project and 3500 samples were

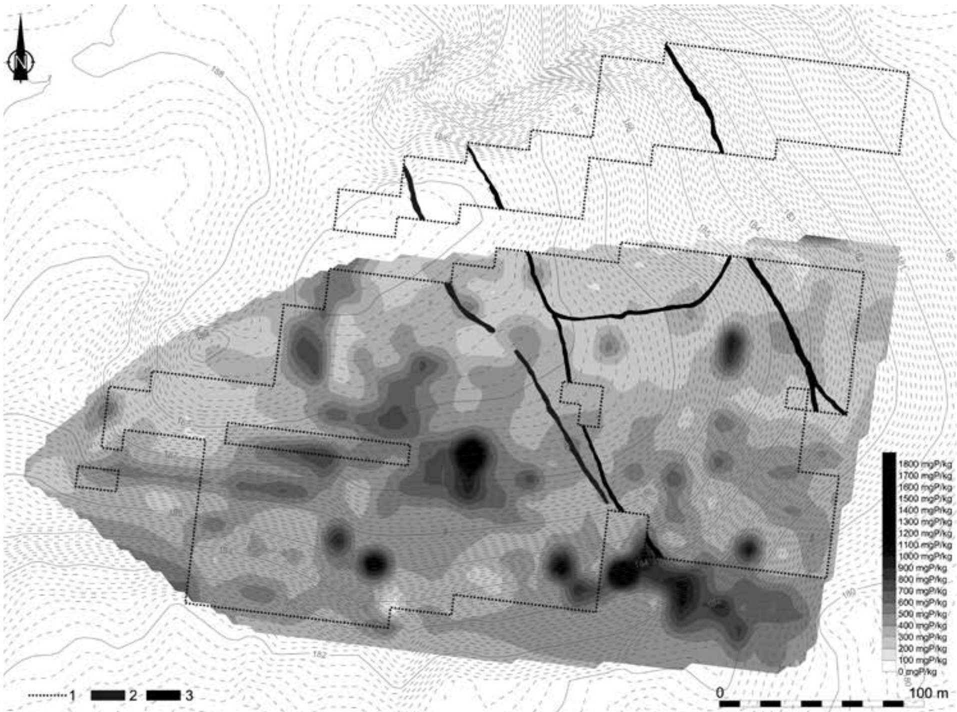

Fig. 2. Map of phosphate content in soil samples (depth 0.4–0.6 m) from Dzielnica: 1 – extent of the magnetic survey, 2 – probable ditch, 3 – ditch

collected and analysed. The studies were carried out following laboratory procedures developed at the Wrocław University of Environmental and Life Sciences (K. Gediga, U. Piszcz). The project took the opportunity to validate some of the methods that allow for a fast analysis of phosphate content in soils with the use of commonly available, portable analytical devices (e.g., Parnell *et al.* 2002; Persson 2005; Lindholm 2006; Rypkemaa *et al.* 2007); these methods included a set of Merck strip tests, a set of Hach phosphate tests (Phosphate Orto Test Kit) and a Merck reflectometer (Reflectometer Rqflex). In all cases, limited applicability of these methods was demonstrated for phosphate determinations on archaeological sites.

Most samples for phosphate content analysis were collected from a regular grid of drillings positioned every 10 m. Apart from these, also three test areas were marked out, where the drillings were made within a 2 m square grid. Soil samples from all of the drillings were taken at three depths: 0.4–0.6 m, 0.6–0.8 m and 0.8–1.0 m. Additionally, samples for analysis were collected, from different levels of the explored archaeological features within a 1 m square grid.

The generally similar character of the results of phosphate analysis obtained from the 10 m square grid and recorded at the three sampling levels bears attention: zones of low and high phosphate content were found in the same parts of the site (Fig. 2). Potential differences are of a local character and arise from the specificity of traces of human activity from the various levels of the site and inside the settlement features. Of major importance is the lack of correlation between the location of high phosphate content zones and the present-day field boundaries, excluding the impact of contemporary factors on the observed variation in geochemical properties.

A comparison of the distribution of phosphate content in the soil and the results of the magnetic surveys indicate that the space between the ditches of the Lengyel culture enclosure is characterized by relatively low phosphate content values. Elevated levels of phosphate content recorded in the southern part of the enclosure can be attributed to the presence of chronologically older households of the Linear Pottery culture in that area of the site. The amount of phosphate is significantly higher in zones located outside the ditches, mostly towards the west and southwest. This may suggest that the area surrounded by the ditches was not used intensively for economic activities. It can also be assumed that animal access to this area was restricted and their permanent presence (stabling) within the enclosure may be ruled out in all probability. The higher phosphate content outside the ditches may point to a conclusion that this zone was used more intensively for agricultural activities, most likely as a pasture, stabling ground, manured fields etc.

The results of an analysis of samples collected in a 2 m square grid within the test areas generally correspond with those obtained from the 10 m square grid. A denser arrangement of drillings allowed for a better mapping of within the test areas spatial distribution. In some cases, there was an evident coincidence between elevated phosphorus content and the occurrence of single magnetic anomalies, which clearly represented archaeological features. Processes responsible for the formation of the infill of dug-in features (e.g., ditches) are the reason, among other factors, behind the variability of phosphate content in the different layers.

Excavation trenches positioned within the above mentioned test areas allowed to verify the outcome of the geomagnetic and phosphate content prospection. In both cases, results obtained by non-destructive methods were confirmed. This repeatability iproves the capabilities and validity of the applied methodology.

The research conducted at Dzielnica not only contributed to the development of non-invasive prospection methodology, but also led to the formulation of procedures regarding the preparation and analysis of phosphate-content samples from archaeological sites. It also emphasized the significant cognitive value of an integrated research approach involving non-destructive methods.

ACKNOWLEDGMENTS

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Geoarchaeological core prospection investigation to improve the archaeological interpretation of geophysical data: case study of a Roman settlement at Auritz (Navarre)

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KEY-WORDS: magnetic prospection, core prospection, geoarchaeology, stratigraphy, Roman town, interpretation

INTRODUCTION

The Aranzadi Society of Science has been engaged in a project to trace Roman roads in northern Navarre since 2011. This research has been focused on the route through the Pyrenees at Orreaga/Roncesvalles and has produced new evidence that suggests some variation from the route known so far. Field investigation detected a roadside settlement and archaeological trenches revealed substantial Roman masonry building foundations (Agirre-Mauleon *et al.* 2012). In order to delimit and characterize the site, a geophysical prospection was undertaken over an area of 18 ha using a magnetic fluxgate gradiometer. Results show a densely occupied area of approximately 5 ha, but also areas either without significant anomalies or with good magnetic contrast but showing poorly defined anomalies (Garcia-Garcia *et al.* 2013). The survey allowed the main characteristics of the settlement to be described and identified new areas of interest.

At this point, Aranzadi approached MOLA (Museum of London Archaeology) in order to develop a cooperative approach to the investigation and further research. It was agreed that the MOLA/Aranzadi team would implement an archaeological coring survey designed to complement and refine the existing geophysical survey. The principle was to conduct a non-invasive field study to further understand the stratigraphic make-up of the site (Agirre-Mauleon and Hill 2013).

OBJECTIVES

The geophysical survey provides a rich template for understanding the buried archaeological resource. Consequently, the objectives of the geoarchaeological investigation were driven by the results of this survey. The main goals of the investigation were to describe and define the underlying geology,

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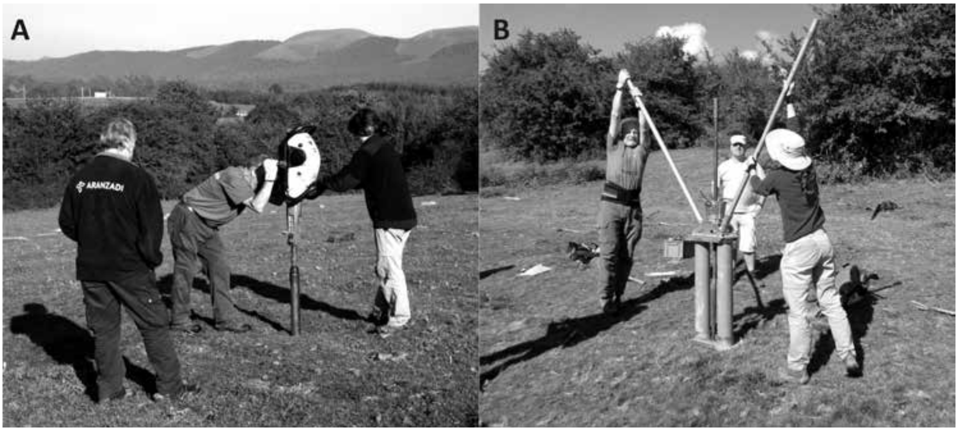

Fig. 1. A – power auger (Cobra TT engine) used for drilling; B – MOLA/Aranzadi team removing the gouge manually

to define the presence or absence of archaeological strata and to characterise the thickness and type of archaeological deposits. This information will help to design future excavation campaigns. In parallel, the core information will be used to correlate the distribution and characteristics of the archaeological deposits with the geophysical survey in order to improve archaeological interpretation. Therefore, some of the cores were undertaken with the specific goal of qualifying geophysical interpretations.

GEOARCHAEOLOGICAL CORING METHODOLOGY

Cores were drilled with a mechanical petrol-driven 2-stroke power auger (Cobra TT engine). This is a hand-held coring machine, which drives 1 m long, open-sided steel gouges into the ground (Fig. 1: A). The sediment-filled gouge is then recovered from the ground using the two-person jacking apparatus (Fig. 1: B). The recovered window sample is then cleaned by trowel, photographed, recorded in a log, sub-sampled as necessary and finally discarded, so that the gouge can be used again. Sediments were photographed and described according to standard sedimentary criteria (Jones *et al.* 1999; Tucker 1982). Preliminary interpretations were made of the depositional conditions represented by the soils and sediments within each core and the deposits or contexts grouped into broad stratigraphic units.

Based on the geophysical survey, the area of investigation was divided into four zones, but the principal focus was on Zaldua, which contains the main area of the settlement, and Otegi, where geophysics have shown some anomalies that could not be interpreted. The survey at Zaldua comprised 80 cores configured as nine approximately parallel, east–west transects, positioned to create a grid of points. A number of specific points was also included, these being points with potential to resolve anomalies apparent in the geophysical survey. The Otegi area is known to have a necropolis in its southern part and could have been settled in its northern part. The core locations are shown in relation to aerial photography in Fig. 2.

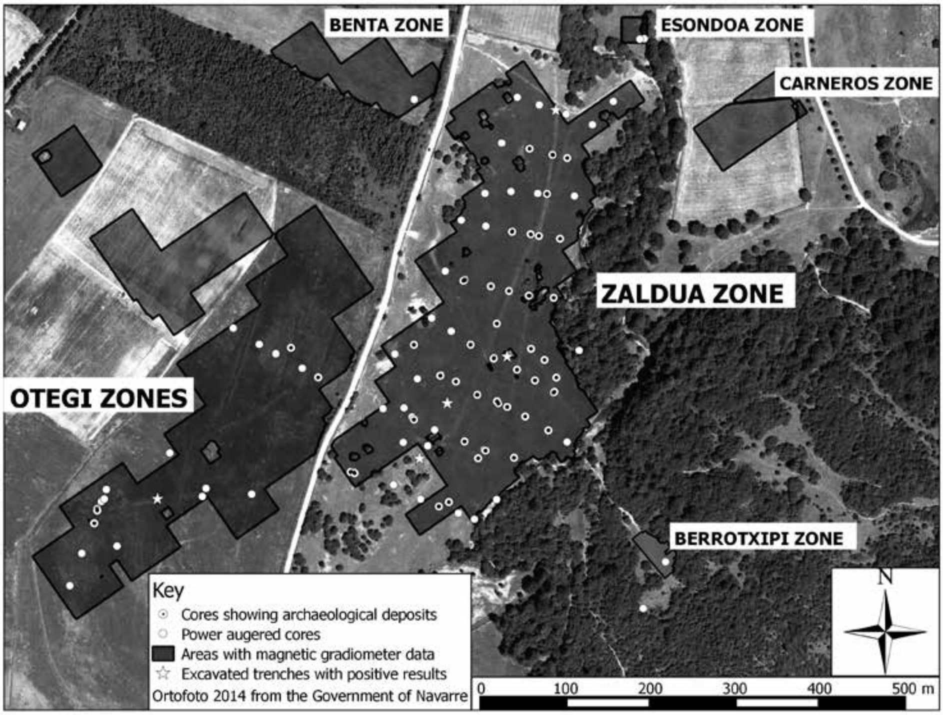

Fig. 2. Plan of the cores, areas with geophysical prospection and trenches excavated in 2012 overlaid on a aerial image (obtained from the Government of Navarre)

RESULTS AND DISCUSSION

In total, 104 cores were drilled and most of the cores reached undisturbed alluvial terrace deposits (silts or gravels) at between 1 m and 2 m depth (MOLA/Aranzadi 2014). One obvious conclusion is that the volume of archaeology across the site is lower than estimated based on trench excavation, due to trenches being located in areas where stratigraphy was deep.

In general, the survey across Zaldua mirrored the presence and absence of archaeological matter in the geophysical survey. Cores that showed natural sequences with no archaeology are mainly those at the edge of the geophysical survey, outside the main focus of settlement. Specifically, the northern transect confirmed an absence of archaeological matter and strengthened the interpretation of this area as the northern edge of the main settlement. The survey also demonstrated the absence of archaeological deposits in the woodland around the settlement, where geophysical data was hard to retrieve.

In areas where strong geophysical anomalies were targeted, the cores generally confirmed the interpretation from the geophysical survey. Furthermore, the extracted sequences allowed these interpretations to be refined and permitted not only a better understanding of the origin of the anomalies, but also provided dating evidence. Some discordance was found, however, and new areas of interest were identified for further investigation.

The core survey across Otegi zone was less intensive. Archaeological deposits were recorded in only five of the 19 holes drilled, but nevertheless, most of the questions posed could be answered. The boundaries of the known necropolis area could not be determined and will require further detailed sampling. Some of the cores confirmed archaeological interpretations based on geophysical results, although in one particular case, the expected archaeological feature was not found, and the core revealed the anomaly to be geological.

CONCLUSIONS

The MOLA/Aranzadi fieldwork undertaken in 2014 has produced an archaeostratigraphic model that can inform future archaeological works at this site. It provides a map of the buried topography and the distribution of deposits across the site, enabling identification of sediment type, character and thickness prior to any further groundwork.

Archaeological deposits are concentrated in the Zaldua zone. Multiple floor surface and levelling deposits have been identified in several locations and distinct deposit sequences discerned in different rooms within buildings. The findings may substantiate the idea that the incoherent geophysical signal in these zones results from multiple phases of deposition.

The predominant conclusion is that, in general, the core survey confirms the results of the geophysical survey in the Zaldua zone. In contrast, at Otegi and Esondoa, the core results differed from the archaeological interpretations made based on geophysics. Further work is needed in the Otegi zone before definitive conclusions can be made about the presence or absence of archaeological remains.

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The Roman settlement at Auritz (Navarre): preliminary results of a multi-system approach to assess the functionality of a singular area

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KEY-WORDS: magnetic prospection, GPR, microtopography, stratigraphy, Roman town, interpretation

INTRODUCTION

The Aranzadi Society of Science has been engaged in an ongoing project to trace Roman roads in northern Navarre since 2011. This research has been focused on the route through the Pyrenees at Orreaga/Roncesvalles and has produced new evidence that suggests some variations from the route known so far. During this research a roadside settlement was detected; archaeological trenches have revealed substantial Roman masonry building foundations (Agirre-Mauleon *et al.* 2012). In order to delimit and characterize the archaeological site, geophysical prospection was undertaken over an area of 18 ha using a fluxgate gradiometer. The results show a densely occupied area of about 5 ha and they have allowed the main characteristics of the settlement to be described, revealing urban occupation organized along the road (Garcia-Garcia *et al.* 2013).

In that context, Aranzadi approached MOLA (Museum of London Archaeology) in order to develop cooperative approaches to the investigation and further research of the site (Agirre-Mauleon and Hill 2013). In September 2014, MOLA led a non-invasive archaeological intervention through core sampling, designed to complement and refine the existing geophysical survey. In the same campaign, a drone survey was performed, providing orthorectified aerial photography and a topographical model with 6 cm pixel size (MOLA/Aranzadi 2014).

OBJECTIVES

Despite the amount of information obtained through the magnetic survey, some areas of the settlement could not be well described. In particular, an area with a singular disposition of anomalies has been detected and flagged as one of the areas of interest for

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further research. Indeed, whilst the orientation of the buildings is in general aligned with the main road through the settlement, in that particular location magnetic data show different groups of anomalies, referred to as P5, observing a coherent orientation and disposed around a rectangle of about 78 m by 32 m (Garcia-Garcia 2013). Furthermore, the area occupied by P5 is slightly elevated above the road level and provides a strategic position from which to control it. The south-eastern side of this rectangle is delimited by parallel linear anomalies showing negative magnetic contrast and interpreted provisionlly as walls. However, their full length cannot be traced because of weak magnetic contrast. Thus, magnetic survey results give some, but not enough evidence to interpret that area as a unique archaeological unit.

This location was targeted during the core sampling campaign performed in September 2014 (MOLA/Aranzadi 2014). To analyze the continuity of the stratigraphic sequence three sediment cores were drilled in the inner part of the rectangle. Given the contrasting results from the three cores and the lack of data from the northern part, the core survey could not corroborate the interpretation of P5 as a single delineated area and further investigation was required.

A new geophysical campaign was thus designed in order to complement the data from the area.

DATA ACQUISITION METHODOLOGY

Based on the previous geophysical survey, the area of interest was divided into several grids. As a first step, a small area was prospected with both GPR and electrical resistance meter in order to get complementary information and to assess the best survey strategy. Despite the high moisture level, the GPR results showed good contrast and penetration; consequently, it was applied in preference because of the higher resolution obtained in lower acquisition time.

The GPR prospection was conducted using the IDS Hi-Mod instrument with two multi-frequency antennae (200 MHz and 600 MHz). Measurements were taken every 2.5 cm along parallel traverses, separated by 0.2 m and in zigzag mode. The time window was fixed on 90 ns for the 200 MHz antenna and on 70 ns for the 600 MHz antenna. Data was processed using GPR-SLICE software, then imported to a GIS environment for combined interpretation. As many molehills were present in the targeted areas, the field had to be cleared in advance in order to ensure satisfactory contact between the antenna and the ground. Therefore, the survey was confined to those areas that could be cleared within the available time. Work will continue in spring.

RESULTS AND DISCUSSION

The preliminary results over approximately 4400 m^2 show complementary information to that obtained in the magnetic survey. The south-eastern limit of the P5 rectangle appears clearly on the time-slice sequence, allowing a more detailed description than the one obtained from magnetic data. Furthermore, the buildings in this area show great contrast and their inner divisions can be properly described, improving notably the architectural information obtained from the magnetic survey. However, the topographical variations of this area, probably related to the collapse of archaeological structures, affect the time-slices and make necessary further processing to adjust the GPR profiles into real vertical position (Goodman *et al*. 2006). The topographical model created from the drone survey has been shown to be a useful tool, given its high spatial resolution, compared to the 5 x 5 m LiDAR data available until now.

CONCLUSION

The combination of both geophysical and topographical information was essential to analyze and interpret rectangle P5. The first magnetic survey provided some evidence to suggest that this area could be a distinct archaeological zone, but complementary geophysical surveying was essential to obtain a more detailed architectural characteristics that would allow a more accurate interpretation. However, the geophysical and archaeological information could not be contextualized without the topographical model obtained from a drone survey. Therefore, this combined methodology has proved useful in improving the interpretation in a complex topographical context.

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Ghosts, surprises, and unsolved mysteries: a multi-technique approach to the enigmatic third guesthouse at Fountains Abbey

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KEY-WORDS: earth resistance, pseudosections, 3D inversion, ground penetrating radar

INTRODUCTION

Founded in the first half of the 12th century, Fountains Abbey was one of the largest and wealthiest of England's Cistercian abbeys. Cistercian ideologies structured the construction of the abbeys and their landscapes in a regular manner as a physical manifestation of their piety to God. Because the abbey landscape was a sacred place, movement of visitors through the site was regulated (Coppack 2003). At Fountains Abbey, guest houses were constructed southwest of the nave, as movement from the east was reserved as a sacred entry into the site. Two of these guest houses remain partly freestanding to this day, with a third buried directly beneath the grassy area directly southwest of the nave. For such an important and iconic site, relatively little intrusive archaeological work has been conducted within the grounds. Much of the understanding of the site relies on written and illustrative sources. One of the enigmatic areas of the Fountains Abbey landscape is this so-called "third guest house." This buried guest house is not drawn or discussed in the earliest plans of the ruins. What was previously known of this building was primarily derived from the results of an a = 0.5 m twin-probe earth resistance survey, conducted in the early 1990s by the University of York. Geophysical investigations led by the University of Bradford in 2013 and 2014 have shed new light on this area.

In 2013, the University of Bradford began investigations over the area southwest of the nave as part of a public engagement for World Heritage Day. Investigations included an earth resistance survey using linear and non-linear arrays, electrical resistivity tomography, and fluxgate gradiometer methods. The range of additional survey techniques suggested a more complex buried landscape than previously believed. Further work undertaken in 2014 sought to better characterise and understand the changes of archaeology with depth. To accomplish this, high-resolution survey strategies were employed, along with multi-depth methods. The work utilised multi-channel ground-penetrating radar, cart-based earth resistance and magnetometry, earth resistance pseudosections, and multi-depth electromagnetic induction techniques.

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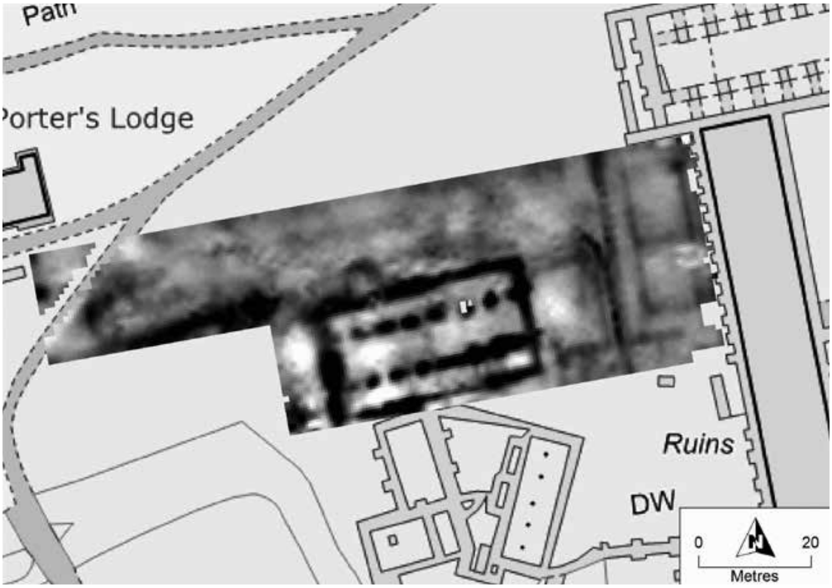

Fig. 1. Earth resistance results using an a=0.5 m twin-probe array. Data were despiked, high-pass filtered and interpolated, displayed from 1.5 SD (white [low] – high [black])

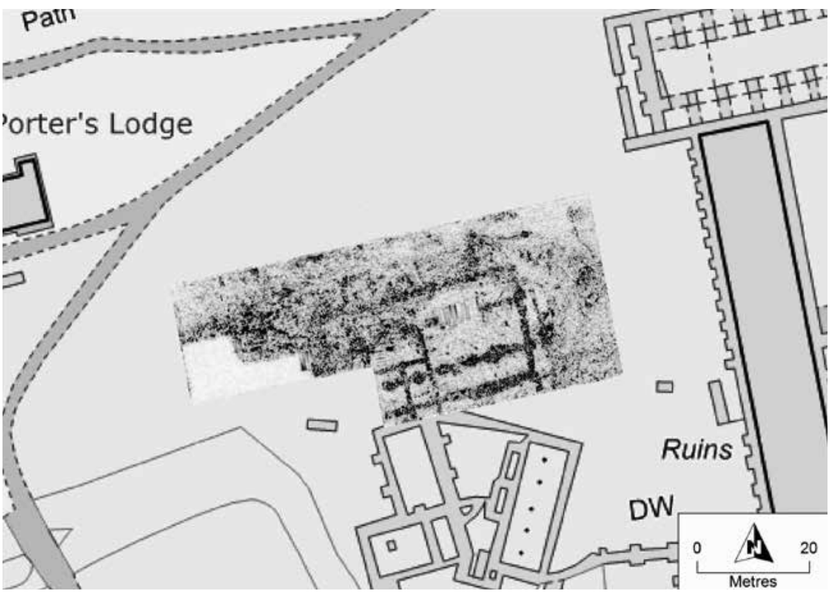

Fig. 2. GPR time slice correlating to a depth of 1.67 m (white [low] – high [black])

Of the range of prospection methods applied over the site, the earth resistance and ground penetrating radar methods were most successful for delineating the structure of the buried guest hall. As a result, these methods have provided us with the most information for developing the archaeological narrative for this structure and are thus the focus of this paper.

METHODS

Technique	Hardware	Sample Interval x Traverse Spacing	Comment
earth resistance: twin-probe array	Geoscan Research RM15	1.0 m x 0.5 m 1.0 m x 1.0 m	a=0.5 m a=1.0 m
earth resistance: square array	Geoscan Research RM85 on MSP25	0.25 m x 1.0 m	alpha, beta, gamma a=0.75 m
earth eesistance: expanding twin-probe pseudosections	Geoscan Research RM85	1.0 m x variable	a=0.25m, 0.5 m, 0.75 m, 1.0 m, 1.25 m, 1.5 m generated into pseudosections and run through 3D inversion
GPR	Mala Mini Mira	0.08 m x 0.08 m	400 MHz antennae

RESULTS

The buried guest house is clearly resolved in the earth resistance surveys, with the walls and pillar bases exhibiting high-contrast from the surrounding soil (Figs 1 and 3). These results agree with previous prospection work at the site. However, through the use of expanding arrays and different electrode configurations, the 2013 and 2014 earth resistance results hint at additional structural changes with increased depth (Fig. 1). These additional, previously unknown, structures are not visible in the 1990s twin-probe survey due to the shallower depth of detection of that survey. Still, the larger earth resistance arrays lacked the required resolution and depth of investigation to provide an adequate understanding of the nature of these anomalies. To better assess the deeper archaeological changes, a high-resolution ground penetrating radar survey was employed. The GPR results (Fig. 2, a selected representative time slice of the structures) delineate a series of walls, beyond a depth of 1.0 m. Because the ground penetrating radar results quantify the changes of features with depth that are visible between the various earth resistance surveys, the radar provided a baseline from which the results could be better understood in relation to one another.

The 2014 earth resistance surveys also utilised a cart-based system, allowing for a higher sampling density, which was able to resolve further internal structuring of the buried remains. The 2014 cart-based square gamma dataset has provided additional information regarding the structure of the guest hall walls, which combined with the radar data, has resulted in a re-evaluation of the 2013 survey results (Fig. 3).

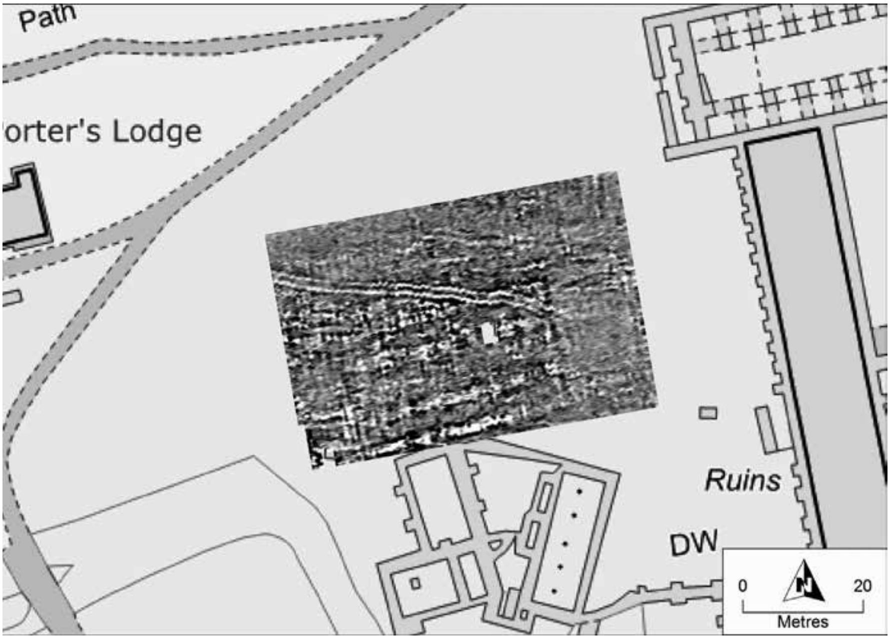

Fig. 3. Earth resistance results using an a=0.75 m square array in gamma configuration. Data were interpolated, displayed from 1.5 SD (white [low] – high [black])

CONCLUSIONS

The cumulative results from the 2013 and 2014 surveys at Fountains Abbey reveal a more complex subsurface than previously known. The multi-method strategy provided information beyond the structure of the buried remains, by revealing the complex changes of features with depth. Examining the geophysical results within the context of the abbey's development has led to the following working theory. From the 1140s–1220s, the abbey grew in size, wealth, and power; historical records describe this as a period of stimulated construction and expansion. With the accruement of wealth came further political administration and an influx of visitors to the site. The deeply buried walls, appearing beyond a depth of 1.0 m in the GPR data, likely formed a smaller guest house to the larger "third guest house," which is more shallow. We propose that the abbey could not accommodate the increased traffic of visitors to the site and demolished the more deeply buried smaller guest house to construct a larger guest house. Due to the lack of historical writings and illustrative sources describing this larger "third guest house", it is postulated that the building may have been constructed rapidly to accommodate less important visitors.

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High Royds: an integrated, analytical approach for mapping the unmarked burials of a pauper cemetery

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KEY-WORDS: graves, GIS, earth resistance, magnetometry, electromagnetic induction, ground penetrating radar

INTRODUCTION

Applying geophysical techniques to detect and map the physical extent of individual unmarked graves proves difficult in many cases. The success of individual geophysical techniques for mapping graves often depends on a site-by-site basis. The failure of geophysical techniques for detecting unmarked graves may be due to a poor understanding of the nature of the graves themselves, the context of which they lie in, and temporal changes to the burial state. Given the unpredictability of these variables, it is surprising that grave prospection is often undertaken using a single method only (Conyers 2006; Bigman 2012; Ruffell *et al.* 2009). This paper presents a multi-methodological survey strategy for detecting unmarked burials and utilises an analytical approach for visualising and evaluating the survey results.

SURVEY AREA AND STRATEGY

This case study presents High Royds Memorial Garden of Menston, West Yorkshire, England. The site contains the burial ground for 'unclaimed patients' from the High Royds Hospital, who died from 1890 to 1969. An archive plan of the cemetery shows 1,000 regularly aligned burial plots; yet the site is believed to contain the burials of 2,861 patients. The primary survey object was to verify the validity of the archival plan.

The cemetery is not an ideal site for geophysical prospection, with wet, clayey soils affected by intensive animal burrowing activity, which has created an undulating surface. As pauper burials, the individuals were likely buried in shrouds or rudimentary coffins, and may exhibit only weak contrast from background soils. Given the uncertainty of succeeding using a single geophysical technique, a multi-method approach was employed over a three year period (Table 1).

RESULTS

Earth resistance methods

Earth resistance surveys can identify the subtle variations of soil disturbance of ephemeral features ("grave cuts"). A standard twin-probe survey was complemented with less conventional non-linear

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Table 1. Geophysical survey techniques and methods of data acquisition

Technique	Hardware	Sample Interval x Traverse Spacing	Comment
fluxgate gradiometer	CartEasyN cart with Bartington 1000L sensors	10 Hz x 0.75 m	
earth resistance: twin-probe array	Geoscan Research RM15	0.5 m x 0.5 m	a=0.5 m probe separation
Earth Resistance: Square Array	Geoscan Research RM15	0.5 m x 0.5 m	alpha, beta, gamma, 0.75 m array size
earth resistance: trapezoid zrray	Geoscan Research RM85	0.5 m x 1.0 m	longitudinal, broad-side, theta, 0.75 m x 0.75 m x 1.25 m array size
ground penetrating radar	Mala Mini Mira	0.08 m x 0.08 m collected at 0.5 second intervals	400 MHz antennae
electromagnetic induction	GF Instruments CMD Mini Explorer	Collected at 5 Hz x 0.5 m, projected to 0.25 m x 0.5 m	conductivity and in-phase (HCP and VCP orientations)

arrays in square and trapezoid configurations. Non-linear arrays facilitate the simultaneous collection of several array permutations. For the square array, these are the "alpha," "beta," and "gamma" configurations, whose trapezoid array counterparts are referred to as the "longitudinal," "broadside," and "theta" configurations.

The earth resistance datasets (Fig. 1) show fewer discrete anomalies than the other techniques. In the north-east quadrant of the survey area, a number of rectilinear, high resistance anomalies are discretely resolved. These individual anomalies fit within the archival burial plots plan and likely correlate with grave or grave construction features. Considering the square gamma measurements, there is a directional bias of current flow in a southwest–northeast orientation, correlating with grave orientation. These responses produce a 'brick'-like pattern, likely a response to the grave cuts.

Magnetic and electromagnetic methods

Magnetic methods are seldom considered effective for detecting individual graves. They may be successful for detecting graves which contain magnetic material, grave goods, or coffin fixtures (David *et al.* 2008: 14–15). Given the economic status of the deceased in life, it is unlikely that such responses would be produced by their graves. Fortuitously, ferrous grave markers have been found on the site and it is assumed that each plot had an associated grave marker. These markers are associated with spatially

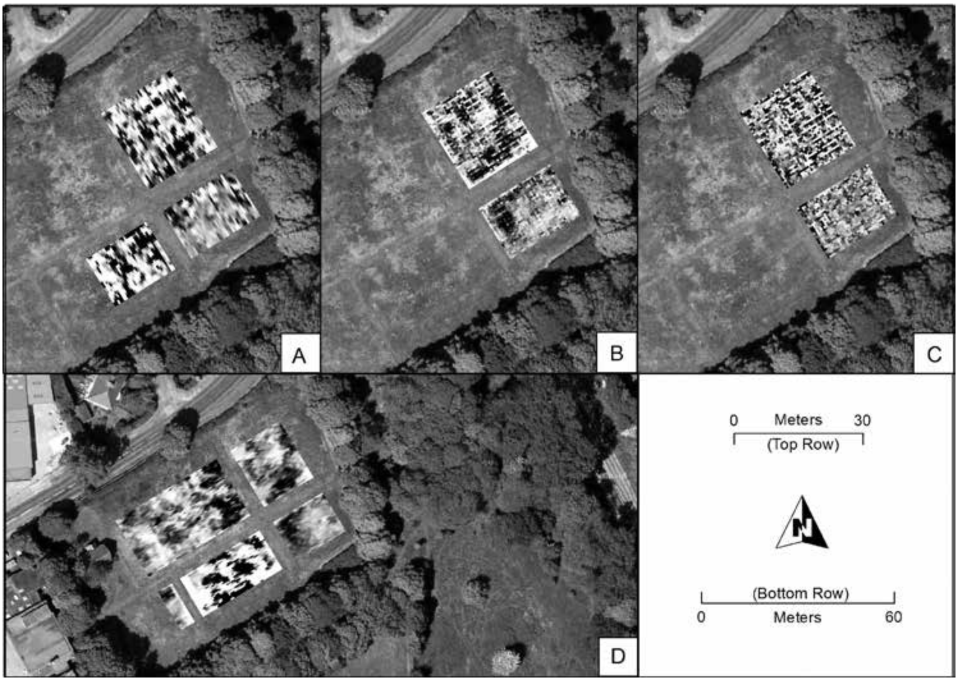

Fig. 1. Earth resistance survey results (plotted 1.5 SD, white [low] – black [high] ohms). Data were despiked, high-pass filtered, and interpolated. From top left: A – trapezoid array, theta configuration; B – square array, alpha configuration; C – square array, gamma configuration; D – twin-probe array

variable, highly magnetic, dipolar anomalies in the fluxgate gradiometer results (Fig. 2). Considering the electroma-gnetic results, a strong in-phase magnetic susceptibility response occurs at those graves containing the suspected subsurface ferrous grave markers. In this respect, the magnetic susceptibility component has a reasonable correlation with the gradiometer survey and these are interpreted as the position of the ferrous grave markers. The EMI conductivity response is strongly linked to the in-phase contribution; therefore, the graves containing the ferrous markers also have a correspondingly strong conductivity contrast (Fig. 2). Many of the grave marker responses appear to be regularly distributed. The random nature in some areas should not be seen as an area without burials or even originally without grave markers; no doubt many markers were removed by accident or intentionally. Those that are mapped give at least the impression of the grave locations and, where they are numerous and regularly spaced, an indication of grave locations and verification of cemetery planning.

Ground penetrating radar

The Mala Mini Mira system was selected for use over the survey area because of its near-surface detection range and high sampling density. Interpretation of the radar data is done with care, as extensive rodent burrowing activity over the survey area has produced anomalies that resemble responses from grave features. The highest number of grave responses have been delineated in the southwestern

Fig. 2. Magnetic and electromagnetic results (plotted white [low] – black [high]). From top left: A – fluxgate gradiometer (-10 to 10 nT); B – fluxgate gradiometer anomaly centres of mass; C – electromagnetic conductivity, HCP C1 (-3 to 8 mS/m); D – electromagnetic in-phase HCP I1 (-0.5 to 1 ppt)

end of the survey area, nearest to the chapel, oriented in parallel lines running NE–SW in direction, which correlate to archival mapping of grave orientation.

RESULTS AND CONCLUSIONS

Due to the differing results between the methods, a stand-alone method could not address the objectives of our project. For a holistic understanding of the results, we employed an integrated interpretation strategy that referenced associated grave responses with the archival burial plot. To resolve the complex responses from the magnetic and electromagnetic techniques, the analytical signal was calculated using open source software. These calculations migrated the broad anomaly responses back to a point source, which was determined by calculating the amplitude centre of mass (Fig. 2). These points were exported as shapefiles into ArcGIS, where a 0.5 m buffer was created around them. For the electromagnetic conductivity data, the association of these point sources with the burial plan were compared between all six datasets (three soil volumes for HCP and VCP orientations) and the associated greyscales. The ArcGIS Intersection tool was applied to compare where the different techniques show discrete anomalies associated with burial plots. The result of this integrated interpretation approach (Fig. 3) shows

Fig. 3. Summary interpretation based on different combinations of different techniques

that many of the graves have associated geophysical anomalies, but no graves were identified by all four techniques (earth resistance, fluxgate gradiometer, GPR, and electromagnetic conductivity). The magnetic and electromagnetic methods can be linked to the largest number of grave plots. However, most of the positive identifications relate to high amplitude grave markers, instead of detecting the grave cuts or coffins themselves.

Our results illustrate the complexity of characterising burials using ground-based remote-sensing techniques and substantiates the assertion that single techniques by themselves are unlikely to provide definitive statements on grave location. At High Royds Cemetery, applying an analytical integration strategy improved our understanding of the separate method results, both independently and in relation to one another. A more thorough understanding of the commonalities and differences between the disparate datasets, has led to a more holistic – and more confident – interpretation of the site.

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"Atypical" use of combinations of geophysical methods for archaeological heritage preservation in the Czech Republic

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KEY-WORDS: geophysical survey, non-destructive archaeology, archaeological heritage preservation, medieval siege camp, flood plain area, archaeology of castle parks and gardens

INTRODUCTION

The scope of long-term application of geophysical methods at the Institute of Archaeology in Prague is fully subordinated to ongoing or planned research and current archaeological projects. Separate funding of non-destructive research projects is rare and limited to threatened sites of recognized cognitive importance. In recent years, however, new applications of methods have been tested outside of big projects and with only limited funds (internal institutional plan AVOZ80020508, institutional support RVO67985912, regional cooperation R300021241). These applications have demonstrated the wider opportunities for monitoring less conventional archaeological situations and terrain which is difficult because of the ground relief or specific geological conditions.

GROUND CONDITIONS AND GEOPHYSICAL METHODS

The paper presents examples of geophysical monitoring or study of specific archaeological sites, monuments and terrain, documenting the different possibilities of the methods. In all of the case studies, it was necessary to apply more than one geophysical method, often producing different information depending on the actual conditions in the field and the type of archaeological situation. A five-channel magnetometer Magneto-Arch with fluxgate gradiometers FMG-650B (Sensys) was used for magnetic research. For geoelectric resistivity surveys the instrument used was a RM-15 (Geoscan Reseach), mainly in a Wenner probe array (A0.5M0.5N0.5B or A1M1N1B) and for profile radar measurements a Cobra-wifi II radar (Radarteam). Clearer and more probable interpretations of observed situations were possible thanks to a combination of methods and sufficient collections of archaeological material.

EXAMPLES OF RESULTS

Geophysical survey of a medieval siege camp

Siege camps are relatively specific archaeological sites with typical short-term and temporary usage, only in connection with a military event. From the point of view of prospection methods, it is a site with many probable metallic remains, disturbances, but with less probable presence of deeper situations. In many cases, the original ground relief has undergone change, having

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Fig. 1. Prague-Kunratice. Compiled new plan of the Hussite siege camp and magnetic map (Plan courtesy of the National Heritage Institute in Prague; total surveyed area approx. 0.91 ha; geophysical survey, R. Křivánek 2014)

been ploughed or afforested, some have been forgotten or are now inaccessible. Variously dated landscape changes also seem to be problematic for interpretation.

A new geophysical survey of the grounds of the Hussite siege camp in front of the conquered castle of Nový Hrad (1420/1421) in Prague-Kunratice was conducted as an experiment to see what kind of results can be achieved with non-destructive methods in a forested area. The remains of fortifications and the internal frame of provisional dwellings are still easily discernible on the ground. The survey was carried out in cooperation with archaeologists from the National Heritage Institute in Prague (Kypta and Podliska 2014). Suitable areas for magnetic and additional resistivity surveys were chosen in relation to the old archaeological probes from the 1950s and the ground topography. Linear magnetic anomalies inside the camp enabled demarcation of the built-up area with sunken dwellings (huts and tents, many with burnt materials or metals inside) and isolation of spaces with different function without sunken features (Křivánek 2014: Fig. 1). The combination of magnetic and resistivity results covering the perimeter fortifications distinguished different materials in the structure of the rampart nearest to the castle. The results also indicated activities outside of the bastions on the opposite side of camp. Geophysical results from different places within the camp confirmed the variable state of archaeological subsurface preservation.

Geophysical survey of sites situated in flood plain areas

Settlement typical of the many lowland areas of the Czech Republic is an intensive polycultural occupation, often closely linked to the presence of the most fertile soil. A relatively

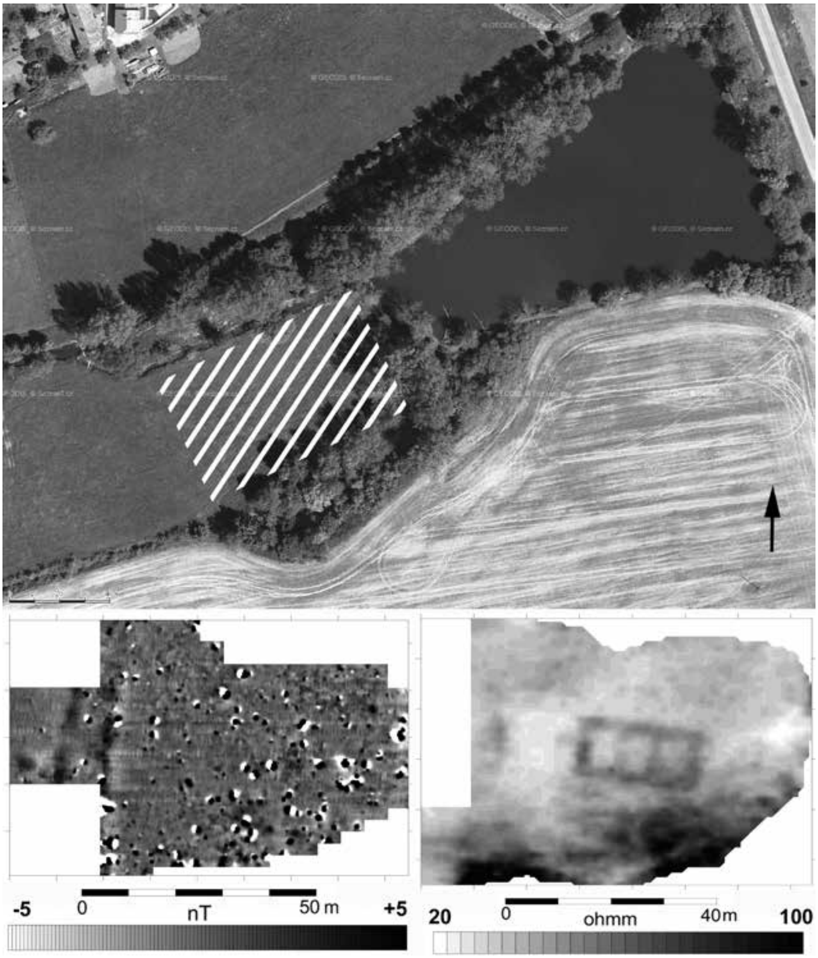

Fig. 2. Neumětely, district Beroun. Aerial image of the site with extinct stronghold (top) and the results of magnetic (bottom left) and resisitivity (bottom right) surveys (source: *http://www.mapy.cz*; surveyed area approx. 0.3 ha; geophysical survey, R. Křivánek 2014)

dense river network played an important role in the selection of a suitable area for settlement. Dramatic and repeated changes in water flows and land use have resulted in parts of settled areas being currently situated in repeatedly flooded areas, making geophysical prospection, not to mention archaeological investigation, hardly easy. Changes of ground water level, variability of sediments, soil erosion and variable accumulation processes can affect significantly the results of geophysical methods. A combination of geophysical methods is essential (without guaranteeing success).

A geophysical survey of an extinct medieval stronghold near Neumětely in central Bohemia (14th/15th century AD) provides an example of efficient combining of three methods (mag-

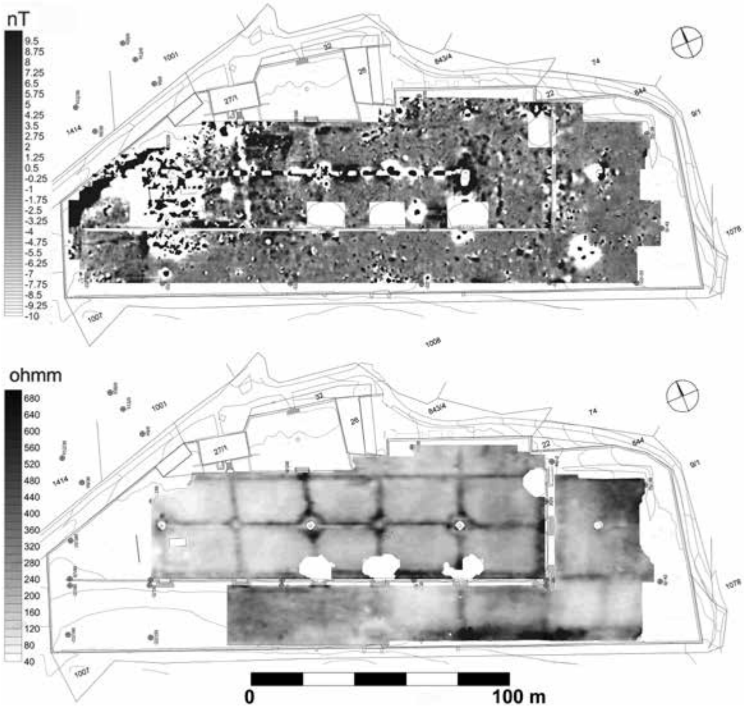

Fig. 3. Breda castle near Lemberk, district Liberec. Combination of a new plan of the gardens and the results of, respectively, magnetic (top) and resistivity (bottom) surveys (source: National Heritage Institute in Liberec; surveyed area approx. 1.15 ha; geophysical survey, R. Křivánek 2014)

netometry, resistivity, GPR). The stronghold was situated originally on an island set in a lake; later the site changed to a promontory jutting from the bank. A magnetic survey helped to identify the original water channel or ditch, but resistivity measurements isolated the subsurface remains of a structured building and the position of another site of stone collapse (Fig. 2). GPR profiles across the identified building verified the limited thickness and shallow depth of the preserved remains of the stronghold.

Geophysical survey of castle parks and gardens

There are several examples from the Czech Republic of the application of geophysical methods in the exploration of castles, but little survey work has been done on castle parks and gardens. In recent years, it has been possible to broaden the experience by cooperation with some departments of the National Heritage Institute. Different geophysical techniques had to be used to satisfy the different heritage goals.

The abandoned Breda castle gardens near the Lemberk castle in north Bohemia (second half of the 17th century–end of WWII) offers an excellent opportunity to observe the different possibilities and results of the applied geophysical methods (magnetometry, resistivity, GPR).

The magnetic survey results have confirmed the existence of a water distribution system with remains of fountains, but in the northern part it was possible to identify only high magnetic contamination with metals (modern greenhouse destruction). The resistivity survey results surprisingly revealed elements of an abandoned castle garden, the high resistivity anomalies being evidence for an extinct system of garden roads, and the low resistivity anomalies for former flower beds (Fig. 3). Some of the identified situations were probed in recent years for the purpose of verification (National Heritage Institute in Liberec, Tišerová). The profile GPR measurements were carried out during archaeological investigations to verify the depth of metal water distribution pipes, as well as the presence of other extinct buildings or subsurface remains in the castle garden.

CONCLUSION

Geophysical methods are used in the long-term for monitoring settlements, enclosures, hillforts, burial cemeteries or production areas, especially in open (mainly agricultural) land. There is a much greater variety of different types of archaeological situations or anthropic activities, as well as the specific conditions of their preservation in the landscape. Some of these specific activities can also be identified in the geophysical results, but one should be aware of a potentially greater margin for error. The application of a single geophysical method may and/or may not achieve the desired result. The success of the prospection grows when combining several appropriate methods and techniques adequate to current conditions on the ground and the expected type of the surveyed situation. In all the examples of geophysical measurements, it was important to choose a suitable period in the course of a year for specific survey methods (the quality of the results of some geophysical methods was dependent on climatic factors, vegetation, moisture conditions on site). Among the positive applications of prospection methods one should mention cases of surveys under difficult ground conditions, in terms of both geology and ground relief and cover, e.g., mined areas with changed landscape, forested areas with specific production activity, sites situated on geologically complex bedrock or on differently sloped terrain). Geophysical methods in archaeology may still turn out to have a broader application than currently used.

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An integrated geophysical survey at the Aizanoi archaeological site (Turkey)

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KEY-WORDS: archaeological prospection, Aizanoi archaeological site, ground penetrating radar (GPR), magnetometry, geophysical data integration, principal component analysis (PCA)

INTRODUCTION

The success of geophysical prospection methods applied on archaelogical sites to detect and identify subsurface structures depends on the nature of the features themselves in terms of their physical and geometric properties, environmental effects such as soil conditions and operational factors such as the sensivity of equipment and the experience of researchers. Consequently, to obtain reliable and complemantary results, it is recommended that multiple geophysical methods be applied using an integration approach for archaelogical geophysical field surveys (Weymouth 1986; Neubauer *et al.* 1997; Piro *et al.* 2000; Clay 2001). Two kinds of methods, qualitative and quantitative, are used. The qualitative approach includes depicting the location of cultural features and interpretation of combined maps generated by different geophysical methods. In contrast, quantitative approaches mostly involve mathematical and statistical solutions forthe integration of integration of the different datasets (Kvamme *et al.* 2006). The aim of this work is to apply mathematical and statistical integration approaches by using different geophysical data obtained from archaeological prospection. To achieve this, synthetic digital images were generated to correlate the integration approaches, then these processes were applied to field data from ground penetrating radar and magnetometry prospection carried out on the Aizanoi archeological site in Kutahya, Turkey.

GEOPHYSICAL METHODS AND DATA PROCESSING

In this study, ground penetrating radar (GPR) and magnetometry methods were conducted on the selected archaeological site. For GPR measurements, a GSSI SIR 3000 equipped with a 400 Mhz antenna was employed with a profile interval of 0.50 meters. Data processing was done using GPR-Slice V 7.0 (ground penetrating radar imaging software, Goodman 2010). For the data procesing, post processing pulse regaining, DC drift removal, data sampling, bandpass and backround removal filtering were applied on the radargrams; filtering and image-processing techniques were then applied on generated 2D time slices. For the presentation, an overlay analysis and 3D isosurface rendering were used.

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For the magnetometry measurements, the caesium optically pumped pumping gradiometer Scintrex SM5 - NAVMAG was used rather than the traditional total-field magnetometer. Magnetic measurements were collected along parallel profiles spaced at intervals of 0.5 meters. A despiking procedure was then applied to remove the spikes caused by localised ferrous anomalies and then the reduction to the pole process was applied on magnetometry data for two sensors. The next signal processing technique to be used was cross-correlation and auto-correlation to estimate the location, orientation, depth range and the susceptibility contrast of an anomalous body. During autocorrelation procedures, theoretical anomalies of synthetic models were calculated using the Talwani equations for different depth variations and different susceptibility variations by using specific software (Piro *et al.* 2000).

INTEGRATION APPROACHES TESTED ON GEOPHYSICAL DATA

As indicated before, there are many different kinds of geophysical data integration approaches. In this study, the mathematical approaches of sums and products and the statistical approach of principal component analysis (PCA) were applied for the integration process. These integration approches were first tested on synthetic digital images before application to field data. Then the same approaches were applied to 2D magnetic maps and 2D GPR time slices, which were obtained from the same unit grids at the Aizanoi archaelogical site. All 2D data sets were normalized prior to being used for integration.

For both integration techniques, data were examined in two different ways. One of these is, considering the depth range information obtained from cross-correlation of magnetometry data, one magnetometry image and three different GPR time slices were used. Then the same integration processes were applied to one magnetometry image and one GPR time slice,which was generated as overlay of three GPR time slices, again considering the depth information obtained from the cross-correlation results of magnetometry data.

RESULTS AND CONCLUSION

Initially, the geophysical data were examined individually by referencing with archeological maps and information obtained from archaeologists working at the Aizanoi archaeological site. Anomalies related to possible walls, roads or foundations were identified in the study areas of the Zeus temple, bath-palaestra complex, borsa-macellum and necropolis. In order to have clearer and detailed information about these anomalies, integration techniques were applied to some parts of the geophysical field data from this site. The results of all integration approaches provided very important and different details about the anomalies related to archaeological features. By using all the applications, one can generate images that provide complementary information on the archaeological relics underground.

ACKNOWLEDGEMENTS

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Magnetic prospection of areas of medieval and prehistoric ore smelting around Miasteczko Śląskie (southern Poland)

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KEY-WORDS: magnetic prospection, soil magnetometry, geochemical analysis, mining and smelting processes

The exploitation and smelting of iron, silver and lead ores in the area of Tarnowskie Góry and Miasteczko Śląskie (Upper Silesia, Southern Poland) has been documented historically since the early Middle Ages (Molenda 1969). The present study aimed at finding archaeological traces of former mining and smelting activity, prescreening archaeological excavation with a combined magnetic prospection and geochemical study. The study was performed on arable soils, meadows and forest soils, as well as on neighboring peat bogs and a local dune surrounded by peat bogs located at Żyglinek, a small village (actually part of Miasteczko Śląskie). The village was founded before 1065 and its name translated into "the settlement of a lone man smelting iron ore" according to the historian Nehring to Sceglino. The magnetic prospection was performed by measurement of magnetic susceptibility (κ) using a MS2D Bartington loop sensor and magnetic gradiometer system Bartington Grad601. The Grad601 gradiometer was used only in an open area where field conditions were favorable for the application of this system. Using Surfer 8 software to plot the data, maps of κ distribution were produced and local soil magnetic anomalies were identified; additionally, 30 cm deep cores were collected using a HUMAX core sampler to increase the penetration depth and to produce 3D maps. Vertical magnetic susceptibility in the cores was measured using a MS2C

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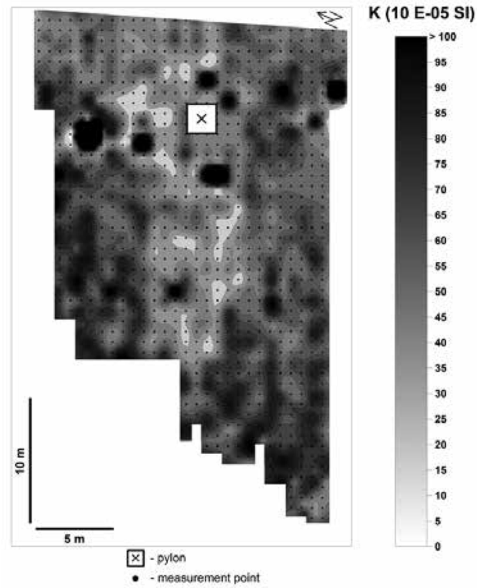

Fig. 1. Spatial distribution of magnetic susceptibility (κ) as a result of MS2D Bartington measurements on the dune

Bartington sensor and magnetic particles from the layers of enhanced κ values were magnetically extracted. Microscopic and SEM analysis of the magnetic extract revealed, in magnetically enhanced layers, the presence of charcoal, ash and ore as well as small ceramic artifacts.

A denser measurement grid was applied on the dune surface where 1083 measurements were carried out in an area of approximately 800 m$^{2.}$ The map of κ value distribution (Fig. 1) produced for the dune near Żyglinek in 2013 revealed the presence of many local magnetic anomalies, pointing to an accumulation of anthropogenic particles. The highest κ values oscillate around 400 $\times 10^{-5}$ SI magnetic units. These anomalies were interpreted as reflecting a concentration of Technogenic Magnetic Particles (TMPs) connected with postindustrial dust deposition. In samples collected from the dune material, beige, dark brown and almost black sand lumps bonded by clay and organic matter and charcoal particles were found. Both sand lumps and charcoal particles exhibited a higher magnetic susceptibility than basic sand material and their concentration created additional local magnetic anomalies (50–100 $\times 10^{-5}$ SI units). Geochemical analyses (EDXRF) of samples taken from the dune and peat cores revealed a higher share of elements like Fe, Ti, Pb, Zn, Ag, Cd, Ni, Cu and Bi. Radiocarbon dating of the charcoal particles and organic materials associated with these sand lumps determined their age at 6821 to 6592 BC, whereas the other lumps collected at the foot of the dune were dated 5615 to 5475 BC. Archaeological excavations to provide feedback on these results brought to light flint tool fragments and flakes, as well as other artifacts connected with ore smelting in the Mesolithic, which was in itself an archaeological sensation in the region.

Additionally, two 100 cm deep peat profiles were taken from peat bogs surrounding the area of historical exploitation. Both magnetic susceptibility and trace element content was measured for every 1 cm of peat profile. Geochemical analysis was performed with AAS methodology after sample extraction in an *aqua regia* solution and with the EDXRF method. It was found that the highest enhancement of κ values in peat profiles located close to Żyglinek was observed in a peat layer dated to about AD 1000. The maximal κ corresponds to a high concentration of Ag (2.39 mg/kg), Cu (48.45 mg/kg), as well as Zn (2517 mg/kg), Pb (4880 mg/kg) and Sn (26.86 mg/kg). The chemical pollution corresponds to the presence of charcoal particles.

Chemical and magnetic measurements are ongoing in the study area, but the preliminary results have already shown that soil magnetometry supported by geochemical analysis is a very effective tool to improve the efficiency of archaeological research identifying human activity thousands of years in the past.

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Archaeological geophysics in the Shahrizor plain (Iraqi Kurdistan)

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KEY-WORDS: magnetic prospection, Chalcolithic, Bronze Age, Shahrizor plain, Kurdistan

ARCHAEOLOGICAL RESEARCH BEFORE THE FIRST GULF WAR

An expedition to survey and map some test sites for an archaeological research project (DFG MU3354/1-1) in Kurdistan was undertaken by the Directorate of Antiquities in Sulaymaniyah province in cooperation with the Ludwig-Maximilians University Munich.

The Shahrizor plain is a valley (covering roughly 1300 km^2) in the piedmont of the Zagros Mountains (Fig. 1) adjacent to the Iranian border. It extends between the cities of Arbat and Halabjah southeast of the metropolis Sulaymaniyah (1.5 million inhabitants). For decades the wider region was distressed by the war between Iran and Iraq, as well as by internal political strife within Iraq. Little archaeological research was carried out in the region apart from some archaeological salvage excavations during the construction of the Durband-i-Khan dam in the late 1950s and early 1960s

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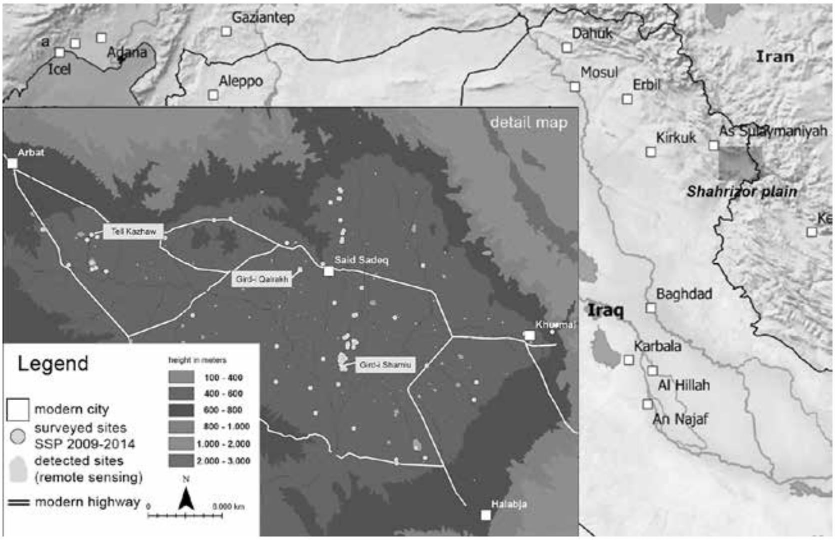

Fig. 1. Map of Iraq and the Shahrizor plain marking sites subjected to magnetic prospection

Fig. 2. Gird-i Shamlu: aerial image of the site cluster and magnetic map of the low mound of Shamlu. Caesium-magnetometer Scintrex, Smartmag SM4G-Special, dynamics ± 10 nT in 256 grey-scales, sampling rate interpolated to 25 x 25 cm, 40 m grid

(Directorate General of Antiquities Baghdad 1960; 1961). Unfortunately, most of the excavation reports from this period have been lost, resulting in limited knowledge of the region's antiquity.

The region appears for the first time in historical cuneiform sources in the 3rd millennium BC; it is referred to as the kingdom of Simurrum, contested in several wars between Mesopotamian rulers. When the kingdom reached its climax around 2100 BC, it encompassed an area that extended from the Shahrizor to the Ranya plain (Potts 1994; Frayne 2011; Mühl 2013). After a gap in the historical records, it resurfaced in the middle of the 2nd millennium BC as Zabban of the Assyrian texts dated to the 12th century BC. In the Neo-Assyrian period (1st millennium BC), the Shahrizor plain and the territories adjacent to it were incorporated into the Assyrian state as a province called Mazamua/Lullumu (Radner 2008).

RECENT RESEARCH

Its rich oil fields have allowed the region to experience an economic boom since the end of the last Gulf war. Sulaymaniyah presently counts among the fastest growing cities in the world. This poses a big challenge for local authorities, as they are occupied both with the fast developing infrastructure, which threatens heritage sites, as well as continually growing amounts of information on newly discovered archaeological sites. In 2006, archaeologists were again allowed to work in the area and in 2009 a Kurdish–German cooperation was established, setting its goals on mapping and surveying archaeological sites by analyzing aerial and satellite imagery, as well as by archaeological field survey. About 300 sites were detected, of which 80 have been investigated through intensive field survey (Mühl 2010; Altaweel *et al.* 2012); soundings were made at two tell sites (Nieuwenhuyse *et al.* in press) and three sites were prospected by magnetic survey.

SURVEY RESULTS

The three mapped sites were Tell Kazhaw (approx. 1.3 ha), Gird-i Shamlu (approx. 4 ha) and Gird-i Qalrakh (approx. 15 ha) (Fig. 1). Surface pottery collections have dated the first site, Tell Kazhaw, to the 4th and mid-2nd millennium BC. The second site, known as Gird-i Shamlu, is a little later, its oldest remains being dated to the beginning of the 3rd millennium BC; remains from the 2nd millennium BC are known from Iraqi excavations carried out in 1960 (Janabi 1961). The third site, called Gird-i Qalrakh, is one of the highest settlement mounds in the Shahrizor plain. It was first settled in prehistoric times and is presumably covered by sizeable deposits from the 1st millennium BC.

Objects collected from the surfaces of Gird-i Qalrakh, Gird-i Shamlu, and Tell Kazhaw show that the ancient settlements did not undergo any major changes. However, Tell Kazhaw, where late historical remains (Islamic and Ottoman period) were concentrated northeast of the tell site itself, may be an exception in this regard.

The magnetic measurements revealed formerly unknown archaeological features at Tell Kazhaw and Gird-i Shamlu. The archaeological site of Gird-i Shamlu appears to be strongly disturbed by military construction, grenade shrapnel and iron waste. However, also with respect to the complexity of such a multi-layered settlement, it was decided to concentrate the magnetic survey on the neighboring mound, which represents the ancient settlement's early 3rd and late 2nd millennium northeastern extension

Fig. 3. Tell Kazhaw. Aerial image fused with magnetic data. Caesium-magnetometer Scintrex, Smartmag SM4G-Special, dynamics ±10 nT in 256 greyscales, sampling rate interpolated to 25 x 25 cm, 40 m grid

(Fig. 2). This part of the site rises 3–4 m above the surrounding terrain and covers an area of approx. 120 m by 100 m, but in order to gain as much information as possible, the survey area was enlarged to approx. 160 m by 160 m. The site lies on the bank of a streamlet, which has created a swampland to the west and between the two settlements. This process was supported by the nearby Darband-i Khan Dam Lake, as it has caused a dramatic rise of the ground water table. The magnetic data reveals that this mound was densely settled. Occupation seems to have been especially high in the southern part of the surveyed area, as it is dominated by small-scale linear features that could indicate small huts or wooden structures. The investigations of the northern part of the mound summitrevealed ground plans of large houses that probably rested upon limestone foundations. Traces of riverbeds and streamlets were found in the neighborhood. This supports the thesis that such ancient settlements were usually established near springs and headwaters. Indications for late 3rd millennium BC irrigation in a more humid local environment were already discovered in the course of environmental investigations in the Shahrizor plain (Marsh and Altaweel in press).

The other test site inspected was Tell Kazhaw. Except for the extremely steep slopes, almost the entire area of the mound including its western extension were investigated (Fig. 3). The mound was surrounded concentrically by settlement structures and by a circular ditch, which measures about 120 m in diameter. Further settlement remains and traces of monumental architecture were discovered in an elevated area in the northern part of the tell.

The remains of the third site, Gird-i Qalrakh, are still visible south of the site. Unfortunately, no structures could be observed in the investigated area between the mound and the city wall. This area may have been used for livestock or as a refuge space for the population from the neighboring countryside during times of political instability. More investigations are needed here, covering a larger surface.

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Large-scale high-resolution GPR and magnetic prospection in West Jutland, Denmark

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KEY-WORDS: magnetometry, GPR, aerial archaeology, Iron Age, Viking Age, medieval period

In the last 30 years aerial archaeology has not been widely used in Danish archaeology. The ongoing project "An aerial view of the past — aerial archaeology in Denmark (2009–2018)" is the first regular work with aerial archaeology in Denmark. Especially in the region of West Jutland, repeated flights over the area have resulted in the discovery of hundreds of new archaeological sites (Helles-Olesen *et al.* 2011). Even though aerial archaeology works very well under the present conditions, new

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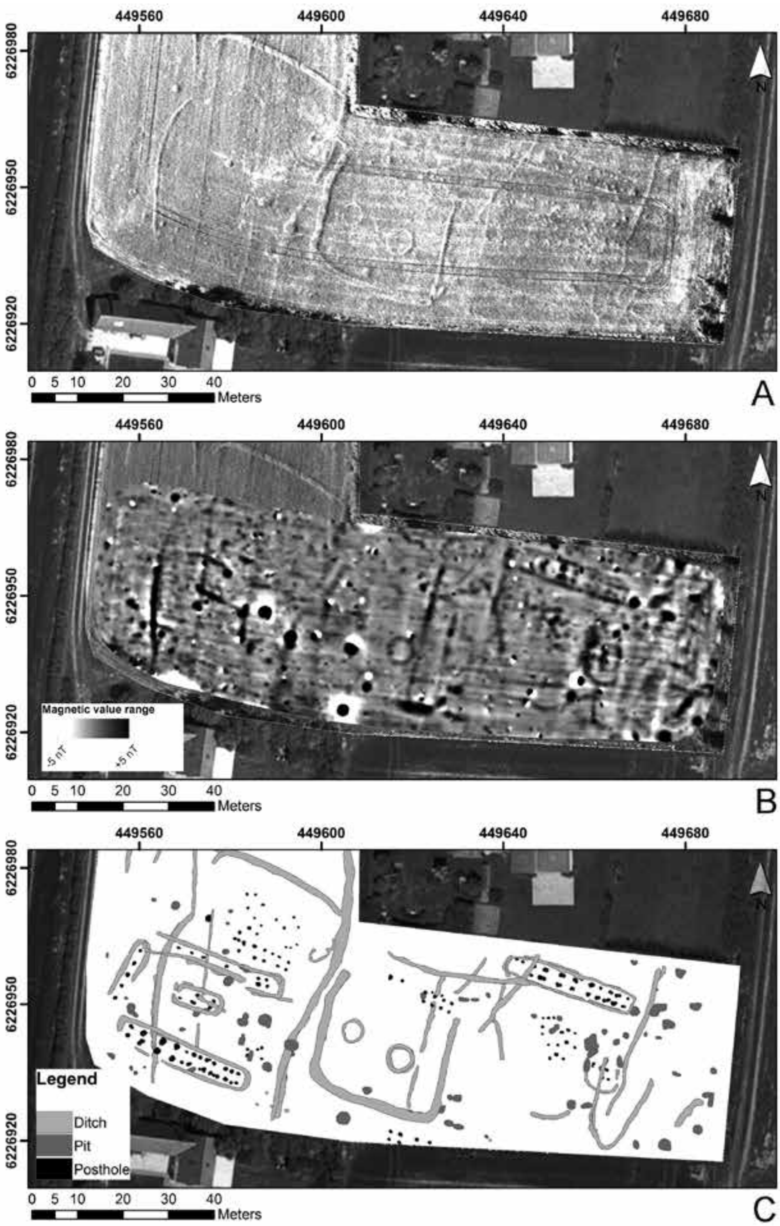

Fig. 1. Vesterager: A – aerial photography showing several remains of longhouses, fences, ditches and pits; B – magnetic data of the same area revealing a high grade of conformity with the aerial image; C – combined archaeological interpretation of aerial images and magnetic prospection results

research avenues have emerged as a result of recent technological and methodological developments in large-scale, high-resolution geophysical prospection methods and the potential arising from the complementary use of both remote sensing and ground-based geophysical techniques. The success of this integrative approach in this part of Denmark is attributable to very favourable environmental conditions, since West Jutland is almost entirely covered by glacial sands, deposited along the melting glacier at the end of the last ice age. The very uniform sandy soils and the flat agricultural landscape offer ideal conditions for aerial archaeology, as well as for large-scale motorized geophysical prospection. Finally, high contrasts between archaeological structures and the homogenous soil matrix turn crop- and soil-marks into a perfect image of buried archaeology.

In the summer of 2014, the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro) joined the ongoing aerial archaeological research project mentioned above, conducted by Holstebro Museum, the added goal being to investigate the complementary use of GPR and magnetic prospection in a pilot study. Over the past five years the LBI ArchPro has gathered considerable experience in implementing large-scale high-resolution geophysical–archaeological prospection surveys in Scandinavian countries and has focused, as one of its research objectives, on the detailed documentation and investigation of Viking Age landscapes (Trinks *et al.* 2014; Gabler *et al.* 2013). Among these case studies are the well-known Viking Age sites of Birka-Hovgården and Uppåkra in Sweden, and Oseberg, Gokstad and Borre in Norway. In order to broaden the focus to include Danish Viking Age and early medieval sites, five test areas at Stadil, Skarum Mølle, Vesterager, Rysensten and Norreby, all located within a 50 km radius of the town of Ringkøbing, were chosen for a pilot study in West Jutland. Thanks to extensive aerial archaeological prospection surveys conducted by experienced archaeologists from Holstebro Museum, solid archaeological reference data and considerable experience already existed for all of the chosen sites.

From August 31 to September 6, 2014, a team from the LBI ArchPro, supported by archaeologists from Holstebro Museum, visited West Jutland for the first campaign of fieldwork. Three different motorized survey systems were applied: a 16-channel 400 MHz MALÅ Imaging Radar Array (MIRA) GPR system with a resolution of 8×8 cm, one 6-channel Sensors & Software SPIDAR GPR array with a spatial sampling resolution of 25×5 cm, and a motorized Fluxgate gradiometer array (Foerster) with a measurement resolution of 25×10 cm. Approximately 37 ha of magnetic prospection data and approximately 22 ha of high-resolution GPR data were collected within five days of fieldwork. The survey conditions at this time could be described as ideal. The fields were harvested and easily accessible, and the weather conditions were good. As expected, the potential of the magnetic prospection method was proven. Sandy soils display a homogeneous, low magnetic signature and present an ideal soil matrix for the detection of embedded archaeological features, supported by the large contrast between magnetic backfill and the surrounding material. Likewise, the well-drained sandy soils in combination with the dry spell that preceded the fieldwork created excellent conditions for the GPR surveys. GPR velocities of up to 16 cm/ns and signal penetration depths of up to 3.5 m, instead of the commonly encountered 1.5–2.0 m, came as a positive surprise for the prospectors.

The paper presents an overview of the project area and detailed results from two selected sites, Vesterager and Rysensten. The rather small site of Vesterager (0.5 ha total investigated area) is a farmstead dating to the Late Iron and Viking Ages. The remains of several longhouses and pits, enclosure fences (ditches and postholes), already known from aerial images, were confirmed by the geophysical prospection (Fig. 1). There was a high level of agreement between anomalies recorded by geophysical prospection and features detected by aerial archaeology, but also several previously unknown pits and ditches were discovered. The orientation of the newly detected ditches indicated several superimposed settlement phases. High-resolution GPR surveys revealed numerous further circular ditches and other settlement structures, like pits and postholes. Furthermore, the dissolution of seemingly larger individual features into several smaller ones (e.g., ditches that are composed of very closely spaced postholes) has led to a substantial increase in detailed knowledge about the site.

The medieval settlement site of Rysensten is the largest of the single sites surveyed within this pilot study, covering some 20 ha of magnetometer and 12 ha of GPR data. The newly collected data revealed a large number of different archaeological features. Many longhouses and other settlement structures were already known from aerial archaeology. Many of these features were confirmed by the results of geophysical prospection and several new features complementing archaeological knowledge were discovered. Especially in the relatively wet parts within the survey area, aerial imagery had difficulty in detecting archaeological features. A more differentiated picture of the settlement structure is to be expected based on several clusters of observed settlement traces distributed over the entire surveyed area.

The picture observed in all the other surveyed areas was much the same. In general, one noted a large degree of conformity of the detected features between the individually applied methods. However, in several cases structures could be seen only in one of the available datasets. While the sedimentological conditions have proven to be very favourable for aerial archaeology and magnetometer prospection, the three-dimensional GPR data demonstrated several issues and showed that actually the assumed homogeneous soils were composed of diverse sedimentological layers within the extensive sand deposits, formed by the periglacial processes. In many cases very complex beddings, massive ice wedges and palaeochannels became visible in the large-scale, high-resolution GPR data, complicating the detection and interpretation of present archaeological features. Further archaeological and geoarchaeological research (targeted excavations and corings) would be desirable in order to derive a better understanding and interpretation of the combined prospection results. Concluding, it can be said that the demonstrated complementary application of a diverse range of prospection methods and in particular their integrated archaeological interpretation has led to considerable new, detailed archaeological knowledge of the archaeological sites under investigation.

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Geophysical mapping of a classical Greek road network: a case study from the city of Elis, Peloponnese

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KEY-WORDS: classical Greek city, Elis, town planning, electromagnetic induction, magnetometry

INTRODUCTION

Many ancient Greek cities are characterised by a regular orthogonal road network. These roads are ideal targets for geophysical investigation mainly due to their extensive geographic extent that makes them challenging to define by excavation. Geophysical mapping of these features will contribute to understanding ancient cities as it can provide considerable information about their geographic extent, spatial arrangement and urban dynamics. Large scale multisensor magnetic and electromagnetic induction methods have been used to map the ancient Greek city of Elis in the Peloponnese (Greece). This work complements other investigations that have been undertaken, employing other methods that include the interpretation of high-resolution satellite imagery (Donati and Sarris forthcoming).

ARCHAEOLOGICAL SITE BACKGROUND

The city of Elis is located on the banks of the Peneios River near ancient Olympia in the Peloponnese. It is particularly known in connection with the Olympic Games, as it acted as a training base prior to the competition, overseer of the sanctuary of Zeus and the administrator of these events (Yalouris 1996). Elis is also remarkable for exerting significant political control over neighbouring communities from the 6th century BC (Roy 1997), despite not being established as a substantial city until 471/0 BC (Roy 2002). The site has been the focus of archaeological investigations since 1910 by the Austrian Archaeological Institute, the Archaeological Society of Athens and the 7th Ephorate of Prehistoric and Classical Antiquities (Andreou and Andreou 2007). To date, the boundaries of the city are poorly defined and most excavation and geophysical prospection have been focused on an area immediately surrounding the agora (i.e., Tsokas *et al.* 2012).

METHODS

Geophysical data was collected during a field campaign in November 2014 (Fig. 1). Previous work on similar sites had suggested that electromagnetic induction and magnetometry were the methods best suited to investigate the buried road networks at Elis. Electromagnetic induction data was collected

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Fig. 1. WorldView Satellite image of Elis outlining areas covered with magnetic and electromagnetic geophysical mapping methods

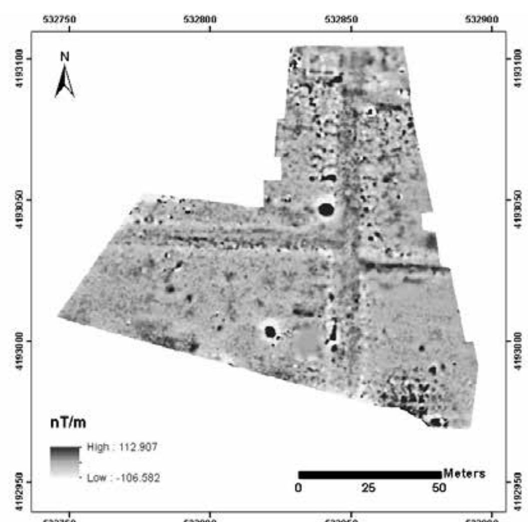

Fig. 2. Results from a Sensys MX V3 Multi-sensor gradiometer survey of the area south of Elis

using a Geophex GEM-2 and a CMD Miniexplorer. In the case of the GEM-2, multiple frequencies were used to capture the data (89430, 43350, 21230, 10230 and 4950Hz). For both instruments, the in-phase and quadrature response was calibrated to generate conductivity and magnetic susceptibility values using the procedures described by Thiesson *et al.* (2014). Magnetic gradiometer data was collected with a Sensys MX V3 with eight fluxgate sensors. Gradiometer data was processed using custom-made Matlab scripts. All the data were displayed and interpreted in ArcGIS. Accurate positioning for both surveys was provided by a suite of Javad Triumph-1 differential GPS.

RESULTS

The road network at Elis was identified using magnetic susceptibility, conductivity and magnetic gradiometer data. It was dominated mainly by N–S and E–W running roads, extending at least one kilometer beyond the central agora to the south. The intersection of the latitudinal with the longitudinal streets was sometimes slightly offset, so that the E–W roads do not meet. This mirrors the arrangement seen at other classical Greek cities, such as at Mantinea and Stymphalos, also in the Peloponnese. Some streets of different orientation appear to exist as well, particularly in the eastern part of the site, which slopes steeply.

The magnetometic results mapped the road network, the road edges appearing as particularly distinct features (Fig. 2). Between the roads there is a plethora of small gradiometer anomalies, many of which can be deemed to be of archaeological origin given the rich material culture record revealed by excavations at Elis and their spatial organisation. Magnetic data collected in the far southern part of the site have revealed many smaller anomalies and the roads are less well defined. This area is in the active floodplain of a stream and may have been subject to frequent flooding.

The road system is also mapped by magnetic susceptibility values, particularly at the 43350, 21030 and 10230 Hz frequencies. Building architecture is visible in some magnetic susceptibility results, but is not generally well resolved (Fig. 3). Other methods employed as part of related investigations, such as resistivity and ground penetrating radar, were far more successful at resolving these features. Conductivity values were able to map road networks in some locations, but these features were more poorly defined and appeared wider. The anomalies that defined these features can be either more or less conductive than the surrounding soil in different parts of the survey area. The presence of electricity power lines in two of the EMI survey areas interfered with the quadrature and in-phase responses at all frequencies, rending the data uninterpretable within 40 m of this feature.

CONCLUSIONS

Electromagnetic induction and magnetometry proved effective as a means of mapping the road network of areas of the classical Greek city of Elis. The results demonstrate the effectiveness of this methodology for investigating the spatial organisation and extent of ancient cities.

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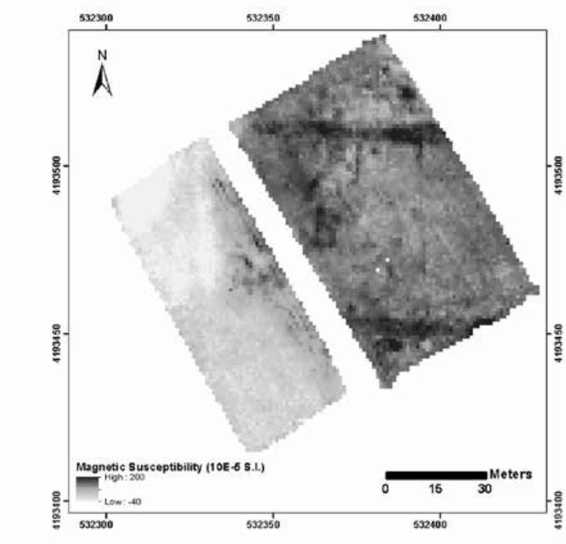

Fig. 3. Results from a 10230 Hz frequency magnetic susceptibility survey collected with a GEM-2 electromagnetic induction instrument from an area southwest of Elis

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Uncovering a Bronze Age landscape. A case study from Krotoszyn Forest (Poland)

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KEY-WORDS: woodland, barrows, Light Detection and Ranging, Airborne Laser Scanning, geophysics, magnetometry, excavations

Several research projects have been carried out since 2007 in the area of Krotoszyn Oak Forest (*Dąbrowy Krotoszyńskie*) in the south of the Wielkopolska region (Kneisel *et al.* 2010; Jaeger, Pospieszny 2011a; 2011b; Czebreszuk *et al.* 2013; Jaeger *et al.* 2014). Their primary goal was to identify cultural landscape relics from the Bronze Age, preserved by 150-year-old oak forests, growing on Pleistocene and moraine sediments and covering an area of about 40 km^2, protected today as a "Natura 2000" reserve. Such forested zones survived radical landscape transformations caused by rapid industry and farming developments starting from the 19th century. Today they are the only places where one has a chance to encounter prehistoric and early historic archaeological monuments in well-preserved form. The forests near the town of Krotoszyn are well known to prehistorians because of the outstanding discoveries made in 1923 and 1924 (to a smaller extent also in 1965, unpublished) at the barrow cemetery in Smoszew site 1 (Kostrzewski 1924), dated to the Middle Bronze Age (approx. 1550–1300 BC).

A search of the archival data at the start of the project brought extensive information produced by surveys and excavations carried out from the 1960s. Next, a large fragment of the forest complex (62.29 km^2) called the Krotoszyn Forest was scanned using ALS/LiDAR technology, with density of 4 points/1 m^2 and Full-Waveform Mode. The captured cloud of points was processed in SAGA GIS 2.0.7 software. Several functions were used to detect archaeological monuments, including analyses of lighting (Analytical hillshading) and terrain geomorphometry (Slope, Slope height and Normalized height). As a result 176 monuments were registered; these were subjected later to archaeological verification in the field and documentation. All in all, 124 barrows hypothetically dating to the Bronze Age were identified, as well as less numerous features from other prehistoric and historic periods, like early medieval strongholds and modern military installations (Fig. 1: A). The diameters of the burial mounds varied from 15 m to 20 m. A photographic and descriptive documentation was prepared for each barrow. The data was integrated in a relational database.

In selected parts of the forest, a geophysical prospection was carried out, followed by coring and small-scale excavations (partly destroyed barrow 15 at the cemetery in Smoszew site 1; Fig. 1: B) to collect further information about the burial mounds and their environs. The surveys were made using a fluxgate gradiometer (Bartington Grad601-1), data was collected in

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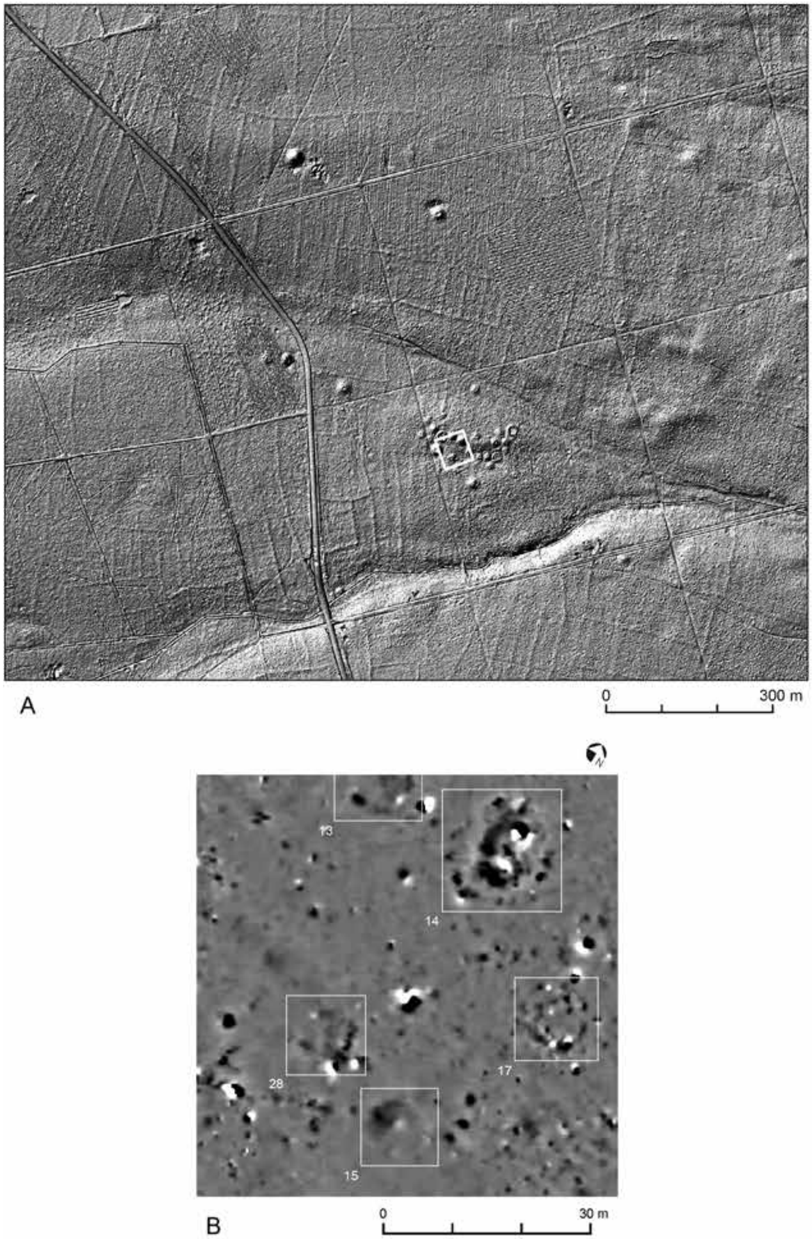

Fig. 1. A – fragment of an ALS-derived DTM of Krotoszyn Forest (shaded map relief); scattered as well as clustered barrows are clearly visible; B – fragment of a geophysical image of the cemetery at Smoszew site 1 (dynamics -10/+10 nT); numbers indicated of prospected barrows (white boxes)

parallel mode with a sampling interval of 0.25 m along transects spaced 0.5 m. Data processing was performed using Geoplot 3 and Surfer 8 software.

The results of fieldwork investigations revealed that the mounds covered complex stone structures, consisting of an outer ring or rings (usually 9 m to 21 m in diameter) and a central core raised above a rectangular grave chamber, placed at the prehistoric ground level. Excavations indicated that the main source of magnetism were the erratic boulders and pebbles of high magnetic susceptibility. They contrasted strongly with the mounds built of sands and clays. All graves unearthed since the 1920s were poorly furnished with small bronze objects (daggers, pins, spirals) and ceramic vessels (pots, vases, bowls). The latter, often fragmented, could cause small magnetic anomalies, together with numerous lumps of charcoal found in various parts of the barrows. The geophysical survey covered also the spaces between the tumuli. Surprisingly, almost all magnetic anomalies detected were caused by shallow lithology, including buried erratic boulders (confirmed by excavations and drillings), and large archaeological features of increased magnetic susceptibility seem to be absent. Numerous magnetic dipoles represented metal trash, like steel food cans, left by previous excavators.

The application of ALS/LiDAR and geophysical survey, combined with excavations, coring and revision of old excavations and surveys reports, brought comprehensive and detailed information about the remains of the Bronze Age landscape, especially the barrows. Accordingly, it was possible: 1) to identify the number of prehistoric and historic monuments, including burial mounds, 2) to recognise the state of preservation and internal structure of the latter and 3) to confirm a reoccurrence of structures typical of Middle Bronze Age monuments, as well as 4) to explore their variability and 5) to calculate the original size of the barrows based on the diameter of the stone rings. The latter is of particular importance considering the erosion and devastation that has transformed the mounds over the centuries. In other words, any attempts at characterising and interpreting the dimension of barrows, e.g., in temporal or socio-ideological terms, had been unjustified before the application of geophysical methods. It should be emphasized that drilling and small-scale but thorough excavation of carefully selected barrows, together with a reevaluation of archival information, enabled a realistic interpretation of the results of the non-invasive part of the research.

Elements of the research were funded by the National Heritage Board of Poland, the Polish National Science Centre, and Krotoszyn District. The produced database is now used as an effective tool for both further scientific investigations and archaeological heritage management in the region.

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Visualizing an integrated landscape through ground-based LiDAR, geophysical archaeology, and archaeological excavation

Michael Rogers[a] and Scott Stull[b]

KEY-WORDS: 3D laser scanning, ground-penetrating radar, magnetometry, earth resistance, integrated landscape, Colonial America

INTRODUCTION

The method of 3D laser scanning (*aka* ground-based LiDAR) provides a new way of digitally connecting above-ground and below-ground imaging, acquired through ground-penetrating radar, magnetometry, and earth resistance methods (Rogers 2014). A multi-year project is investigating pre-American Revolutionary War era house forts in the Mohawk River Valley west of Albany, New York (Stull, Rogers, and Hurley 2014). During the 18th century the Mohawk River Valley was New York's colonial frontier (Venables 1967: 7). The area was being settled through British colonial expansion, Dutch colonists, and Palatine Germans (Kammen 1975: 177–178; Otterness 2004: 71) amidst villages of the Mohawk Nation of the Haudenosaunee (Iroquois) confederacy. The threat of attack or invasion by the French based in western New York and Canada, as occurred in the end of the 17th century as far east as Schenectady (Kammen 1975:143–145), resulted in the construction of forts and fortified houses.

In the mid 1800s two fortified houses were built about 25 miles apart on the north side of the Mohawk River. One was Fort Johnson, built by William Johnson, later Sir William Johnson, Superintendent of Indian Affairs for the Northern Region. The second was built by Johannes Klock, a German-Dutch trader, and the house is referred to as Fort Klock. Both structures were fortified houses of stone, built to display a specific status in this mixed social context, and served as strong points for defending the residents and neighboring settlers in case of attack. Despite their functional similarity, date of construction

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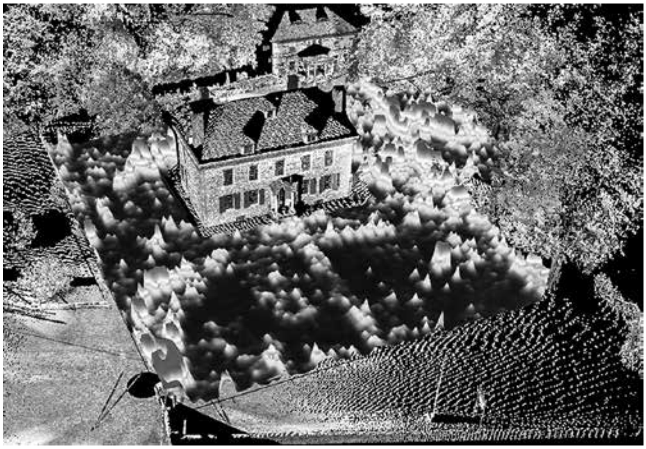

Fig. 1. Integrated landscape view of the Old Fort Johnson National Landmark site combining 3D laser scan with results from GPR analysis at ~0.35 m to 0.42 m below the surface. The GPR slice is shown with the z-axis representing reflection amplitude

and nearby location, these two houses are markedly different in appearance and spatial organization. The houses were built to create a cultural identity for each owner and those cultural identities were quite different (Stull *et al.* 2014).

DATA COLLECTION METHODS

A ground-penetrating radar survey was conducted using a Geophysical Survey Systems, Inc. SIR-3000 ground-penetrating radar system and survey cart with a central antenna frequency of 400 MHz. The control unit was set at 100 scans per linear meter, which corresponds to a radar pulse into the ground every centimeter along each transect with transects spaced 0.50 m apart. A time window of 30 ns with 512 samples per scan was used, corresponding to a reading taken every vertical 0.002 m down to a depth of approximately one meter. An earth resistance survey was conducted using a Geoscan Research RM-15 with multiplexer configured in the twin parallel probe array mode with five mobile probes at 0.25 m intervals and readings taken every 0.50 m along each transect. A fluxgate gradiometry survey was conducted using a Geoscan FM 256 fluxgate gradiometer sampling at a rate of 16 data points per meter, resulting in a data point every 0.06 m along each transect with transect lines spaced 0.25 m apart. A caesium magnetometry survey was conducted using a Geometrics G-858 optically pumped magnetometer system. The two sensors were spaced horizontally 0.25 m apart on a cart to cover two transects with each pass. The sampling rate was set to 10 Hz corresponding readings, taken every 0.05 m along each transect at the chosen walking speed. All instruments gathered data using a zigzag mode along N–S traverses. The 3D laser scan was conducted using a Leica C-10 whilst taking readings every 5 mm with multiple scan stations outside of the house and a minimum of two scan stations per interior room.

RESULTS

Through geophysical archaeology, 3D laser scanning, and targeted archaeological excavation a better understanding of the integrated landscape was achieved. The landscapes in front of each house serve as an indicator of social practice and behavior in the same manner as the houses themselves. The area in front of Old Fort Johnson contained protected outbuildings and formal paving that served as an active working space. The identity created by the form of Fort Klock and the use of the yard was purposefully and distinctly different from the English elite. Johannes Klock was appealing to the Dutch, German Palatine, and Native American inhabitants of the region, whereas William Johnson was appealing to the colonial elite and Native Americans. The activities pursued in and around the houses were constructed to establish different types of presence. The fortified nature of the houses and enclosing defenses along with the material goods is similar at Old Fort Johnson and Fort Klock, but the identity and status of the two owners and houses were deliberately and distinctly different (Stull, Rogers and Hurley 2014).

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Geoarchaeology as an essential supplement for large-scale, high-resolution archaeological geophysical prospection: case study of Gokstad in Norway

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KEY-WORDS: geophysical prospection, geoarchaeology, landscape archaeology, Viking Age

High-resolution, large-scale geophysical prospection had not been applied in Norwegian archaeology until recently. One reason for this were the challenging environmental conditions, which can include magnetic bedrock masking large areas, as well as moist, unsorted glacial sediments and clay-rich soils limiting the penetration depth of GPR signals. However, new developments in motorised data collection, data processing and visualisation, as well as the use of complementary prospection techniques have solved most of these issues rather successfully and have resulted in large-scale, high-resolution archaeological geophysical prospection (AGP) datasets. Since 2011, research carried out by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro) and its Norwegian partners, the Vestfold fylkeskommune (VFK) and the Norwegian Institute for Cultural Heritage (NIKU), has focused on selected Viking Age landscapes in the province of Vestfold, among them the Slagen valley with the well-known Oseberg mound, the royal burial site at Borre, the harbour town Kaupang and the landscape of Gokstad (*http://lbi-archpro.org/cs/vestfold/*).

In 2011 and 2012, the surrounding area of the Gokstad mound, which accommodated Norway's largest ship burial, was subjected to large-scale, high-resolution geophysical prospection surveys carried out by a team from the Austrian ZAMG ArcheoProspections® in cooperation with the LBI Arch Pro, NIKU and VFK (Bill *et al.* 2013). This investigation was part of the interdisciplinary research project "Gokstad revitalised" (*http://www.khm.uio.no/english/research/projects/gokstad/*), led by the Museum of Cultural Heritage at the University of Oslo. The magnetic and GPR surveys covered several hundred hectares and subsequent data interpretation yielded detailed maps of a Viking Age settlement and cemetery site located approximately 500 m south of the Gokstad mound, thus providing significant new information for an overall understanding of the archaeological landscape at Gokstad. Not surprisingly, a substantial amount of the areas and corresponding prospection data was void of any kind of archaeological remains. It does not mean, however, that there was no relevant information contained in these areas. They displayed a range of anomalies, features and patterns that were believed to be of

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Fig. 1. Using a liner sampler to evaluate the interpretations of GPR and magnetic data sets

natural origin. In order to investigate these non-archaeological elements of the archaeological landscape in more detail, a pilot study was conducted, dealing specifically with the analysis of palaeoenvironmental information hidden in large-scale, high-resolution AGP data.

The geophysical prospection surveys at Gokstad covered 454 ha of high-definition GPR and 403 ha of magnetometry and were conducted using state-of-the-art motorised systems. Resolution varied between 8-12 cm cross-line spacing for GPR and 25 cm for all magnetic surveys. All data were processed using the in-house developed APsoft (ArcheoProspections®) software and visualised as georeferenced greyscale images (Trinks *et al.* 2010; Gabler *et al.* 2013). Where necessary, volumetric visualisation of the GPR data was generated using AVSExpress. Data were integrated in ArcGIS 10.2. Geoarchaeological investigations were conducted to further evaluate the interpretation of previously unknown elements in the AGP datasets and to better understand their sources. Augering was carried out at selected locations, based on the GPR data using handdriven gauge augers and liner samplers (Fig. 1).

Results of palaeoenvironmental analysis yielded information on the palaeo-hydrology of the Gokstad area, on the former Viking Age shoreline, as well as on the palaeotopography and geomorphological processes. Palaeochannel systems were the most distinct palaeoenvironmental features in the AGP data sets and three different systems have been identified. The significance of the palaeochannels for the archaeological interpretation of the Gokstad area became most evident at an intersection between the largest dendritic palaeochannel system and a burial mound potentially dating to the Viking Age. Stratigraphy inferred from the GPR data at this location helped to establish a relative chronology of events and marked the palaeochannel system as an

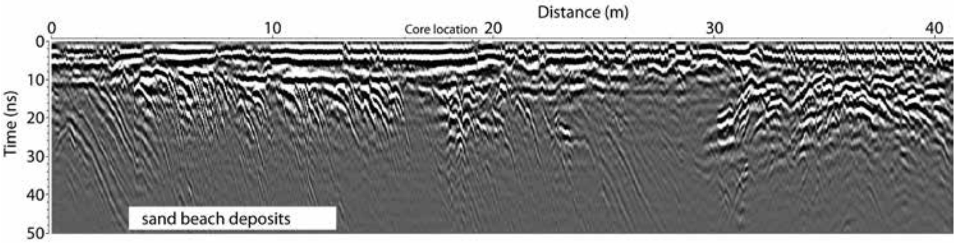

Fig. 2. Radargram displaying alternating reflective and absorbing layers interpreted as sand beach deposits. Note the core location for the geoarchaeological evaluation

important element of the Viking Age landscape at Gokstad even without a robust scientific dating strategy in place. The stratification was supported by volumetric data extraction as well as geoarchaeological investigations.

Palaeoenvironmental analysis yielded particularly valuable information on the former Viking Age shoreline. A pattern consisting of alternating reflective and absorbing features in the GPR data was detected close to the settlement traces and subsequently interpreted as sand beach deposits (Fig. 2). Geoarchaeological evaluation confirmed this initial interpretation and revealed layers of varying grain size classes as a potential source for the alternating pattern. The presence of sand beach deposits raised further questions regarding its formation and subsequent implications on the choice of settlement location and aided in the interpretation of some of the features situated close to the former Viking Age shoreline (Ambrosiani 2013).

The absence of archaeological features in the slope areas attracted attention. However, both GPR and magnetic datasets showed a wide range of unprecedented patterns of presumably natural origin that frequently occur in Norwegian datasets. Patterns included strongly reflective bands, areas indicating shallow buried bedrock as well as highly absorbing areas in between. Visualisation benefitted greatly from animating the datasets, which highlighted deviations from the current topography. These patterns were associated with the palaeotopography of the Gokstad area and illustrated erosion and accumulation processes since the land was exposed due to post-glacial land-rise more than 4000 years ago (Sørensen *et al.* 2007). Augering proved particularly helpful in verifying the initial interpretations and demonstrated that, when it comes to GPR data interpretation, one cannot infer soil texture information based only on amplitude strengths, as it only illustrates local contrast. Our analysis suggests that the slope areas present a more dynamic environment compared to the more stable lowlands, and that it provides more oxidised soils which could have been better suited for agriculture or pasture.

In conclusion, the pilot study demonstrated the potential of large-scale, high-resolution AGP data for providing valuable new information on past environments. It also highlights the importance of geoarchaeological evaluation, not just to address palaeoenvironmental interpretation, but as an essential element of the prospection work flow. In most cases, AGP data are readily available for palaeoenvironmental investigations and even if generated for archaeological purposes, can be used as a complementary source of information on further, more targeted investigations regarding landscape development and a comprehensive palaeoenvironmental understanding of the site under investigation.

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Archaeological prospection results in the surroundings of the Serapeion at Ephesus, Turkey

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KEY-WORDS: refraction seismics, magnetics, GPR, GIS, archaeological interpretation

For more than 15 years, the ZAMG (Central Institute for Meteorology and Geodynamics in Vienna), in cooperation with the Austrian Archaeological Institute (ÖAI), has been carrying out archaeological prospection using magnetics, georadar (GPR), resistivity and seismic methods in Ephesos, Turkey (Scherrer 2005).

In 2005, 2011 and 2014, an area of roughly 50,000 m² surrounding the Serapeion, one of the best preserved archaeological structures in Ephesos, was surveyed, partly in very difficult field conditions.

The Serapeion was built in the 2nd century AD on the northern slope of the Bülbüldag (*http://www.ephesus-foundation.org*). It takes up an area of approximately 100 m by 75 m. From the viewpoint of architectural history, this building is very significant, for one thing because it is so very well preserved (Heberdey 1915). Building blocks can still be found where they collapsed after the destruction of the temple, enabling archaeologist to reconstruct the temple with considerable accuracy (*http://www.ephesus-foundation.org*).

Refraction seismics were used along two lines running from north to south and positioned right and left of the ruined temple. The objective was to detect the rock surface and the thick-

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Fig. 1. Refraction seismic fieldwork (left) and GPR fieldwork (right) in Ephesos

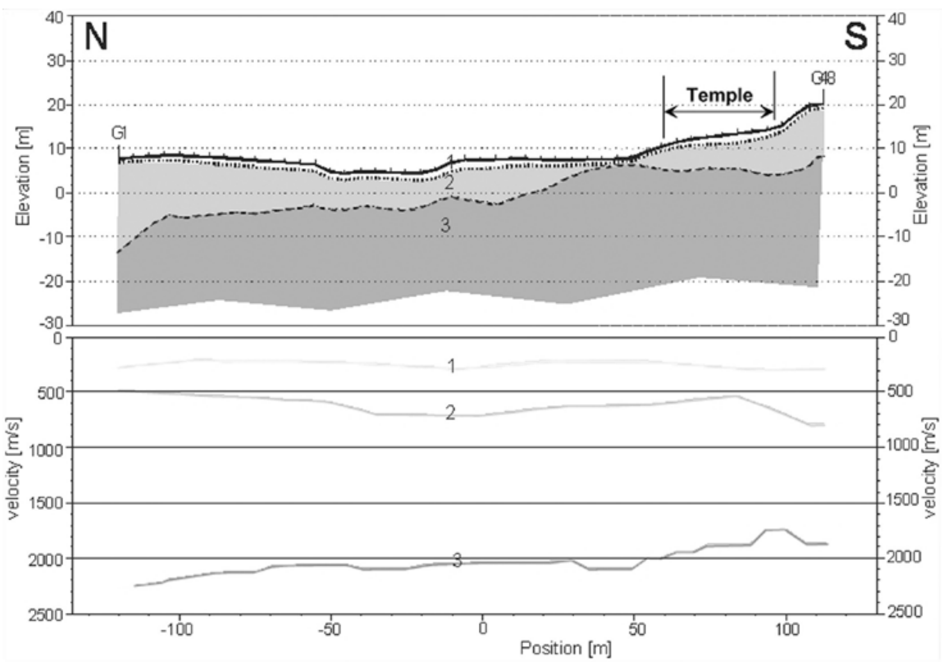

Fig. 2. Result of refraction seismics: upper plot – depth section; lower plot – layer velocities

Fig. 3. The results of GPR prospection in the area of the Serapeion in Ephesos above (black: high amplitudes – reflective, white: low amplitudes – absorbent) and the archaeological interpretation below

ness of slope materials covering it (Fig. 2). At every 6th geophone, a seismic wave was generated by using a sledge hammer. The geophone distance was set at 5 m.

The results of the refraction seismics are shown in Figure 2 with seismic layers (upper plot) and seismic velocities (lower plot). Three layers were determined, namely, the surface topsoil (1), debris/loose rock (2) and solid rock (3). The thickness of debris varies from 1 m in the close vicinity of the temple to 20 m at the start of the profile in the north. In general, the solid rock (3) shows a lower velocity (1750 to 2250 m/s), which indicates a large fault zone in this area. This can be seen especially in the last part of the profile.

For the GPR a Noggin (Sensors and Software) and for magnetics a 4-sensors Fluxgate magnetometer (Förster) was used. The survey grid was 50 cm by 16 cm for the magnetics and 50 x 5 or 25 x 5 cm for the GPR (Fig. 3).

The magnetics and GPR data were evaluated with the software APMAG and APRadar developed by the ZAMG (Seren *et al.* 2007). The images produced by APMAG and APRadar are imported and interpreted archaeologically in a GIS together with all the other information available. These are mainly structures already known through excavation, topographical lines, digital city maps and historical photographs.

The geophysical prospection, especially the GPR prospection, shows a densely built up area east and west of the Serapeion. In the north and northwest of the Serapeion, it is possible to distinguish the Weststraße, a colonnaded street approximately 160 m long and 24 m wide, running from the Tetragonos Agora to the Medusentor. On the southern side of this street, it is possible to see the remains of single colonnades in the GPR data. Lined up along this street one can identify numerous structures possibly resembling small shops, so called tabernae. Apart from these structures, it is possible to see large areas of debris west of the temple. This debris probably derives in part from loose rock coming down from the Bülbüldag, possibly covering archaeological structures in this area. In the prospected area south of the temple one can see the remains of terrace houses situated on the northern slope of the Bülbüldag. In all of the measured areas it is possible to identify streets, helping the archaeologists build up a more accurate plan of the street system running through the Roman town.

Due to the good preservation of the temple, it was possible to use GPR and magnetics on top of the Serapeion only in its part, so this exploration must be done through archaeological digs. Nevertheless, these two methods give us a good understanding of the areas surrounding this important archaeological structure.

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To not see the forest for the trees. A non-invasive approach to the Góra Chełmo medieval hillfort

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KEY-WORDS: magnetometic gradiometry, phosphate, electrical resistivity, LiDAR, aerial photography, Middle Ages

The hillfort in Góra Chełmo was described for the first time in archaeological literature by J. Kamińska. It was excavated in 1955–56, during the construction of an observation tower for the forestry authorities. Only two trenches were completed and a basic chronology of the site established to the 10th–13th centuries AD (Kamińska 1958). Kamińska reported only three lines of ramparts, covering the top part of Góra Chełmo, which at 232 m a.s.l. is the highest hill in the relatively flat area of the Łódź region. In the early 2000s, during a fieldwalking survey, J. Sikora (2008) discovered two more embankment lines of the hillfort.

The 15th century chronicler Jan Długosz described Góra Chełmo among the most important mountains in the Kingdom of Poland and attached great symbolical meaning to it. According to this description, the church on the hilltop had been founded by Piotr of Skrzynno, one of the most prominent Polish noblemen from the first half of the 12th century. The church building was said to be surrounded by seven lines of moats.

A non-invasive survey in 2013–14 was aimed at identifying the spatial structure of the fortifications, interior features (among others, buildings and possible remains of the church) and elements of the communication infrastructure. It also aimed at determining the purpose of the fort (in archaeological literature it was supposed to be connected with pre-Christian ritual activity). One of the objectives was also to ascertain the state of preservation of the stronghold and identify potential threats. The project started with a study of aerial images and analysis of aerial laser scanning-derived maps (using LAS point clouds prepared for a national ISOK program). Aerial prospection revealed only crop marks connected with the denudation valley located south of the mount, which was likely used as a road connecting to open settlements recorded around the hillfort, mostly on its southern side. It could not bring any new data about the hillfort itself, as the area is completely forested. In this situation, LiDAR-derived DTM maps proved very helpful (Fig. 1). They allowed two previously unknown lines of moats and ramparts to be detected, giving a total of seven ramparts, which is which is the number that Jan Długosz described. The area enclosed by this rampart system covers 11.7 ha, making the Góra Chełmo defensive structure the largest known early medieval stronghold in central Poland. For the sake of comparison, the ring-fort in Łęczyca, which was a local power center and a princely seat in the 13th century, is thought to encompass an area of about 1 ha. The

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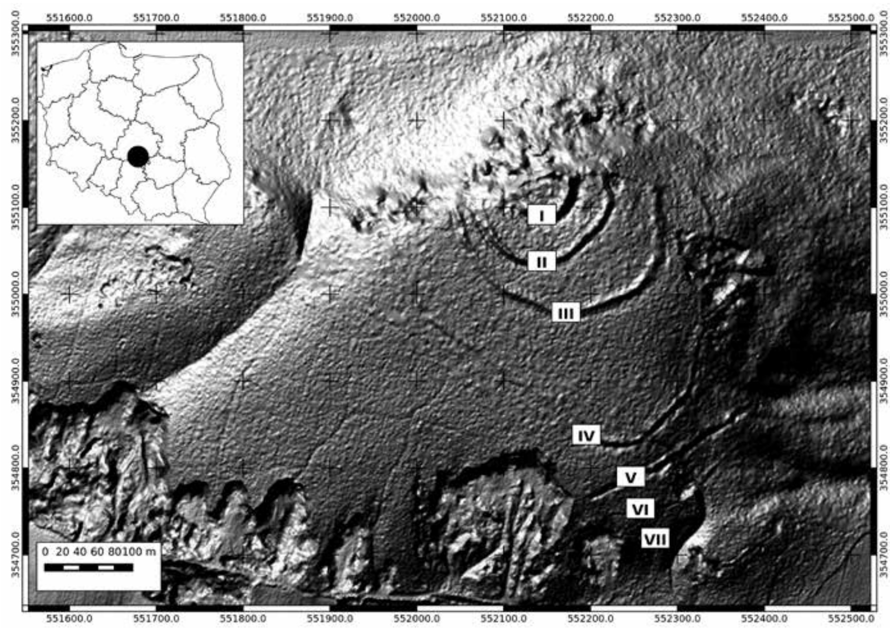

Fig. 1. Góra Chełmo: LiDAR-derived hill-shaded Digital Elevation Model with a numbering of the ramparts used in the text

ring-fort in Sieradz, an important administrative (castellan and later even princely) seat, takes up about 3 ha, the stronghold in Spicymierz, the favourite seat of the Gniezno Archbishop in the 12th century and also a castellan seat, about 1,5 ha.

Additional data came from the magnetic gradiometry survey, which took place in unfavourable forest conditions (Fig. 2). The surveyed area covered 5 ha and it was augmented by a small-scale earth-resistance survey. Different magnetic anomalies corresponding to elements of the rampart were registered. While the course of the second rampart was determined by two parallel linear dipolar anomalies, the course of the third, fourth and fifth ramparts generated a single positive linear anomaly. A rectangular anomaly adjoining the fourth rampart suggests the existence of a stone gate foundation, perhaps similar to the one excavated at the ring-fort in Kaszów (Dzieduszycka 1977: 73–75, fig. 2). Such an interpretation is further supported by the presence in this place of another magnetic anomaly, oriented N–S, which could be seen as a communication route. Another interesting feature recorded during the prospection was a linear magnetic anomaly concentric to the first rampart, the area of the bailey between it and the second rampart. It was interrupted by another rectangular-shaped object, probably an anthropnic feature (gate?). These anomalies can be interpreted as traces of the spatial organization inside the hillfort. A similar linear anomaly, although with a weaker magnetic characteristic, was registered between the second and third ramparts. It ran partly parallel to the axis of the ramparts, but in the southern part was combined with the third rampart. None of the recorded anomalies could be interpreted as the remains of the church known from the written source.

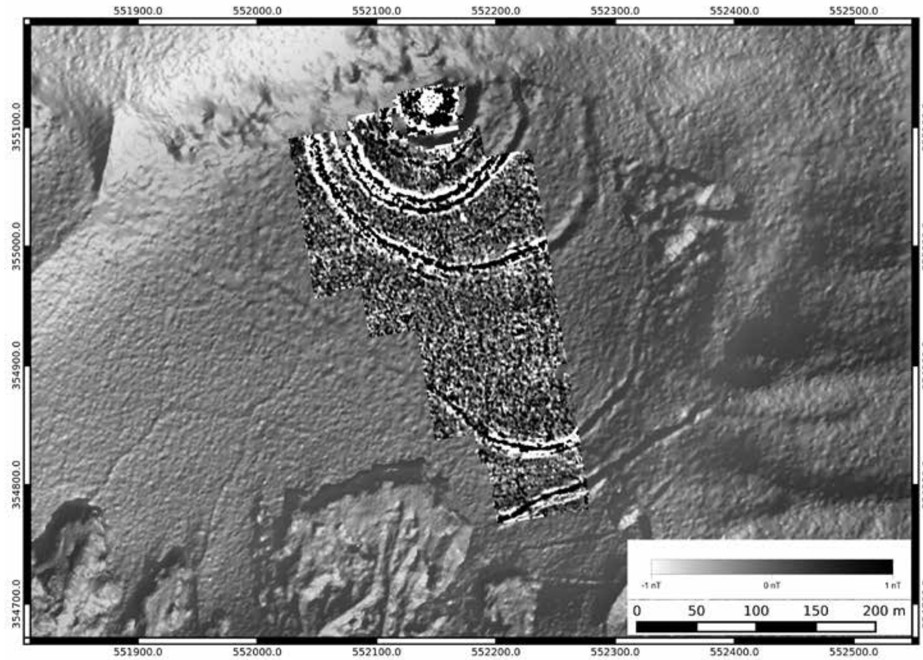

Fig. 2. Góra Chełmo: results of the geophysical (magnetic) survey (background: LiDAR-derived hill-shaded DEM)

A phosphorus survey yielded further information (Fig. 3). It was carried out in an area of 7.7 ha, using a simplified field method developed by Kittel and Sygulski (2010). Data analysis clearly demonstrated the existence of zones of high or extremely high phosphorus content in an area enclosed within the rampart system. These can be understood as being a geochemical record of either a skeletal cemetery (an unlikely option as burial grounds were seldom associated with ring-forts) or intense settlement activity in the past. This observation is of utmost importance in the context of hypotheses proposed in a previous paper on the cult function of the Góra Chełmo hillfort with regards to pre-Christian religion (Kamińska 1971: 56; Chmielowska and Marosik 1989: 101). The recorded high phosphorus rate is new important evidence suggesting settlement rather than ritual activity.

ACKNOWLEDGMENTS

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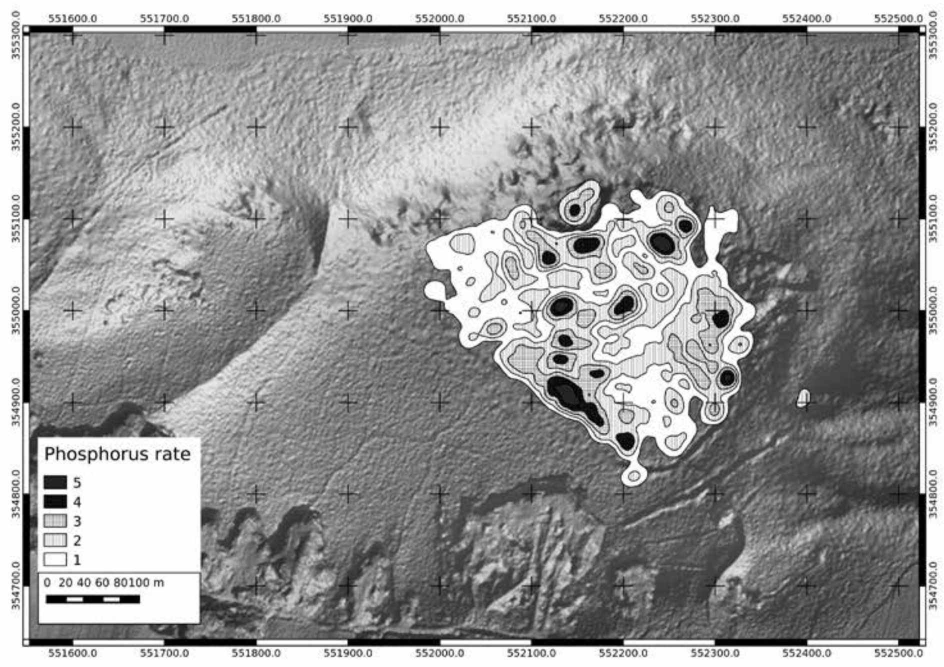

Fig. 3. Góra Chełmo: results of the phosphate and geophysical survey superimposed on a LiDAR derived hillshaded DEM (Legend: phosphorus level in the ground: 1 – low, 2 – average, 3 – high, 4 – very high, 5 – extremely high)

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From a point on the map to a shape in the landscape. Non-invasive verification of medieval ring-forts in Central Poland: Rozprza case study

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KEY-WORDS: magnetometry, surface survey, phosphate, electrical resistivity, aerial photography, Middle Ages

In the last decades several research projects were undertaken in Poland to verify remnants of medieval ring-forts, and also smaller fortified objects, mostly motte-type structures, which were private residences of the late medieval nobility. The main focus of those projects were issues related to the chronology of strongholds via the study of material culture through excavation. Since the 1990s an attempt to broaden this knowledge with absolute dating acquired by dendrochronological analysis supplemented by the 14C method provided detailed dates of many rampart features. As a result, ring-forts or mottes were understood as dots on maps, detached from their landscape contexts, attempting to illustrate mutual synchronic processes of establishment, operation and destruction in specific chronological horizons. They were used to support a number of historical theories, such as the development of pre-state (so called "tribal") territorial organization, development of the early Piast monarchy, transformation of the administrative network of the monarchy (e.g., Kara 2009), as well as the development of a network of private residences of the nobility from the mid-13th century on.

In 2013 and 2014, a research project based on non-invasive verification of ring-forts in the area of Central Poland was conducted. The main difference between this project and former actions was an attempt to implement large-scale, solely non-invasive and geomorphological surveys, in order to explain broader environmental and spatial intra-site and landscape contexts of the studied ring-forts. A wide variety of methods was implemented, including geophysical (magnetic gradiometry and earth resistance), geochemical (phosphate), aerial archaeology, aerial laser scanning, analytical fieldwalking, topographic survey and geomorphological mapping.

Nine ring-fort complexes have been surveyed to date: Chelmo site 1 (Polish Archaeological Record AZP 81-54/1), Ewinow sites 1, 2, 3 (AZP 62-44/160, 162, 161), Krzepocinek site 1 (AZP 61-48/20), Rękoraj sites 1, 17 (AZP 71-54/1, 18), Rozprza sites 1, 5, 6 (AZP 76-54/13, 6, 14), Spycimierz site 1 (AZP 62-45/74), Stare Skoszewy sites 1, 2 (AZP 64-33/31, 32), Szydlow sites 1, 2 (AZP 66-48/56-57, 62), and Zarnow sites 1, 2, 3 (AZP 77-58/1, 2, 3) (Fig. 1). Earlier work on these sites comprised solely excavations, from regular digging projects by teams of the University of Łódź, Archaeological and Ethnological Museum in Łódź and the Łódź branch of Polish Academy of Sciences to limited test trenches carried out mainly for heritage management reasons.

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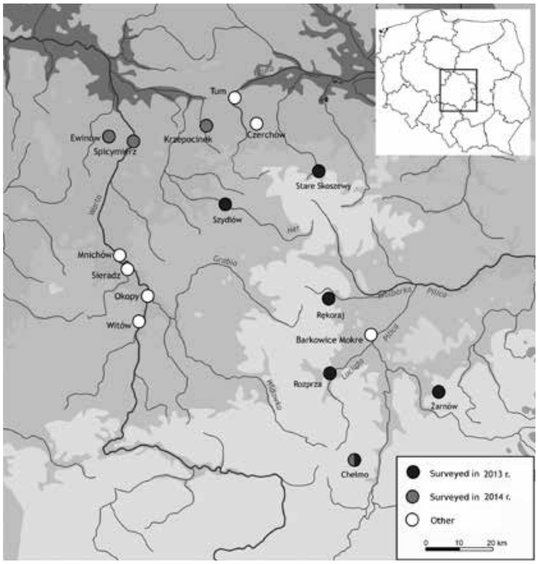

Fig. 1. Map of early medieval ring-forts in Central Poland

The results from Rozprza, a site situated approximately 60 km south of Łódź in the middle of the Luciąża river valley, have so far been a prime example and case study of the new types of information that such non-invasive approaches may bring forth.

The Rozprza ring-fort settlement complex functioned as a "tribal" centre from the second half of the 9th century to the middle of the 10th century AD. From the 10th to the 13th century, it played an important role in the Polish state as a local administration unit. In the second half of the 13th century, it was the seat of a local officer (*castellanus*), and in the 14th century it became the seat of a noble family. In the early Middle Ages, Rozprza was one of the most important medieval strongholds in Central Poland. Remains of the ring-fort defensive system are poorly preserved, but still visible in the field as earthworks. Currently, the site occupies an area covered by meadows and fields, located between the main channel of the Luciąża and Rajska rivers (the latter is a secondary channel of the Luciąża river system) in the central part of the river valley, on the Plenivistulian residual terrace adjoining the Late Vistulian and Holocene floodplain.

Ongoing non-destructive surveys of the ring-fort surroundings have included diverse prospection methods integrated in a GIS environment. The data already collected have provided useful information for a reconstruction of the spatial structure of the ring-fort and surrounding settlement, as well as elements of the natural environment.

Geophysical prospection (Fig. 3) revealed the presence of several strong linear magnetic anomalies, which can be interpreted as sub-fossil palaeochannels of the Luciąża river (evidenced also in aerial images, Fig. 2). Earth resistance prospection revealed the presence of anomalies around the ring-fort earthworks, recognized as traces of previously unnoticed moats and ramparts. Very narrow, linear magnetic anomalies intersecting the large palaeochannel were

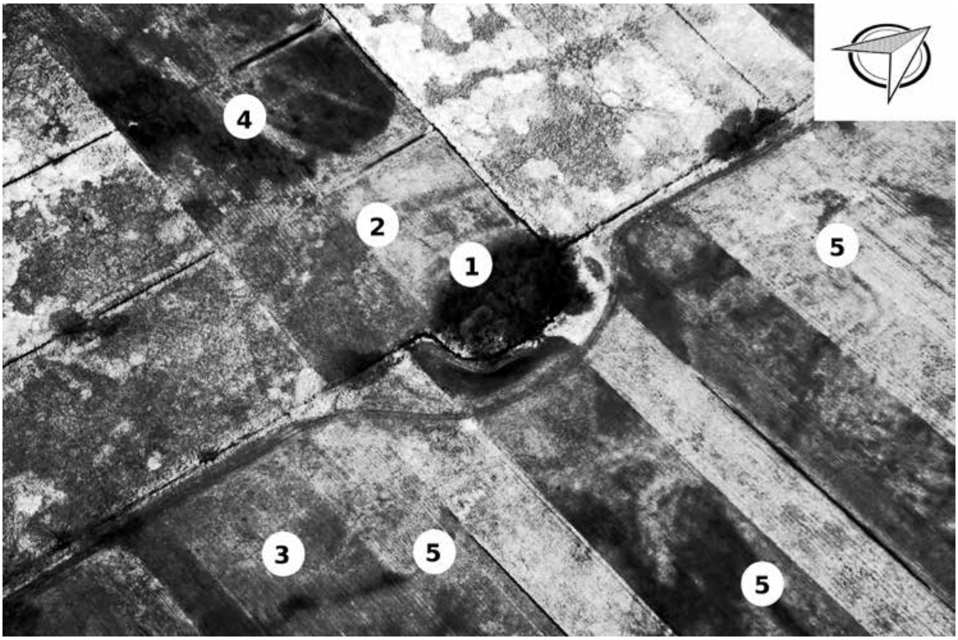

Fig. 2. Aerial photo of the ring-fort area in Rozprza (Photo: W. Stępień, 2013). Legend: 1 – remains of the ring-fort; 2 – outer rampart; 3 – second bailey; 4 – possible causeway; 5 – sub-fossil palaeochannels

registered in the western part of the study area; they were also visible in aerial images as crop marks. Based on geological soundings and the spatial orientation toward the ring-fort earthworks, this feature has been interpreted as a possible bridge or causeway.

Fieldwalking around the ring-fort revealed a large number of potsherds from early and late medieval times in the area of the presumed defensive structures and near a small hillock, which had been identified as an open settlement (Chmielowska 1966). The phosphate survey has also shown a higher level of phosphorus in the ground in the area of the ring-fort and hillock only. However, the relatively low levels of phosphorus could be the effect of specific wetland area conditions.

The geological survey confirmed the existence of moats filled with organic (gyttja and peat) and partly inorganic deposits with abundant remains of wood. The results correspond to various geophysical anomalies and features recorded in earlier archaeological research. The radiocarbon dating of organic materials from the moat fill confirmed the existence of a moat system as early as the 9th and 10th century.

The survey confirmed the highly favorable, naturally defensive conditions of the area (swamps, natural ground obstacles). The geophysical and aerial record of the ring-fort remains gave an entirely new view of the monument with the ring-fort being protected by concentric walls and moats and an additional bailey, probably surrounded by separate fortifications from the south. A road accessed the ring-fort from the west and southwest. A single open settlement was located on the eastern side, on a nearby hillock.

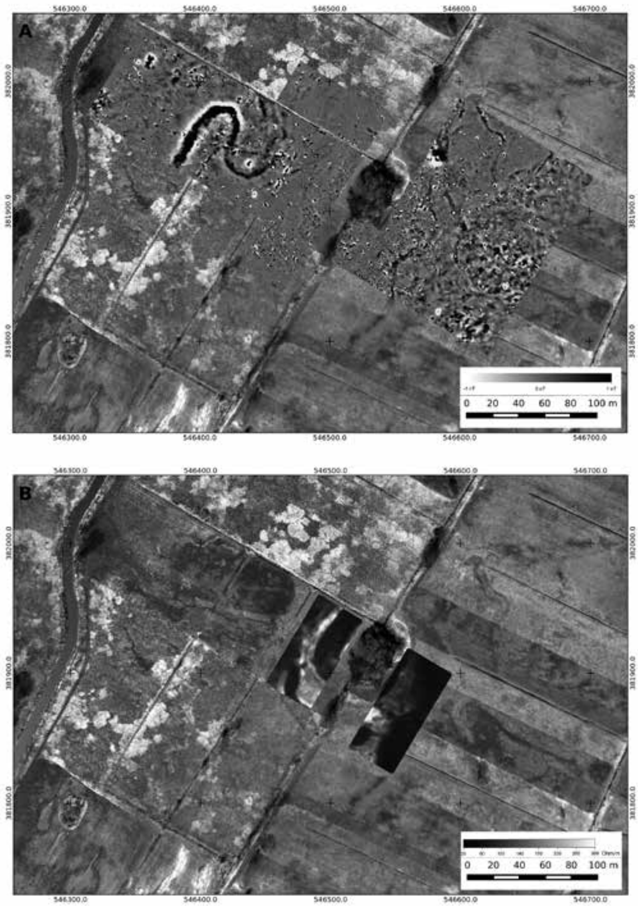

Fig. 3. Results of the geophysical survey in Rozprza (background: orthophotomap based on aerial pictures by W. Stępień); A – magnetic prospection; B – earth resistance prospection

The Rozprza survey is an interesting case study, illustrating in empirical terms the ups and downs of various approaches in archaeology. The ring-fort may now be recognised as a series of structures embedded within a wetland setting, with open settlements, road systems and impressive defensive features showing a much more informed view of man's attempt at mastering a unhospitable landscape. This was possible for the most part thanks to the application of multi-method non-destructive prospection.

ACKNOWLEDGMENTS

The non-invasive survey programs were conducted by the Scientific Society of Polish Archaeologists (Lodz branch) and the Institute of Archaeology of the University of Lodz, financed by the Polish Ministry of Culture and National Heritage in 2013 and 2014. Radiocarbon dates from the moat and palaeochannel fill in Rozprza and the non-invasive survey in 2015 were financed from a National Science Centre grant (DEC-2013/11/B/HS3/03785).

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Manipulating mud: (re-)constructing cosmogonical landscapes in the Nile Valley, Thebes, Egypt

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KEY-WORDS: Nile, landscape, fluvial, canal, temple, floodplain

The Egypt Exploration Society / Uppsala Universitet Theban Harbours and Waterscapes Survey (THaWS) has carried out four seasons, working on the east and west bank of the Nile in Luxor (Graham 2012; Graham *et al.* 2012; 2013; 2014). The principal goal of the project is to elucidate the technical ability of ancient Egyptians to manipulate the floodplain through canal and basin construction. Contemporary pictorial and written evidence from Egypt suggests that canals and basins used as harbours were associated with the temples to the cult of the deceased kings on the west bank at Thebes (Jaritz 2005; Lacau and Chevrier 1977; Schlüter 2009), and they may also have played a key role in the festival processions of Thebes. Reconstructing them would thus help further our understanding of the sacred landscape. Canals would also have enabled the transportation of construction

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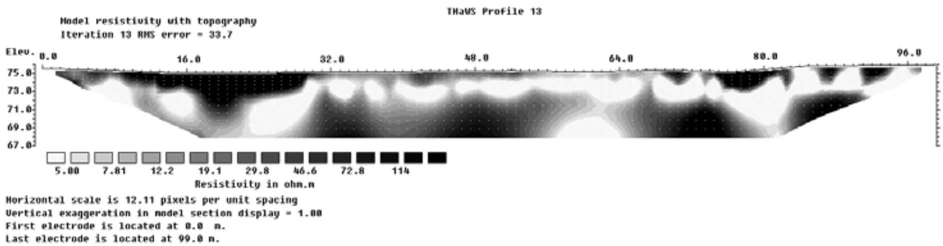

Fig. 1. ERT profile (P13) across the Second Court of Amenhotep III's Temple of Millions of Years at Kom el-Hettan, showing the presence of a rubble-filled channel between profiles at 8 m and at 32 m; feature verified in an archaeological section approximately 50 m northwest of the profile at the rear of the Second Court. The elevation of the channel shows that it post-dates the reign of Amenhotep III

stone and monoliths weighing hundreds of tonnes to temples (Kitchen 1991; Wehausen *et al.* 1988). Furthermore, the massive spoil mounds surrounding Birket Habu (Kemp and O'Connor 1974) and the smaller more enigmatic 'Birket el-Hubeil/Birket Luxor' (Graham *et al.* 2012) provide important evidence for the infrastructure of anthroprogenic basins, but their dimensions and navigability have never been established. This paper presents a brief discussion of the survey methodology, as well as some of the results of the ongoing project, including those from the 2015 season.

The scope of this interdisciplinary project allows for the integration of geomorphological, archaeological and geophysical lines of inquiry, with a methodology that combines geophysical survey (principally electrical resistivity tomography (ERT) and ground penetrating radar (GPR) complemented by magnetometry) with geoarchaeology (using an Eijkelkamp hand auger and percussion corer) to ground-truth the geophysical survey data and construct geological transects across the floodplain. Total Station and global positioning system (GPS/GNSS) equipment is used to georeference all of the work and record elevations relating to historical and recent datums, information that is essential for relating results to the ancient Nile floods. Ceramic fragments found in the augering and percussion coring have been used to date the facies presented in the geoarchaeological data. The project is collaborative, with the survey and borehole fieldwork being conducted closely with a number of other archaeological projects in the area.

Other sources have also been drawn on to help with the analysis and interpretation of the field data. Maps from the last 200 years (from the Napoleonic map to the Survey of Egypt maps of the area) provide evidence for broad changes in the course of the Nile in this period. Satellite imagery, including CORONA, Landsat, and high resolution Quickbird imagery, together with airborne photography (including photos from the Franco-Egyptian Centre), have also facilitated the mapping of geomorphological and archaeological features for comparison with the results of the geophysics and borehole surveys.

Initial findings have revealed key archaeological discoveries at the edge of the floodplain at Thebes, including the important discovery of a natural paleo-channel of the Nile lying within a few hundred metres of the modern-day desert edge, close by the Ramesseum and the Colossi of Memnon. This may well have been associated with access to the funerary complexes and the immense harbour of Birket Habu to the south. Infrastructure leading to the entrance to

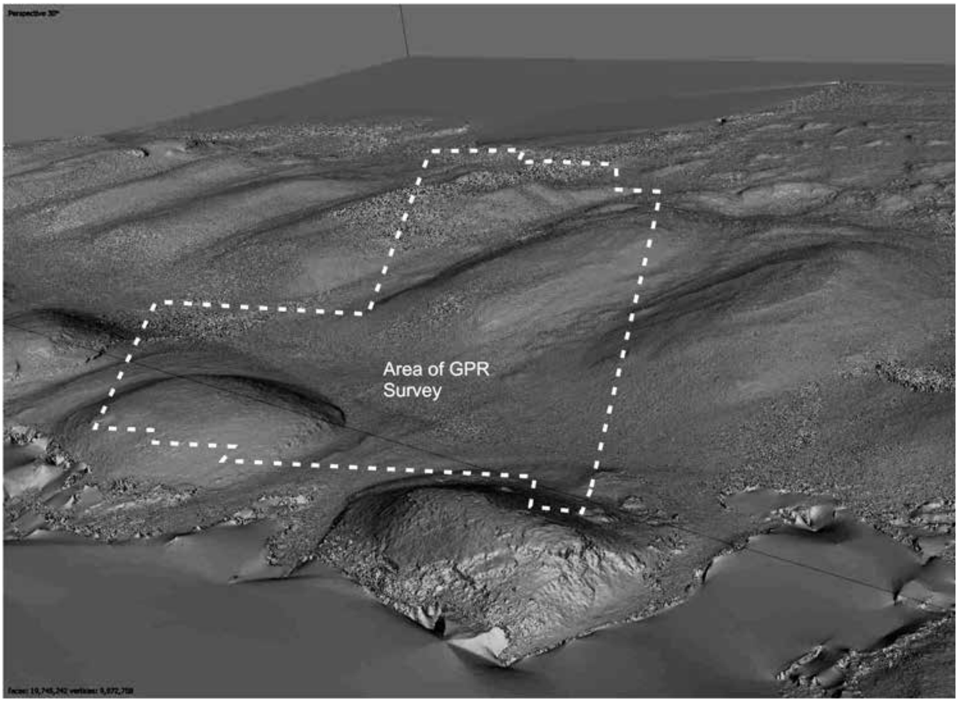

Fig. 2. A 3D photogrammetric image of the spoil mounds to the west of Birket Habu with the GPR survey area shown in Fig. 3 marked on the image

the Royal Cult temple of Thutmose III has also been confirmed by magnetometer and GPR surveys, whilst in 2012 ERT confirmed the existence of recent former channels and canals as recorded by John Gardner Wilkinson in the 1830s, as well as a channel within a courtyard of Amenhotep III's Temple of Millions of Years (Fig. 1). Work close to the Colossi of Memnon has also revealed evidence of remains of the different courts of the temple. Work along the western side of the harbour at Birket Habu has allowed the 3D mapping of the mounds through photogrammetry (Fig. 2), and GPR across the mounds has provided insight into the construction of these substantial features (Fig. 3). In addition, survey work at Karnak on the east bank of the Nile has revealed important evidence of the deposits underlying the temple, with GPR outlining possible foundations of an extension of one the ramps lying west of the vast temple complex of Amun (Graham *et al.* 2013).

Whilst not of primary importance on the project, the four seasons of fieldwork to date have also highlighted a number of points associated with technical and logistical aspects of the survey. The aridity and salinity of areas of the landscape have affected the use of geophysical survey techniques, especially GPR and ERT, and the integration of non-intrusive survey results with borehole survey data has also underlined issues of analysis and interpretation between diverse datasets of differing resolution and depth.

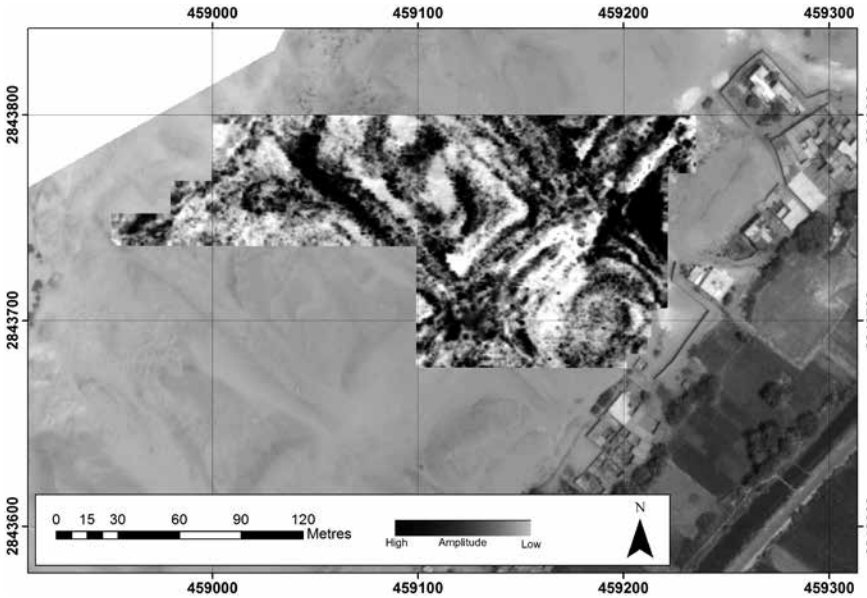

Fig. 3. Results of the GPR survey across the mounds at Malqata, showing the presence of retaining walls for terraces in the mound construction

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Mapping the Bronze Age settlement of Akrotiri on Santorini: digital documentation and archaeological prospection

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KEY-WORDS: GPR, ERT, Akrotiri, Santorini/Thera, Greece

The Bronze Age settlement of Akrotiri on the Greek island of Santorini/Thera was covered by thick layers of volcanic pumice during the massive eruption of the Thera volcano in approximately 1613 BC. Archaeological excavations conducted since 1967 have revealed the archaeological remains of an affluent prehistoric society, living in up to three-storey-high buildings that were richly decorated with vivid frescoes and furnished with sophisticated sewer systems. To date, three buildings have been excavated completely and approximately seven buildings have been partly uncovered in an area measuring some 90 m by 120 m (Doumas 1983). Archaeological excavation at Akrotiri inevitably exposes the archaeological remains and often fragile prehistoric architecture to the risk of destruction in case of stronger seismic events, which are very likely to occur at some point in the future, since the site is located in one of the world's seismically most active regions (Chouliaras *et al.* 2012), being located on an active volcano. Additionally, gradual decay caused, for example, by mud wasps and accidental damage threatens with the collapse of exposed architecture at this unique site.

While it is impossible to prevent partial or total destruction of the excavated architecture in case of a larger earthquake, and while the long-term preservation of this cultural heritage is an extremely difficult challenge, it is possible to document the site digitally in three dimensions and in great detail. In 2013 and 2014, the LBI ArchPro documented the excavated areas in very high resolution, using laser scanning and latest photogrammetric methods. Within this project, which has been supported by the Conservation Trust of the National Geographic Society, additional geophysical archaeological prospection techniques have been tested in the vicinity of the archaeological site of Akrotiri in order to evaluate their potential to map still buried archaeological remains without exposing them to the risk of destruction.

With exception of the location Kokkino Vouno (Red Mountain) west of the archaeological site, all other nearby areas are covered by more or less thick layers of volcanic ash and pumice, rendering the application of standard near surface geophysical archaeological prospection approaches challenging. The volcanic geology and the mostly large distance between the surface and the target structures renders the use of the otherwise commonly used magnetic prospection method less than promising. Early magnetic measurements were conducted in the area by Dr. Elizabeth Ralph from the University of Pennsylvania Museum in 1967 using a caesium magnetometer, still prior to the substantial archaeological discoveries made by Spyridon Marinatos (Mavor 1969).

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Fig. 1. Ground penetrating radar measurements with a 250 MHz antenna system and 25 cm profile spacing on top of Kokkino Vouno (Red Mountain) near the archaeological site of Akrotiri. Photo: LBI ArchPro, Klaus Löcker

However, the magnetically highly inhomogeneous volcanic subsurface prevented any positive results. Sledge-hammer seismic measurements for archaeological prospection were attempted at that time, yet without any great success (Vermeule 1967).

Ground penetrating radar (GPR) measurements were to our knowledge first attempted at Akrotiri by Gregory Tsokas and colleagues in September 1996 (The Thera Foundation 1996), using a 225 MHz PulseEkko antenna as well as an EPRIS system from Coleman Research. The published results indicate limited signal penetrating depths between two and three metres in case of the 225 MHz PulseEkko, thus not yet reaching layers containing antiquities. However, these tests conclude that GPR can be successfully used, if the alluvium layer, which is the medium causing greatest signal loss, is removed. Further GPR tests conducted at Akrotiri by Russel and Stasiuk (2000), using a PulseEkko 100 system and 50 and 100 MHz antennae with large trace stacking numbers (256 respectively 128), resulted in reflectors successfully mapped at depths as large as 22 m. A geoelectrical tomography test was also conducted by Tsokas and colleagues in 1996 (The Thera Foundation 1996), resulting in the mapping of a resistive layer between two higher conductive ones, possibly imaging the volcanic basement at 6 m depth.

In February 2014, we tested several GPR antennae systems in the vicinity of Akrotiri, including a shielded 80 MHz MALÅ Geoscience GroundExplorer prototype antenna, as well as unshielded 100 MHz, and shielded 250 MHz and 500 MHz PulseEkko Pro antennae with 25 cm profile spacing. The latter two antennae were used to map an area on top of the Red

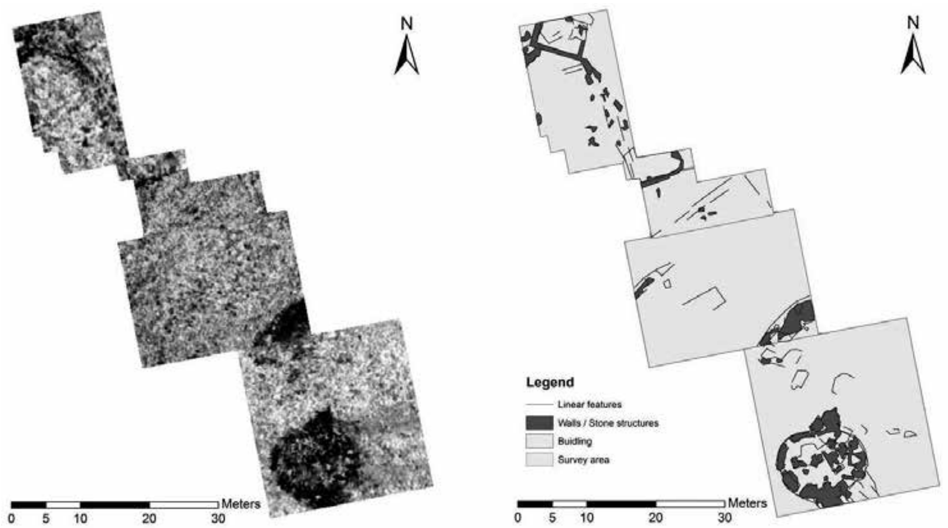

Fig. 2. GPR depth-slice from the Red Mountain (approx. 30 cm depth) and corresponding data interpretation

Mountain west of the Akrotiri excavation site. Georeferenced GPR depth-slices were generated after basic processing of the GPR traces. The GPR data shows anomalies caused by the buried remains of three buildings of great archaeological interest.

Additionally, electric resistance tomography (ERT) measurements were conducted using a 48-channel IRIS SYSCAL Pro system on the Red Mountain in two adjacent areas (grids) that had also been covered with GPR measurements. Each grid comprised a set of several 2D ERT lines, which were processed in full 3D mode. The inter-line and inter-electrode spacing was set to 0.75 m and every ERT line had 24 electrodes, resulting in a total line length of 17.25 m. Data were collected using an automated 10-channel resistivity meter using the dipole–dipole array with dipole separation up to n=8 and dipole spacings of a=0.75 m and 2a=1.5 m. Due to the generally very high resistivity environment, the signal-to-noise-ratio was very high, resulting in high quality measurements.

Each ERT line was initially processed using a standard 2D smoothness constrained inversion algorithm (Tsourlos 1995) to test the overall data quality and to reject possible outliers. Subsequently, all individual 2D ERT data were merged in a single dataset that was processed in full 3D mode: 3D inversion results were obtained after six iterations and the total RMS error was below 2%. Subsurface resistivity images produced from the 3D inversion are presented in the form of depth-slices.

Two buildings were located on the top of Red Mountain, where a trial excavation conducted by S. Marinatos in 1968 and surface finds of fresco fragments had indicated remains of Bronze Age architecture. There was also a circular structure of uncertain date, roughly 12 m in diameter. Both results of the GPR and ERT measurements are in good agreement.

For the first time it was possible to map substantial new archaeological structures in the vicinity of the archaeological excavation site of Akrotiri, using high-resolution GPR as well as ERT measurements. State-of-the-art non-invasive near-surface geophysical prospection has the potential to generate important new archaeological information about this fascinating archaeological site.

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The Big Five. Mapping the subsurface of Iron Age forts on the Island of Öland, Sweden

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KEY-WORDS: ring-fort, Iron Age, Öland, Sweden, ground-penetrating radar, MIRA, magnetometer

INTRODUCTION

The island of Öland in the Baltic Sea is home to several large ring-forts dated to about AD 200–700 (Fig. 1). Eighteen ring-forts are known from historical maps and records, but only 15 have been preserved. Only one of these forts, Eketorp, was subject to large-scale archaeological investigations and the fort was completely excavated in 1964–74 (Borg *et al.* 1976). During the

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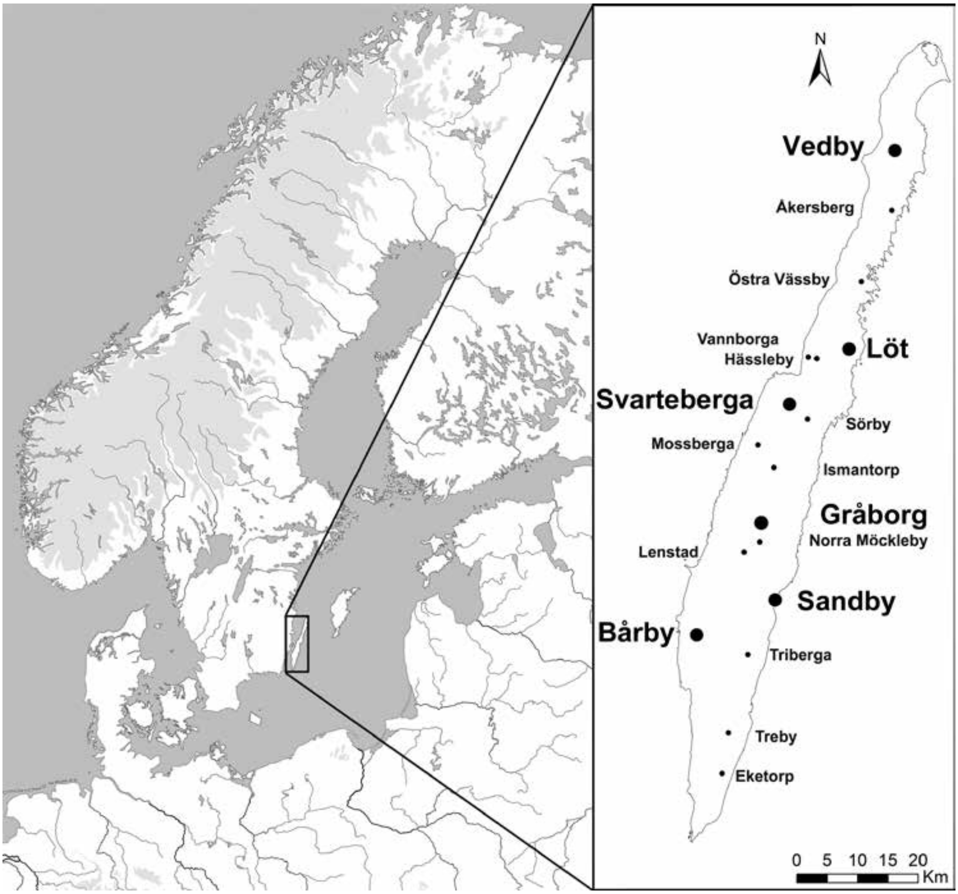

Fig. 1. Map of the island of Öland, on the east coast of Sweden, and the location of its ring-forts

excavations some 53 stone house foundations were discovered inside the fort (Fig. 2) and surveys and archaeological testing have confirmed the existence of similar foundations in at least ten other forts on the island (Fallgren 2008). Since Eketorp is the only completely excavated ring-fort, it is seen as a model for all the other Ölandic forts, despite the fact that the other forts may have held different functions. Several ring-forts are also too large for traditional archaeological excavations and as a consequence little is known about them. Many forts, at least since the beginning of the 17th century (e.g., Tegnér 2008: 44), were subject to intensive agricultural activity, which may have had a detrimental effect on the preservation of archaeological remains.

"The Big Five" is a project funded by the Swedish research council and the Royal Academy of Letters History and Antiquities to use geophysical prospection methods in the investigation of five of these ring-forts: Gråborg, Vedby borg, Bårby borg, Löts borg and Svarteberga borg. The purpose of the surveys is to nuance the picture of the Ölandic forts by providing new

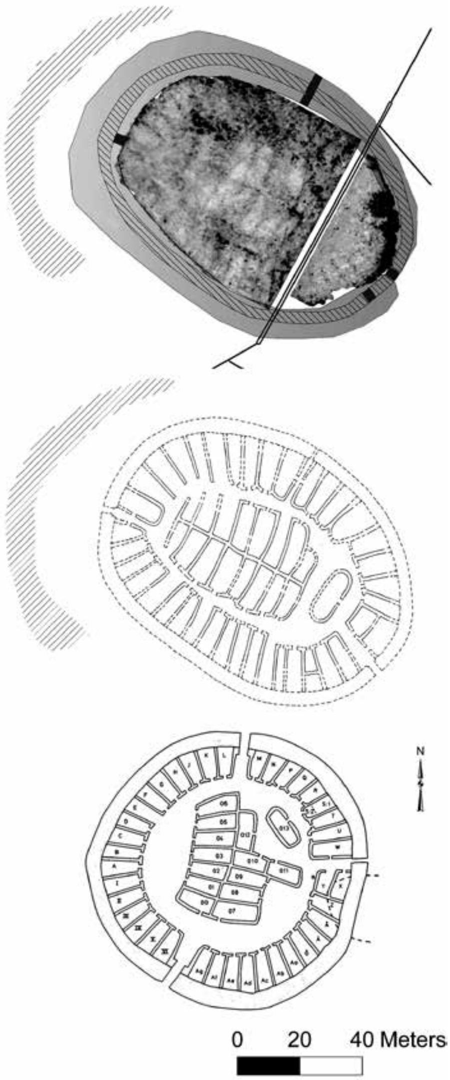

Fig. 2. GPR results from Sandby borg: top, GPR depth-slice of 2 ns thickness at a depth 15 cm below the surface; middle, interpretation of the GPR results from Sandby borg showing multiple Iron Age house foundations inside the fort; bottom, spatial layout of the already excavated Ölandic ring-fort Eketorp II (Borg *et al.* 1976)

information regarding any preserved remains buried in the forts. An underlying purpose is also to evaluate the deleterious impact of earlier agricultural activity.

The forts will be surveyed using the motorised ground-penetrating radar (GPR) system MIRA (MALÅ imaging radar array). This system can be used to survey large areas at high speed and collect high-resolution data without affecting the buried remains below ground and has been tested successfully in Sweden before (e.g., Trinks *et al.* 2010; Trinks and Biwall 2011; Trinks *et al.* 2013). The GPR measurements will be complemented by magnetometer surveys in selected areas and also include mobile mapping system (MMS) documentation using the GeoTracker at Gråborg and Vedby borg (see Viberg and Larson: 396-399 in this volume). The geophysical results would advance our understanding of these forts by providing information regarding their spatial layout and by identifying different activity areas. This information can be used for 3D reconstructions and provide archaeologists with detailed maps of the subsurface, which can enable future targeted excavations.

FEASIBILITY STUDY AT SANDBY BORG, ÖLAND

For the purpose of testing the suitability of the proposed methods, a feasibility study was carried out at one of the Ölandic forts. Sandby borg (RAÄ 45:1) is situated in the parish of Sandby on the eastern coast of Öland and is the only fort situated close to the sea (Fig. 1). The quaternary deposits in the area are dominated by outcrops of outwash gravels overlying very shallow limestone bedrock. The fort is oval in shape with an inner area of approximately 95 m by 64 m (about 5140 m^2), as measured from exposed parts of the original dry wall. Compared to other ring-

Fig. 3. Measurements with the MIRA system outside the northwestern gate at Gråborg, Sweden. (Photo: Magnus Larson 2014)

forts proposed in the project, Sandby borg is quite small. Aerial photographs from the 1970s showed faint traces of buried structures within the fort and a geophysical survey was carried out to map these remains and to produce a spatial layout of the fort.

The survey was carried out in 2010–2011 and included a single GPR antenna of the X3M-system by MALÅ Geoscience, collecting data with a sampling density of 0.03m by 0.25 m.

The GPR results provide clear evidence of buried stone house foundations, similar to what was located in Eketorp during the excavations in the 1970s (Fig. 2). An interpretation of the data along with the excavation results from the second phase at Eketorp show great similarities (Fig. 2). Subsequent excavations, carried out by the Kalmar County Museum in 2011, provided archaeological evidence of the high accuracy and resolution of the geophysical measurements and the geophysical maps proved to be a valuable asset when planning strategies for the excavation campaign (Viberg *et al.* 2014). The results clearly show the suitability of geophysical prospection methods on structures found within the forts.

2014 FIELD SURVEY CAMPAIGN

The first field campaign was carried out in May 2014 during which time MIRA data were collected at the forts in Vedby, Löt and Bårby (Fig. 3). Several test profiles were also surveyed at Bårby borg, using the new MALÅ GX HDR antenna (160 MHz), in order, to study the bedrock under the fort. Additionally, the inside and 1.3 ha outside the largest ring-fort at Gråborg was surveyed. These measurements will be complemented by additional GPR and magnetic surveys during the coming years. In addition to the previously mentioned forts, surveys will be carried out in 2015 at two smaller forts, Hässleby borg and Triberga borg. The data from the Ölandic fort sites can then be used to revitalize and nuance the archaeological discussion and understanding of the Ölandic forts, their interior design, their relationship to the surrounding landscape and to one another.

ACKNOWLEDGEMENTS

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Geophysical investigation of past harbours: challenges and application examples

Dennis Wilken[a], Tina Wunderlich[a], Jasmin Andersen[a] and Wolfgang Rabbel[a]

KEY-WORDS: marine, magnetics, ERT, seismics, GPR, harbour

The demands on harbours of the past were variegated: A harbour needed to provide shelter against enemies and weather, but also good accessibility for various types of vessels as well as a working logistic network. Therefore, the geological setting at the time the harbour was active is of crucial importance for the understanding of the harbour situation. Sea level changes and sedimentation may let a prosperous harbour of the past become a swampy or even dry area today. Beside the geological setting, the connection to settlements onshore is also of importance for the harbour system. Thus, access routes, storage facilities and even harbour-related settlements have to be investigated. These demands can be summarized in four topics describing the site conditions of a harbour:

- Do we have a sheltering environment for inactive shipping?
- What was the accessibility for certain types of vessels (extent of a water body)?
- Do we have related settlements, transport networks and trade?
- Do we expect fixed harbour structures or a natural hythe?

Within the frame of the priority program "Harbours from the Roman period to the Middle Ages" of the German Research Foundation, different possible harbour sites in Germany, Poland, Iceland, Italy and Turkey have been investigated using geophysics. The tasks of these investigations ranged from prospecting harbour structures and basins, access routes and settlements to the reconstruction of the past landscape by investigating the near-surface stratigraphy. The latter aimed at answering questions about, e.g., past courses of shippable rivers, waterdepths inside harbour basins and past coastlines. Unfortunately, today most of the investigation areas are silted up, characterized by swampy or lagoonal sediments, or covered by water of depths between a few centimeters to a few meters. To deal with these tasks, different geophysical methods have been applied and adapted to the transition zone between land and water. This includes GPR, ERT, magnetic prospection on- and offshore, EMI, and seismic methods on- and offshore.

To resolve the interesting upper few meters of the stratigraphy of a harbour area, GPR and geoelectric methods would be most feasible. Unfortunately, harbour areas are mostly characterized by high electric conductivity, which impairs the applicability of these methods. Therefore, seismic methods were used to a greater extent, including refraction seismics and surface-wave analysis. Furthermore, equipment carriers were constructed specifically for this wetland transition zone. This included lightweight high-resolution marine reflection seismics and a magnetic gradiometer array for very shallow water, a sled-based magnetic array for swampy areas and the construction of underwater geophone-systems (Fig. 1).

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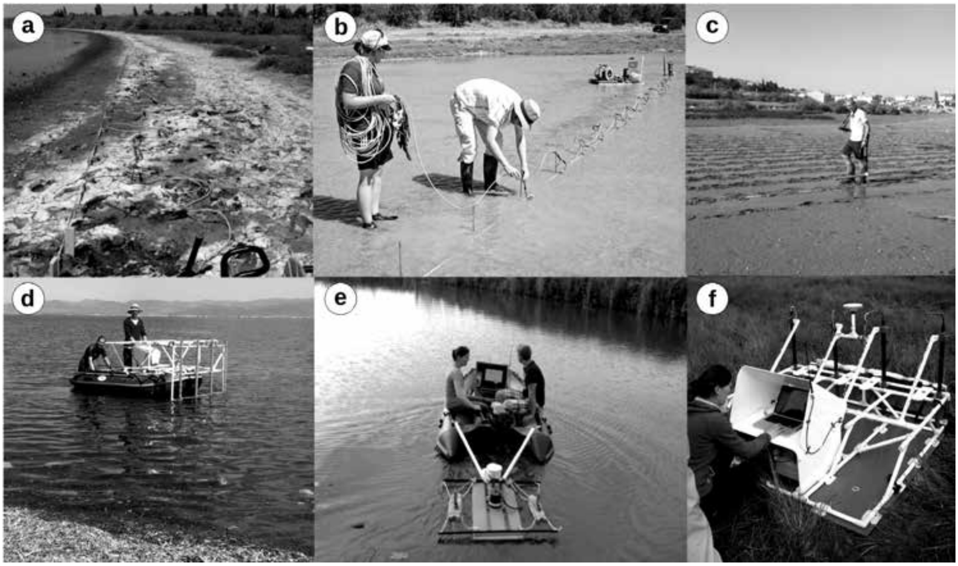

Fig. 1. Setting of measurements: a) and b) wetland seismic measurements and c) wetland EMI measurements in Enez (Turkey); d) lightweight marine magnetic gradiometer array and e) high-resolution reflection seismic system, during measurements in, respectively, Kane (Turkey) and Grimersum (Germany); f) sled-based magnetic gradiometer array for swamps and salt marshes during measurement in Iceland

The presented paper comprises examples illustrating the kinds of geophysical method or system that can be applied to specific tasks. The possible geophysical contribution for solving the above listed questions is illustrated with examples comprising:

- prospection of breakwater structures or natural, sheltered harbour basins,
- reconstruction of old riverbeds and coastlines by marine and land seismics,
- mapping of near-coast settlements by magnetics, and
- prospection of harbour structures, beaches and shoreline stabilization.

ACKNOWLEDGEMENTS

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Seismic resonance analysis for mapping a Viking Age pit house: comparison to GPR and magnetics

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KEY-WORDS: pit house, seismics, GPR, magnetics, resonance analysis

INTRODUCTION

Seismic surface waves may show amplitude resonances at certain frequencies depending on the thickness and elastic parameters of near-surface layers. The question is whether the resonance frequencies of Rayleigh-waves can be used to prospect archaeological remains of small-scale buildings, such as pit houses.

Pit houses are small houses consisting of a man-made pit with a depth of up to 1 m and a diameter of a few metres, covered by a wooden roof. Their shape varies from rounded to rectangular. In the archaeological record, these houses are preserved as refilled hollows in the subsurface. The investigated pit house is part of a multiphase settlement on the island of Föhr (North Germany), dating mainly from the 8th to the 11th century AD. The settlement was first discovered in 2006 through crop marks found in aerial pictures (Mauritsen *et al.* 2009). The settlement has a size of approximately 10 ha and is located close to the shore on the southern edge of the Pleistocene core of the island, overlooking a salt marsh. Upon discovery, the entire settlement was prospected with magnetics (Wunderlich *et al.* 2013).

The position of the house on good accessible grassland, its small size, its clear shape observed on the magnetic map and the extensive set of collected geophysical data made it a good target for a feasibility study of the seismic method presented in this paper.

Wynn (1986) mentioned a technique called bosing (introduced by Aitken 1974). This technique is a qualitative version of the method used in this work. Bosing refers to thumping the ground with a seismic source to detect different sounds caused by resonant effects over hollows, structures, and soils of different compaction (Wynn 1986). The present paper summarizes the work of Wilken *et al.* (2015), who introduced a method based on surface-wave oscillations. The method uses an artificial seismic impulse applied at a certain point in the measurement area. The subsoil will react with its natural impulse response. The properties of this oscillation depend on the velocity-depth structure underneath the point of measurement. Oscillations on top of anthropogenic structures will thus react differently than points above undisturbed soil.

The results from resonance analysis are compared with magnetic gradiometer data and ground penetrating radar (GPR) results.

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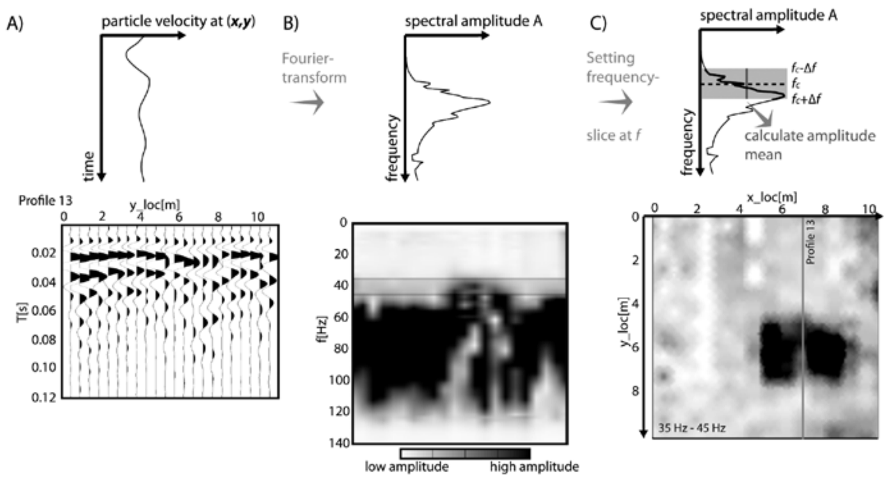

Fig. 1. Schematic view of processing steps to extract the changes in surface wave resonance frequency resulting from the pit house (A, B and C, top); sample constant offset section and amplitude spectrum of a profile crossing the pit house (A, B, bottom); sample frequency slices from 35 Hz to 45 Hz as indicated by the grey box in B, bottom (C, bottom)

METHODOLOGY

The proposed method uses an artificial seismic impulse triggered on a grid of measurement points above the pit house. The subsoil will react with its natural impulse response oscillation, which is recorded with a geophone mounted on a steel plate at 1 m distance to the source point. The spectral properties (resonance/peak frequencies and amplitudes) of the oscillation depend on the velocity-depth structure underneath the point of measurement. In order to analyze and visualize changes in resonance behavior, "frequency slices" were calculated, representing the recorded spectral energy in a narrow frequency band as a function of geophone coordinates (x, y).

RESULTS

The results of the frequency slice analysis of the Rayleigh-wave resonance dataset are shown together with schematic diagrams of the processing (Fig. 1). One sample profile was chosen to highlight the occurring effects. The profile crosses the centre of the pit house. Looking at the 1 m constant offset section (Fig. 1: A), the profile shows fairly coherent phases outside the pit, whereas a slight traveltime delay and, looking at the signal length, a shift to lower frequencies can be observed inside the pit. The latter effect can easily be observed in the amplitude spectra of the profile (Fig. 1: B). To map this effect on the measurement area, a frequency slice from 35 Hz to 45 Hz, where the effect is observed, was plotted (Fig. 1: C). A clear rectangular shape is visible here; it corresponds to the higher amplitudes in lower frequencies due to the described frequency drop. The high amplitude area correlates well with the position of the pit house.

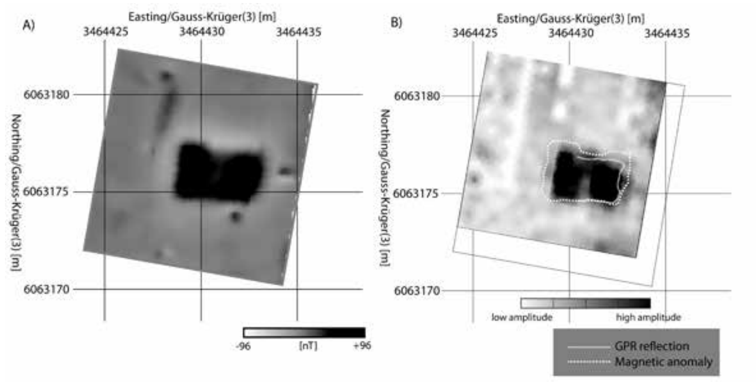

Fig. 2. Magnetic result (A) and 35 Hz to 45 Hz frequency slice from the seismic experiment, together with perimeters of the pit house signal from magnetics and GPR (B)

A final comparison was made between magnetic data showing the signal of the pit house (Fig. 2A) and the GPR data with reflection signals of two different depths (black and grey lines) and Rayleigh-wave resonance mapping data (Fig. 2B), which also shows the frequency slice derived from the seismic data. The perimeter of the house has been marked with a dashed, black line. The comparison evinces the good correlation between magnetic and seismic results. The magnetics also show that the pit house signal is somehow split into two parts, a characteristic also reflected by the seismic result. In terms of the GPR, only the reflection that corresponds to the bottom of the pit correlates well with magnetics and seismics. This effect is due to the non-horizontal shape of the reflection of the top of the pit. The seismic result furthermore shows the highest amplitudes, where the deepest part of the pit is situated (derived from GPR) and where the largest magnetic anomaly was observed.

CONCLUSION

The test showed that the pit house can be mapped by Rayleigh-wave resonance analysis with an adequate lateral resolution. The progress of seismic field measurement is slow compared to GPR and magnetic methods.

The method in the present application is a promising add-on to conventional prospection methods and can be used on specific targets as a support method with access to elastic subsoil parameters or as an alternative approach in areas were electromagnetic or magnetic methods show no contrast or only weak contrast.

A second example from a comparative study to image a Viking Age turf house in Iceland is presented in Wunderlich *et al.* (2015).

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Imaging the AD 1500 Katla tephra inside the Leiruvogur "Inner Skiphóll" harbour using GPR

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KEY-WORDS: GPR, Iceland, tephra, topographic migration

INTRODUCTION

After the discovery of Iceland in the 9th century, people from all over Scandinavia emigrated to the island. Mosfell Valley, which is found in the southwest of Iceland, was settled during

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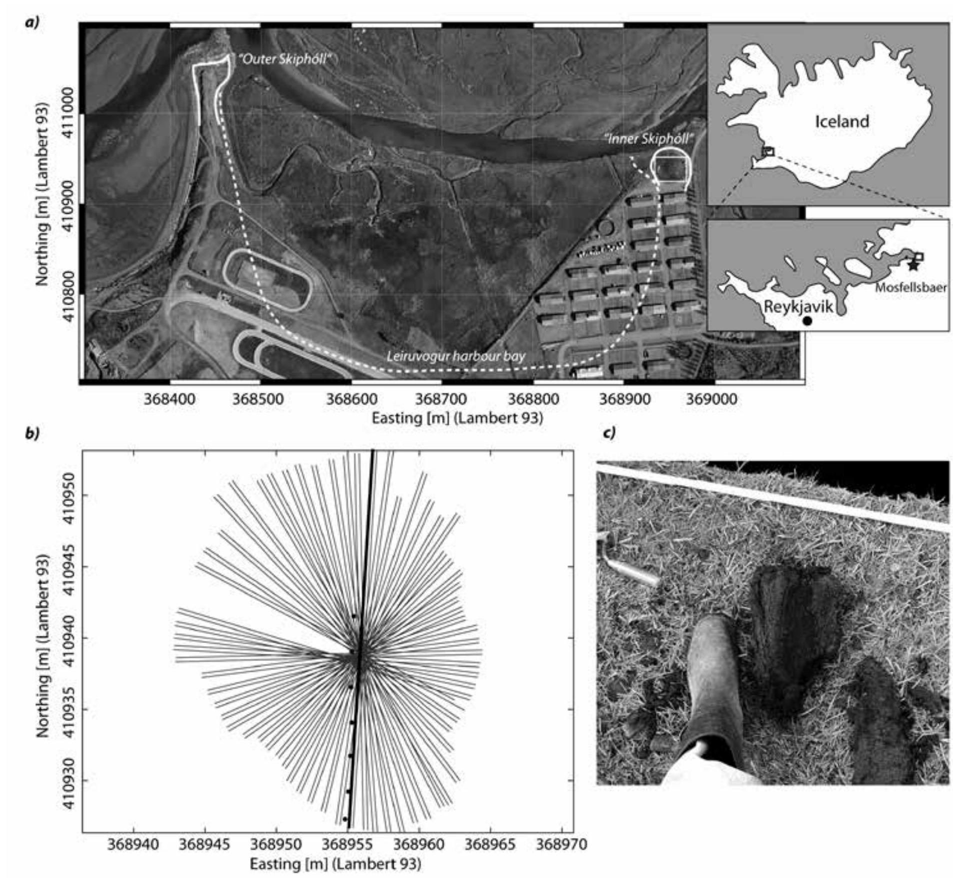

Fig. 1. Map showing the Leiruvogur site with its possible coastline (white dashed line) and the two Skiphóll landmarks, flanking the possible harbour bay (a) and map of the measured GPR profiles (grey lines) (b), position of the sample profile in Fig. 2 (line) and coring positions (dots); image of the AD 1500 Katla tephra layer (c)

the early days of the *landnám* (period of land-taking, AD 870–930). As "home to the Mosfell chieftains, a powerful Viking Age family of leaders, warriors, farmers and legal specialists" (Byock and Zori 2013), the region was one of the country's cultural centers. Leiruvogur Bay connects the valley to the sea (see map in Fig. 1). The coastal landscape of Leiruvogur itself has all the makings of a natural harbour, where ships could anchor to "wait out winter storms and load cargo and passengers" (Byock and Zori 2013). Modern structures in the area make the exploration difficult; one of the few places that seem to be left untouched is the so-called "Inner Skiphóll", a hill that could have once been used as a landmark for incoming ships.

A GPR survey was conducted on the Inner Skiphóll. The first aim of that study was to image the volcanic ash (tephra) layer of the AD 1500 Katla eruption. Every subsurface structure beneath this layer must be older and could already have existed during the Viking Age. Furthermore, if it were possible to determine the depth of the tephra throughout the mount, then the topography of the AD 1500 Inner Skiphóll could be reconstructed in more or less general terms.

METHODOLOGY

A GSSI SIR 3000 with a 400MHz antenna was used. 69 profiles were performed, crossing the top of the hill (Fig. 1 b). Topography measurement and positioning was done with a RTK-DGPS system. The profiles show one gap to the east, which was an area that was not accessible during the time of measurement. Standard processing steps included averaging of traces, resulting in a 2 cm trace distance and adjusting of time zero.

Problems for GPR on structures with strong topographic changes have been well documented in, e.g., Goodman *et al.* (2006) and Leckebusch and Rychener (2007). The main issue is that profiles have to be corrected for pitch and roll when pulled over a variable surface. Collecting data on profiles crossing the center/crown of a mount minimizes the roll variation of the antenna (Baldwin 2013). Nevertheless, the tilt movement along the profile has still to be considered. Common topographic correction approaches are geometric corrections and cannot lead to better images of the subsurface reflectivity without proper migration of the data, because the wave energy is not confined to a ray perpendicular to the surface. Goodman *et al.* (2006) and Leckebusch and Rychener (2007), for example, proposed to perform migration prior to topographic correction. The migration would focus the energy distributed over to the radiation pattern of the GPR antenna. This is not feasible because diffractions appear deformed due to topographic changes in the time sections, which leads to migration errors. Lehmann and Green (2000) proposed a topographic Kirchhoff migration and showed that topographic migration should be applied when the topographic change is of the same order as the investigation depth and when the surface gradient exceeds 10%. Both arguments apply in the presented case.

In this presentation, we used a simple migration approach based on semicircle superposition (Schneider 1978). The basic idea of semicircle superposition is that the energy recorded at traveltime t may be reflected from all scattering subsurface points on a half-circle with the radius $(t/2)v$ (v is the wave velocity). The recorded energy is thus smeared along this circle in the x–z (depth) domain. Based on Huygen's principle, reflecting events and diffractions are superposed. In our migration algorithm, this circle smearing is done only along a circle section defined by an assumed aperture of the antenna (which was determined to be 30°) and oriented regarding the topographic slope. The velocity used for the migration was estimated to 6 cm/ns by diffraction curve fitting.

In addition to GPR, seven shallow coring samples were taken, wherein the Katla tephra was identified as a black ash layer with a thickness of a few centimeters (see sample in Fig. 1c). The depth of the tephra in the corings enabled identification of the corresponding GPR reflector, which was then picked where possible.

RESULTS

An example GPR section appears in Fig. 2a, whereas Fig. 2b shows the same section but with topography migrated. The image also comprises the depths of the tephra layers in the cores (white rectangles). A clear tephra reflector can be assigned (dashed line). This reflector was picked up where

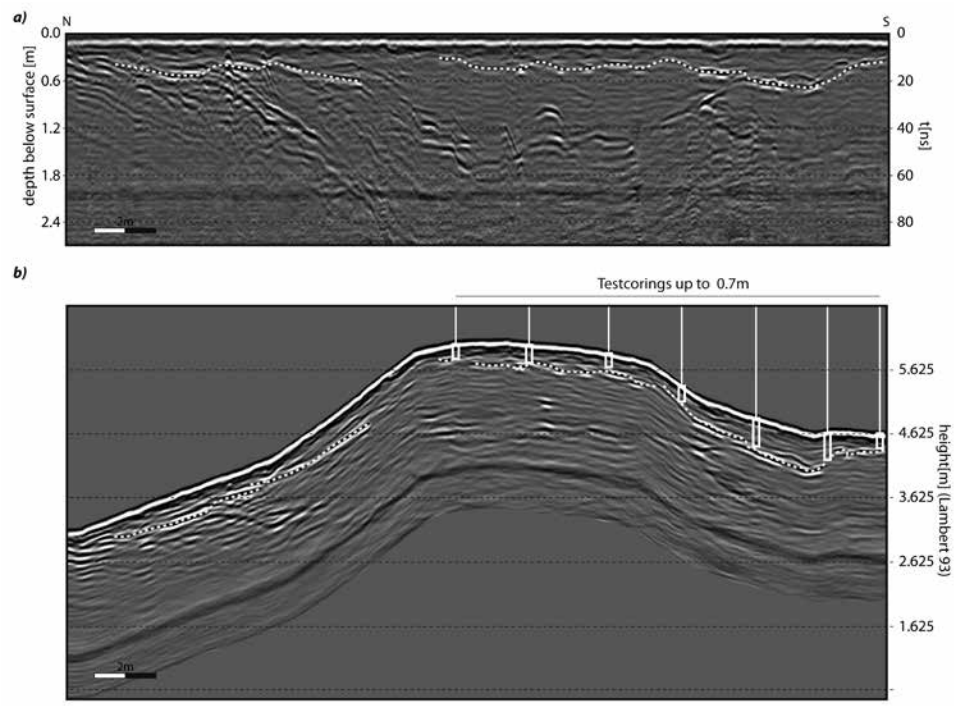

Fig. 2:. Sample GPR time section (a) and migrated GPR depth section (b); white rectangles indicate the depth of the AD 1500 tephra layer in the core samples. The dashed line shows the interpreted tephra reflection event

possible in all the profiles, resulting in a map of tephra depths. The topography of the mount is shown in Fig. 3a and the tephra depths below that topography in Fig. 3b. The depths of the Katla tephra could be identified in most of the area and changes by up to 0.5 m throughout the mount. From that depth an approximate topography of the AD 1500 Skiphóll was reconstructed (Fig. 3c). The mount has basically kept its shape in time, while showing more soil accumulation in the western part.

CONCLUSION

The project showed the potential of using GPR to image a distinct volcanic ash layer inside a mount structure at the Viking Age harbour site of Leiruvogur. Accurate topographic migration led to an almost complete image of the depth of that ash layer, which coring identified as the AD 1500 Katla tephra. The GPR results enabled the part of the mount that is below that layer and thus younger than AD 1500 to be reconstructed. By showing the potential of GPR to image such layers, dating of anomalies in GPR measurements becomes possible in Iceland whenever tephra layers can be attached to reflections with the help of coring.

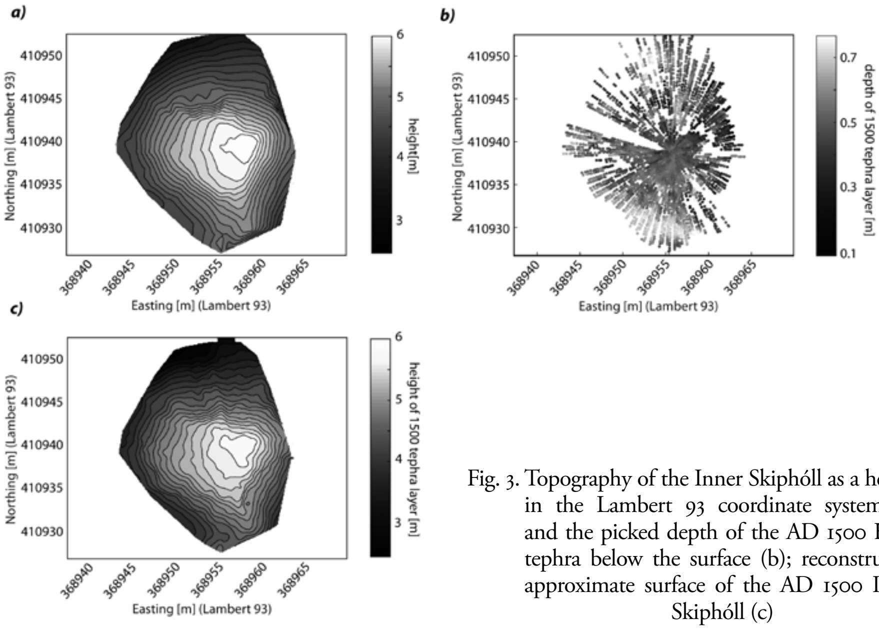

Fig. 3. Topography of the Inner Skiphóll as a height in the Lambert 93 coordinate system (a) and the picked depth of the AD 1500 Katla tephra below the surface (b); reconstructed approximate surface of the AD 1500 Inner Skiphóll (c)

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Mapping medieval turf buildings with geophysical methods

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KEY-WORDS: magnetics, GPR, ERT, EMI, seismics, turf building

INTRODUCTION

The successful application of geophysical methods in archaeological prospection is conditioned by a contrast in the physical parameters between the object of interest and the surrounding material, mostly soil. Geophysical methods commonly applied in archaeological prospection include magnetics, ground penetrating radar (GPR), electromagnetic induction (EMI) and electrical resistivity romography (ERT). These techniques are based on contrasts in magnetic susceptibility, dielectric permittivity and electrical resistivity, respectively. The application of seismic surface waves is less common, but a small number of studies exists (e.g., Castellaro *et al.* 2008; Woelz and Rabbel 2005; Grandjean and Leparoux 2004; Nasseri-Moghaddam *et al.* 2007). Seismic measurements depend on contrast in elastic constants.

The objective of the present article is to test which geophysical prospection method or combination of methods is most suitable for investigating the remains of ancient turf buildings. The challenge lies in the fact that turf buildings can be expected to show only slight physical contrast with the surrounding soil, because both consist of basically the same material.

METHODS

Five methods were tested on the ruins of a known turf building that was part of the Viking-age farm at Skeggjastaðir in Western Iceland. Remains of the turf walls are visible as elevations barely a few centimeters high, contrasted with the surrounding soil.

Magnetic, GPR and EMI (both electrical conductivity and in-phase component) measurements were carried out in an area covering the whole ruin. Two ERT profiles with electrode spacing of 0.25 m were measured across the turf building. Seismic data were acquired with a

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source-geophone pair moved over the whole area with 0.5 m grid point spacing. The data were analyzed for changes in surface wave resonance frequency resulting from anthropogenic changes in the subsoil. More details of all the methods can be found in Wunderlich *et al.* (2015).

RESULTS

The magnetic, seismic, EMI and GPR measurement results of the investigated area show the location of the turf building (Fig. 1; indicated by the dashed line). The magnetic map shows some strong and intermediate anomalies in the area of the building, mainly on the north and south walls, and the southeastern corner (Fig. 1a). The EMI IP signals (Fig. 1c) integrate over an effective depth of 1 m and correlate well with the magnetic anomalies as expected, because the IP component is proportional to the magnetic susceptibility.

The line of anomalies in the southern part of the ruin is also found in the GPR timeslice between 8 ns and 14 ns (Fig. 1e), corresponding to an approximate depth of 20 cm to 35 cm (calculated with a velocity of 5 cm/ns). This high reflection energy corresponds to stones and tumbled turf blocks that are visible as diffraction hyperbolae in the radargrams.

The seismic Rayleigh wave frequency slice between 30 Hz and 40 Hz (Fig. 1b) shows a fall in the middle part of the amplitude. This corresponds to the ruin. An effect of the thinning of the top soil layer is also visible on the northeastern side of the area.

The electrical conductivity measured by EMI shows a rectangular anomaly of lower values (<1 mS/m) compared to the surroundings (Fig. 1d). This corresponds to the turf walls. The existence of a conductivity contrast between the turf walls and the surrounding turf is also visible in the inverted ERT profiles crossing the building (Fig. 1f). They show the walls as high electrical-resistivity anomalies. At a depth below approximately 1 m, the resistivity increases sharply to values larger than 3000 Ωm, corresponding to bedrock.

CONCLUSION

Because the methods depend on different physical parameters, they map different parts of the turf building. Methods measuring electrical conductivity (or resistivity), such as EMI (conductivity component) and ERT, are sensitive to the turf in the walls. Stones lining the inside or outside of the turf walls as part of the foundation can be seen by methods sensitive to the magnetic susceptibility of volcanic stones, that is, magnetics and the EMI IP component. Sometimes bog iron incorporated in the turf walls can also be imaged by these methods. GPR maps the stones, but also the turf walls due to changes in dielectric permittivity. In the case of turf walls, permittivity is influenced mainly by differences in porosity and water content compared to the surrounding turf. The amplitude decrease of the seismic Rayleigh wave resonance peak is to be explained by an increase in seismic velocity in the building area (Wunderlich *et al.* 2015; Wilken *et al.* 2015).

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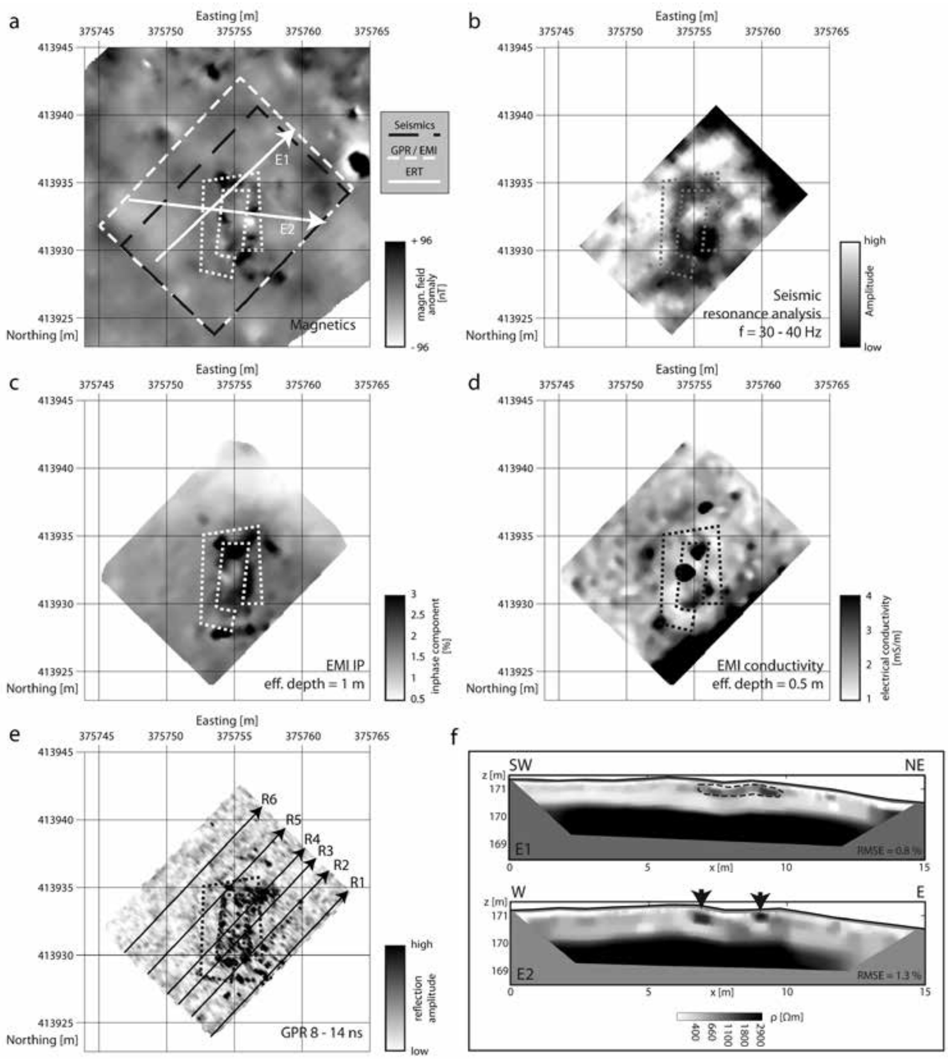

Fig. 1. Resulting maps of magnetic (a), seismic (b), EMI (c and d), GPR (e) and ERT (f) measurements of an area surrounding the turf building in Skeggjastaðir (ruin indicated by dotted lines) (modified from Wunderlich *et al.* 2015)

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The harbour(s) of ancient Ostia. Archaeogeophysical prospection with shear wave seismics, geoelectrics, GPR and vibracorings

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KEY-WORDS: ERT, seismics, GPR, vibracoring, ancient harbour

INTRODUCTION

The ancient city of Ostia is situated at the mouth of the river Tiber. Together with the neighbouring harbour of Portus, it was the largest distribution centre of the Mediterranean

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in the 2nd century AD. Before that Ostia was a secondary transit harbour for Rome, mostly responsible for the safety of the mouth of the Tiber.

The central urban area of ancient Ostia has been investigated thoroughly and large parts excavated, whereas the harbour area to the west of the archaeological site, today silted-up completely, has hardly been explored. Recent geoarchaeological investigations revealed two different harbour types: an early lagoonal and subsequently fluvial harbour, separated by a high-energy event layer of most likely tsunamigenic origin (Vött *et al.* 2015).

The aims of the recent joint geophysical–geoarchaeological exploration effort at the port of Ostia presented here were:

1) to determine the depth and extent of the original harbour basin,
2) to determine the stratigraphy of the sedimentary fill, and
3) to search for remains of harbour structures.

The paper at hand presents the results of geophysical investigations by shear wave seismics, electrical resistivity tomography (ERT) and ground penetrating radar (GPR) covering the whole harbour area. The geophysical results are then interpreted in correlation with the local stratigraphical records obtained by vibracoring (Vött *et al.* 2015).

METHODS

ERT

Thirteen profiles covering all of the harbour area were measured using Syscal R1 Plus Switch 48 (Iris Instruments) and RESECS (GeoServe) equipment with dipole-dipole, Wenner and Schlumberger configurations. The inversion was done with BERT (boundless electrical resistivity tomography, e.g., Günther *et al.* 2006) software.

Seismics

Seismic measurements using SH-waves were acquired on eight profiles in the harbour area, partly at the same locations as the ERT profiles, using three Geodes (Geometrix) and 4.5 Hz OYO horizontal geophones. The profiles were processed by multi-channel analysis of Love-waves (MASW) (e.g., Park *et al.* 1999) yielding S-wave velocity–depth profiles. Local wavefield segments were transformed into the slowness-frequency domain. Spectral maxima were fitted with dispersion curves for 1D S-wave models at each position using prticle swarm optimization (Wilken and Rabbel 2012). Forward modelling was done with the modified Thompson-Haskell code of Wang (1999).

GPR

GPR measurements were applied in the area around the harbour site to map probable buildings and to detect the floor of the silted-up harbour basin. The equipment used was a 400 MHz antenna and SIR-3000 (GSSI). Parallel profiles were interpolated in a 3D data cube and horizontally cut into timeslices.

Corings

Within the harbour area, vibracoring was carried out in order to study the stratigraphical record of the harbour basin and as a base to calibrate geophysical datasets. Eight vibracores

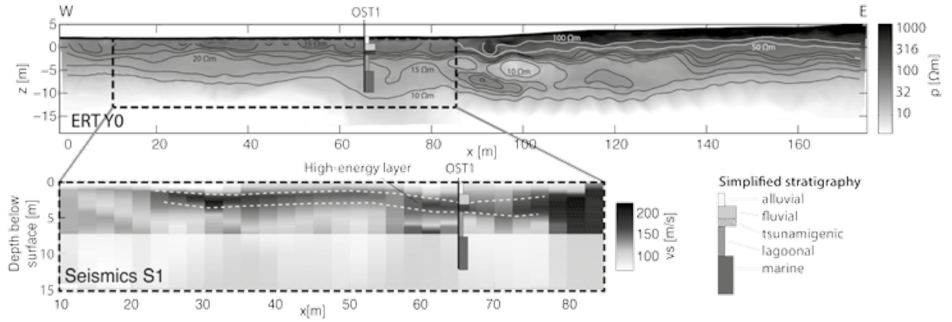

Fig. 1. Comparison of ERT and a seismic profile crossing the harbour basin from west to east. Together with vibracore stratigraphy, the high seismic velocity layer is assigned to the high-energy facies separating a lagoonal and a fluvial harbour phase

were drilled down to 12 m below ground surface (m b.s.) using a Nordmeyer RS 0/2.3 automotive drill rig. Vibracores were photographed, described and sampled with regard to different facies. The position and elevation of each vibracoring site was measured using a Topcon HiPer Pro DGPS device (type FC-250). In the laboratory, selected sediment samples were analysed to determine grain size distribution, geochemical parameters and microfossil content. The geochronological framework is based on radiocarbon dating and age estimates of diagnostic ceramic fragments.

RESULTS

The 2D-inversion of all ERT profiles and the compilation into a 3D-model show very clearly the outline of the harbour basin by a distinct change from higher resistivities (outside) to lower resistivities (inside) with an overlap of a near-surface high-resistivity layer from outside about 10 m into the basin. The "electrical stratigraphy" inside the basin seems to be quite homogeneous laterally, but shows a continuous decrease in the electrical resistivities with increasing depth. The inversion of Love-waves shows that the basin fill consists of fine-grained sediments with typical S-wave velocities of about 120 m/s (Fig. 1). A special feature is a horizontal, 1–2 m thick band of 100%(!) increased shear wave velocities about 2 m below the surface. The top of this layer can also be seen in the ERT results, while the bottom of this layer is not resolved. Vibracore stratigraphy allows shear wave velocities and electrical resistivities to be assigned to distinct sediment facies and geoarchaeological layers, to be tracked across the harbour area. Compared to all vibracore stratigraphies (Fig. 1), our results show that this band corresponds to a high-energy event layer made of coarse-grained deposits, mostly sand and gravel, separating a lagoonal from a fluvial harbour phase (Vött *et al.* 2015).

Because of high electrical conductivity and attenuation of GPR waves in the harbour basin, the GPR measurements provided results only outside the harbour area. GPR timeslices in the area surrounding the harbour basin show foundations of buildings and infrastructure (possibly sewage tunnel or gully), reaching as far as the previously assumed border of the harbour.

CONCLUSION

Based on a combination of seismics, ERT, GPR and vibracoring, a two-phase harbour was explored at ancient Ostia: a) an older lagoonal and b) a subsequent fluvial harbour. Inversion of seismic surface waves visualized a 1–2 m thick band of 100% increased shear wave velocities associated with a coarse-grained high-energy layer of most likely tsunamigenic origin documented in the vibracore stratigraphies, whereas ERT could only resolve the top of this layer. GPR helped to map foundations and infrastructure around the basin.

ACKNOWLEDGMENTS

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Marine magnetic and seismic measurements to find the harbour of the early medieval Slavic emporium Groß Strömkendorf/Reric, Germany

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KEY-WORDS: marine magnetics, marine reflection seismics, coastline, harbour

INTRODUCTION

Groß Strömkendorf, situated north of Wismar on the coastline of the Baltic Sea, was an emporium in early Slavic times. Large parts of the emporium and the adjoining burial ground have been excavated (Schmölcke 2004; Pöche 2005; Tummuscheit 2011; Jöns 1998), but no evidence for a harbour place has been found. This might be due to erosion of the coastline and a rising sea level, which is 0.5–1 m higher compared to early medieval times (Klug 1980). This leads to the conclusion that large parts of the former mainland are today underwater or have been destroyed by erosion. In the shallow water in front of the emporium, a linear structure that may be associated with a channel is visible in aerial images; in combination with an inlet to the open waters further to the south, it suggests the position of a perfect natural harbour place.

Geophysical surveys in the shallow water in front of the emporium were aimed at investigating the structure and the inlet, as well as its surroundings to find evidence of probable harbour structures of wood and indications of further settlement activity on the former mainland.

METHODS

To map the relatively large area underwater a small boat was used with four Fluxgate magnetometers mounted in front of it. The sensors can be lowered 0.5 m into the water to bring the sensors closer to the ground (Fig. 1a). Positioning was made with a RTK-DGPS with 1–2 cm accuracy. To delete the influence of metal on the boat, a mean value was calculated for every profile and subtracted from the measurements. Although the height of the sensors can be varied, it is not possible to measure with a constant height above the ground. Therefore, a downward field continuation was applied to transform the magnetic measurements to a constant level above ground during processing.

In addition to the magnetic measurements, high-resolution marine reflection seismic measurements were carried out to gain also depth information for the structures. These measurements were done by pulling a seismic pinger source and two hydrophones on small floating

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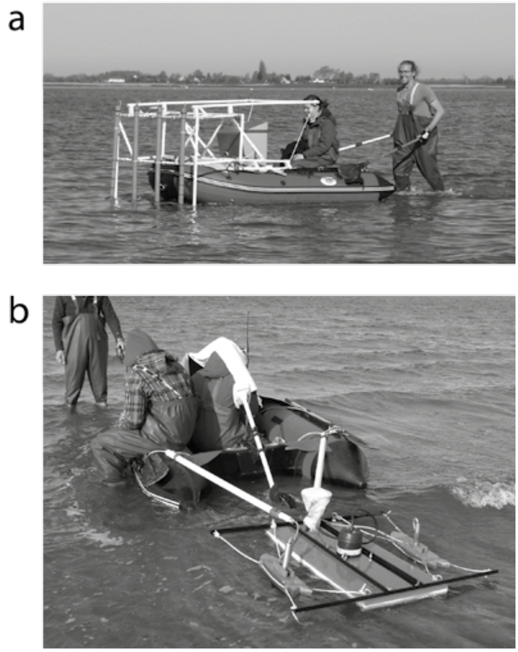

Fig. 1. Measurement setups for magnetics (a) and seismics (b)

bodies behind the boat (Fig. 1b). The pinger emits an acoustic pulse (4kHz Fuchs-Müller wavelet) into the water, which is reflected from the sea bottom, but also transmits into the ground and is reflected at geological interfaces. The reflected energy is recorded by the hydrophones. The processing consists of bandpass filtering, deconvolution to sharpen the signal, trace normalization and smoothing of the sea bottom, which is necessary to eliminate the effect of small waves moving the boat up and down. The recorded traveltime of the seismic waves can be transformed into depth by assuming a full water saturation of the marine sediments that allows using a constant propagation velocity of approximately 1500 m/s.

RESULTS AND CONCLUSION

The magnetic map shows strong linear anomalies around 80 m in front of today's coastline, coinciding very well with the landward border of the channel feature seen in aerial images, and is thus interpreted as the former coastline. Seismic profiles running from the coast seawards show slightly dipping reflectors beneath the aerial photo anomaly; these die out at the points where the linear magnetic signals were observed. A channel-like structure is visible below the aerial-image anomaly, but westward of it.

The magnetic map shows also some areas with accumulation of round anomalies. Their interpretation is at this moment unclear. One of these areas was used as a test for downward field continuation (Fig. 2). The water depth in this area ranges from about 0.5 m close to the shore in the east to about 1 m seawards. Magnetic measurements were made with sensors 10 cm below the water surface.

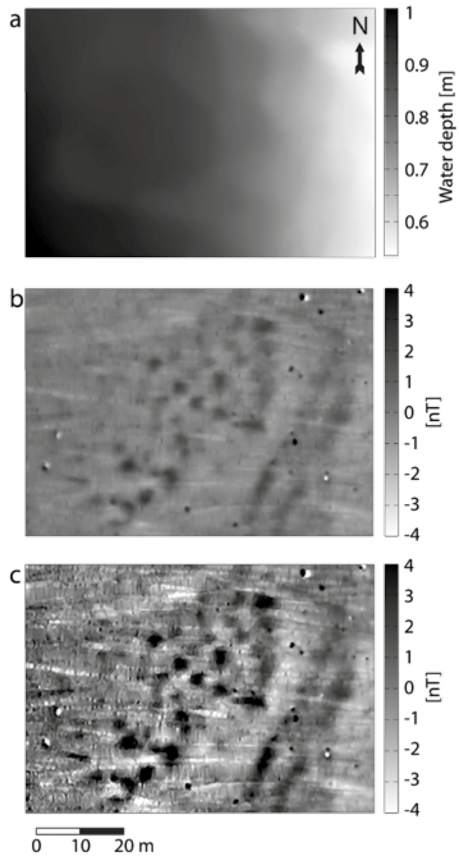

Fig. 2. Example of downward field continuation of the magnetic data: (a) water depth derived from seismic measurements, (b) originally measured magnetic map with sensors 10 cm under the water surface, and (c) downward continuation of the magnetic data to a constant level 20 cm above the ground

This distance from sensors to the ground, growing to the west, weakens and widens the anomalies. Compensating for this effect was a downward field continuation, using an approximation given by Fedi and Florio (2002). The procedure of analytical continuation can be performed in source-free space for any harmonic function (e.g., Kellog 1929: 384), also for the magnetic vertical component difference, as the output of processed fluxgate data. This was tested by us for complex magnetic models (not shown in this abstract, using REGCONT software, Pasteka *et al.* 2012). This produced a magnetic map, as if it was measured 20 cm above the seafloor. The procedure of downward field continuation increases the amplitudes and sharpens the anomalies. Unfortunately, also the noise is strongly increased. To minimize this effect, the magnetic maps were 2D-median-filtered median filtered before and after the downward continuation over three samples.

The combination of marine magnetic and seismic measurements has great potential in finding and investigating former coastlines, and narrowing down the position of the possible harbour site. Reflection seismic measurements can be used to provide depth information for anomalies found on the magnetic map, which is easier to measure over larger areas.

ACKNOWLEDGMENTS

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Processing and visualisation of data

Role of potential field derivatives in delineating buried archaeological ruins

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KEY-WORDS: total magnetic field, potential derivatives, tilt derivatives, analytical signal amplitude, total horizontal derivative, generalized derivative

Potential field derivative techniques are intensively used in various geophysical large-scale investigations. The current work applies some of these techniques to small-scale high-resolution surveys commonly conducted in archaeological prospection and environmental investigations. The techniques include: spatial orthogonal derivatives, analytical signal amplitude (ASA) (Nabighian 1972; Roest *et al.* 1992), total horizontal derivative (THDR) (Cordell and Grauch 1985; Phillips 2000), tilt angle derivative (TDR) (Miller and Singh 1994; Wijns *et al.* 2005), total horizontal derivative of TDR (TDR-THDR) (Verduzco *et al.* 2004), horizontal tilt angle (TDX) (Cooper and Cowan 2006), tilt angle of total horizontal derivative (TAHDR) (Ferreira *et al.* 2010; Cheyney 2012; Jacques *et al.* 2014), and generalized derivative operator (GDO) (Cooper and Cowan 2011).

A high-density total field magnetic survey was conducted at an ancient Egyptian archaeological site located in northeastern Sinai. The region is part of the old delta of the river Nile (Aziz *et al.* 2013). The chosen site was proposed by field archaeologists, aiming to delineate the eastern extension of the buried southern wall of Tjarou citadel (Abd El-Maksoud and Valbelle 2005). The citadel was erected mainly of mud brick, resulting in a low magnetic susceptibility contrast between the buried wall and the surrounding fill (Shendi and Aziz 2010).

A proton precession magnetometer was used to measure the total magnetic field. The instrument is also equipped with two sensors to measure the vertical gradient of the magnetic field. Three squared grids, covering an area of 20 m by 60 m, were laid out. The shortest side of the surveyed grids was parallel to the course of the wall: N80^{0} E. Traverses were surveyed perpendicularly to the wall azimuth, and were spaced 0.5 m apart. Measurements were recorded every

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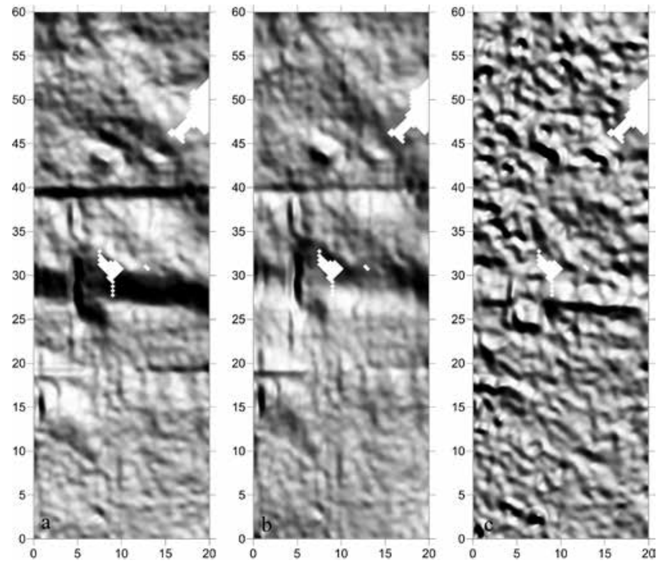

Fig. 1: a) Total magnetic field anomaly map; b) total magnetic field after reduction to the pole, c) actual vertical magnetic gradient measured in the field

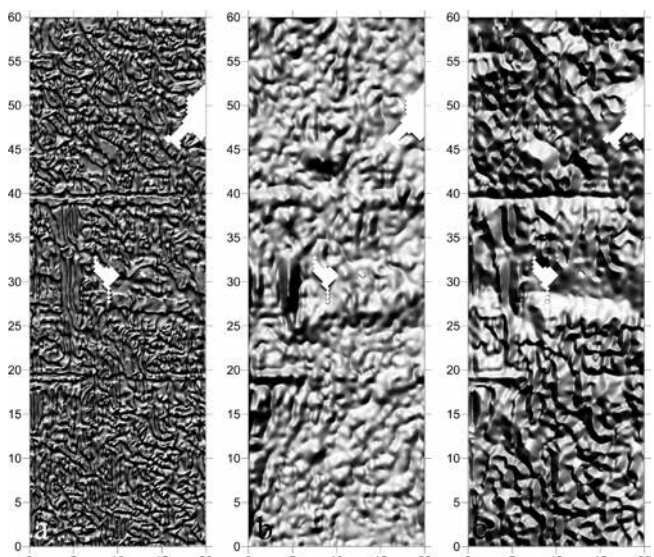

Fig. 2: a) Total horizontal derivative map $THDR = \left((\partial T/\partial x)^2 + (\partial T/\partial y)^2\right)^{1/2}$; b) analytical signal amplitude map $ASA = \left((\partial T/\partial x)^2 + (\partial T/\partial y)^2 + (\partial T/\partial z)^2\right)^{1/2}$, c) tilt angle derivative map $TDR = \cos^{-1}(THDR / ASA)$

0.5 m along each traverse. The acquired total magnetic field measurements were corrected for the effect of diurnal fluctuations of the Earth's magnetic field. The corrected data were reduced to the pole to eliminate the effect of the inclination and declination of the Earth's magnetic field. Oasis Montaj software was used to carry out the computation of derivatives and illustrate the results in black and white shaded relief maps (Figs 1, 2 and 3).

Examination of derivative mapping revealed more information about the buried sources of anomalies than those deduced from the original total magnetic map or the actual vertical gradient map. The spatial derivative map on the Y axis (northward) emphasizes the E–W azimuth of the wall. While both the orthogonal derivatives on the Y and Z axes showed that the buried wall had a higher magnetic susceptibility than its surroundings. THDR and ASA maps enhanced the edges of the subsurface magnetized bodies, and both were invariant with field inclination. Edge enhancement of the THDR map was approximately depth independent; while ASA enhanced the shallower and larger objects more than the deeper ones. Inflections of the TDR from positive, over the wall, passes through zero, over or near the edge, are superimposed by zero vertical derivative and maximum Y horizontal derivative. Negative horizontal Y derivative values are outside the source region. THDR contacts that overlie the analytical signal amplitudes ASA contacts indicate that the edges of the wall are vertically dipping. TDR-THDR and TAHDR show sharper delineation of the edges. GDO produces good horizontal locations for contacts and edges, independently of dip, inclination and depth. In addition, it is less susceptible to noise, and clarified other buried deeper and smaller walls, even if they have different runs, that is, not perpendicular to the direction of the surveyed traverses.

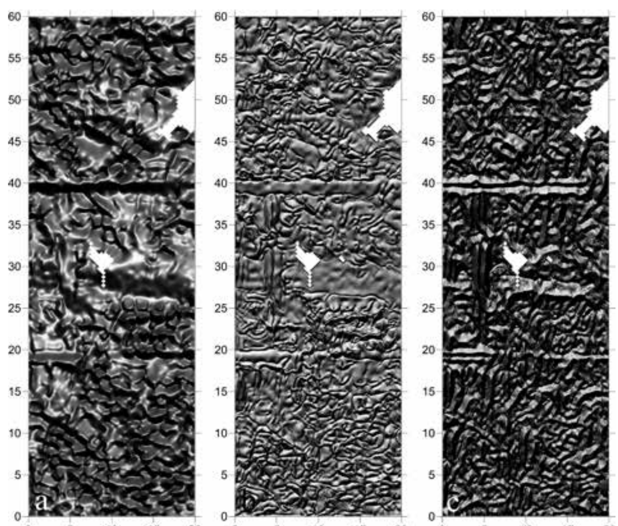

Fig.3: a) Generalized derivative operator $GDO = \frac{1}{ASA} * \left(\left(\frac{\partial T}{\partial x}\sin(\alpha) + \frac{\partial T}{\partial y}\cos(\alpha) \right)\cos(\beta) + \frac{\partial T}{\partial z}\sin \right.$, where α and β are the azimuth and the dip of the filter in the horizontal plane; b) total horizontal derivative of tilt angle $TDR\_THDR = \left((\partial TDR/\partial x)^2 + (\partial TDR/\partial y)^2 \right)^{1/2}$; c) tilt angle of total horizontal derivative $TAHDR = \tan^{-1}((\partial TDR/\partial z)/TDR\_THDR)$

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Resistivity modelling and inversion of square array for archaeological investigations

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KEY-WORDS: square array, electrical resistivity inversion, modelling, archaeological investigation

INTRODUCTION

Electrical resistivity tomography (ERT) investigations are a growing field due to adequate data acquisition of subsurface resistivity distribution regarding the sufficient contrast between the buried archaeological structures and covering soil (e.g., Papadopoulos *et al.* 2006; Drahor *et al.* 2008). In resistivity surveys, the electrode configuration is a crucial factor in the identification of the apparent resistivities of the subsurface. Apparent resistivities can also be affected by the dimension and depth of the target, moisture content of the soil, bedrock position and climatic conditions (Berge and Drahor 2011). Therefore, various electrode configurations can be used in the field to determine the subsurface archaeological features considering their resolution capability.

Presented in this study is a resistivity modelling and inversion of the square array that was firstly described by Habberjam and Watkins (1967). Application of this array in archaeological prospection is also given by Tsokas *et al.* (1997) and Aspinall and Saunders (2005). However, two- and three-dimensional inversions of the square array data were not sufficiently examined except for Papadopoulos *et al.* (2009). They present the results of 3D inversion for ARP configuration, which is an acquisition system developed from the square array (Dabas 2009). The present study aims to investigate the efficiency of the square array on some synthetic archaeological models by comparing with commonly used arrays (Wenner and dipole–dipole).

METHOD

Modelling studies are an important tool for simulating buried objects. Thus, the case similar to real position of subterranean structures could easily be investigated by modelling studies before the archaeological application. In this study, the simulation of the square array is carried out by using three-dimensional forward modelling and an inversion algorithm.

Forward modelling was achieved by the finite-difference solution of Poisson's equation. Thus, the apparent resistivities for various electrode configurations are calculated by using a mesh system constituted from a number of homogeneous cells. In the inversion, observed apparent resistivities are used to obtain a subsurface model in an iterative manner. A parameter update, which is

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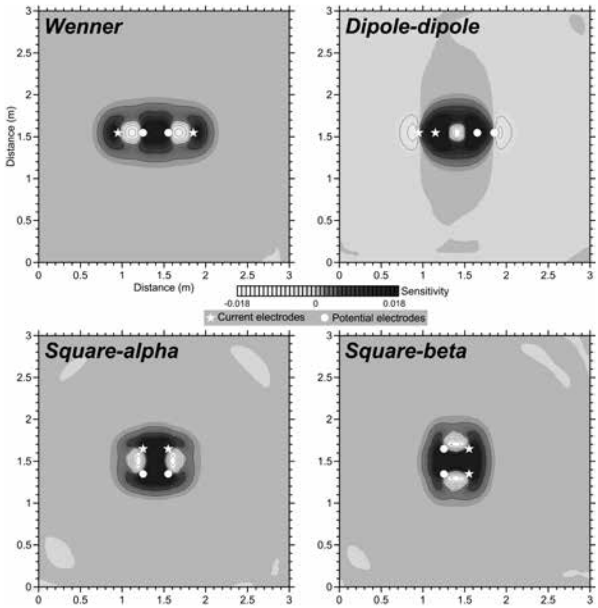

Fig. 1. Sensitivity depth slices of square-alpha, square-beta, Wenner and dipole–dipole arrays for a homogeneous earth model that has a resistivity value of 100 ohm-m. Depth is set to 0.25 m. Stars and circles indicate current and potential electrodes, respectively

necessary to optimize the subsurface model, is solved in iterations by minimizing the difference between observed and calculated data. A Matlab code implemented by Berge (2011) is used for this purpose. Computation time of this three-dimensional smoothness-constrained inversion routine is reduced by using the parallel computation facility of the Matlab software.

RESULTS

In order to define the resolution capability of the square array, the sensitivity of this array is first calculated for a homogeneous medium. In Figure 1, sensitivity depth slices of square-alpha and square-beta arrays are given together with Wenner and dipole–dipole configurations. Depth value is set to 0.25 m in these slices. It is seen that the sensitivity values of the square arrays is enough in comparison with the Wenner and dipole–dipole. The maximum value is on the centre of the configuration and the result is that the target will give a reasonable high anomaly when it is located in the middle of the array. This encouraged us to investigate the efficiency of the square array for inversion results.

For this purpose, a simple idealized model, which simulates a highly resistive (1000 ohm-m) structure, such as a wall in a homogeneous medium (100 ohm-m), is generated to explore the inversion result of the square array (Fig. 2a). The depth of the target is 0.5 m and its dimension is 2 x 2 x 1 m. To optimize the computation time for the inversion process, the modelling area dimensions are fixed to 20 x 10 x 5 m and cell dimensions are 0.5 m in

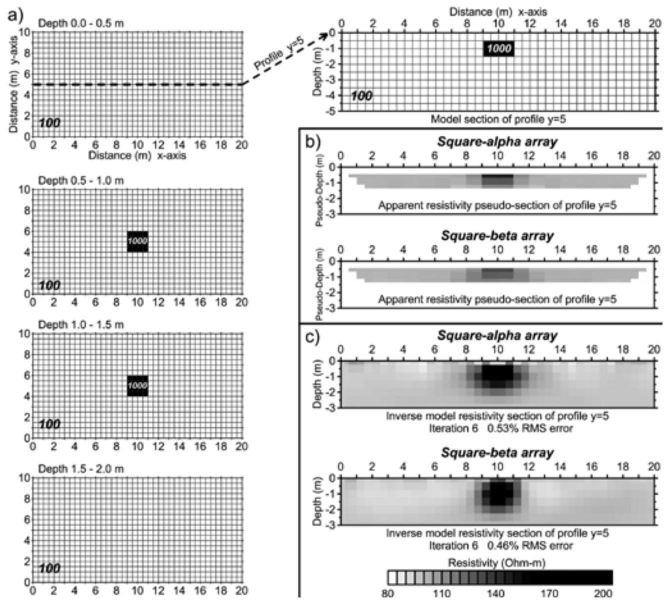

Fig. 2. a) Model section used to simulate the resistive target (1000 ohm-m). Background resistivity is 100 ohm-m. Black dashed line marks the measuring profile traversed through the target (profile y=5). b) Apparent resistivity pseudo-sections and c) inverse model sections of square-alpha and square-beta arrays derived from the profile y=5

each direction. In total, five measuring profiles (y=3, 4, 5, 6 and 7) were designated with an electrode spacing of a=1 m. Used configurations have a maximum of three investigation depths, where the maximum separation is 1a to 3a for square and Wenner arrays and n=1, 2, 3 for the dipole–dipole array, respectively. Synthetic data is corrupted with ±0.02 mV/V random noise. Afterwards, synthetic data of the overall arrays is processed by using the three-dimensional inversion routine. Maximum iteration is fixed to six.

Apparent resistivity pseudo-sections derived from square-alpha and square-beta arrays over the profile (y=5) traversed through the target are given in Fig. 2b. Pseudo-depth is calculated by using median depth of investigation value of the square array. The arrays present high apparent resistivity values (between 131 to 144 ohm-m for square-beta and square-alpha arrays, respectively) around the target as expected.

In Fig. 2c, three-dimensional inversion results of the square arrays are presented as 2D model sections. Considerably high resistivities are produced over the target. But, the different resistivity distributions obtained from the square arrays are remarkable. The target dimensions can be estimated from these inverse model sections.

In order to compare square arrays with Wenner and dipole–dipole configurations, depth slices of the inversion results are plotted up to 1.5–2.0 m depths (Fig. 3). Results show that the target location is defined in overall arrays. However, the bottom of the target is not accurately

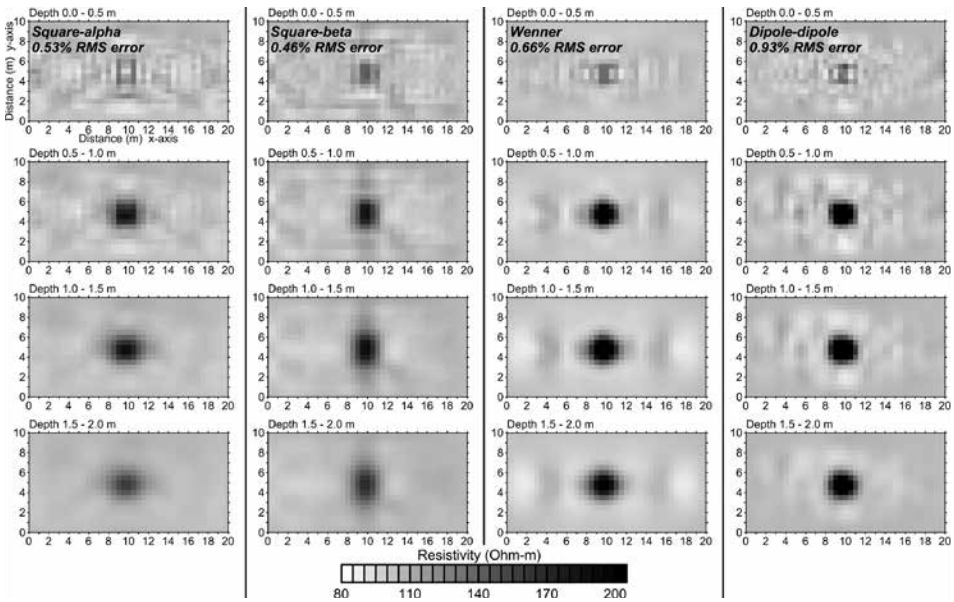

Fig. 3. Inverse model depth slices of square-alpha, square-beta, Wenner and dipole–dipole arrays over a prismatic resistive target (1000 ohm-m). Background resistivity is 100 ohm-m

determined due to the lack of more investigation depths for the used arrays. Inversion of the square arrays generates moderately lesser resistivity values around the target in comparison with Wenner and dipole–dipole configurations. In addition, the square arrays present different resistivity distributions around the target than is expected from their sensitivity maps.

CONCLUSIONS

In this study, the modelling and inversion results of the square-alpha and square-beta arrays are examined for a model based on the archaeological target. In comparison with the presentation of apparent resistivity pseudo-sections, the inversion results are more accurate to resolve the target location as a means of resistivity value and dimensions of the target. However, a comparative study between used electrode arrays indicates that the square array gave partially low resistivity values around the target.

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The influence of sampling interval on accuracy of probabilistic attenuation correction for GPR signal

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KEY-WORDS: GPR, attenuation correction, Bayesian statistics, belief propagation, FDTD method

INTRODUCTION

A new method has been proposed to correct the attenuation of ground-penetrating radar (GPR) signals using probabilistic signalprocessing based on Bayesian statistics (Chishima *et al.* 2013: 173–175). The advantages of this method are the selective amplification of GPR signals without the amplification of the noise and the automatic estimation of the medium attenuation coefficient. However, this method is easily affected by the sampling interval employed during data acquisition. In this paper, this problem is demonstrated by some results of numerical experiments, and a way to avoid the problem is discussed.

METHOD FOR ATTENUATION CORRECTION

The proposed attenuation correction method is briefly described below.

Let a list of sampled data of a GPR trace be a vector $\mathbf{d}=(d_1, d_2, \dots, d_N)$, and let an ideal signal be a random variable vector $\mathbf{f}=(f_1, f_2, \dots, f_N)$ that is not affected by either medium attenuation or noise, where each di, fi represents the amplitude value at time $i\Delta t$ (Δt: sampling interval). For the method, it is essential to search for $\mathbf{f}_{est}$ maximizing $p(\mathbf{f}|\mathbf{d})$, where $p(\mathbf{f}|\mathbf{d})$ is the

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Likelihood	Prior Distribution
$p(\boldsymbol{d}\|\boldsymbol{f}) = p(\boldsymbol{d}\|\boldsymbol{f}, \alpha, \sigma_n) = \dfrac{\exp\left(-\frac{1}{2\sigma_n{}^2}\Sigma_{i=1}^{N}(d_i - e^{-\alpha i \Delta t} f_i)^2\right)}{Z_{lik}}$	$p(\boldsymbol{f}) = p(\boldsymbol{f}\|\sigma_f) = \dfrac{exp\left(-\frac{1}{2\sigma_f{}^2}\Sigma_{i=1}^{N-1}(f_i - f_{i+1})^2\right)}{Z_{pri}}$

Table 1. Likelihood function and prior distribution modeled for the proposed attenuation correction method. Z_{lik} and Z_{pri} are a normalization constant

conditional probability distribution for **f** given **d**. In Bayesian statistics, the p(**f**|**d**) is referred to as the posterior distribution and can be constructed using the Bayes formula p(**f**|**d**) = p(**d**|**f**) p(**f**)/p(**d**), where p(**d**) equals ∫p(**d**|**f**)p(**f**)d**f**.

The term p(**d**|**f**) on the right side of Bayes formula is called the likelihood function of **f** (hereafter likelihood). Another term, p(**f**), is called prior distribution, and represents prior knowledge or information about **f**. Table 1 shows the likelihood and prior distribution modeled for the attenuation correction. The likelihood is based on an assumption of the forwarding process from **f** to **d**, where **f** is affected by the medium attenuation, and the noise is then added to the attenuated **f**. For the prior distribution, a multidimensional Gaussian distribution was adopted so that as the differences between adjacent variables f_i and f_{i+1} decrease, p(**f**) will increase. This is because **f** does not fluctuate widely between the adjacent variables.

In modeling the p(**f**) and the p(**d**|**f**), three parameters, σ_f, σ_n, and α, were employed, which represent the standard deviation (SD) of (f_i- f_{i+1}), the SD of noise, and the attenuation coefficient [ns^{-1}], respectively. These parameters are called hyper-parameters and determine the shapes of each distribution. The hyper-parameters are estimated using the maximum likelihood method (MLM): considering p(**d**|σ_f, σ_n, α) to be a likelihood function of the hyper-parameters, and then searching for (σ_f', σ_n', α') maximizing ∫p(**d**|**f**, σ_n, α)p(**f** |σ_f)d**f** which is equivalent to p(**d**|σ_f, σ_n, α). Finally, the corrected signal for **d**, $\mathbf{f}_{est}$, is searched for by maximizing p(**f**|**d**, σ_f', σ_n', α').

In practical implementation of this method, an iterative algorithm has been constructed by incorporating belief propagation into the EM (expectation-maximization) algorithm. The belief propagation is a mathematical technique that is employed to calculate efficiently the posterior distribution. The EM algorithm is a popular numerical calculation algorithm that is used for hyper-parameter estimation with the MLM.

EXPERIMENTS

In the experiments, three signals that were acquired at different Δt values, from a synthetic GPR trace were used. First, a GPR trace was numerically made by the finite-difference time-domain (FDTD) method for simulation of electromagnetic wave propagation. Figure 1a shows a model of the FDTD simulation. The transmitting and receiving points, which are regarded as two imaginary GPR antennae, are 0.02 m above ground, and the distance between the two points is 0.4 m. A boundary is at a depth of 0.4 m in the ground. The upper part is assumed to

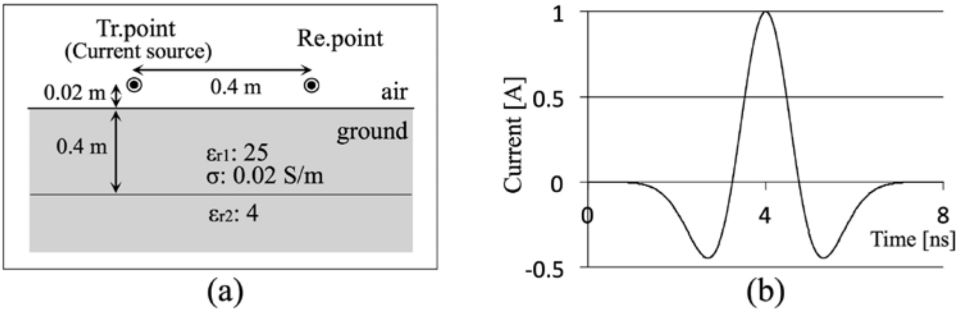

Fig. 1. (a) Model of FDTD simulation and (b) input signal at Tr.point in the model

be loamy wet soil with a relative permittivity, ε_{r1}, of 25 and a conductivity, σ, of 0.02 S/m. The lower part is assumed to be granite with ε_{r2}=4. Figure 1b shows the signal input at the transmitting point as a current source. The center frequency is 300 MHz and the amplitude peak is at 4 ns. For sufficient precision, the FDTD simulation was performed with a time step of 0.01 ns. Then, the FDTD simulation result was quantized to 8-bit data (with amplitude values raging from -128 to 127 in integer form), and white Gaussian noise (average 0, variance 2^2) was added to the 8-bit data, as shown in Figure 2a. The reflection signal from the ground surface is at around 4 ns, and the one from the boundary is at around 18 ns. The three signals considered in the experiments were made by resampling the signal in Figure 2a with Δt = 0.05, 0.2, and 0.4 ns.

Figure 2b, c, and d show the correction results, $\mathbf{f}_{est}$'s, for the signals at deferent Δt values, overlapping an ideal **f** simulated by FDTD, which is a signal without both medium attenuation and noise. As shown in Figure 2c for Δt = 0.2 ns, the corrected reflection signal from the boundary appears to be very close to the ideal **f**. In Figure 2d for Δt = 0.4 ns, the corrected reflection signal and the noise after 20 ns appear to have been much more amplified than in Figure 2c. Fundamentally, a sampling interval of 0.4 ns is not appropriate for actual GPR surveys using a 300 MHz antenna due to the coarse sampling points. In contrast, the sampling points for Δt =0.05 ns would be sufficiently dense, but the method has not worked: the signal at Δt = 0.05 ns in Figure 2c has not been amplified and appears to be almost the same as Figure 2a.

DISCUSSION

The reason for which the reflection signal at Δt = 0.05 ns was not amplified is considered as follows: For any time-domain discrete signals, when the sampling interval becomes shorter, the distribution of the differences between the adjacent values, f_i and f_{i+1}, gradually deviates from the Gaussian distribution; ultimately, the values are only 0 or 1.

Therefore, if an input signal is known, it is important to verify whether the differences between the adjacent values at Δt in the input signal are normally distributed. This may be done using a statistical test of normality, such as the Shapiro-Wilk test. Actually, in the case of the input signal

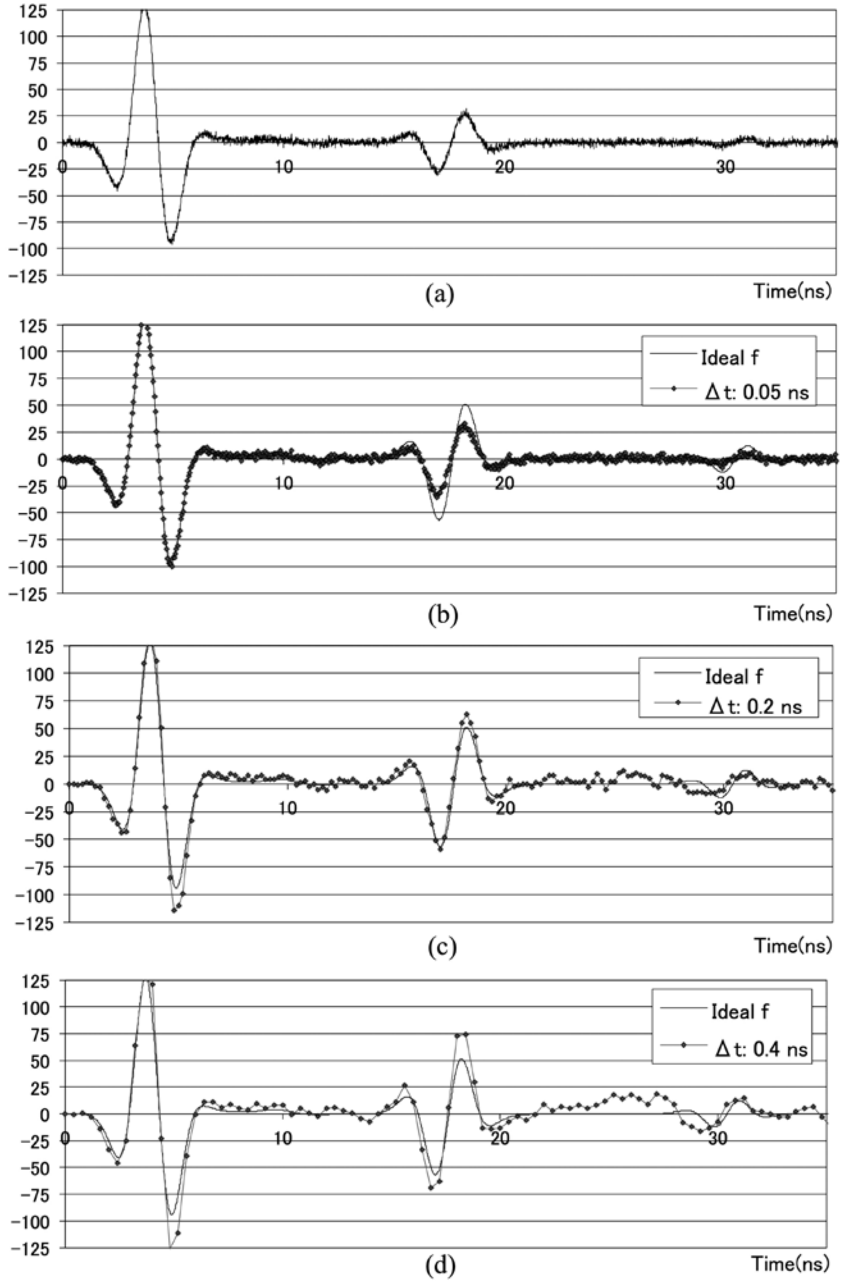

Fig. 2. (a) Simulated signal by FDTD with 8-bit quantization and noise addition, and (b), (c), (d) the results of correction for the signal at different Δt

shown in Figure 1a, the Shapiro-Wilk test revealed that the normality of the distribution of the differences between the adjacent values at $\Delta t = 0.2$ ns was accepted with a *p*-value 0.2502, and the normality at $\Delta t = 0.05$ ns was rejected with a *p*-value 0.0004 (5% significance level).

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The Canterbury Hinterland Project: understanding dynamic rural landscapes through the semi-automated interpretation of geophysical survey results

Paul S. Johnson[a], Alex Mullen[b], Lieven Verdonck[c] and Lacey Wallace[d]

KEY-WORDS: ground-penetrating radar, magnetic survey, feature extraction, template matching, Roman Kent

The Canterbury Hinterland Project represents a collaboration between researchers at the Universities of Cambridge, Ghent, Oxford, and Nottingham to use non-intrusive techniques in order to understand landscape transformations and changing rural settlement patterns through time. From 2011 to 2015, the project has studied four sites within a 10 km radius of Canterbury, both extensively and intensively. These have ranged from small rural, agricultural settlements to complex multi-period landscapes demonstrating elite power. These sites present a number of interpretative challenges, both in the nature of superimposition of features and in understanding isolated and morphologically ambiguous anomalies.

This paper will focus on technical and methodological developments during the course of this project, particularly through our ground-penetrating radar (GPR) survey, which enable us to develop more robust archaeological interpretations from our data. We will primarily discuss these issues in relation to our work at Bourne Park, the first and most fully investigated site within the project (Wallace *et al.* 2014). One avenue of our research has been to investigate the reliability of automated and semi-automated means of classifying geophysical responses in order to refine possibilities for feature-recognition in complex datasets.

The principal focus for our survey at Bourne Park was identified through a study of aerial photographs of the area and has been subjected to geomagnetic, earth resistance, and inten-

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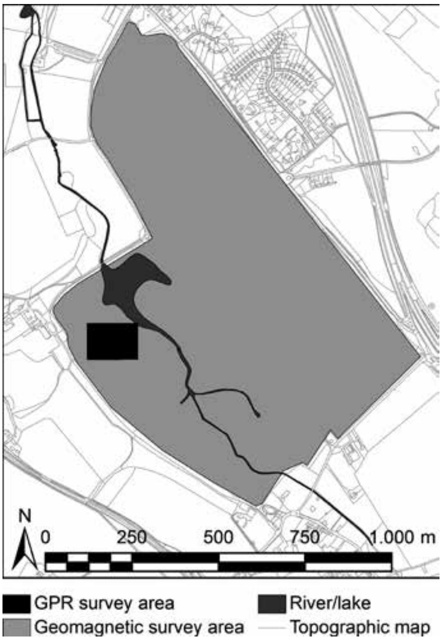

Fig. 1. Location of the surveys at Bourne Park

sive GPR survey as part of the Canterbury Hinterland Project. Geomagnetic survey totalling approximately 50 ha provided the context within which to situate the high-resolution GPR. Approximately 1.6 ha were surveyed (Fig. 1), using a Sensors & Software Spidar GPR network comprising single 500 MHz antennas (Verdonck *et al.* 2013). The inline sample interval was 0.05 m, the transect spacing ~0.125 m. The GPR data were processed using a standard sequence including dewow, time zero alignment, gain, low-pass filtering, background removal, and equalizing of amplitude differences between the channels. Migration velocity analysis resulted in a velocity of ~0.07 m/ns. After 3-D migration and time-to-depth conversion, conventional static corrections were applied since the maximum surface gradient was ~7% (Verdonck *et al.* 2015).

An extraction strategy was designed extraction strategy for Roman wall features employing template matching, which is rarely used in archaeological geophysics but more common in remote sensing for the detection of circular structures (burial mounds or kilns, Schneider *et al.* 2015), or linear shapes such as fallen trees (Nyström *et al.* 2014).

A 2D plot is generated, which synthesizes the GPR reflections at different depths. This can happen for example through the calculation of attributes such as the median frequency (Zhao *et al.* 2013), or by using principal component analysis (Linford 2004). A large time window is used, depending on the occurrence of the archaeological structures. The image in Fig. 2a was generated by calculating the standard deviation of each GPR trace, between 8 and 21 ns. Rectangular templates of different sizes were matched to this image, using 2D normalised cross-correlation (NCC). This resulted in a number of correlation matrices. For each pixel in the GPR image, the maximum NCC was used to create a single correlation image. This process generated a large amount of false positives, indicated in grey in Fig. 2b. Most are small sized, while most true positives abut onto other structures. Therefore, wall detections smaller than half the size of the smallest wall template were removed, and only the detections abutting on at least one other structure were kept (white in Fig. 2b). By fitting rectangular bounding boxes to the areas remaining after this classification, and extruding them, it was possible to select 3D regions for the creation of iso-surfaces. Because the noise caused by non-archaeological soil heterogeneities is removed, visualisation by means of iso-surfaces becomes more effective (Fig. 3).

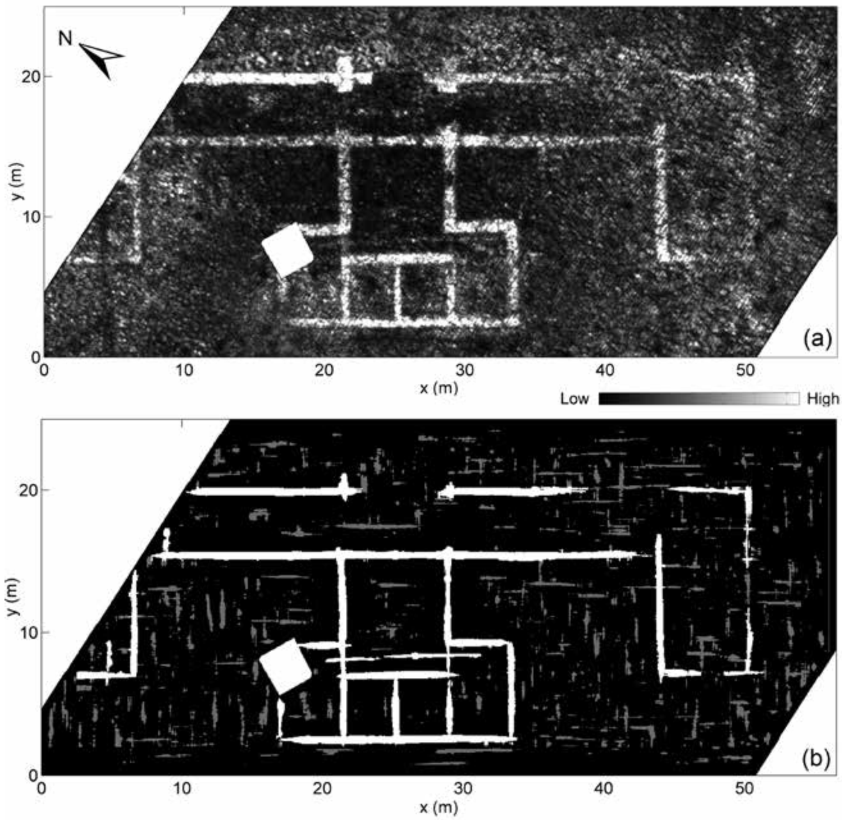

Fig. 2. (a) 2D GPR plot showing part of the area surveyed at Bourne Park, generated by calculating the standard deviation of each GPR trace (between 8 and 21 ns). (b) Image showing areas with a cross-correlation coefficient higher than 0.18 (grey). The areas selected after classification are shown in white

ACKNOWLEDGEMENTS

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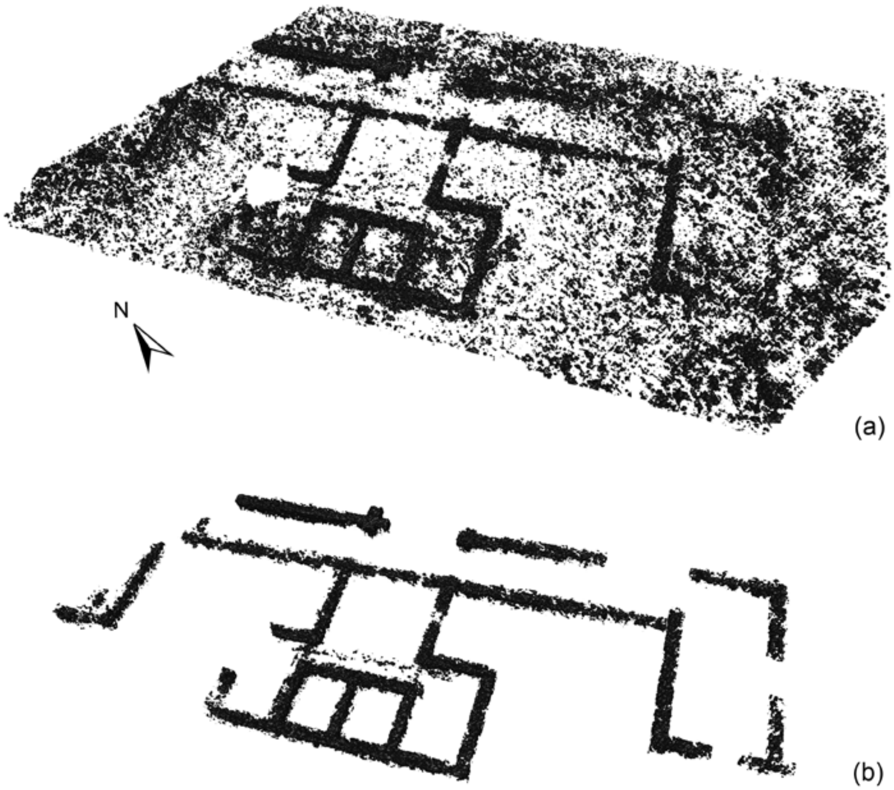

Fig. 3. (a) Iso-surface calculated from the GPR data cube after conventional processing (but before topographic correction). (b) Iso-surface applied to regions selected by means of template matching and classification. The threshold is the same for both iso-surfaces

fellowship of the Research Foundation – Flanders (FWO). Students in Classics from the University of Cambridge and the University of Oxford, and local volunteers assisted with the fieldwork. Special thanks are due to Ashley Chhibber, Gabriella Jeakins, Michael Loy, Alex Mirosovic-Sorgo, Sean O'Connor, and Rob Stroud for assisting the survey in multiple seasons. Thanks are also due to Dr Ben Croxford (previously at the Kent HER) for his help and especially to our collaborator Chris Blair-Myers, whose expertise with aerial photography has been invaluable.

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WuMapPy - an open-source software for geophysical prospection data processing

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KEY-WORDS: geophysics, prospection, software, open-source, python, data-processing, image-processing

Wumap is the outcome of successive software developments achieved by the archaeological prospection group (Centre de Recherche Géophysique de Garchy and UMR 7619 Sisyphe, now Métis) for processing and interpretation of archaeological surveys (and also other Near Surface Geophysics observations or measurements). It is devoted mainly to the processing of magnetic, electromagnetic (EM) and resistivity data. A first software, “TGP”, had been developed at the beginning of the 1980s for the PC/DOS environment. The Windows version was initiated in the mid 1990s and regularly adapted until its “stabilized” WumapN version (2002) was developed together with its English version, WumapA (both using FORTRAN in the Windows environment).

Wumap integrates a large number of features for visualizing and processing geophysical prospection data (Fig. 1):

- data can be imported in several file formats.
- different map visualization options:

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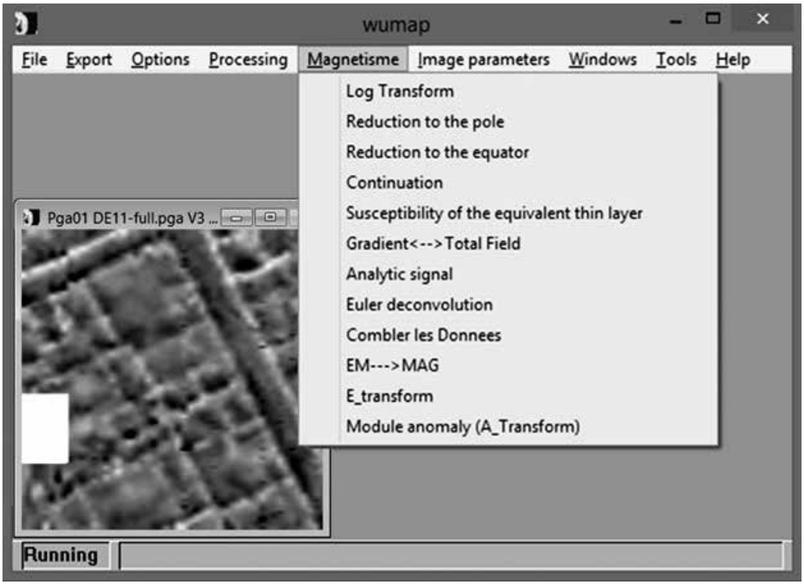

Fig. 1. Wumap menu screenshot

Fig. 2. WuMapPy to Google Earth integration example

  - ° 15 colour scales
  - ° adjusting of the minimal and maximal data values to the scales
  - ° application of logarithmic or arithmetic scale
  - ° trimming
  - ° adjustment of areas
- numerous data and image processing functions:
  - ° median filtering
  - ° outlier removal
  - ° elimination of regional drift
  - ° destriping
  - ° wallis filtering (increasing contrast)
  - ° directionnal filtering
  - ° FFT
  - ° zigzag (festoon) correction
- Magnetic data interpretation (both magnetics and EM):
  - ° magnetic pole/equator reduction
  - ° continuation
  - ° gradient – total field conversion
  - ° euler deconvolution
  - ° conversion of magnetic prospection data to EM susceptibility and vice versa
- Simultaneous processing of several surveys or several parameters of a single survey.
- Different export options of the processed data in various formats, including image file (bmp, grd, dat).

With time, software maintenance started to be difficult as the programming language and graphic interface became obsolete. Hence, in order to keep these functionalities working, and to facilitate maintenance and update efforts, a deep re-engineering of Wumap in modern computing language was vital.

Why Python?

- It is a programming language with open-source development environments.
- More and more scientists and engineers are computing under a variety of operating systems, motivating the choice of a multi-platform language (Windows, Linux, MacOS …).
- Many drivers are being developed by a large "Python community" and are freely distributed on the *http://pypi.python.org* website.
- WuMapPy will also be freely distributed on the "pypi.python.org".

While still featuring all functionalities present in Wumap, WuMapPy will be enriched with other functionalities:

- 1D to 3D resistivity interpretation/inversion algorithms for data acquired with miscellaneous types of DC electrical resistivity arrays and EMI devices.
- Transform raw EM data into soil physical properties (electrical conductivity, magnetic susceptibility, magnetic viscosity)
- Build a dataset directly from several geophysics prospection data files.

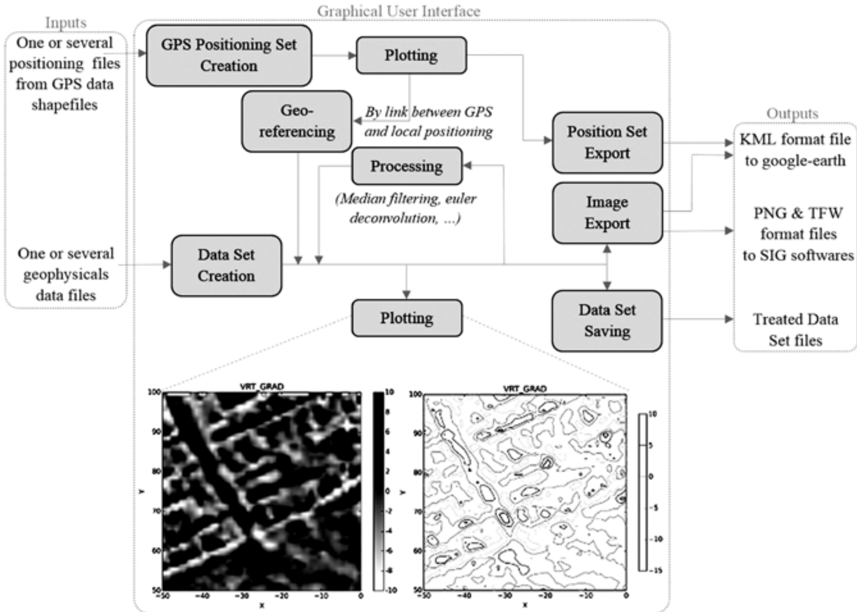

Fig. 3. WuMapPy workflow

- Select among several data interpolation algorithms (linear, cubic …).
- Select among several data display options (surface, contour …).
- Georeference prospection data with GPS points issued from several file formats.
- Export geophysical post-processed prospection data in the kml, png+tfw, grd, asc or other raster formats, allowing easy import within GoogleEarth or GIS software (ArcGis, Qgis … cf. Fig. 2) without requiring third-party application.

Finally, WuMapPy workflow can be summarized as in Fig. 3.

WuMapPy is an open-source and multi-platform software project to user-friendly display, processing and georeference surface and sub-surface geophysical survey data. It can be used by anyone wishing to post-process geophysical datasets or just perform basic processing and display of the geophysical image in a mapping application.

A short description and tutorial of the former Wumap, as well as an English version of the software are still available at the following address: *http://www.sisyphe.jussieu.fr/~jtabbagh/wumap.htm*

The new WuMapPy software development is being documented at the following address: *http://134.157.44.234/*

Role of regularized derivatives in magnetic edge mappers evaluation

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KEY-WORDS: archeogeophysics, magnetometry, transformation, regularization, edge mapper

INTRODUCTION

In qualitative and quantitative interpretation of archaeomagnetic data (total field and/or vertical magnetic gradient), the use of so-called edge mappers (detectors, delineating methods, transformations) can bring additional information on the shape, size and character of archaeological features. Edge mappers enhance the anomalous features of the magnetic fields on the edges of explored structures and help to improve the interpretation. In past decades, several types of edge mappers have been developed and tested (a good review is given in Stampolidis and Tsokas 2012). Most of these methods are based on the evaluation of various ratios of derivatives of different kind, mostly horizontal and total derivatives and their components. Among them, transformations that are used the most are: vertical and horizontal gradients, total gradient (called also analytical signal, when calculated from the total magnetic field), so called tilt-derivative, theta-derivative, balanced horizontal gradient (TDX) and TDX multiplied by analytical signal, that is, the so called TDXAS transformation (Stampolidis and Tsokas 2012).

METHOD

When using edge mappers, one has to be very careful with the numerical evaluation of higher derivatives of the interpreted magnetic field due to their inherent weakness; they strongly enhance noise, remaining processing errors, edge effects, etc. These operations belong to the so-called ill-posed problems of mathematical physics, therefore there is a need for their stabilization, in other words, their smoothing. There exist several approaches to this problem, from simple moving-window smoothing filters in the space-domain to more sophisticated methods, built upon the concept of Wiener optimum filtering (Pawlowski and Hansen 1990), enhanced derivatives evaluation (Fedi and Florio 2001) and Tikhonov regularization (Pašteka *et al.* 2009).

The lattermost approach will be applied in this contribution. It is based on the application of a specially derived low-pass filter in the Fourier domain (derived in Appendix A in Pašteka *et al.* 2009). This filter is managed by the value of a regularization parameter (*alpha*), which is changed in a large interval

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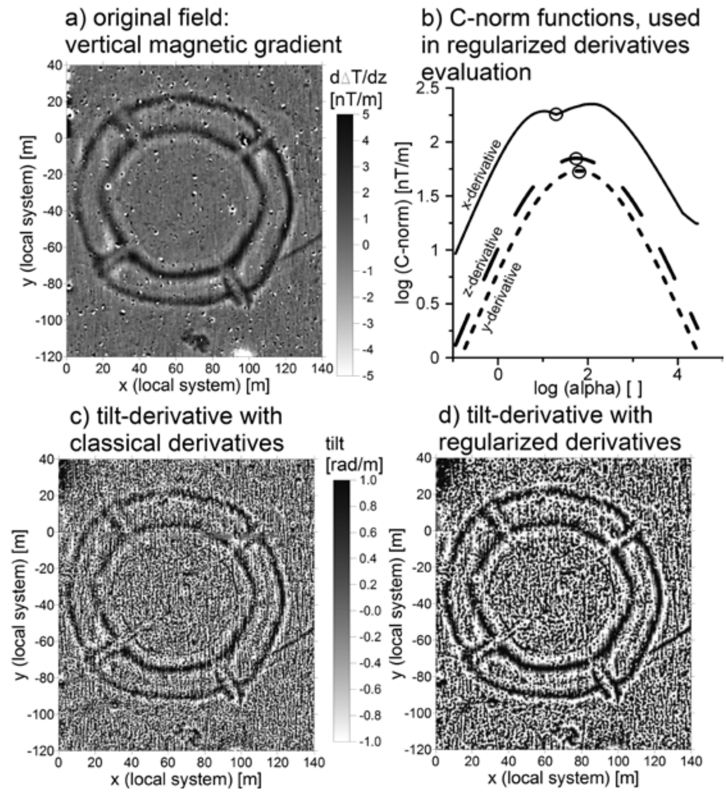

Fig. 1. Results of the transformation by means of regularized derivatives incorporation into edge mappers evaluation: Milovice site (Czech Republic). a) Original field: vertical magnetic gradient; b) C-norm functions: x-derivative (solid line), y-derivative (short-dash line), z-derivative (long-dash line), circles detect the values of optimum regularization parameter; c) tilt-derivative with classical derivatives (non-regularized, Fourier domain); d) tilt-derivative with regularized derivatives (Fourier domain)

(in a geometrical sequence) and the obtained solutions for the numerical derivative are compared to describe their "closeness" by means of the evaluation of special C-norms functions (Fig. 1b). Properties of such a C-norm function (local minima close to their global maximum or global maximum itself, circles in Fig. 1b) define the optimum regularization value, a solution where equilibrium between a correct and smoothed solution has been achieved. This processing step can be automated and more reliable solutions can be achieved; this was used during the analysis of several case studies.

SELECTED CASE STUDIES

The first presented site is a site close to Milovice (Czech Republic) with a Lengyel culture roundel structure (Milo *et al.* 2015). The roundel has a nearly circular shape and consists of an internal palisade trench and two parallel ditches. Magnetic field data acquisition was achieved by means of a fluxgate magnetometer Ferex 4.032 DLG Foerster with four sensors (line distance: 0.5 m, sampling interval: 0.25 m). Numerical derivatives of the interpreted magnetic field (Fig. 1) were performed by means of the proposed method; the C-norm function has been evaluated (Fig. 1b) for a geometrical sequence of the regularization parameter and analyzed with the aim to find the best (optimum) solution (circles in Fig. 1b). Evaluated tilt-derivative maps with classical derivatives (without regularization) (Fig. 1c) and with incorporated regularized derivatives (Fig. 1d) show the great advantage of this kind of derivative stabilisation. In the map with regularized derivatives utilisation (Fig. 1d), the high frequency content was removed permitting better analysis of the interpreted structures. In this transformed field (Fig. 1d), the palisade in the central part of the roundel is well recognisable and it seems to have some kind of continuation into its centre at two of the four entrances.

In the second case study (Fig. 2), the proposed approach was analyzed on vertical magnetic gradient data, acquired over an early medieval settlement at Witsum on the island of Föhr (northern Germany), this within the frame of an Erasmus LLP summer school (INCA International Course on ArchaeoGeophysics). For the data acquisition, the equipment of the University of Kiel, MUSELOGG-1 with six Foerster sensors, was used (line distance 0.5 m). In the anomalous magnetic gradient field, several well developed features can be observed (Fig. 2a displays a selected part of the measured area): pit-houses, ditches, boundaries of fields(?), road, graves and wells(?). When we compare the maps of the horizontal gradient evaluated with classical derivatives in the Fourier domain (Fig. 2b) and with regularized derivatives utilisation (Fig. 2c), we can see that several disturbing (high-wavelength) features, originating in the close vicinity of high amplitude anomalies (Fig. 2b) have been removed (Fig. 2c). In the TDXAS transformation, the shape of the detected objects is well defined (mainly houses, wells and graves) (Fig. 2e) due to the "loss" of the dipolar character, typical of magnetic fields. Here the comparison between classical derivatives and regularized derivatives did not give any significant differences (this fact speaks for the high quality of the acquired dataset with high signal-to-noise ratio).

CONCLUSIONS

We understand the use of the edge mappers as an additional tool in qualitative archaeomagnetic data interpretation. In the prevailing majority of cases, we could recognize the anomalous features directly in the original magnetic field (total field and/or vertical magnetic gradient), but edge mappers helped us in their better understanding and determination. The introduction of regularized derivatives have improved the signal-to-noise ratio on the evaluated derivatives and, in effect, also the properties of the discussed edge mappers (detectors). In general, we are not able now to recommend the "best" edge mapper (in most cases the tilt-derivative and TDXAS transformation delivered the best results). It is rational to evaluate several of them and then to confront the obtained results with the original magnetic field.

The presented concept was realized in the MATLAB programming environment and the script REGTILT is free for potential users upon request.

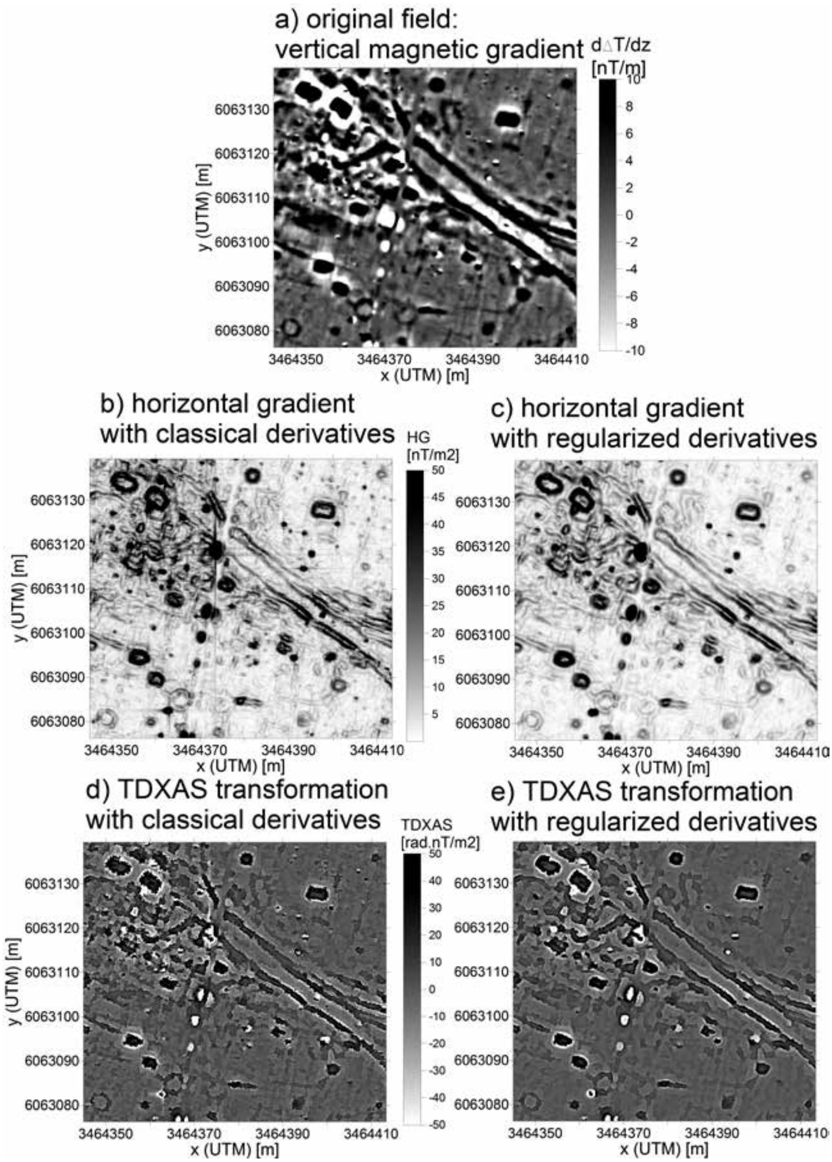

Fig. 2: Results of the transformation by means of regularized derivatives incorporation into edge mappers evaluation: Witsum site (Germany). a) Original field: vertical magnetic gradient; b) horizontal derivative with classical derivatives (non-regularized, Fourier domain); c) horizontal derivative with regularized derivatives (Fourier domain); d) TDXAS transformation with classical derivatives (non-regularized, Fourier domain); e) TDXAS transformation with regularized derivatives (Fourier domain)

ACKNOWLEDGEMENTS

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Easy targets, or "who has marked out my anomalies"?

Armin Schmidt[a]

KEY-WORDS: GPR, Anatolia, Byzantine, basilica, looting, visualisation, processing

The Roman city of Pessinus is famous as the cult place of Cybele, the Magna Mater, goddess of the Roman Empire. The city is situated in central Phrygia, about 150 km south-southwest of Ankara and 15 km southeast of Sivrihisar in the modern village of Ballıhisar. The Phrygian settlement and its temple, attested by several ancient authors, developed subsequently into a Greek and Roman temple-state led by a high priest. In Late Antiquity (c. 500–700), an early Byzantine citadel was built next to one of the late Roman cemeteries and evidence for Christian architecture was found in the city (e.g., several Byzantine pillar capitals, Tsetskhladze 2013). However, the location of the actual church remained elusive.

During intensive surface surveys several sites were identified to the west of the city, on the expanse of the Neogene continental high plateau pediment south of a metamorphic massif. Some of these sites seem to be related to a chain of defensive instalments, linked to the early Byzantine citadel. Slightly outside (i.e., west) of this chain and close to the Western Cemetery lies a site that was characterised during fieldwalking as having "extensive earthworks, including terracing and walls, dense tile and artefact scatter, as well as marble". These earthworks are clearly visible on current aerial photographs and show linear as well as circular shapes.

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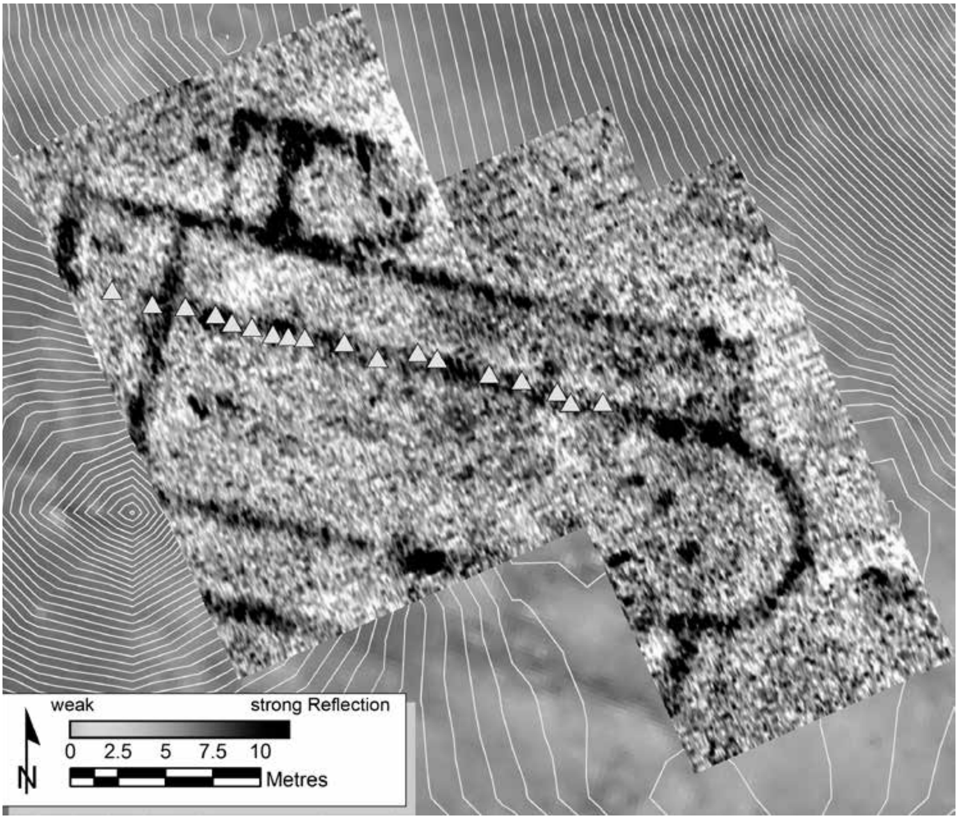

Fig. 1. Time slice at 1.2 m depth, showing the GPR data and the shallow soil heaps (triangles)

A ground-penetrating radar (GPR) survey was therefore undertaken over this site, using a 500 MHz Malå system with 0.25 m line spacing.

The processed time slices (Fig. 1) clearly show the foundations of a Byzantine basilica, oriented east-southeast, with linear wall foundations and an apse at the eastern end of the nave. The morphological interpretation of the data is supported by surface finds, which include many fragments of thin polished marble panels, presumably from wall revetment. When the survey area was tied into the project using a Total Station, a line of 18 shallow soil heaps was noticed (Fig. 2) that appeared to be similar to the spill that is often found around auger holes. By plotting these in the project's GIS together with the GPR data, it became clear that they were exactly aligned over the northern wall of the central nave, following exactly a GPR anomaly. Who had marked out this foundation wall for augering and how? Unfortunately, Pessinus and its environs are frequently targeted by looters as the expanses of the various cemeteries are very hard to protect and even the core area of the city is frequently

Fig. 2. Total station survey of the site in low light, showing the line of shallow soil heaps to the right

targeted by illicit diggers. The first few weeks of every field season are spent recording and cleaning the crudely dug pits and smashed marble pieces. The majority of these extractions seem to target underground chambers that were constructed as sometimes elaborate burial houses (Schmidt and Tsetskhladze 2013). It was noticed that some of these looted sites were unknown before and it must hence be assumed that some sort of detection equipment was used by the grave robbers to locate them. We were passed information from an anonymous informer explaining that criminal gangs are operating in separate teams for detection and extraction, pointing to a considerable level of sophistication of organised heritage-crime. But what equipment do they use and can they detect buried wall foundations like the one of the Byzantine basilica? Underground cavities can be found with low-frequency electromagnetic (LFEM) devices in the form of metal-detectors with large coincident coils, or separate transmitter and receiver coils (Slingram devices, e.g. White's TM808). It is conceivable that similar equipment was used on this site and allowed to trace the course of the foundation wall, which was then probed further with an auger. According to the GIS results the westernmost auger hole went beyond the foundation and appears to have been the last one dug (triangles in Fig. 1).

To understand better how this foundation may have been detected, advanced vector processing was applied to the GPR data to visualise the anomaly. The transects were first processed using gain adjustment, bandpass filtering and background removal. A soil velocity of 0.078 m/ns was estimated from migration tests and used to migrate all 2D transects, before the data were combined into a 3D cube, from which time-slices were derived. These raster data were then converted to polygons by applying a threshold, so that a sequence of vector processing steps could be used (Schmidt and Tsetskhladze 2013). A newly developed overlap analysis allowed the separation of these vector features into individual structural bodies.

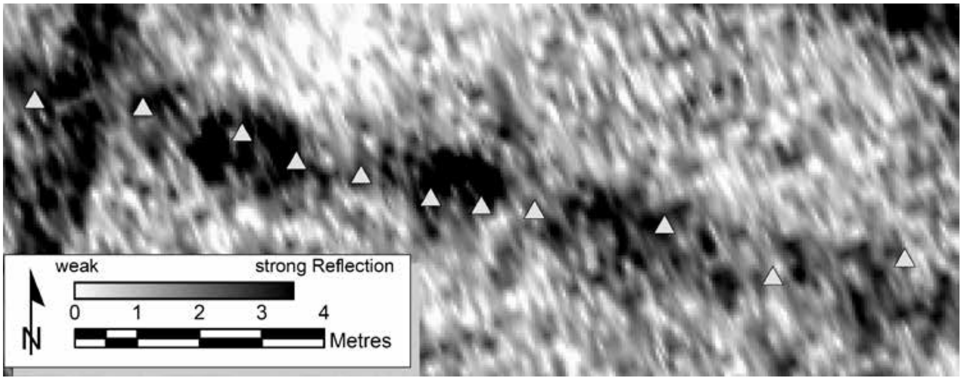

Fig. 3. Enlarged time slice at 1.2 m depth, showing the GPR data and the shallow soil heaps (triangles), which are denser over the presumed pillar bases that reach closer to the surface

The results show that the densest augering (Fig. 3) is located over two presumed pillar bases (0.8 m wide), which are preserved up to 0.6 m below the surface. The rest of the foundation is preserved at 0.9–1.4 m below surface and attracted fewer auger holes. It must hence be concluded that the detection equipment used by the looters provides some degree of depth discrimination and a fairly sophisticated metal-detector is most likely.

The combination of detailed geophysical measurements, advanced data processing and GIS analysis allowed some glimpses into the operations of the looters on this site. It would be desirable to develop cheap active or passive EM devices that could scramble the signals of the metal-detectors so that this and other sites could be protected better.

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Using archaeological models for the inversion of magnetometer data

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KEY-WORDS: magnetometer data, modelling, inversion, archaeological model, Calabria, Raganello river

The Raganello Archaeological Project, undertaken by the University of Groningen, explores the mountainous area around the basin of the Raganello River in northern Calabria with substantial fieldwalking. The investigations are mainly concerned with the transition from Iron Age settlements to the Greek colonial period and aim to supplement earlier data from large central sites with information about the hinterland. Fieldwalking results are complemented by detailed geophysical investigations using electromagnetic and magnetic susceptibility (van Leusen *et al.* 2014) and magnetometer (Ullrich and de Neef 2010; Armstrong and van Leusen 2012) surveys. Since only a few key-hole excavations are possible as part of this extended project, the information gained from the geophysical data has to be maximised. For the magnetometer data, the aim is to obtain a detailed characterisation of buried features and to test various archaeological models that can describe them.

The shapes, size and position of magnetic anomalies differ from the buried archaeological features that cause them. It is necessary to use modelling and inversion to link the measured magnetometer data to magnetic soil properties. The magnetic inverse problem has no unique solution; there are many different subsoil distributions of magnetic susceptibility and remanence that could create the same magnetic surface data, and given small variations in magnetometer readings ('noise'), an infinite number of matching subsurface models could be found. Inversion of magnetic data, therefore, always has to make some assumptions to reduce the number of possible solutions and the assumptions determine the final results.

Based on the work by Li and Oldenburg (1996), most inversion schemes rely on 'objective functions' that use a particular depth weighting to derive a subsurface magnetic susceptibility distribution to fit the measured data. These schemes therefore have no knowledge of the nature of features that may cause the magnetometer results. By contrast, this project includes *a priori* archaeological information by using models of possible subsurface features and restricts the model parameters to archaeologically plausible limits. The inversion then progresses by adjusting automatically the model parameters (not the subsurface properties directly) until the best possible match with the measurements is achieved. Each of these parameters is changed separately to minimise the deviation from the measurements, since it is virtually impossible to derive a Jacobian inversion matrix for a closed formulation of this forward model. The adjusted model that results from this process depends on the order in which the parameters are adjusted during the inversion as there are many local minima that can trap the process. Several runs with

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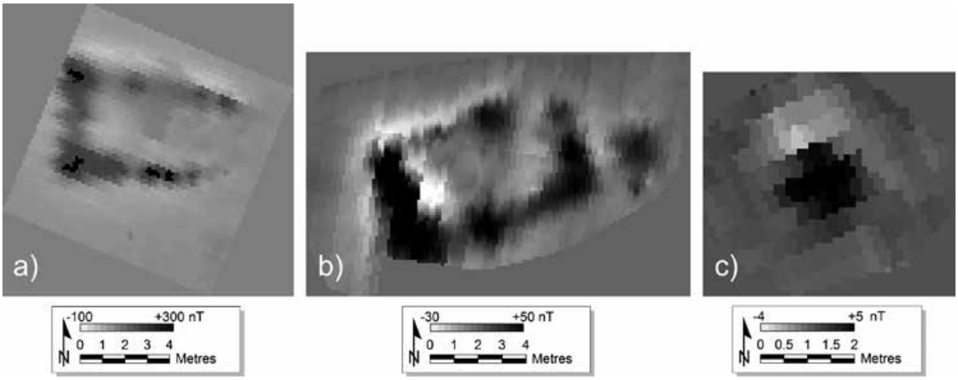

Fig. 1. Fluxgate gradiometer data for three classes of anomalies: (a) U-shaped building, (b) C-shaped building and (c) pit-like anomaly

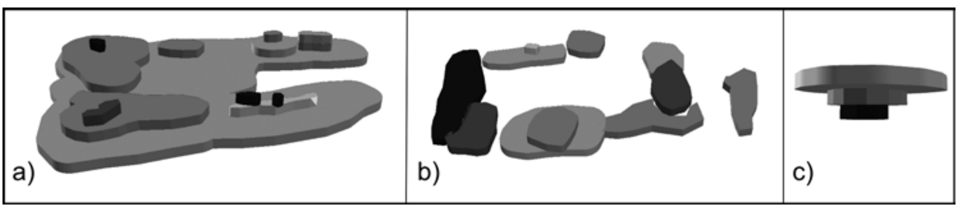

Fig. 2. Geophysically informed polygonal models adjusted through inversion to obtain the best possible match with the magnetometer data (see Fig. 1)

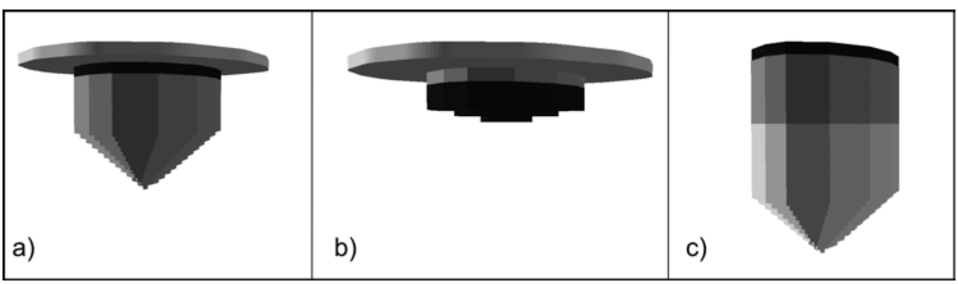

Fig. 3. Archaeologically informed model for the pit in Fig. 1c. The parameters for this model (e.g., thickness of layers, diameter) were adjusted through inversion to obtain the best possible match with the magnetometer data. The three different inversion results (a to c) fit the data nearly equally well

parameters in randomised order are therefore performed to obtain an overview of the possible solutions from which those can be selected that have a good overall fit and are archaeologically plausible. Since it is unlikely that the chosen generalised archaeological models fit the buried features of a site exactly (e.g., slight deviations in angles, depth layering), some mismatch with the actual measurements is to be expected. It is acceptable therefore to assume that remanence is roughly oriented in the direction of the current Earth's magnetic field and that remanent and induced magnetisation can be described together by an apparent magnetic susceptibility that the inversion process determines. The remanence can then be derived by comparison with magnetic susceptibility measurements of actual soil samples.

Two different approaches for designing the parameterised models were tested in this project; they can be referred to as geophysically and archaeologically informed models, respectively. For the first approach an archaeological geophysicist may estimate the approximate shape and location of possible archaeological subsurface features from the anomaly map of the data. The model is constructed from polygons at different depths that are chosen so that they may recreate the measured anomalies. The inversion process then proceeds to adjust three parameters for each polygon: its magnetic susceptibility, its size (expressed as a positive or negative buffer radius around the polygon), and a shift of the buffered polygon along the magnetic north-direction. For the second approach, an archaeological model is designed based on known archaeological structures, for example, a pit with two layers of fill. Parameters are chosen to describe the different aspects of the model (e.g., thickness of layers, diameter, tapering at the bottom) and are varied in the inversion to achieve a good fit with the measurement data.

For the Raganello Archaeological Project, detailed magnetometer surveys were undertaken with handheld magnetometers over anomalies of particular interest. For some sites, this was followed by trial-trenching and magnetic susceptibility sampling. From these results, three classes of anomalies were selected for the test of the inversion methodology: (a) U-shaped buildings, (b) C-shaped buildings and (c) pit-like anomalies (Fig. 1). Following the first approach, polygonal models were designed to reproduce the measured magnetometer data and their parameters were adjusted through the inversion process resulting in subsurface features that matched the measurements well (Fig. 2). After inversion the size of the deeper polygons was often considerably larger than initially estimated, which may be due to destruction layers at the base of the archaeological features. In most cases, the inversion shifted the polygons slightly north, thereby accounting for the fact that a buried feature lies to the north of the peak of its anomaly. Hence, the resulting polygons were better approximations of the buried features than the initial interpretation diagrams. When adjusting the polygon parameters in different order, models were calculated that looked considerably different but fitted the data nearly equally well. In particular, the contribution of the lower layers was dissimilar between the various runs of the inversion.

For the second approach, parameterised models of archaeological features were created. For example, a pit was described by a spread-out plough layer, followed by top and bottom layers of different magnetic susceptibilities with a tapering at the bottom. The inversion then progressed to optimise the parameters of these models, including thickness, radius and magnetic susceptibility. The various runs of the inversion resulted in considerably different models (Fig. 3). This is attributed to the strong decrease of the magnetic signal with depth so that variations in deeper layers have little effect on the overall magnetic anomalies.

Both model-based inversion approaches produce results that contribute to a better understanding of the features that cause the measured magnetic anomalies. Although the inherent non-uniqueness of magnetic inversion cannot be overcome, using archaeologically informed constraints allows feature interpretations to be created with a greater level of confidence.

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Refinement of ALS point cloud through the assessment of bare-earth classification algorithms: the AYPONA Project case study

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KEY-WORDS: ALS, point cloud processing, freeware, Celtic oppidum

INTRODUCTION

Aerial laser scanning (ALS) data are frequently used for archaeological survey, especially over forested areas where other methods are limited by visibility (aerial or satellite imagery) or accessibility in the field (geophysics). The emergence of these new datasets promotes the development of new tools for data visualisation through a multitude of spatial filters focused on archaeological detection (Lastools, RVT, LiVT). These specific software packages, despite some limitations regarding the size allocated to the processed files are increasingly helpful for the exploration of the data. Processed images can be used for automated detection and for exploring large areas where traditional data interpretation is time consuming. All of these developments are based on an efficient classified dataset, often delivered by the contractor. In the case of the AYPONA Project, this classification was rough and some inconsistencies were quickly detected. In order

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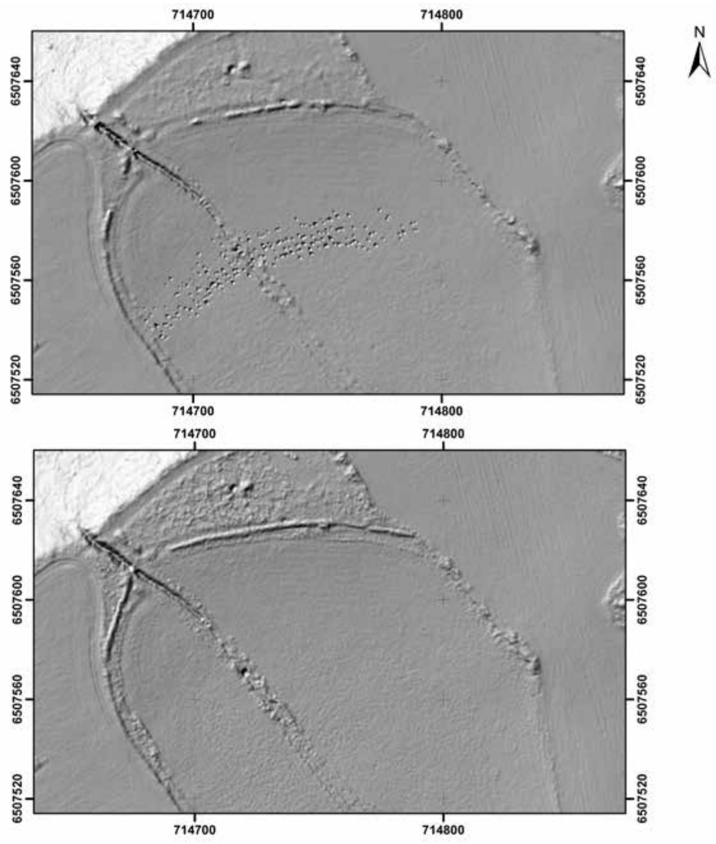

Fig. 1. Hillshade filtering applied to the presented procedure (b) and to previously processed data (a). The new filter keeps walls under low dense vegetation and removes outliers

to improve the full exploitation of our dataset, different algorithms were assessed through free scripts/software available on the Web in order to find the best way to classify the return points in the specific case of slope and flat areas with low and dense vegetation.

THE AYPONA PROJECT

Corent is a major site for understanding patterns of proto-urbanisation in Gaul, revealing the complexity of the Arverni territory and the close connection it had with the Mediterranean world from the Bronze Age to the Gallic Wars. The settlement covers an area of 50 ha and is located 15 km south of Clermont-Ferrand (France), on a volcanic plateau. According to the results of excavations undertaken since 2001, Corent reached its prominence during the Gallic period, but proved also to be a major settlement during the Bronze Age and Antiquity. Religious and assembly buildings, areas for handcraft activity and a commercial complex have been unearthed. The tremendous archaeological potential of the site is the main driving force of the AYPONA Project "Landscapes and faces of an Arverni agglomeration: an integrated and diachronic approach of the settlement of the oppidum of Corent." Its goal is to merge different approaches such as environmental archaeology, GIS, geoarchaeology and remote sensing to model the spatio-temporal trajectories over the long-time, and to understand the human impact and the appropriation of this settlement until the development of an urban agglomeration. The project is based on high spatial and temporal resolution analysis, in order to understand the landscape changes and define the challenges faced by the local population in the context of the environmental evolution of the site. In addition to current excavations, our work is based on coring, trenching, environmental analysis and a geomatic approach that utilizes LiDAR.

ALS DATASET

The ALS dataset was collected over an area of 22 km^2 with a Lit Mapper 6800 by IMAO aerial survey. It delivered a high point density (18 pt/m^2) and a full dataset cut into 140 slabs. The data were initially processed for bare-earth classification and a DEM was generated by the contractor. Erratic outliers and effects induced by the reattachment of the slabs affected the quality of the processed data. Moreover, the first visual analysis showed some inconstancies from a strong filtering process that removed ground points which could be potential archeological remains. This problem was obvious under low and dense vegetation, where walls could not be distinguished because of the plant coverage. The vegetation was a challenge in any case, because of the proximity of the trees to the remains/ground and on the slopes. After classification, open areas revealed a strong decrease of point density as well. In order to improve this classification, different algorithms were tried.

ASSESSMENT OF ALGORITHMS

In an initial step outliers were removed. These outliers were characterized by a lower intensity than other returns. This simple filtering produced an initial processed dataset which was especially useful regarding the effects generated by these points during the classification. At a second stage, three different algorithms partly tested in other studies were tried (Lugmayer-Klimczyk *et al.* 2014). They were selected because they have been developed specifically for the classification of bare-earth and vegetation. The first is an algorithm implemented in SAGA software developed through a slope-based filtering (Vosselman 2000). The second one is the BCAL algorithm developed by the Boise Center Aerospace Laboratory of Idaho for shrub-steppe ecosystems (Tinkham *et al.* 2011). The last one, Multiscale Curvature Classification, was developed by the Moscow Forestry Sciences Laboratory of the USFS Rocky Mountain research Station (Evans and Hudak 2007) for high biomass forest ecosystems.

CONCLUSION

In our case study, the Multiscale Curvature Classification algorithm proved superior for the classification of points (Fig. 1), while BCAL and Vosselman algorithms failed under the low dense vegetation, especially on the slopes. Nevertheless, this solution was not perfect, because of the persistence of some artifacts. The filter removed the remains of a medieval tower in the vicinity of the settlement as well as small bridges, although other contemporary buildings were not interpreted as vegetation points. In the future, other algorithms should be assessed, like the Opitz algorithms that produce a classification between trees and bare-earth, but also archaeological remains. Work will now be continued, checking different hypotheses about rampart and door systems of this settlement, using geophysical methodologies (ERT, etc.).

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Optimization of electrical resistivity tomography protocols for detecting archaeological structures in a shallow water marine environment

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KEY-WORDS: marine, electrical tomographies, archaeological survey, protocol optimization

INTRODUCTION: THEORY

Electrical resistivity tomography (ERT) has proven to be a valuable tool in onshore archaeological prospection applications (e.g., Papadopoulos *et al.* 2011). There is an increasing tendency in recent years to incorporate this technique in offshore geophysical surveys for solving geological and engineering problems (Rucker *et al.* 2011), since there is no need to use any special equipment. However, its

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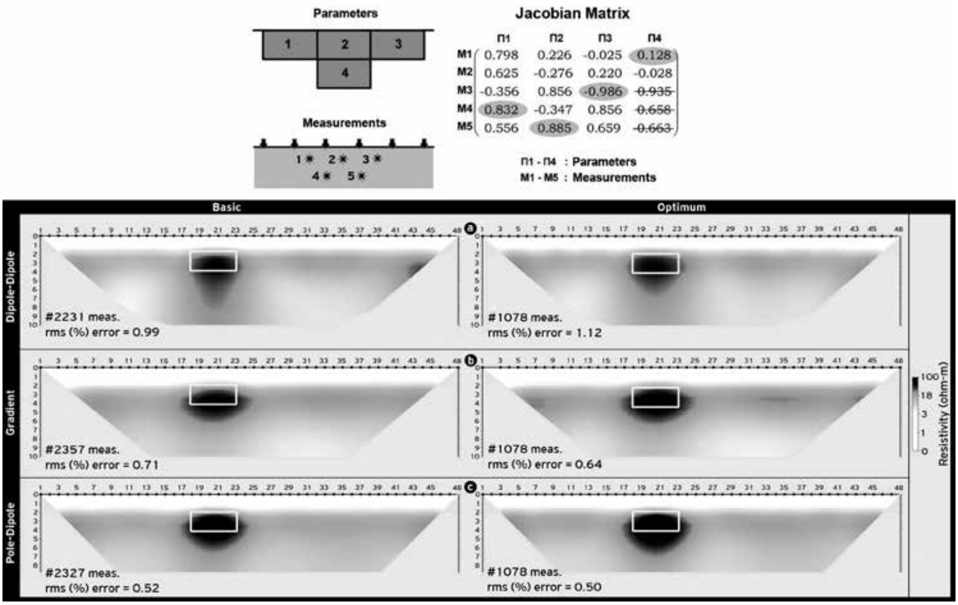

Fig. 1. (top) Array optimization using a Jacobian Matrix criterion; (bottom) inversion results with synthetic data between protocols (a) dipole–dipole, (b) gradient and (c) pole–dipole (rows), comparing basic and optimum protocols (columns). Black dots indicate electrode position. The target (indicated with white rectangular, ρ=500 ohm-m) is embedded in a homogeneous medium (ρ=10 ohm-m). Seawater column depth is set to D=1 m (resistivity ρ=0.2 ohm-m)

employment in marine environments for the detection of buried cultural features close to the coastline is rather limited (Passaro 2010). Still there are some methodological issues that need to be solved, mainly dealing with the installation of the electrodes on the bottom or on the surface of the sea and the data processing using appropriate modeling and inversion approaches (Loke 2004) able to cope with the special conditions found in such environments (i.e., seawater is a very conductive medium in comparison with resistive archaeological targets).

The maximum number of independent and non-reciprocal resistivity measurements that can be collected with four-, three- and two-electrode arrays depends on the actual probes that are installed in an investigation area. For an ERT survey considering a N number of electrodes, the total number of resistivity measurements (S) regarding four-electrode arrays is given by the formula $S=N(N-1)(N-2)(N-3)/8$ (Xu and Noel, 1993). For example, even for a small number of electrodes (e.g., 30) the data points exceed the 80,000 independent measurements.

The inability to capture this amount of data is mainly related to the instrument's memory limitations and actual field time constraints. Conventional ERT surveys use specific electrode configurations like dipole–dipole, Wenner, gradient or pole–dipole. Recent advances in ERT include the extraction of specific resistivity measurements from a wider dataset (known as comprehensive) that have the ability to highlight and extract the maximum possible information

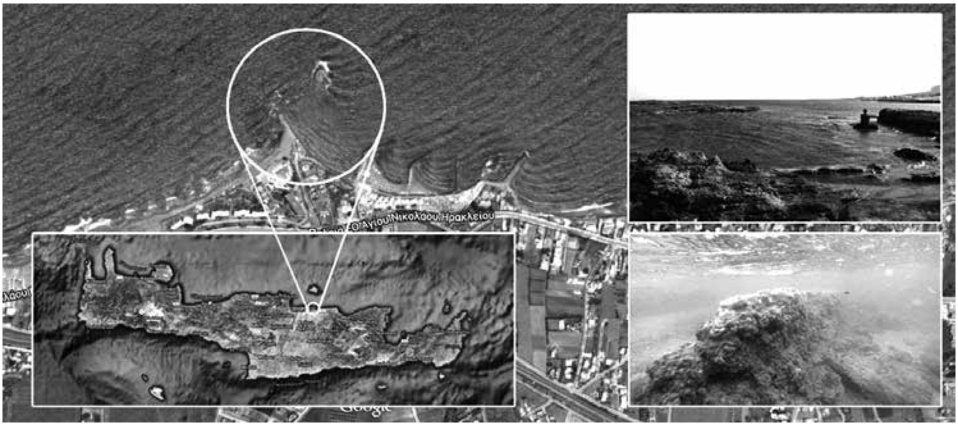

Fig. 2. Site for marine investigation and detecting archaeological targets (Heraklion, Crete)

of the subsurface resistivity structure. These methodologies use specific optimization criteria based on the numerical calculation of the resolution matrix and exclude from the original dataset "weak" measurements that carry minimal subsurface information (Stummer *et al.* 2004; Wilkinson *et al.* 2006; 2012; Simyrdanis *et al.* 2015)

METHODOLOGY

This work focuses on the optimization of the marine ERT protocols using the Jacobian (or Sensitivity) matrix criterion (Athanasiou *et al.* 2009) in order to reduce the measurements of the "basic" protocol without compromising the quality of the inversion results by rejecting some "weak" measurements. The Jacobian Matrix is a metric that represents the sensitivity of every resistivity measurement to changes of the subsurface parameter property. The Jacobian matrix criterion was incorporated in an existing forward and inversion resistivity algorithm ("2DInvCode", Simyrdanis 2013). The algorithm divides the subsurface into a specific number of blocks known as parameters and the Jacobian matrix is calculated given the number of measurements and model parameters. At the same time, the norm of the Jacobian for each parameter is also calculated. The measurements that exhibit the highest sensitivity absolute values for each parameter are chosen, through an iterative procedure, to compromise the optimum data set on the condition that they have not been already chosen in the previous step (Fig. 1 top). Thus, based on an original dataset of measurements (called "basic") assuming a specific array configuration (e.g. dipole–dipole or gradient, or pole–dipole), the algorithm selects only a set of measurements (called "optimum") that exhibit the highest resolving capability given a specific subsurface discretization. After the compilation of the optimized protocols, the 2.5D inversion software "DC2DPro" (Kim and Yi 2010) was used to reconstruct the resistivity models applying the basic and the optimized array protocols. All synthetic data are corrupted intentionally with random Gaussian noise (e.g, 3%).

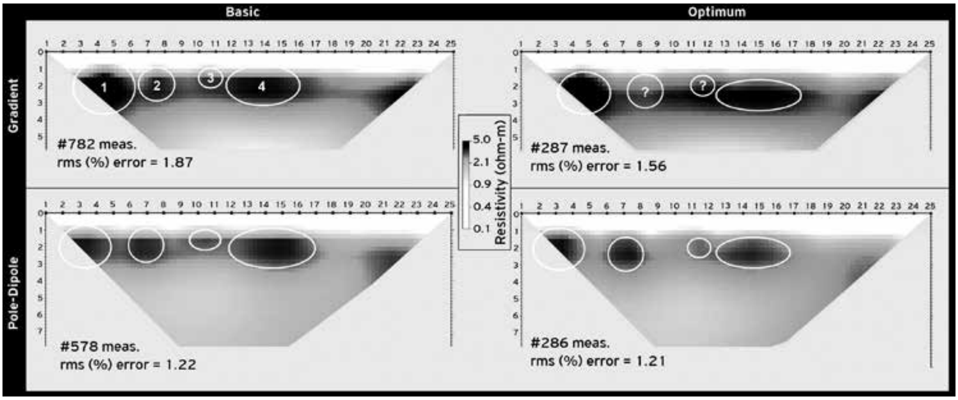

Fig. 3. Inversion results with real data between protocols (a) gradient and (b) pole–dipole (rows), comparing basic and optimum protocols (columns). Black dots indicate electrode position. Areas indicated in white represent target position

SYNTHETIC DATA

A 2D ERT line was assumed with 48 electrodes equally spaced every a=1 meter. The thickness and the resistivity of the seawater layer were set to D=1 meter and ρ=0.2 ohm-m respectively. The subsurface below the water layer consists of a homogeneous medium with resistivity ρ=10 ohm-m. A resistive target (ρ=500 ohm-m) simulating a wall structure with dimensions 5 m by 2 m was placed inside the subsurface layer at a depth d=1 m below the bottom of the sea.

Synthetic modeling was at first implemented in order to compare the inversion results and the reconstructed models employing the optimum protocols for different electrode arrays. Figure 1 (bottom) shows the comparison between the basic (left side) and the optimum (right side) protocols for the arrays dipole–dipole ("dd"), gradient ("grd") and pole–dipole ("pd"), where the electrodes are placed on the surface of the water layer (floating electrodes). No extra constraints were imposed onto the inversion procedure. Generally, the optimum arrays (dd: #1078 meas., grd: #1078 meas., pd: #1078 meas.) are able to reconstruct the target equally well as the basic arrays (dd: #2231 meas., grd: #2357 meas., pd: #2327 meas.), despite the fact that only 50% of the measurements are used.

REAL DATA

The first effort for testing the optimum ERT protocols was made at the coastline archaeological site in Agioi Theodoroi, located about 10 km east of the city of Heraklion in Crete, Greece (Fig. 2). Early surveys revealed the existence of seaside buildings and wall structures from Minoan times, continuing towards the sea.

The survey line was laid out in order to cross already known structures mapped by an earlier archaeological underwater survey. This was done to correlate the targets reconstructed by inversion with the already mapped underwater archaeological targets. The line is composed of a total of 25 electrodes equally spaced every a=1 meter. The average water column thickness is less than a meter. The "basic" gradient and pole–dipole protocols use #782 and #578 measurements, respectively. After the optimization procedure #286 measurements are used for both "optimum" arrays. Areas indicated in white depict the position of remains ("1", "2" and "4") that were mapped by the underwater survey.

Generally, as shown in Fig. 3, the inversion models demonstrate comparable accuracy despite the fact that the optimized protocol uses only half of the measurements of the basic protocols. The targets are reconstructed at a depth of d= 2 m below the seawater surface, with resistivity values close to ρ= 5 ohm-m. Comparing the two arrays, the gradient shows itself to be generally slightly superior from the gradient array when the basic protocols are used. The walls are more pronounced in the gradient inversion model when the basic protocols are considered. On the contrary, the optimum gradient array fails to reconstruct target "2" and merges target "3" with target "4". The pole–dipole optimum array clearly shows target "2" and only faintly target "3".

CONCLUSIONS

The numerical modeling results of this study show that ERT has potential and can be used for detecting archaeological remains in shallow marine environments. Furthermore, optimization of the initial measurement protocol can yield to equally well reconstructed resistivity models, minimizing at the same the actual field time for data collection, without compromising the quality and resolution of the inversion results. Further improvements on the final inversion images of the optimized protocols can be achieved by using a larger initial dataset for selecting the optimum configurations. This strategy will minimize the inferior results indicated by the transition of the "basic" to the "optimum" gradient protocol in our case.

ACKNOWLEDGMENTS

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Good practice in high-resolution EMI data processing for archaeological prospection

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KEY-WORDS: electromagnetic induction survey, signal stability, data processing, high-resolution EMI data, drift correction, micro-drift

As the application of frequency domain electromagnetic induction (EMI) sensors in archaeology is rising, the need for adaptive processing schemes that allow exploiting the full potential of EMI data grows. The ability for conducting expeditious EMI surveys is rapidly expanding, generating large-scale datasets using fine measurements grids. While most emphasis in archaeo geophysical prospection has historically been on processing magnetometry data, EMI data requires a different set of processing steps related to the inherent characteristics of survey instruments. Although often ignored in archaeo-geophysical literature, the issue of signal instability with time (or drift) can have the most severe influence on EMI survey data, sometimes even rendering interpretation impossible. While levelling procedures from

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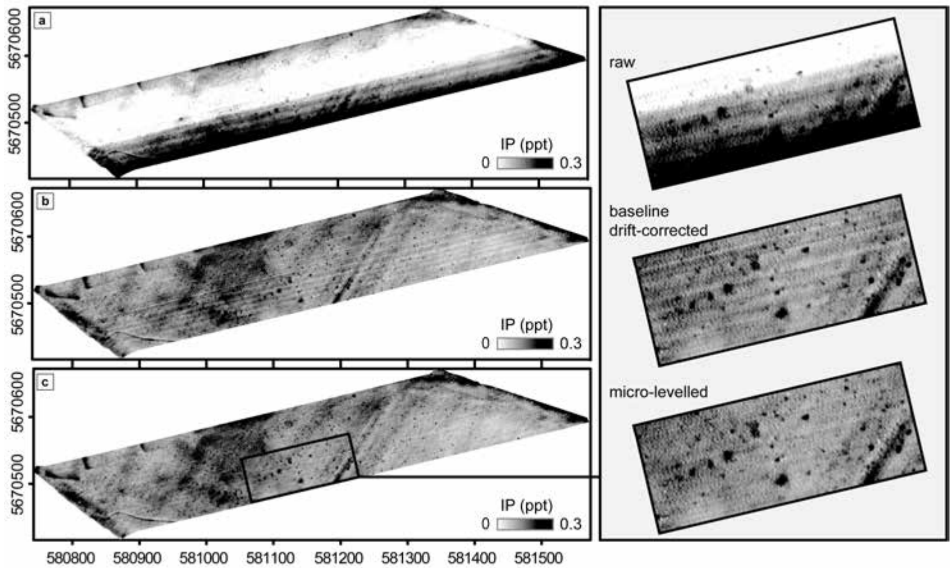

Fig. 1. The impact of adaptive EMI processing. Comparison of pre- and post-processed in-phase (IP) EMI data gathered with the 1 m perpendicular (PRP) coil configuration of a Dualem-21s sensor. Raw IP data is shown in (a), while (b) shows the same data after base-line drift correction. In (c), aberrant corrugations, i.e., remanent micro-drift, has been removed through micro-levelling. On the right hand side, a detailed view is provided of the impact of each step on data visualisation

resistance or magnetometry processing can be (and sometimes unfortunately are) transferred to EMI data, these often cause drift overcompensation. This can result in rejecting subsurface information from the survey datasets.

Drift-correcting strategies for EMI surveying are commonly available (e.g., Minsley *et al.* 2012; Delefortrie *et al.* 2014) and, especially when tie-line data is available, effortlessly implemented into survey and processing workflows. When drift correcting procedures are applied, these do not guarantee a noise- or fully drift-free dataset. Often, although sometimes unnoticed, micro-drift remains present in corrected datasets. The most common effects of such systematic errors are broad corrugations, accounting for 1% to even 20% of the data range (example presented in Fig. 1). While some coil pairs suffer more than others from such aberrant fluctuations, even when only little micro-drift is attested in original data plots, errors can build up in further processing stages (e.g., through image enhancement, geostatistical analyses or inversion procedures). The attention to such remanent drift is particularly relevant in archaeological prospection as, being the most aesthetic application of geophysics, it is also the most demanding in terms of data resolution and signal stability.

The discussion of consecutive processing steps needed to warrant accurate EMI data interpretation forms the core of this paper. Emphasis lies on different drift and noise levels present in the EMI survey data and the final visualization of the obtained results. However, the inevitable starting point is good practice in field strategies, and taking into account the practical considerations of EMI survey in early project stages.

Advocating widespread implementation of EMI in archaeological prospection, we would like to motivate archaeological geophysicist to adopt EMI-specific processing schemes, warranting substantiated and transparent data use.

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GIS and prospection

Non-destructive survey of Iron Age cemeteries: testing the topographic support system

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KEY-WORDS: topography, Iron Age, QGIS, mobile GIS, geophysical prospection, aerial reconnaisance, burial sites

BACKGROUND AND PROBLEMS

Since the 1960s fieldwalking has been the primary field method employed in the incomplete Archaeological Topography of Hungary (MRT) project. This method of site identification was more suitable for identifying settlements rather than cemeteries as pottery sherds on the surface are indicative most often of formal settlements. The completed volumes of the MRT, covering only about 12% of the country (Wollák 2009), show that most of the burials were found by chance and mainly during development work. The major reasons for this are the differences in taphonomic processes between settlements and cemeteries and the fact that it is difficult to locate individual archeological features based on a scatter of surface finds. Although aerial photography and magnetometry are now frequently able to identify small archaeological features, the predominance of settlement survey sites is still more significant in international archaeological topography research. While many excavations have taken place after the discovery of cemeteries by aerial photography, reports of investigation of burial mounds (especially with geophysical methods) are seldom made available. In addition to the methodological issues, it can be said that cemeteries are not located and investigated certainly to some extent because the topographic data are missing for analysis, leaving largely unanswered questions concerning burial place selection in different periods. This issue is not only a scientific problem, but it also has great practical significance: cemeteries are the most preferred targets of illegal treasure hunters.

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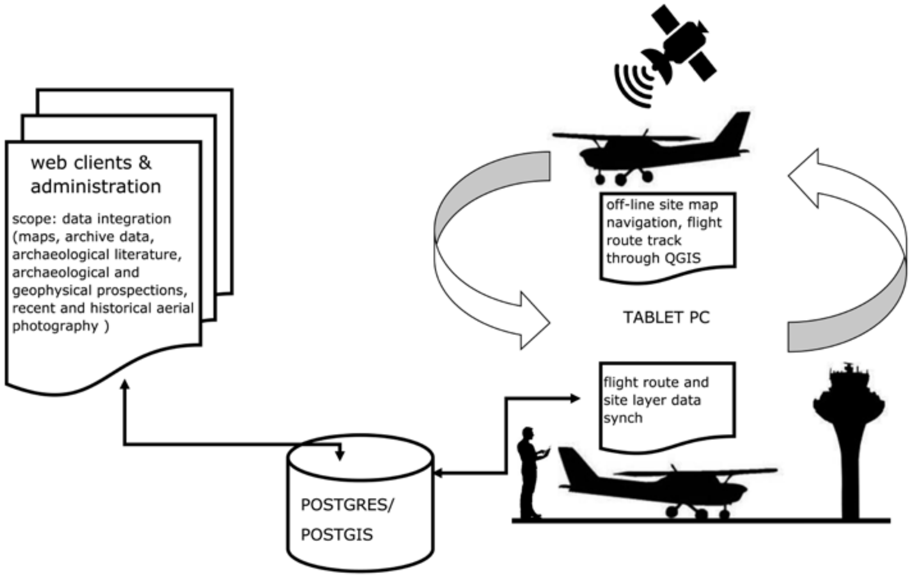

Fig. 1. Concept of the topographic support system (TSS)

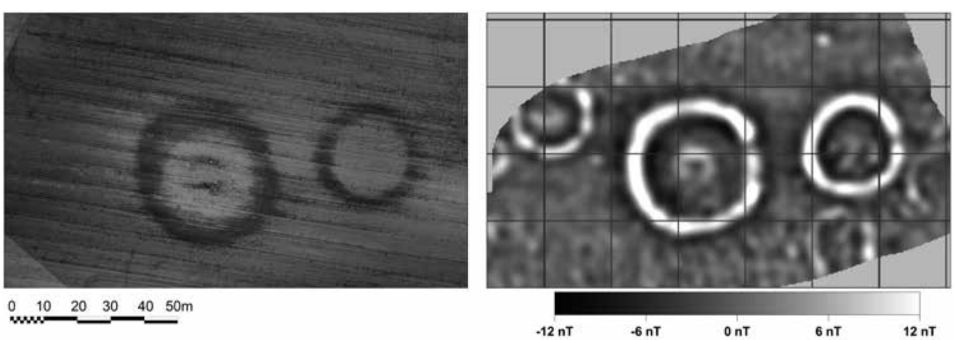

Fig. 2. Example of TSS data prepared for a fieldwork test: an Early Iron Age tumulus at Érd-Százhalombatta-Százhalom, Hungary. Burial mounds Nos 120 and 46 in aerial photograph (left: Z. Czajlik, 11 March 2014) and magnetic results (right; Sándor Puszta, Fractal technology, 2012). Survey carried out with a GSM-19FG GEM System Overhauser magnetometer (instrument resolution 0.01 nT, survey line spacing 0.50 m, standard recording time 0.5 sec, height of probe above ground surface approx. 0.30 m)

KEY QUESTIONS AND TECHNICAL BACKGROUND — TOPOGRAPHICAL SUPPORT SYSTEM

One of the technical objectives of the topographical support system (TSS) was to set up efficient topographical architecture for detecting and documenting archaeological sites. The system provides data on geographically located archaeological sites known from literature and explored, documented and verified sites. It is similar to the field survey solutions used by Eke and Kvassay (2011), but first of all it was adapted to aerial archaeological research.

Why was it necessary to set up a TSS? The use of mobile GIS equipment (Tripcevich 2004) or a GPS-connected PC for aerial archaeological research (Heller 2000; Campana and Sordini 2006) is hardly new technology. However, there was no adequate equipment to create a real-time archaeological database in flight, because common hardware was too large and the operation time and efficiency were unsuitable for long aerial reconnaissance flights. An adequate open source software solution was also not available. The great number of documented aerial archaeological sites and the demand for information on the sites during an aerial archaeological exploration flight led to the development of a device pack which, firstly, could be used during the flight; secondly, could present information about known archaeological sites, and thirdly, could record the accurate position of the airplane/photographer. Fourthly, it could operate for hours during the exploration stage, an aspect of the technology that has become available only recently.

The central information database of the TSS is based on a powerful server (with an open-source, but robust Postgres-PostGIS database system), which could be accessed by the operator's so-called thin client device from anywhere through an internet connection. The possibility for data upload directly from the field proved to be a great advantage. Before the flight, a small-sized tablet device with open source QGIS software, long-lasting batteries and a built-in GPS-module synchronizes the necessary data from the server through the internet connection, allowing the information to be used during the airborne survey. The built-in GPS shows real-time position of the airplane in a cartographic environment on a tablet, which also displays the previously synchronized layered spatial data of the known archaeological sites and the desired topographical (background) maps. Thus, the rediscovery of known sites can be avoided and consequently the efficiency of the time spent on the airplane improved.

Simultaneous site-monitoring is also possible with the assistance of this device as it can display previously documented conditions (with georeferenced, accurately transformed aerial photographs) of the respective archaeological sites.

TEST ON IRON AGE CEMETERIES

The chosen test period was the Iron Age, because all the morphologically identifiable burial categories (ditch enclosed, unenclosed inhumation and the least observable cremation graves) were present in this period. Simultaneously with the technical development, tests were carried out on some Iron Age cemeteries (Százhalombatta, Paks and Fadd), followed by a detailed aerial archaeological and field survey of four to five other cemeteries in Hungary and in Romania, chosen after consideration of different morphological, vegetation and geological attributes.

The great number of well-structured, representative data integrated in a GIS database will enable complex queries, while giving the tools to analyze them. The TSS system and the effectiveness of nondestructive methods in this case could be verified by the archaeological testing of burials of apparent Iron Age date, identified from aerial photographs. With the integration of settlement data in the TSS, one could also analyze the topographic relationship between cemeteries and settlements. This verification in the field with methods discussed above will be the last phase of the field part of the program.

EXPECTED RESULTS

Technological development in this case leads to the development of a scientific topographical database, which can serve other topographical research (requiring only limited modification to integrate the characteristics of other periods). The aerial photography module will improve the efficiency of aerial archaeological surveys and the field module will help object-level observation on archaeological sites. The usefulness of geophysical survey for burial research, not only settlement archaeology as has been to date, is thus confirmed and its efficiency will grow definitely as a result of system-level planning.

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A binocular view of a marginal landscape: GIS and geophysics in the Yorkshire Dales National Park

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KEY-WORDS: landscape archaeology, prehistoric field systems, magnetometry, LiDAR, GIS

The Yorkshire Dales National Park in Northern England contains some of the best preserved and most extensive Late Prehistoric landscapes in the United Kingdom. The subject of frequent investigation by antiquarians and surveyors of the late 19th to mid 20th centuries (e.g. Speight 1895; Curwen 1928; Raistrick 1937), these remains have undergone limited modern research and are poorly known or understood in relation to comparable resources elsewhere in Britain and Northwest Europe. Of particular interest, a collection of so-called 'coaxial' field systems, taking the form of low stone and turf banks, runs across the landscape (Fig. 1).

The landscape of the Dales is a product of its geology: an uplifted area sculpted by ice, it is characterized by extensive areas of limestone and gritstone moorland, cut through by the discrete valleys, each of unique character, that give the area its name (Waltham 2007). The lack of pressure from development (restricted by both the physical topography and the planning authority) has not only contributed to the survival of a rich archaeological heritage, but limited the motivation for field investigation seen in many other (lowland) areas.

This research is the product of two related strands of work conducted at the University of Bradford, in collaboration with the Landscape Research Trust and the Yorkshire Dales National Park Authority, funded by the AHRC. The first strand looks at the extensive prehistoric field systems across the National Park at a macro level, collating various disparate data sources in a GIS in order to investigate the relationships between the archaeology and the landscape. The second project complements this by zooming in to investigate the microlevel, using a fieldwork based approach. A battery of geophysical techniques is being applied, which are helping to construct an increasingly complex picture of the past landscape.

The GIS draws on antiquarian records, the Historic Environment Record database (a record of known finds and features held by the National Park Authority), the National Mapping Project data (aerial photograph transcriptions from English Heritage (Horne and MacLeod 1995), Ordnance Survey data, LiDAR, aerial photographs, ongoing community fieldwork and field observation. These sources have been combined to provide information about known and previously unknown archaeology in combination with local and regional landscapes. Interrogation of this data, facilitated by the GIS, is allowing consideration of questions relating to the spatial and temporal distribution of the later prehistoric field systems. This includes, for example, consideration of topographical trends and elements of slope, aspect, shadow, altitude, geological variation, and alignment on natural features, which may shed light on the origins and development of the field systems. Similarly, issues of seasonality and movement through the landscape, related to the distribution of water and other resources, are being examined. The prehistoric boundaries, which demonstrate considerable time-depth, also suggest an intricate

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Fig. 1. A network of field boundaries on the limestone terraces above the village of Grassington

relationship with the later, medieval patterns of land use; the GIS provides a means to test these observations.

The second research strand focuses on an area to the north of the village of Grassington in Upper Wharfedale, an area subject to much of the antiquarian and early twentieth-century investigation. Because of the work that occurred here, together with the resulting publications, this area is often presumed to be fully understood. However, by considering an area of approximately 200 ha in some detail, it can be seen that the archaeology is far more complex, multi-faceted and has a far greater temporal span than has previously been assumed. Where LiDAR exists for this area, an attempt has been made to interpret and phase the visible features, prior to the application of a barrage of geophysical and survey techniques in several focus areas. Geophysical survey, particularly in the form of magnetic susceptibility and magnetic survey, begins to elucidate the function of parts of this landscape and suggests the presence of intensive manuring and possible deep soils (Fig. 2). Where such deposits are indicated by geophysical survey, coring will be used to test soil depth and to attempt to retrieve datable material. In other landscapes, such as in the Northern Isles (e.g., Simpson 1997), it is known that similar remains originate from the Neolithic period and this would fit with finds of flint previously noted from across the study area. Rather than there being one large, single phase, field system in this area, the results of this fieldwork and associated analysis very much suggest a multi-phase, evolving palimpsest of features, together with the re use and rebuilding of existing remains in later periods. Rather than being constructed out of nowhere, it now seems that the idea of the monumental enclosure of the landscape evolved from an existing tradition of delineation and demarcation, likely to have originated in the Early Bronze Age, if not before. The use of LiDAR in particular has also brought into sharp focus the number of funerary monuments present in the area and suggests that rather than being a purely agricultural, functional landscape, this was an area where both the living and the dead were held in equal regard. By drawing out the

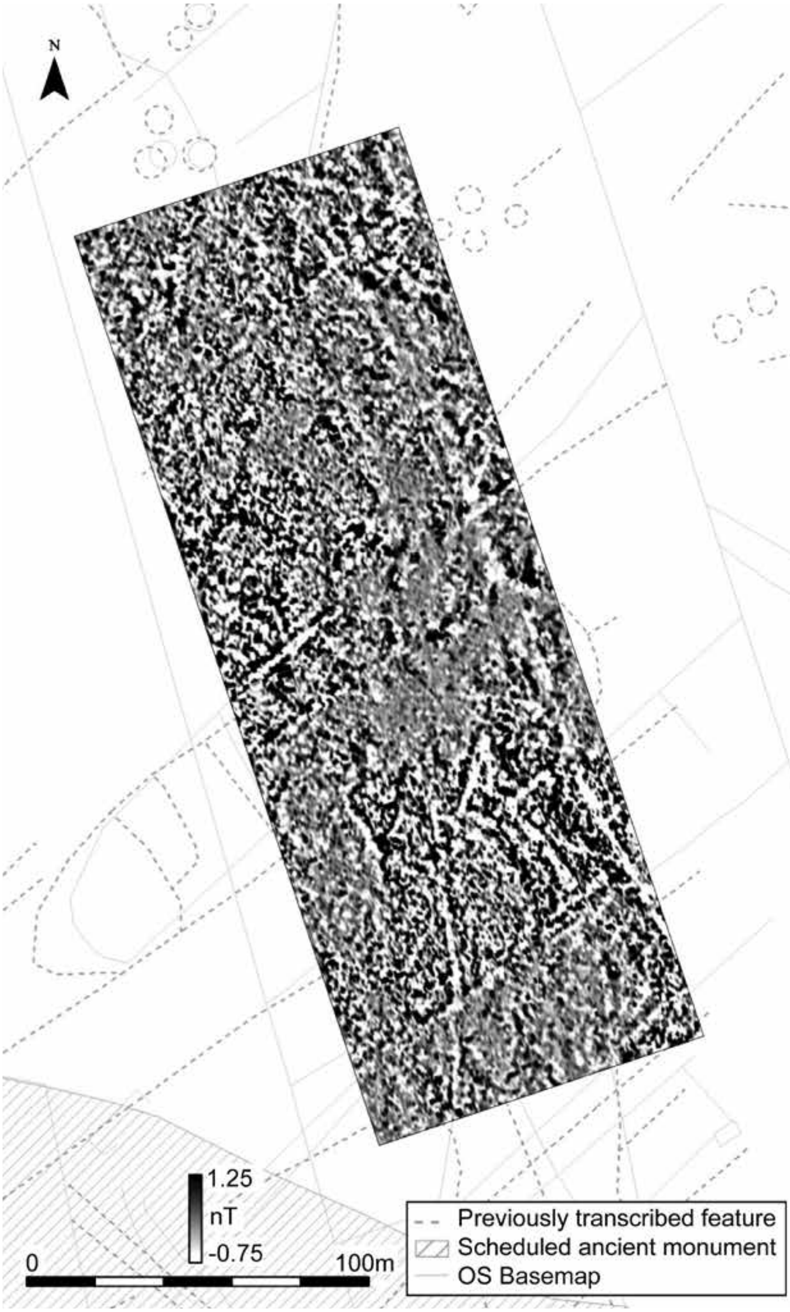

Fig. 2. Magnetic survey of part of a field system near Grassington

phasing and function of this area, it is possible to begin to interpret the factors in society that were driving the development of this landscape and this will form one of the main outcomes of the research.

While the GIS approach offers a broad-brush, outward-looking overview, it also facilitates the incorporation of the focused, inward-looking fieldwork approach; the collaboration has in turn ensured that the subsurface investigation will enhance the understanding of the extant archaeological resource and can be extrapolated through the GIS to characterize the landscape on a wider scale. Moreover, the format also works in conjunction with the Historic Environment Record, aiding public interpretation and heritage resource management, with the potential for further research.

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Cultural landscape. Geomorphometric studies in the Chełmno Land

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KEY-WORDS: GIS, archaeological landscape, spatial analysis, geomorphometry

Research on prehistoric settlement has gone forward significantly in recent years thanks to developments in spatial data processing and analysis technologies. New tools offering a broader range of analyses have been adapted to archaeological needs with the application of methodology typical of the geographical sciences, resulting in an obvious change of approach to settlement research. The way in which data are treated has also touched the Archaeological Record of Poland project. The process has been guided by recommendations included in studies

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concerning systems of spatial information (Smith *et al.* 1987; Clarke 2001; Gotlib *et al.* 2007) and the usefulness of these developments have been evaluated repeatedly (Miałdun *et al.* 2005; Zapłata 2011). The practical implementation of GIS technologies in archaeological projects has also become increasingly frequent (Gawrysiak and Reda 2011; Jankowska *et al.* 2012; Kalicki and Jedynak 2012).

One such project was the geospatial inventorying of ARP objects in Chełmno Land (Kozioł *et al.* 2014). A GIS database was prepared, including a digital map of this region of Poland localizing effectively georeferenced archaeological sites. Data edition and database query are supported by online services (Kozioł *et al.* 2014). GIS Open Source technology and connecting the base with a Desktop tool have created a platform for complex analyses of the extra resources of geospatial data.

Chełmno Land is a district in Poland with a rich and organized prehistoric settlement from the Mesolithic to the early Middle Ages that lends itself well to the application of modern noninvasive surveys and analytical methods. The GIS database prepared for the region contains 6500 sites with their exact location, filtering data by category: location, physiographic location, chronology, culture, determination of records status, description of risks, soil thickness and subtypes. The results were exported as an Excel file, generating a digital map for a given group of sites. Then all the vector and raster maps resulting from the study and generated from pre-built packages of spatial data were integrated in one system. Further data processing include cartometric map accuracy analysis, selection of attributes (SQL) and analysis by spatial relations, neighborhood analysis, equidistant (buffers), network analysis, overlapping and intersecting sets of data, geocoding, interpolation, geostatistics and visibility analysis.

The results of research on representative archaeological sites has constituted the starting point for a more general analysis based on the creation of spatial models grounded in the digital terrain model (DTM) correlated with soils, agricultural and hydrological vector maps. This part of the spatial analysis was based on GIS software designed for complex analysis. Methodology based on the use of the topographical positions index (TPI) (Weiss 2001) was also applied. TPI is a primary indicator of topography, obtained on the basis of data from the DTM, that allows the automatic classification of forms of terrain, e.g., shape complexity index (SCI). On the basis of the primary indicators, it is also possible to calculate topographic secondary indicators, which are used for example to determine the influence of the topography effect on various ecological phenomena. The other topographic secondary indicators, such as: specifying the degree of erosion (EROS), solar radiation (SRAD), potential drainage network density (DDENS), compound topographic index (CTI), wind exposure potential (WINDE), have also been taken into account in the complex analysis. The latter were standard in geographical or ecological research (Lach and Kozioł 2009), but were not tested on the large-scale on archaeological sites. The expected results of the project can greatly expand the range of questions posed in case studies concerning the reconstruction of prehistoric settlement. They bring in more modern documentation of archaeological sites, enabling at the same time a reconstruction of their position in the broader context of an archaeological landscape. The use of tools typical of geographic analysis can help in many cases to determine settlement preferences in particular periods of history, taking into account such factors as ground relief, distance from water sources, visibility and lighting, location in relation to possible transport routes. All of these factors are usually taken into account in settlement research, but require labor-intensive studies related to analyzing different types of sources, including maps and not always precise topographical sketches.

Gathering in a single database all information on the environmental context of archaeological sites, combined with data collected from the surface, but also found in the course of archeological research, makes a comprehensive analysis of settlement contexts much easier.

Establishing a directory of possible issues, to be resolved by spatial data analysis, gives grounds for evaluating the effectiveness of this method in further studies on settlement patterns. Adding survey results to a database accessible via the Internet will facilitate their wider use by other researchers.

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Neolithic settlements in the Tavoliere Plain (Apulia, Southern Italy): predictive probability maps

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KEY-WORDS: Neolithic settlements, hydro-geomorphology, digital terrain todel, remote sensing data; statistical analysis; predictive model; Apulia (Southern Italy)

INTRODUCTION

Predictive models are often based on the extrapolation of geographical patterns and correlations between environmental and human parameters with the main aim being to describe and identify settlement patterns and various usages of the landscape.

Two different approaches can be considered for the implementation of these models: inductive and deductive. The inductive approach is based on the correlation between the location of the known archaeological sites and the attributes connected to the current natural landscape. By contrast, the deductive approach is based on *a priori* knowledge of social aspects (anthropological, historical, archaeological, etc.) and the location of known sites is used to evaluate the model (Kamermans 2006). The prediction of areas with a potential archaeological interest is a kind of investigation debated by several authors. Archaeological predictive maps can be produced correlating different information in GIS environment (Pappu *et al.* 2010) through the application of specific mathematical methods, such as Fuzzy logic (Alexakis *et al.* 2011) or linear logistic models, such as the Classification and Regression Trees (Espa *et al.* 2003).

In order to study the causality between the environment and the history of habitation, it is possible to build models correlating the choice of sites for settlement with a set of independent variables. The variables can be chosen on the basis of features regarding the study area (for instance, altitude in respect to the current sea level, topography of the area, slope orientation (aspect)), but they could also result from spatial analysis in GIS environment regarding, for example, sun exposure, visibility and accessibility (Garcia 2013). The variables can be represented as thematic maps containing environmental information organized in typological classes (geology, geomorphology, soil chemical–mineralogical composition, etc.).

Starting from this articulate background, an inductive predictive model has been implemented for the Tavoliere Plain (Southern Italy) taking into account several environmental features and a set of 120 reference Neolithic sites (mostly dwelling sites) known from archaeological field surveys, geophysical surveys and remote sensing data. This set of reference sites was divided into two groups: 80 were considered for model implementation, the model training step, and the remaining 40 (selected by a regular squared grid) were used to evaluate the archaeological predictive maps, the model validation step (Fig. 1).

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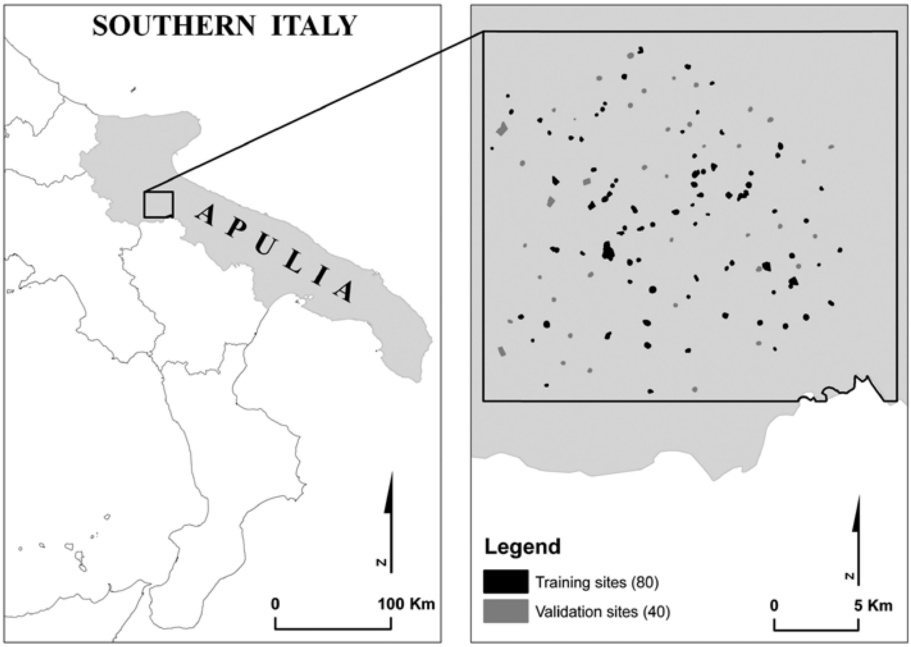

Fig. 1. Study area (left side); location of 120 known reference Neolithic sites (right side)

DATA AND METHODS

The inductive approach entails the choice of specific environmental features to evaluate the most favourable areas for human settlement. The following environmental features were considered:

- topographic characteristics (altitude, slope and aspect; processed from a Digital Terrain Model with a grid step of 8 m and altitude accuracy of 1 m),
- geomorphology (catchment basins, river modeling forms, that is, river bank borders, river erosion banks and quarries; from Apulia Region GIS shape files),
- covering vegetation stress generated by underground ancient remains (six vegetation indices processed from Landsat 8 image, acquisition date 20 June 2013).

Their importance was established by computing appropriate probability weights (PW). On the basis of the PW, an operation of reclassification was applied (after a resampling to make the pixel dimensions uniform for all the images) and the resulting maps became the input parameters of the model. They were organized in three categories: Terrain, Hydro-geomorphology and Vegetation Indices. All categories and relative parameters were multiplied by specific weighting values (respectively, Wcat and Wpar), producing their different significance in the processing of the archaeological predictive map. The set of Wcat for the three categories was defined by two different methods.

1) The arbitrary Weights of Significance (WS) method establishes several triads of numbers on the basis of three criteria: equal significance to each category (e.g., 33/33/33),

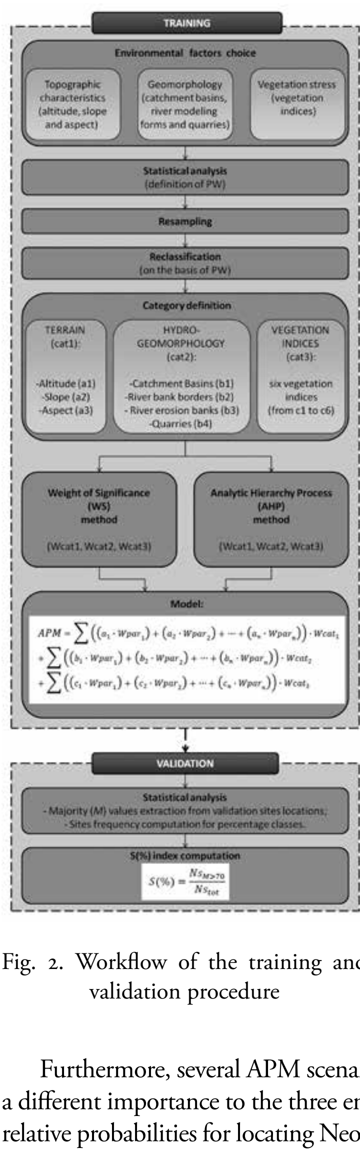

Fig. 2. Workflow of the training and validation procedure

medium participation to two categories (e.g., 60/20/20) and very high participation to one category (e.g., 80/10/10).

2) The statistical Analytic Hierarchy Process (AHP) method (Saaty and Peniwati 2013), based on a decisional matrix, results in a priority matrix containing values indicating choice preferences, in this case three numbers (e.g., 73/22/5). These numbers were used as Wcat and were combined in the six possible ways.

The implemented model gives as output an archaeological predictive map (APM) for each iteration. ArcGIS and ERDAS Imagine were employed for the data processing.

The workflow of the training procedure described above, followed by the validation step (next section), is shown in Fig. 2.

RESULTS AND CONCLUSIONS

The analysis for the calculation of the PW enabled also the extraction of statistics for the Neolithic sites in relation to environmental factors. Considering the topography, for example, a large set of the 80 training sites (42.5%) is situated at altitude values included in the 150–200 m range. Slope was reclassified every 2.8° (approximately corresponding to 5% slope) and aspect was reclassified every 45°. As a result, most of the settlements (86.25%) were shown to be located on very flat ground (slope between zero and 2.8 degrees). Moreover, where the slopes are greater than zero (82.5% of the sites occur in zero slope areas), the preferential aspect is towards N-NE-E (11.25%) and N-NW (6.25%).

Furthermore, several APM scenarios were processed with different Wcat combinations, giving a different importance to the three environmental categories at each iteration. As a result, different relative probabilities for locating Neolithic settlements were produced. One representative scenario map was chosen for the WS method and one for the AHP method (shown in Fig. 3). These operations were carried out by applying a validation procedure consisting in the computation of the S(%) index. This index gives the percentage number of the validating reference sites corresponding to a predictive probability (pixel values in the predictive maps) higher than 70%, an arbitrary threshold. The best scenario in Fig. 3, with S(%) equal to 63%, shows a high archaeological predictive probability zone in the central area and a gradual decreasing trend toward the top and bottom of the map. The map was obtained assigning the highest Wcat value to the Terrain category.

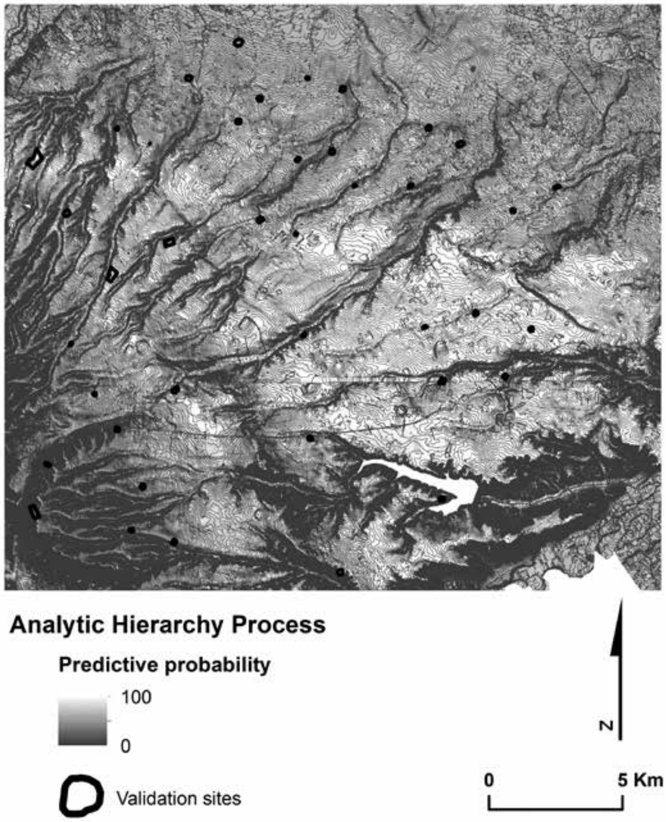

Fig. 3. AHP method (scenario 73/22/5): the resulting best scenario showing the probability of finding a Neolithic archaeological site in the study area

On the basis of the results, the implemented predictive model, combining different types of data in a synoptic investigation, may allow for a good identification of habitation loci during the Neolithic period.

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Improving the GIS-based 3D mapping of archaeological features in GPR data

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KEY-WORDS: GPR, GIS, 3D mapping, data visualization

INTRODUCTION

The archaeological interpretation of ground-penetrating radar (GPR) data involves the precise mapping and classification of 3D subsurface features detected by GPR. This is generally performed by digitalizing the GPR anomalies in a GIS environment (e.g., Leckebusch 2001; Neubauer *et al.* 2002) by means of vector features (typically polygons). Both manual processes and semi-automatic methods (e.g., Leckebusch *et al.* 2008; Schmidt *et al.* 2013) can be used to map the subsurface features detected in the GPR data. In most cases, especially for complex archaeological sites, manual processes are preferred as they offer a more intuitive way to "extract" archaeological features in an accurate way. Structures like walls, pillars, pits are easily recognizable to the human eye in a very complex and noisy GPR dataset and they can be mapped with high precision when they are mapped manually. In contrast, automatic and semi-automatic feature extraction methods are not yet sufficiently developed to allow for a precise extraction of complex subsurface structures (e.g., Leckebusch *et al.* 2008).

Among the methods used to display the GPR data, horizontal amplitude maps (so-called time or depth slices), extracted from the GPR 3D data block, are widely used for data analysis in a GIS environment. For example, when using ArcGIS software, the GPR depth slices are usually imported into an ArcMap or ArcScene project as georeferenced TIFF images and displayed on different layers. In a traditional approach, the digitization is usually performed first in the 2D environment (ArcMap) by means of polygons. These are then extruded in the 3D environment (ArcScene) in order to obtain an interpretative 3D visualization of subsurface features. The method is generally very time-consuming, especially if graphically accurate 3D models are to be created.

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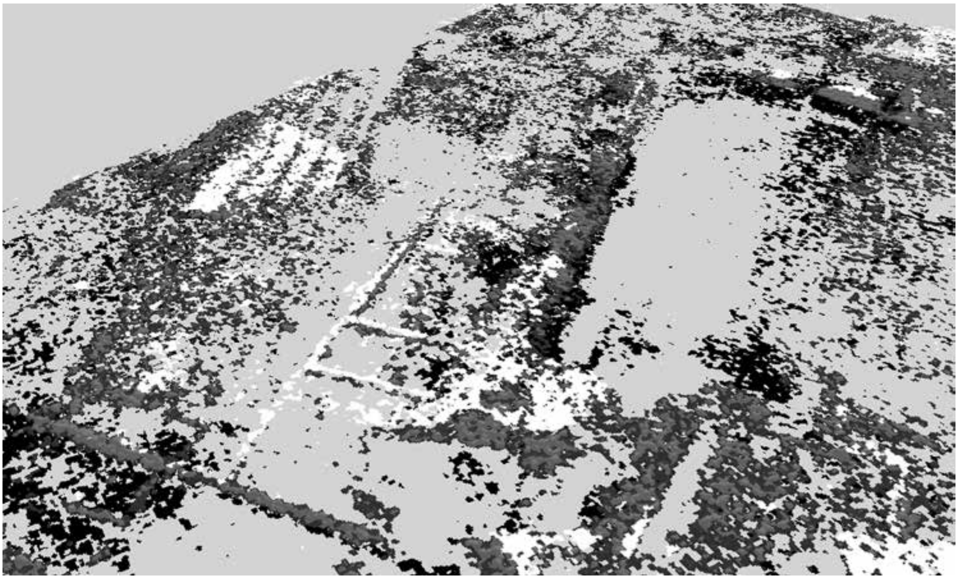

Fig. 1. GPR amplitude maps from different depth levels visualized in ArcScene by setting a "classified display". The shallowest features are represented in light grey, the deepest ones in black

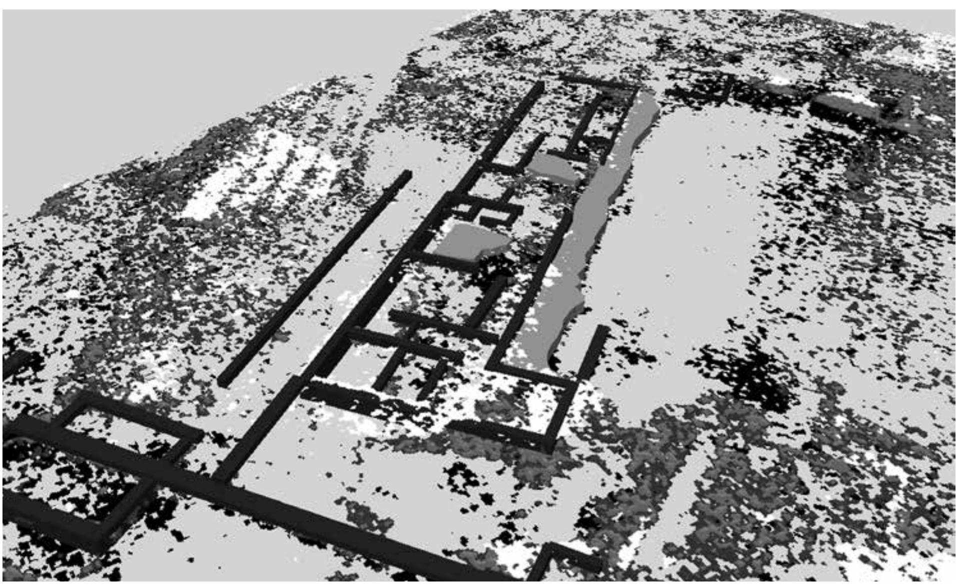

Fig. 2. 3D mapping in ArcScene by means of extruded polygons (1.5x vertical exaggeration)

The paper presents a good method for mapping GPR anomalies in ArcGIS, combining interactive 3D mapping in ArcScene with feature enhancement in GPR raster images.

PROBLEM

One of the main problems in manually mapping 3D subsurface features from 2D amplitude slices is the difficulty in generating rapidly an accurate and easily readable 3D interpretation model of the subsurface features. Even though good practices developed by one of the authors, based on the animated visualization of depth slices in a GIS environment, have greatly improved the interpretation of GPR data (Poscetti 2013), the mapping process remains a fairly complex and time-consuming task.

In a typical approach, features are first mapped in the 2D environment by means of 2D or 3D polygons (with z values in the vertices) that are then extruded in the 3D environment to obtain a 2.5D model. When using ESRI ArcGIS, the extruded polygons can be converted into 3D features (so-called multipatch) resulting in a true 3D interpretation model of the buried archaeological remains. This can be useful, for example, when we need vertically textured objects for a more "realistic" representation of walls, pillars and other elements in our GIS-based three-dimensional map (Poscetti 2013).

Beside the true 3D modeling, which generally represents the final step of the interpretation process, the fundamental problem related to visualization in a 3D environment is that the numerous stacked extruded polygons, resulting from 2D mapping at the different depth levels, in most cases do not offer a clear image of the buried archeological remains. Time-consuming refining work is generally needed to improve the 3D visualization. The problem can be resolved, at least in part, if the features are mapped directly in a 3D environment (ArcScene), in a more intuitive way. Moreover, in relation to the GPR amplitude maps, different types of visualization can be applied, like the so-called "classified display", in which the values of the raster image are grouped into a few main classes, allowing for the enhancing of the most relevant features in the GPR data.

METHOD

In our application, the georeferenced TIFF images displaying GPR data (the abovementioned amplitude maps or depth-slices) are single-band grey scale images using 8-bit unsigned integer cell values (from 0 to 255) to represent different intensities of the reflections (signal amplitude) in a ramp of 256 shades of grey (from 0 [black] to 255 [white]). In our case, the lowest values (dark shades) correspond to the strongest reflections, while the highest values (light shades) correspond to the weakest reflections. The georeferenced TIFF images are imported into the 3D display environment (ArcScene) and displayed on different layers. For each layer, the base height is set according to the depth of the corresponding depth-slice. By considering that relevant features, like stone walls and concrete floors, are generally visualized as dark features (e.g., values from 0 to 100) in a relatively light grey noisy background (e.g., values from 100 to 250), in order to enhance these features, we can group the 256 cell values of the raster into a few main classes and display only the most relevant class of values. By working in ArcScene, this can be done by simply operating on the symbology of the layer. For a slightly better contrast, a so called hillshade display can also be applied to the layer. By conducting the same operation on different depth slices in the ArcScene project, the resulting

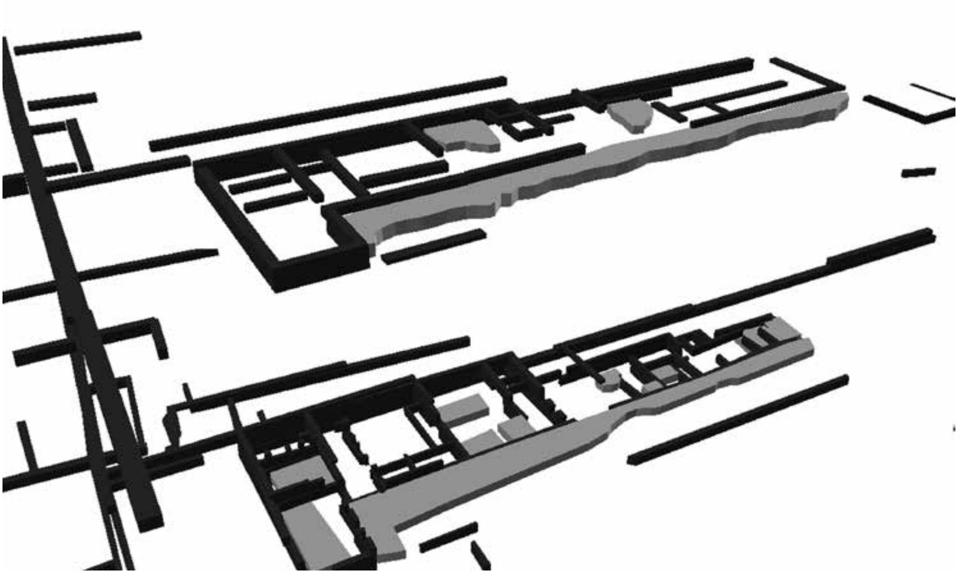

Fig. 3. 3D mapping in ArcScene by means of extruded polygons (1.5x vertical exaggeration: above 3D model in the new approch; below, 3D model in a traditional approach)

image is, apparently, very similar to a 3D visualization through isosurfaces, the fundamental difference being that in our case 3D features were not extracted, but only enhanced as 2D features in the raster images (Fig. 1). The visualization permits the immediate perception of the most relevant archaeological features in a 3D environment, allowing the interpreter to map the features directly in a 3D approach by using a 3D editing tool. The advantage in analyzing the data directly in ArcScene is represented by the possibility to observe immediately the vector features created as extruded polygons and to edit them interactively in a more intuitive way (Fig. 2).

In order to evaluate the efficacy of the method, GPR data from a Roman site in Austria were analyzed independently by two of the authors, respectively with a traditional approach, based on previous mapping in the 2D environment (ArcMap), and a 3D approach, in which the interpreter makes use of classified raster images and directly digitizes the relevant features in a 3D environment.The results were then visually compared in the same GIS project (Fig. 3).

The first interpretation model, even though very detailed and accurate, is affected by a series of small graphic errors in the representation of the Roman structures that become apparent, especially when they are visualized in a 3D environment. The structures mapped in the so-called 3D approach look cleaner and therefore more readable. However, a few details, like internal walls and pillars in the Roman building, represented in detail in the first approach, are missing from the latter model, because they were not clearly visualized through the classified display.

In order to further improve the 3D GPR data interpretation, other methods were also tested by combining the GIS-based 2.5D interpretation models with 3D visualizations of the GPR data, such as isosurfaces. This was made in ArcGIS by importing the isosurfaces into a so-called "multipatch feature class". Another approach is to export the polygons and visualize them in a volumetric viewer like Voxler, combined with the GPR data block. The polygons can thus enhance the somewhat "foggy" image of the volumetric display.

CONCLUSIONS

The main advantage of the presented method, developed by the first author, lies in the possibility to efficiently obtain accurate 3D interpretation models by simplifying the whole interpretation process. The method can be applied effectively especially in the case of Roman archaeological sites, where numerous high-reflective anomalies, generated from stone walls and foundations, are normally detected. Further improvements of the method should be made by testing more sophisticated feature extraction techniques, to efficiently generate more detailed 3D models.

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Evolution of human settlements and natural risk factors. A case study of Chalcolithic archaeological sites in the Valea Oii watershed (Romania)

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KEY-WORDS: Chalcolithic, natural hazards, landscape, management, settlements

Settlement takes into account the physical and geographical factors of a targeted area and dwellings are placed generally in the upper sectors of small watersheds. These represent the most uniform territorial entities from a geographic and strategic perspective. On a large scale, the situation is similar regarding the villages within large watersheds. The same principles have applied to settlement location throughout history (Postel *et al.* 1996: 785–788).

The Valea Oii watershed is where the largest settlement belonging to the Pre-Cucuteni culture in the territory of Romania has been discovered. The Pre-Cucuteni culture (c. 4200–3700 BC uncalibrated radiocarbon dates) played an important role in the genesis of the most representative Chalcolithic civilization of Europe, the Cucuteni–Tripolie. In the course of three evolution stages, the Pre-Cucuteni communities spread between Transylvania, the Bug–Dnieper interfluve, the upper streams of the Pruth, the Dniester, and northwest of the Black Sea. Thus was formed a core area from which the Cucuteni–Ariusd–Tripolie cultural complex later emerged (Boghian 2001: 79–85; Nandris 1987: 201–222).

Based on new interdisciplinary research, this study attempts to delimit, for the first time in Romania, areas suitable for settlement within a watershed, depending on the natural and socio-political circumstances. The main historical periods, from the Chalcolithic to the present, are considered from this perspective. The focus is on the connection between the location of human settlement and the dynamics of natural risk factors, which include floods, landslides, gully erosion and fluvial erosion. The Valea Oii watershed is situated in the northeast of Romania and it covers, for the most part, the Moldavian Plain, except for a small part of the upper basin situated in the Suceava Plateau (Fig. 1).

Archaeological sites/settlements were mapped with a GPS Leica 1200 System. The data were georeferenced and processed in STEREO 70 coordinates. Old maps were georeferenced through the correspondence method (finding the same topographical marks, oldest and newest, on both maps); the final maps were obtained with the help of AutoCAD, TNTmips and ArcMap 9.3 software. CorelDRAW was used for graphic processing. To determine lake basin evolution, topographical maps and plans were used and the lake limits extracted. The following cartographic materials were used: topographical maps scale 1:50000 (edition 1894), shooting plans scale 1:20000 (1957–1958), topographical

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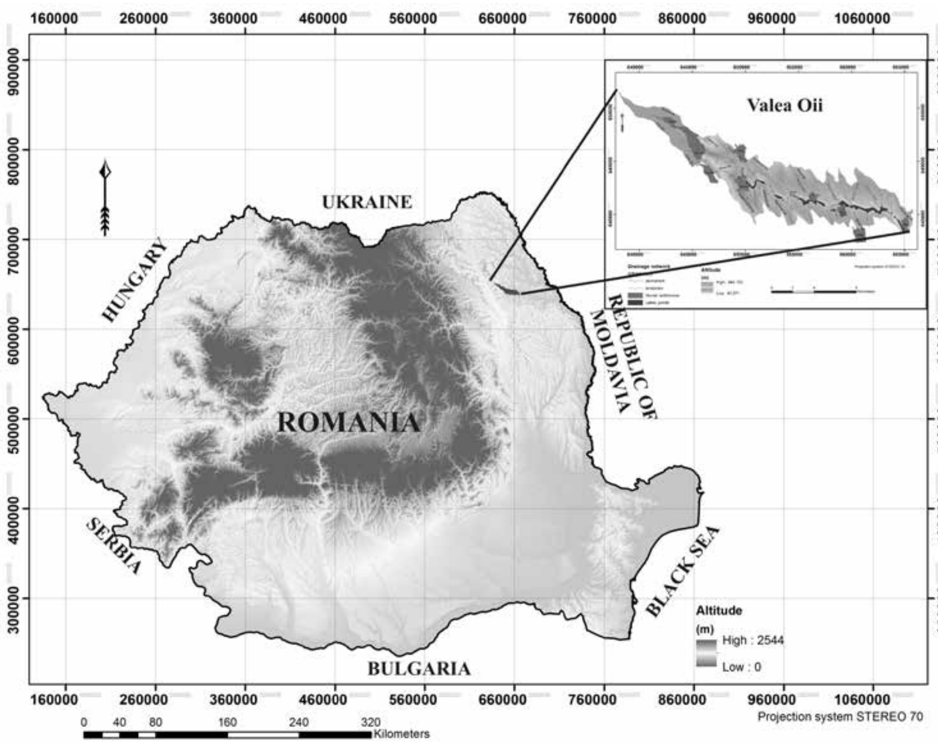

Fig. 1. Geographic location of the Valea Oii watershed in Romanian territory

plans scale 1:5000 (1982), and orthophotoplans scale 1:5000 (2005). Austrian topographical maps scale 1:200000 (1910) and Soviet topographical maps scale 1:200000 (1942) were excluded from the study, because most of the lakes were too small to be represented in this scale. At the same time, data from the Water Cadastre Atlas and the Prut–Barlad Water Headquarters in Iasi were consulted.

The Valea Oii watershed represents an old habitation area, still inhabited today, the settlement there dating back to the Chalcolithic. Traces of the Cucuteni–Tripolie culture, going back about 4,000 years, were discovered inside this basin (Fig. 2). The high density of archaeological sites should be emphasized, mostly in the upstream sector of the basin, at the junction of the higher area (plateau) and the lower zone (plain) (Romanescu and Nicu 2014: 509–523).

Chalcolithic settlements in the upper sector of the basin created the conditions for the spread of the population to the lower basin. The migration process was caused by hydrological and geomorphological hazards, such as catastrophic floods, landslides and gully erosion (Romanescu *et al*. 2012: 953–966). These were the result of deforestation that was the result in turn of extending cultivated land, which led to strong soil erosion processes creating non-productive soils (anthrosols, protosols). In this situation, settlement shifted its focus to the lower-lying areas, which were exposed to floods, but which had more water resources and agriculturally more productive soils. The migration coincided with progress in “land management” knowledge and the growing

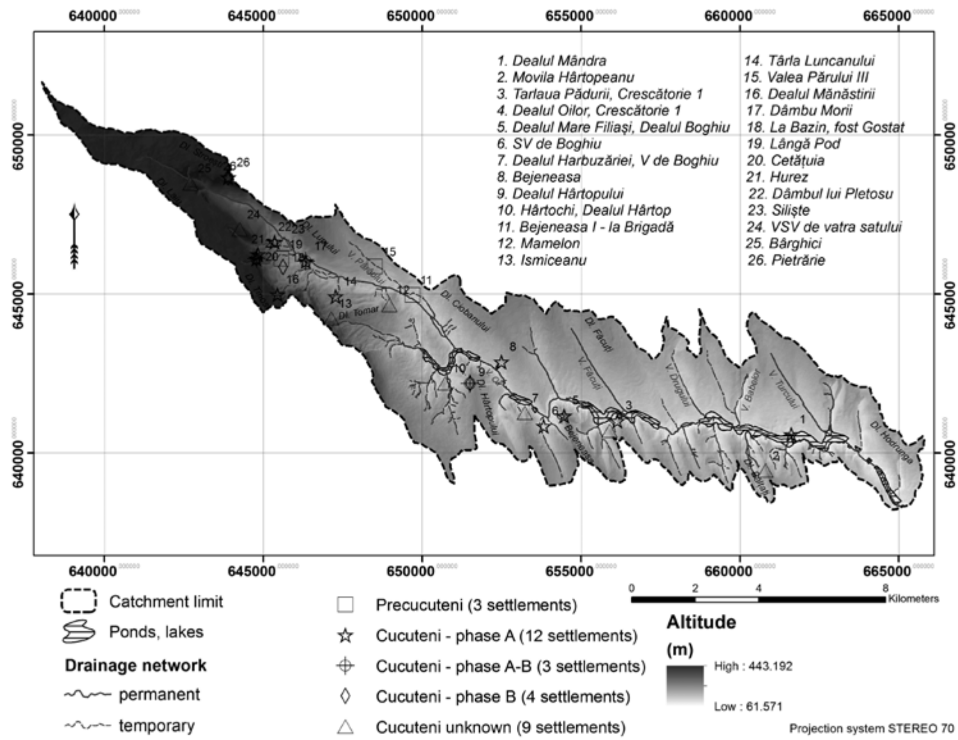

Fig. 2. Location of the Chalcolithic settlements in the Valea Oii watershed

pressures of natural hazards. Dwellings were now placed on the floodplain or the never flooded primary terraces, close to the river mainstream. Water conditions all human settlement (Fig. 3), hence limited water resources force the construction of ponds. The current large size of the aquatic surface of the basin indicates reduced water resources, explaining why all settlement in the lower basin, whether ancient or modern, is concentrated along the Valea Oii River.

New territories in the Valea Oii were occupied because of intensified natural hazards, such as floods, landslides and gully erosion, occurring in the upper sectors of the basin sectors. Deforestation and superficial erosion reduced the food resources, while the floodplain, continuously supplied with recent alluvia, gave rise to highly profitable agriculture, providing food for a larger number of individuals. This was why settlement extended to the lower sector of the Valea Oii watershed.

ACKNOWLEDGMENTS

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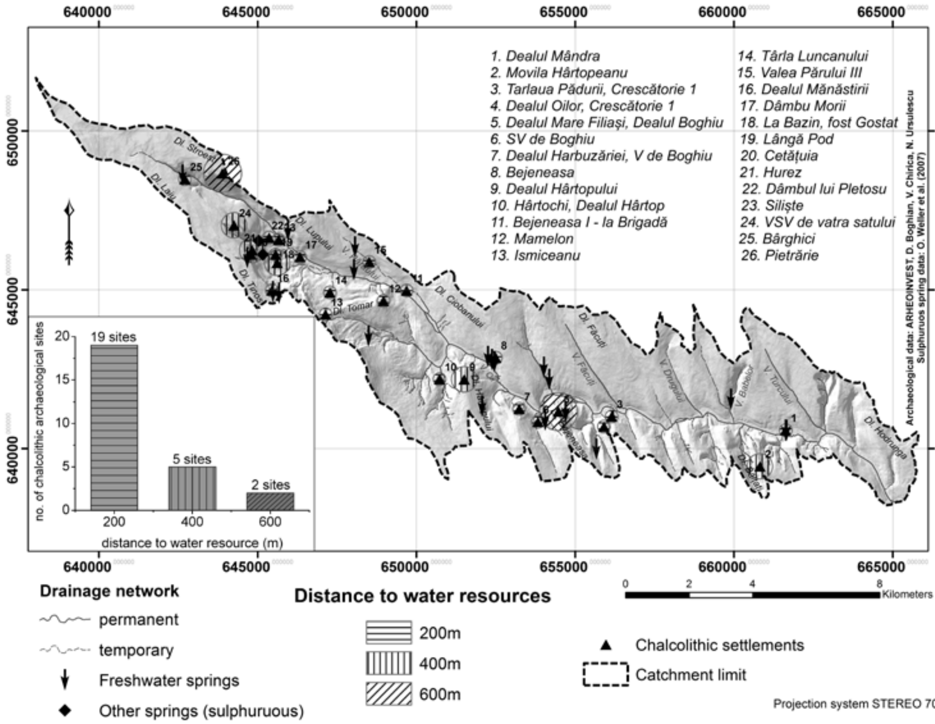

Fig. 3. Location of archaeological sites depending on water resources

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Exploring free LiDAR derivatives. A user's perspective on the potential of readily available resources in Poland

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KEY-WORDS: LiDAR, GIS, armchair archaeology, desk based assessment, archaeological prospection

INTRODUCTION

Airborne laser scanning (ALS), that is, the use of laser scanning devices from airborne platforms to record surface topography, is a technique used for archaeological prospection that has evolved from being a new technology to common practice in the course of the past decade (Holden *et al.* 2002). Data recorded through the employment of remote-sensing techniques find numerous applications for public use. Among them are government spatial databases created and developed to foresee, monitor and prevent potential environmental and natural disasters in high-risk areas (e.g., flood plains). Such were the intentions of the ISOK (IT System of the Country's Protection against Extreme Hazards) programme, which included initially, among others, ALS and the creation of DTM and DSM models of river sub-basin areas for more than 204,000 km^2 of the territory of Poland (over 65% of the total area of the country). This processed and visualised data is available free to the public as a WMTS layer in Poland's national geoportal (Geoportal.gov.pl) administered by the Head Office of Geodesy and Cartography (GUGiK). Data for particular areas, provided in .LAS and its derivatives, i.e., ASCII formats, can be purchased for further enhancement.

The potential for prospection of landscapes, including remote and forested areas, is inestimable. The area covered by ALS contains numerous islands, mountain ranges, bogs and forests. The lattermost are of utmost importance where ALS data is concerned, because about a third of the territory of Poland is densely forested (Zajączkowski *et al.* 2014), making regular fieldwalking (the fundamental prospection technique applied in Poland) in search of known and new archaeological resources a challenge over large parts of the country. The possibility of exploring these areas provides a new dimension for national heritage management in Poland as far as earthworks are concerned (Kiarszys and Szalast 2014; Banaszek 2014).

CURRENT TRENDS

In recent years, the emphasis on making use of ISOK data has been placed mainly on case studies of particular areas, geographical units, mostly forested (example in Banaszek 2014), or detection of specific types of archaeological features within a cultural landscape (see Przybył 2014). The use of ALS data has become relatively common in site or landscape field projects

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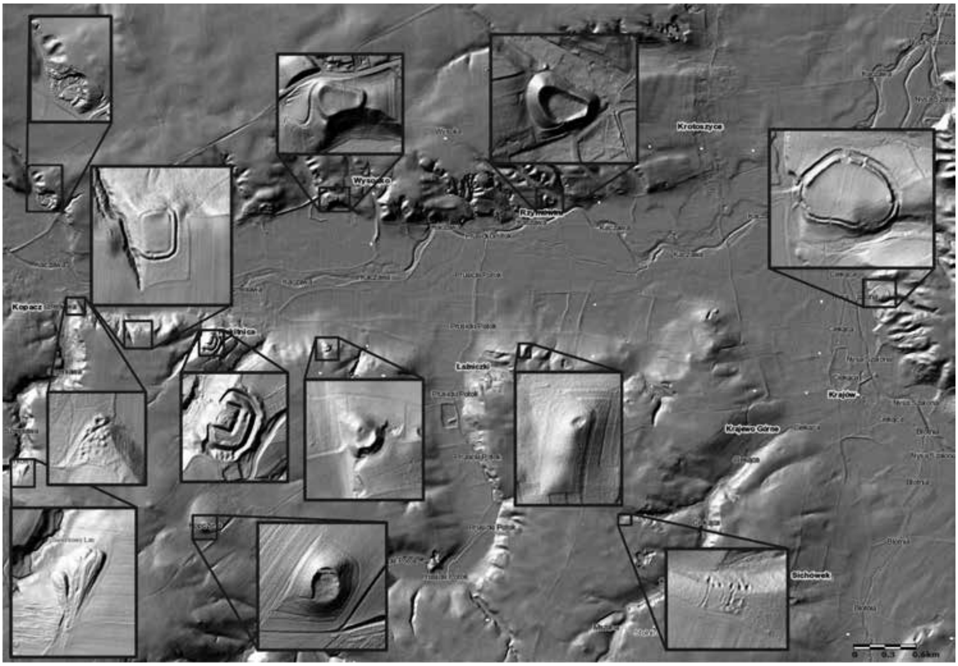

Fig. 1. Example of an abundance of archaeological resources in the cultural landscape of the Kaczawa river valley (North at top)

and this rising trend has been reflected at archaeological conferences in Poland (e.g., *Computer Applications in Archaeology*, Poland, 12–13 June 2014) and in the development of scientific projects aimed at exploring the skill of local communities for recognising historic monuments in LiDAR visualisations (Laser Discoverers project, Sztampke 2014).

The potential of this data in Polish archaeology has yet to be recognized. Past landscapes can now be perceived as a continuum rather than as separate 'islands'. Through the perspective of LiDAR-derivatives, evidence of past human activities can be seen almost everywhere, creating meshworks and connecting individual places into broader landscapes (Mlekuž 2012). Research should be focused on this issue, as the ALS data clearly show how much there is still to be learned.

The number of users other than archaeologists browsing through the free data is also growing, as is the general interest in this kind of geographical visualisation. This is revealed by visit statistics of thematic articles on various Internet sites (e.g., archeolog.pl). Browsing through free ALS resources complies with the needs and social aspects of "armchair archaeology". It has also become unwittingly a resource beyond archaeological control, activating spreading social interest in archaeology (the processes of discovery and viewing) and the ALS technique itself. Exploring readily available data leads thus not only to recognition of various archaeological and historical earthwork features in rural or secluded environments (Fig. 1), but also to enhancing landscape perception of already studied and documented sites in a broader spatial context (Fig. 2).

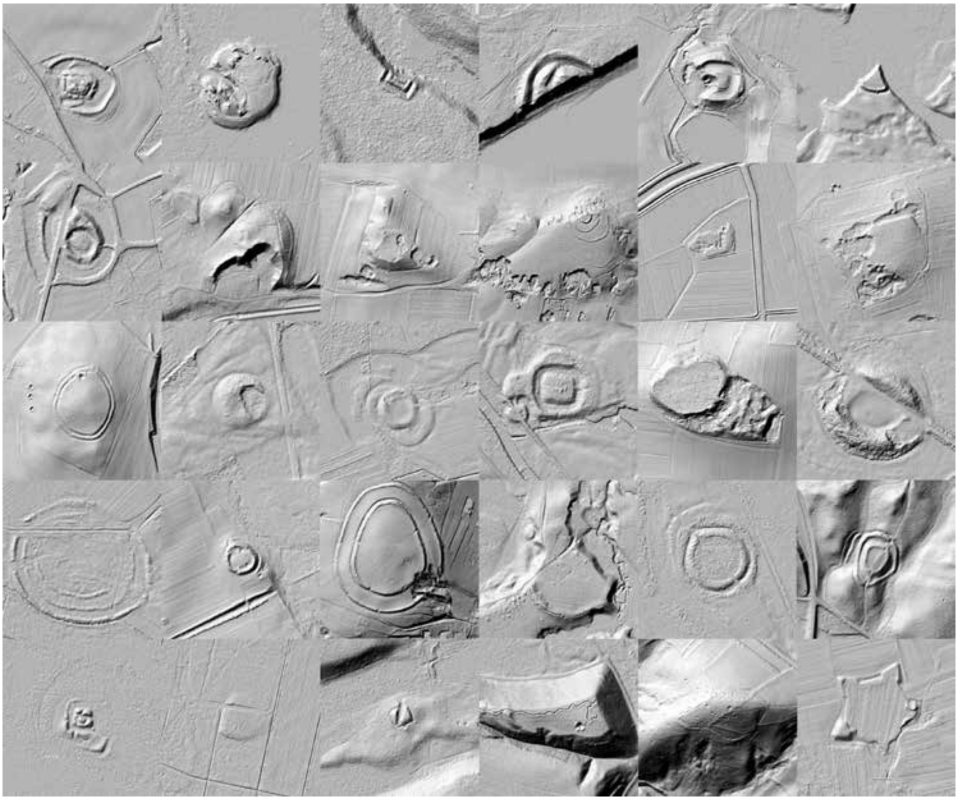

Fig. 2. Various types of archaeological earthwork monuments throughout Poland in different phases of destruction (North at top, scales differ)

The authors of this presentation have been browsing through the ALS visualisations available on Poland's national geoportal, systematically cataloguing various types of manmade ground features that include already known archaeological resources, as well as potentially new archaeological sites. Initially a strictly hobbyist initiative, it has expanded into a regular collection of over 1500 places of interest, including extensive prehistoric fortified settlements, gords or burgwalls, single barrows and barrow complexes, fortification systems, castles, mottes and baileys, abandoned granges, villages, homesteads and farms, mines and mine dumps, charcoal piles, enclosures, communication tracts, ditches and other earthworks connected with past human activities, not to mention innumerous scars on the landscape left by military battles and other army activities of the past 500 years in Poland. All these features are pinpointed in a simple GIS database, developed with open-source software. Every observed ground feature is located within existing administrative regions, classified and supplied with additional information (local name, historic meaning). The database enables a broad landscape perspective for examination of topographical features and factors, relations between close and distant sites and potential

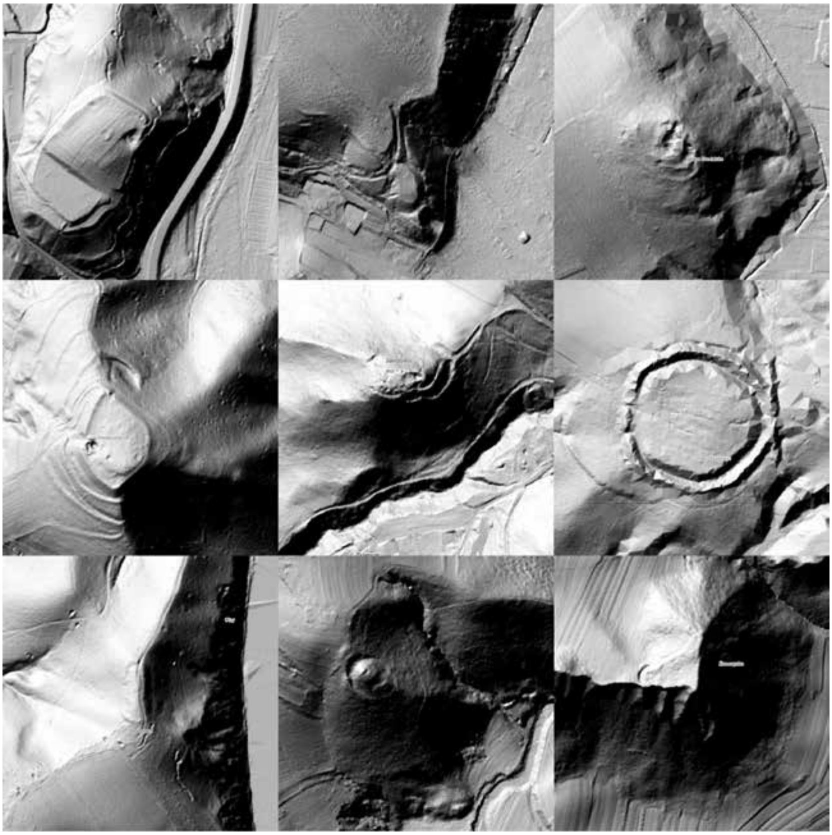

Fig. 3. Examples of reliefs with prominent hillshade visualisation covering archaeological features (North at top, scales differ)

management of archaeological resources. Integration with the national register of heritage sites and monuments and the (still undigitized) AZP database (Archeologiczne Zdjęcie Polski, that is, Polish Archaeological Record, a nationwide fieldwalking survey project conducted since the late 1970s) (Konopka 1981) is the next natural step in enhancing the potential of the developed database. It offers the possibility to cross-reference with other data.

CONCLUSIONS

At a basic level, detection and registration of ground features bearing potential for archaeological research requires nothing but a keen eye and awareness of possible feature types. Basic processing of detected features is possible in any available GIS software or even the national geoportal browser-based viewer. Readily available visualisations are quite suited for this task. In the long run, however, they would benefit from further processing that would allow enhanced feature analysis, simply because extraction of their full potential requires more advanced analysis (Zakšek *et al.* 2011; Kokalj *et. al.* 2013) than simple *hillshaded* reliefs (Fig. 3). The potential of this new dimension of information is enormous, yet due to the fragmentation of initiatives aimed at its systematic exploration and the absence of any central hub for sharing, cataloguing, describing and verification, ALS data are still an untapped resource. Surely untapped for research projects, but foremost for heritage offices, which could stand to benefit from the application of "armchair" approaches, especially taking into account their severe underfunding.

From a social perspective this situation has many implications in view of the fact that in Poland information regarding archaeological sites is not in the public domain. As the ISOK DTMs reveal archaeologically sensitive information, but are officially for the purposes of hydrology or forestry, they have become a rather interesting way of circumventing restrictions on archaeological data and are being used intensively by hobbyists and professional exploration groups. The irony of this situation is that archaeologists continue to rely heavily on outdated fieldwalking documentation that serves as the basis for research projects and heritage management, while unofficial groups have long-ago embraced high-quality ALS approaches, allowing them to streamline their legal and (more often than not) illegal activities.

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Comprehensive field survey at Gebelein: preliminary results of a new method in processing data for archaeological site analysis

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KEY-WORDS: mobile GIS, remote sensing, near-infrared imagery, magnetic prospection, Egypt, archival data, mud-brick tombs, Gebelein

GEBELEIN ARCHAEOLOGICAL SITE COMPLEX

The Gebelein archaeological site complex is located 28 km southwest of Luxor, on the western bank of the Nile in the Qena Governorate in Egypt. Practically all kinds of archaeological sites known in Egypt are represented in the site complex, dating from the Paleolithic through the Islamic Period (Marochetti 2013; Ejsmond 2013). The area has been visited by scholars from the 18th century on and the first excavations were conducted in 1885 (Marochetti 2013). Modern expansion of the cultivation zone and settlement development is threatening the survival of many of the sites, hence the project, which is carried out under the auspices of the Polish Centre of Mediterranean Archaeology of the University of Warsaw, proposes to investigate the site complex with a new form of comprehensive field survey.

The novelty of the method depends on combining the results of gathering, managing, storing, post-processing and interpreting different types of individual data from the field. The team has carried out a magnetic prospection of selected parts of the site and combined the results with an analysis of data coming from a number of other research and survey methods, including most recently an anthropological and ceramological survey.

RESEARCH METHODS AND RESULTS

A fast and effective way of collecting field data needed to be developed owing to the size of the area, which measured approximately 3 km by 4 km, and the extensive number of archaeological sites recorded in the complex. Mobile GIS together with remote sensing analysis (four spectral band satellite images from which one was near infrared [NIR]) gave the opportunity to prospect and examine sites, as well as to document archeological remains (see Chyla 2012). Mobile GNSS tools with GIS applications were used to document both position and information about archaeological features. Trimble Juno and MobileMapper 20 and ArcPad – ArcGIS applications were used to create a features database concurrently with the fieldwork. The objective was to connect features with positions and with information regarding the state

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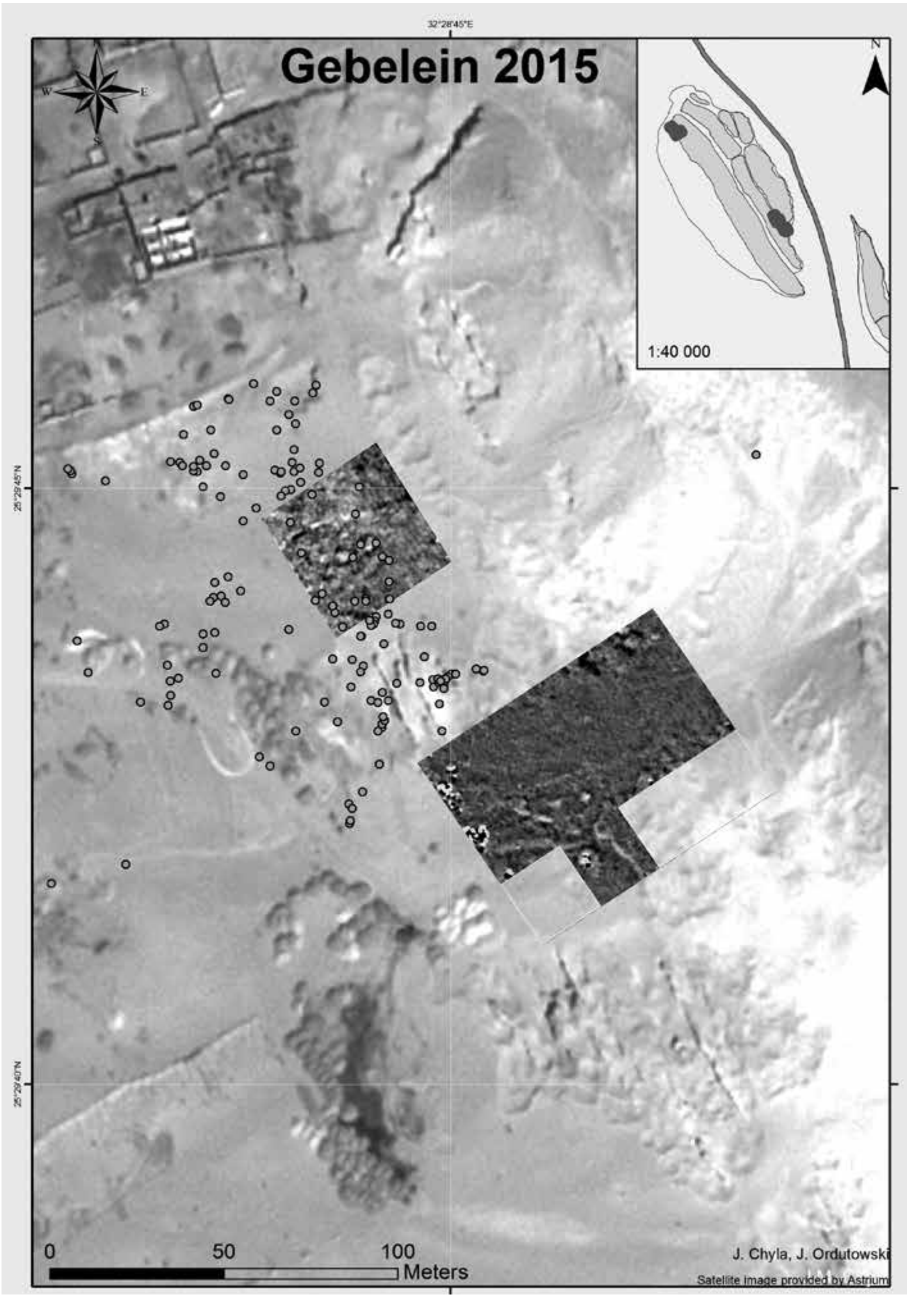

Fig. 1. Combined results of geophysical prospection and ceramological survey (processing J. Chyla, J. Ordutowski)

of preservation and recognized threats, archaeological finds, if present, basic description and photographic documentation (Chyla 2012).

Prior to the fieldwork, archival maps (of which Pierre Jacotin's [1826] map from the time of Napoleon's expedition to Egypt was the most useful) and contemporary satellite imagery (Corona, Landstat and Google from 1969, 1974/2013 and 2009–2014, respectively) were correlated and analyzed in GIS. A comparison of archival information and the situation today confirmed the expected expansion of agriculture into archaeological sites and beyond. Results and documentation from previous research (Chyla, Ejsmond 2013) were imported into the GIS, subsequently into a mobile GIS application and then used during fieldwork. The information helped in understanding the partly published research results from the beginning of the 20th century (Chyla 2012; Ejsmond, Chyla, Baka in press). Additionally, it proved possible to locate presumed ancient waterways by analyzing contemporary NIR and archival satellite images and archival maps, which reveal possible traces of an old riverbed and channels, as well as by reading ancient written sources from the Late and Greco-Roman periods, which describe numerous waterways in the Pathyrite district, the Greek name of the area administered from Gebelein (Andrews 1994).

One of the goals of the survey carried out in 2015 was to gather anthropological and pottery data with mobile GIS, which allowed all the human bone and pottery finds within the test areas to be positioned in the field. The pottery database included information on localisation, material, surface finish, diagnostic form (e.g., base, body or rim) and dating. It is an open database, in the process of being developed for the purpose of conducting a spatial analysis of the distribution of different kinds of pottery. This information was paired with the results of geophysical prospection (Fig. 1), in effect providing easy access to more precise information on the archaeological sites, as well as the dating and interpretation of structures traced on the magnetic map. The proposed method of gathering data, managing, post-processing and combining the information together with the results of other surveys, such as the pottery and anthropological collections, turns out to be a new approach to fieldwork methodology.

The magnetic prospection carried out on 22–28 February 2015 used a Geoscan Research fluxgate gradiometer FM 256 with 0.1 nT resolution. The sampling grid was 0.5 m by 0.25 m, giving eight readings per each square meter collected in both parallel and zigzag modes. Measurements were taken in squares 20 m by 20 m and covered approximately 1.5 ha. The method was chosen based on the presumption that mud brick (used in the region for tomb construction in antiquity) would be traced easily in the mostly sand and limestone bedrock geology of the site. Nile silt has been proved to be a highly magnetic material (Herbich 2003: 16).

The survey covered areas estimated to be under the greatest threat from modern expansion of arable land and which were researched in the ceramological survey. In the southern part of the valley (Area 1), no evidence of tombs was discovered over most of the valley floor, the sole exceptions being a few highly magnetic anomalies in the southwestern part of the map, corresponding with remains of mud-brick tombs explored in 1996 (Bergamini 2005: 33). In the second area located in the western part of Gebelein (Areas 2A and 2B), modern rubbish encroaching into the surveyed ground on the west caused a strong anomaly. Another highly magnetic anomaly in the northeastern part of Area 2A corresponded to an archaeological feature that could well be constructed of mud brick. A rectangular feature exhibiting fairly high

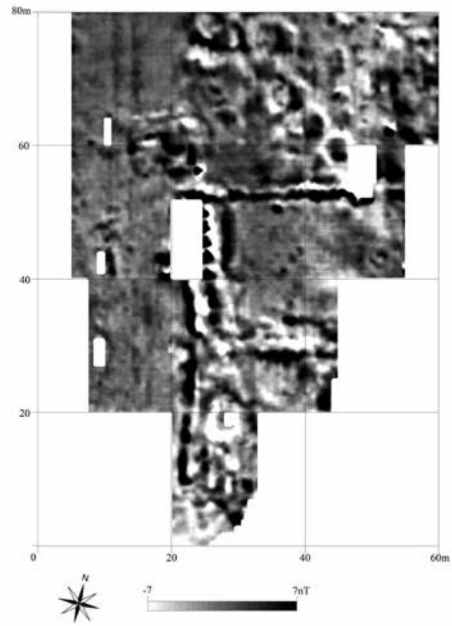

Fig. 2. Geophysical prospection of Eleventh–Twelfth Dynasty structures in Area 3 (processing J. Ordutowski)

magnetic values, measuring some 2 m by 5 m, was observed on the magnetic map of Area 2B. Finally, in Area 3, the magnetic survey discovered some new features around a tomb partly excavated in 1996 (Fig. 2), dated to the Eleventh and Twelfth Dynasties (Bergamini 2005: 33–36). Mud bricks were noted scattered over the surface of the site to the south of the tomb already during remote sensing analysis and confirmed during the survey in 2014. The geophysical anomalies recorded this year gave additional argument for the presence of yet another mud-brick tomb of similar construction and dimensions. Evidence of another rectangular feature, possibly a mastaba-type tomb, was observed as an anomaly with high magnetic values situated to the north-west of the tomb mentioned by Bergamini. West of this feature was a linear structure of low magnetic values, probably the remains of a boundary wall. Several anomalies over the entire northern part of the map may correspond to remains of brick-cased pit-graves, some of which were recently destroyed. This area was researched also in the anthropological survey. All human remains visible on the disturbed surface were individually documented, including data, such as type of bone, size, preservation and, if possible, interpretation. A comparison of the results from different survey methods (anthropological, geophysical and remote sensing) attested to the presence of at least four features and a minimum of five individuals buried in the area.

Overall, the results of the magnetic survey, despite disturbances caused by encroaching vegetation and earlier archaeological excavations, have proved satisfactory in providing data for the interpretation of the surveyed areas and determining places for future excavations that could provide archaeological feedback for the observed anomalies.

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Technical aspects

You know it's summer in Ireland when the rain gets warmer: analysing repetitive time-lapse earth resistance data to determine 'optimal' survey climate conditions

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KEY-WORDS: time-lapse, temporal, seasonal, earth resistance, resistivity, Ireland

The purpose of this paper is to determine whether there are temporal changes/variations observable in time-lapse earth resistance surveys carried out in Ireland, how important those variations are and whether geophysicists can be confident of interpreting data from such surveys undertaken all year round in Ireland. Temporal or 'seasonal' weather changes impact the results of earth resistance surveys by altering rainfall and temperature, which influence the amount of net moisture entering the soil. It is known that these changes influence the moisture contrast of archaeological features, which can be quantified via repetitive time-lapse earth resistance surveys over a given study area. The timetable of most development-led assessments (and many research programmes) is not conducive to the use of earth resistance surveys at the 'optimum' time of year (if there is an optimum time of year). However, if levels of confidence for the detection of archaeological features can be achieved throughout the year, then geophysicists and curators can be made aware of the potential limitations of the technique for a given set of climatic conditions. It is important to establish the impact of temporal variations on earth resistance data to determine how effective such a survey will be for a given climate.

Extensive time-lapse studies on archaeological features and the near surface have been performed across Europe (Al Chalabi and Rees 1962; Hesse 1966; Clark 1980; Coombes 1991; Cott 1997; Parkyn 2012; Fry 2014), but the impact of temporal variations on the archaeological prospection of Irish soils has not been examined. Annual average precipitation in Ireland exceeds evapotranspiration by over 500 mm (Walsh 2012). Average annual rainfall figures are approximately 1230 mm. To determine the influence of this climate, a 14 month time-lapse investigation was designed to review, investigate and test the temporal variables that impact the success or failure of earth resistance geophysical surveys.

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LOCATION OF THE TIME-LAPSE SURVEY

The time-lapse research site at Kilcloghans, Tuam, Co. Galway was adjacent to a proposed road scheme, the excavation of which (McKinstry 2008; 2010) revealed a ringfort enclosure ditch, half of which was excavated within the road scheme, while the remainder was persevered beyond it. Subsequent geophysical investigations (Bonsall and Gimson 2007) determined the presence of a second larger enclosure adjacent to the ringfort and demonstrated that both were suitable for an earth resistance assessment.

The time-lapse surveys were carried out over a 40 m x 40 m survey area located across each of the curved enclosure ditches. The survey area was located 5 m beyond the area of excavation, upon undifferentiated limestone, overlain by limestone tills and well drained soils, which are representative of the most frequent soil types found across Ireland. The ringfort enclosure ditch was 1.25–1.45 m deep, 2.06–3.58 m wide and V-shaped in profile. The larger enclosure has not been excavated and is only known from the earlier geophysical survey (Bonsall and Gimson 2007).

TIME-LAPSE SURVEY METHODOLOGY

The time-lapse study used Twin-probe, Square and Wenner arrays (Table 1) to determine which obtained the most/least favourable outcome. The earth resistance surveys were conducted once a month for 14 months; all of the data were collected on the same day per month.

Table 1. Method of data capture in a 40 m x 40 m survey area at Kilcloghans

Instrumentation	Probe separation	Sample interval	Traverse interval
Square array (alpha and beta)	0.75 m	1 m	0.25 m
Twin-probe array	0.5 m	1 m	0.5 m
Wenner array	0.5 m	1 m	0.5 m

DATA ANALYSIS

Three different methods were used to analyse the data.

Can archaeological features be visualised in earth resistance data throughout the year? Geophysicists carrying out a single assessment on one occasion will need to make informed interpretations on the basis of the data collected, as well as climate-induced influence. To determine this, greyscale images of each earth resistance dataset (per month, per array) were visually inspected at ±2 standard deviations to determine whether the two enclosure ditches were clearly appreciated in the data. The data from each earth resistance array were also compared to climate extremes to examine the differences in earth resistance response between the driest and wettest periods studied.

The mean apparent resistivities of each dataset were corrected for temperature variations using the Keller and Frischknecht (1966: 31) method and were compared to the net moisture change in the ground per month. This allowed for an investigation of the influence of climate on the earth resistance surveys to determine which array(s) are most/least affected and what impact can be expected for a given weather history.

Apparent resistivity values were corrected to a standard temperature equivalent, which is an important variable to account for intime-lapse studies (Keller and Frischknecht 1966; Scollar *et al.* 1990; Hayley *et al.* 2007). A standard reference temperature of 10.9° C was selected, which represents the average annual soil temperature and compares well with the reference temperatures used by other recent studies (Parkyn 2012; Pellicer *et al.* 2012) and the annual mean of 11° C for Ireland (García-Suárez and Butler 2006).

RESULTS

The most favourable time for an earth resistance survey (using any array) was found to be between March and July (a period when net moisture was considerably lower than rainfall, caused by spring/summer temperatures and moderate evapotranspiration, which for this study happened to occur between March and July).

The least favourable period was found to be between December and February (a period when net moisture and rainfall are very similar, caused by cold winter temperatures and low rates of evapotranspiration, which for this study happened to occur between December and February).

While the Twin-probe array returned lower contrasts for archaeological features (which was expected), it was found to be less influenced by weather changes throughout the year than the Wenner or Square arrays.

In practical terms, a Twin-probe array (the industry default) may normally be more than adequate, but it is quite possible that other arrays would be applicable (or preferable) across variable landscapes, particularly with reference to survey speed (i.e., an articulated Square array) and ease of movement across areas of rough terrain or dense vegetation (i.e., a Wenner array). The most appropriate array for a given survey area must make allowances for ground conditions as well as the best temporal or 'seasonal' response.

An important variable highlighted by the study of contrast factors is the correction of apparent resistivity data for soil temperature. This strongly suggests that apparent resistivity data should be routinely corrected for soil temperature and that it is particularly important for surveys that may occur over several days or weeks.

CONCLUSION

Temporal changes in Ireland do not conform to those established elsewhere. The results from Kilcloghans differ from those from other studies and much of this can be attributed to the local and regional weather patterns in the west of Ireland compared to those in other countries. This unexpected outcome validates the research and highlights the importance of carrying out time-lapse studies in different regions and countries in response to local climates and soils. This also has implications for earth resistance surveys in the short term, which currently occur on the assumed limitations based on previous (non-local) research that could be irrelevant depending on the location of the survey.

ACKNOWLEDGEMENTS

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Comparative study of the accuracy of caesium, Overhauser and fluxgate magnetometers in field conditions

Annika Fediuk[a], Ercan Erkul[a], Tina Wunderlich[a] and Wolfgang Rabbel [a]

KEY-WORDS: magnetometers, accuracy study, repetition profiles, inclination

INTRODUCTION

The presentation is a comparative study analyzing the accuracy of different types of magnetometers in field conditions. Long-term registrations and repetition profiles were measured in the field with a caesium magnetometer (Fig. 1, bottom), an Overhauser magnetometer (Fig. 1, top right) and a fluxgate magnetometer (Fig. 1, top left). In addition, the influence of the sensor carrier on the measurements for different orientations of the registration unit was investigated.

METHODOLOGY

The following tests regarding accuracy and repeatability were conducted with all magnetometers:

(1) long-term measurements at a fixed point to determine the standard deviation,

(2) repeated profile measurements in both directions,

(3) area measurements on an archaeological site to investigate the spatial resolution of the magnetometers,

(4) horizontal rotation of the sensor carrier at a fixed point to determine its influence on the measurements depending on orientation,

(5) controlled inclination tests at a fixed point tilting the sensors inline and crossline (Fig. 1, top right).

RESULTS

Long-term measurements at the same point of the gradient values of the fluxgate, caesium and Overhauser magnetometers showed standard deviations of 0.15 nT/m, 0.03 nT/m and 0.3 nT/m, respectively. Regarding reproducibility on the same profile, the best value was obtained with the caesium magnetometer combined with its carrier (3% standard deviation). The Overhauser and fluxgate magnetometers showed a standard deviation of 15%. The results of area measurements showed that the fluxgate magnetometer has a better spatial resolution of contiguous anomalies than the caesium-magnetometer, although the latter has higher resolution. The measurements could not be improved using smaller profile spacings with the Overhauser and caesium magnetometers.

A 360° periodical azimuthal rotation of the equipment carrier and installations on the sensors influenced measurements with fluxgate and Overhauser magnetometers. Depending on the type of construction, the standard deviations are between ±1.5 nT/m and ±6 nT/m.

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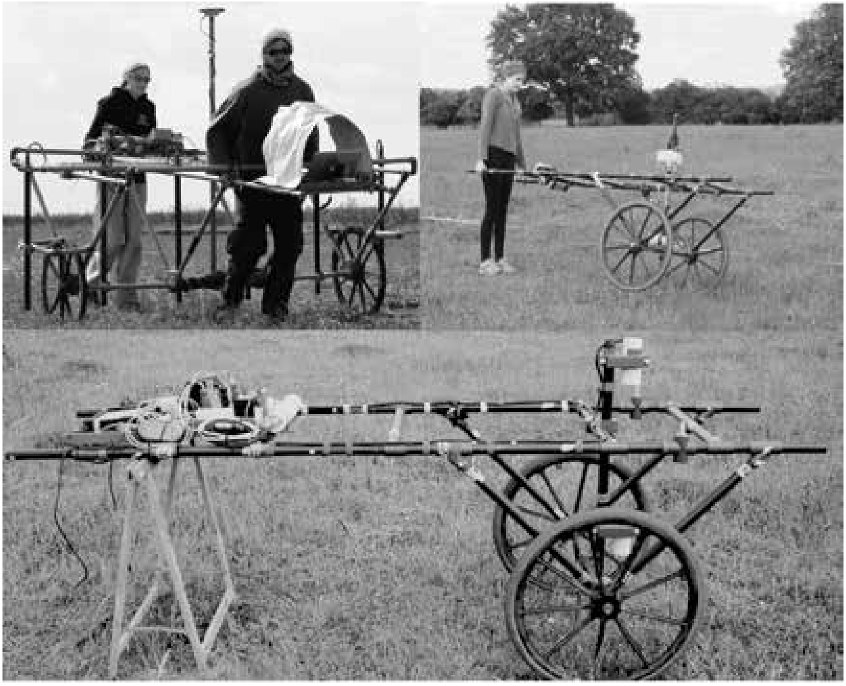

Fig. 1. Top left: equipment carrier of the fluxgate magnetometer with DPGS positioning; top right: inclination tests with Overhauser sensors; bottom: measurement setup for caesium magnetometers with manual positioning

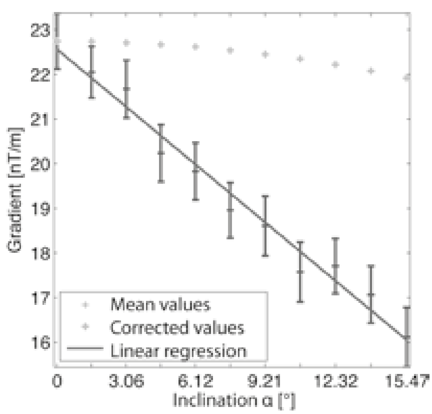

Fig. 2. Mean value and standard deviation of the gradient of the Overhauser magnetometer, plotted with regression curve and geometrical correction

The results of the inclination tests for the Overhauser magnetometer are presented in Fig. 2.

The mean gradient values of the Overhauser and caesium magnetometers show a linear change of 0.5 nT/m per 1° with increasing tilt angle of the instrument carrier and the sensor. This is confirmed with a regression curve of -0.4205 α+22.5585 nT (with the inclination angle α). The correlation coefficient is -0.9895. The linear change is mostly due to geometrical effects, a "back tilting" reduces the effects to a remaining non-linear tilting of about 0.04 nT/m per 1°.

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Terrestrial laser scanning of the landscape around Stonhage

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KEY-WORDS: Stonehenge, Stonehenge Hidden Landscapes Project, TLS

The landscape of Stonehenge became the first and so far the largest case study for developing and testing highly accurate and efficient methods of archaeological geophysical prospection and remote sensing, applied at the landscape level by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology. The University of Birmingham (UK) and the LBI ArchPro (Austria) started the Stonehenge Hidden Landscape Project and has run annual campaigns since 2010, focusing on high-resolution magnetic and ground penetrating radar (GPR) prospection to investigate the *terra incognita* around the iconic stone monument (Gaffney *et al.* 2013; Löcker *et al.* 2013; Gaffney *et al.* 2012). An area of approximately 8 km^2 within the view shed of the stone monument, the so called Stonehenge Envelope, has been covered so far, applying the latest technology developed by LBI ArchPro and its international partners. The surveys revealed in unprecedented detail and scope a variety of new monuments, features and detailed information on monuments in the surrounding landscape of Stonehenge.

A highly accurate topographic model was needed for a detailed 3D analysis of the data. Airborne laser scanning was not an option owing to the presence of Royal Air Force units nearby, hence the decision to implement a terrestrial laser scanning (TLS) survey, accompanying the geophysical prospection.

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Fig. 1. DTM of the landscape of Stonehenge derived from terrestrial laser scanning

The initial plans, which were based on a decade of experience in the documentation of archaeological sites and landscapes using TLS, were quite traditional. Challenges facing the project included :

- more or less flat topography, which had to be scanned with high resolution over more than 10 km^2;
- part agricultural use of large fields and limited permissions necessitated the breaking down of the work into several individual surveys with varying vegetation;
- every scan position required the registration of several retro reflectors by means of a total station, slowing down the work significantly.

A Riegl LMS Z420i scanner using a well approved workflow was applied for the first three surveys. For each scan position, a set of 8 to 12 cylindrical retro reflectors was put in place and registered with a total station. Using a mobile scanning platform 6 m high, the scan positions were set out at an average distance of 150 m to 200 m. The scan positions were registered using global coordinates and Multi Station Adjustment (MSA) was applied for better alignment. This procedure allowed for a maximum of 10 to 12 scan positions to be completed per day. After three seasons, 105 scan positions were in place, covering most of the Stonehenge Envelope.

Recent surveys with a Riegl LMS VZ400 scanner and on-board GPS promised the development of a faster long range TLS workflow. Additionally, Riegl LMS provided a *beta* license for testing the new software RiSOLVE, which was designed for connecting scan positions easily without using retro reflectors. The last survey at Stonehenge took place in September 2013, operating a Riegl LMS VZ400 on a tripod approximately 2 m high. A few "core" positions were used, setting up reflectors and measuring them with a total station. These positions were later used for georeferencing the surface model. All other positions were roughly located using the on-board GPS. When no reflectors were being used, the scanner was operated by one person. A lightweight tripod and an additional battery pack proved sufficient and comfortable for a day's work.

After removing the vegetation with different filters, this procedure resulted in a high density and georeferenced DTM (Digital Terrain Model). Applying the initial workflow with the Riegl LMS Z420i scanner operated by three persons, it was possible to complete 10 to 12 scan positions per day. The new workflow, using the Riegl LMS VZ400 in combination with RiSOLVE, made it possible for just one person to complete 30 to 40 positions per day, increasing dramatically efficiency while providing higher data quality.

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First results from a new ground-coupled multi-element GPR array

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KEY-WORDS: ground penetrating radar, ground-coupled array, multi-channel, continuous wave stepped frequency

The 3D-Radar GeoScope continuous wave stepped frequency (CWSF) GPR system was originally introduced with a multi-element, air-launched antenna array. Whilst this system could certainly produce high resolution results over archaeological targets, there was some debate over the suitability of an air-coupled antenna for all site conditions, particularly where

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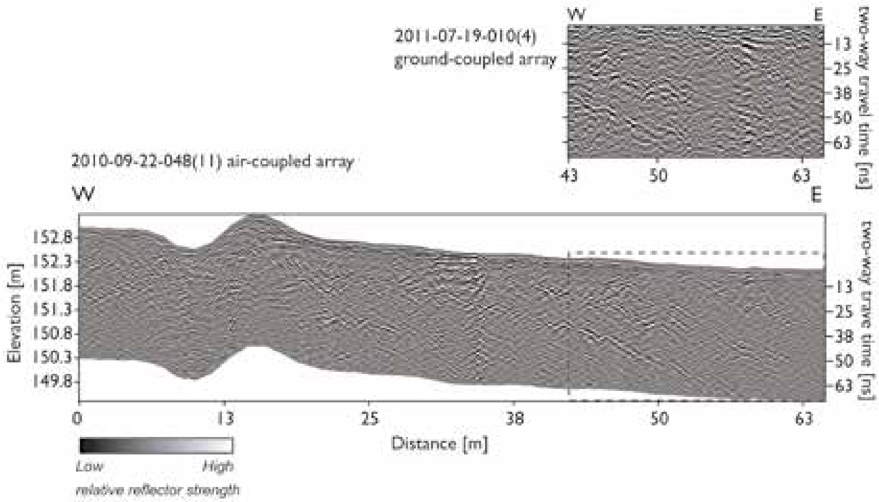

Fig. 1. Topographically corrected GPR profile through the ditch and bank at Stonehenge, collected with an air-coupled V1821 antenna. The inset shows comparative data collected from 43 m with a prototype ground-coupled G0605 antenna

a conductive surface layer, typical of many archaeological sites in the UK, could impede the transfer of energy into the ground (Leckebusch 2011). In addition, to obtain the best quality results from the air-coupled data, alternative data processing routines were required to cope with the strong reflections from the ground surface and varying velocity between the air and subsurface (Sala and Linford 2012).

The English Heritage (now Historic England) Geophysics Team first had an opportunity to test the GeoScope system with a ground-coupled array during a survey at Stonehenge, Wiltshire, in September 2010 (Linford *et al.* 2012; Field *et al.* 2014). Here, most of the survey was conducted over open ground, where our air-coupled V1821 array could operate without impediment. However, to extend the survey into the stone circle required a narrower, hand-operated system to pass between the upright stones. 3D-Radar kindly loaned an early prototype ground-coupled G0605 antenna for this survey, compatible with the Mk III GeoScope console, which combined five individual antenna elements spaced 0.075 m apart within a 0.6 m wide housing, providing highly complementary data that could be readily integrated with overlapping areas collected with the air-coupled array. On further analysis, the ground-coupled array was found to have produced, perhaps as expected, data with a greater signal-to-noise ratio evident in the later returns, beyond ~50 ns, with longer "tails" to hyperbolic point reflectors (Fig. 1). Some very minor discontinuities in the linear reflectors and surface "ringing" could, perhaps, be attributed to a loss of coupling with the prototype antenna over the uneven ground surface that might, potentially, be worse for a wider ground-coupled antenna array.

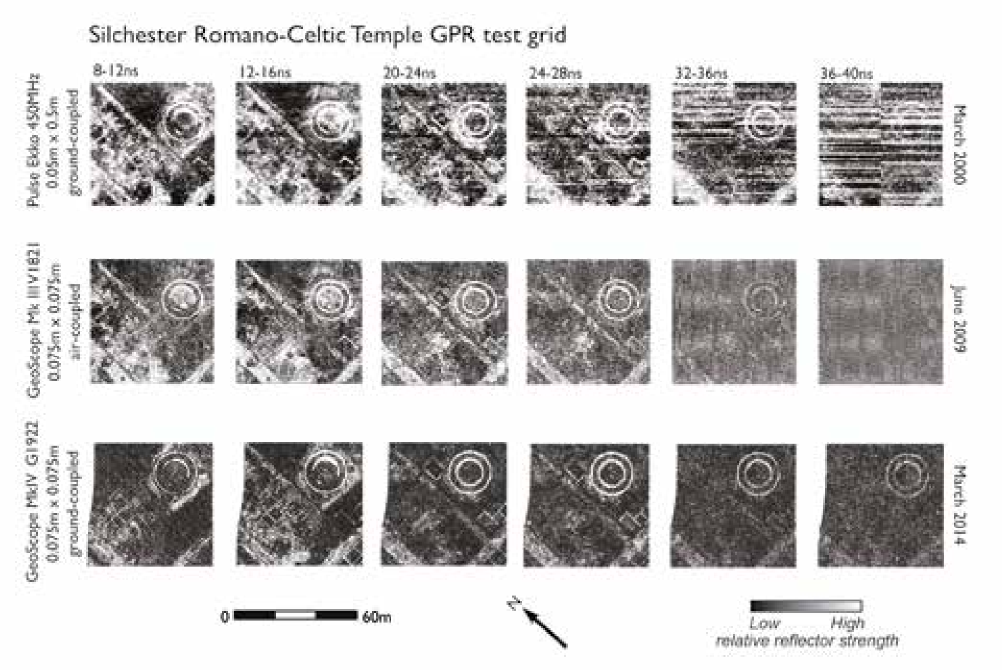

Fig. 2. Extracted data from a 60 m x 60 m square over the Romano–Celtic temple at Silchester, Hampshire, UK. Results from the G1922 pre-production prototype array (bottom row) combine a high signal-to-noise ratio similar to the PulseEkko 1000 single-channel 450 MHz centre frequency ground-coupled antenna (top row), but with higher spatial resolution. The depth of penetration is greater than in the case of the V1821 air-coupled array (middle row)

It was of great interest, therefore, to test a full-width 22 channel G1922 version of the ground-coupled antenna, which became available in March 2014 for use with the MkIV GeoScope console, offering faster acquisition across a wider frequency bandwidth (60MHz to 3GHz) and the same 0.075 m spacing between the individual elements in the array. Field tests over the Roman remains at Silchester corroborated the results from the earlier prototype, demonstrating an increased depth of penetration at the site compared to the previous air-coupled array (Fig. 2). Whilst the comparative ground-coupled data set shown in Fig. 2, collected with a single-channel PulseEkko 1000 using a 450 MHz centre frequency antenna at a lower crossline spatial of 0.5 m, has suffered some loss of coupling along individual lines evident in the later returns, this does not appear to have affected data collected with the new G1922 array. This could suggest that a suitably mounted wider antenna array can offer a good compromise between manoeuvrability and stability over typically uneven surface conditions.

Field tests have been conducted over a range of sites, including further Roman villa sites, formal post-medieval garden remains and a medieval farmstead, to assess the response of the ground-coupled antenna to more challenging site conditions, particularly through water-saturated soils (Linford 2015; Linford and Payne 2015). Results collected over the medieval

Fig. 3. Amplitude time slice between 8.4 and 9.6 ns (0.46 m to 0.53 m) from over the medieval settlement at Catridge Farm, Lacock, Wiltshire, UK. Despite the presence of water-saturated soils, the ground-coupled GPR array produced useful results to complement the analytic earthwork and magnetic surveys

farmstead at Catridge Farm, Lacock, Wiltshire, UK, proved to be of interest as they corroborated and enhanced the existing analytical earthwork plan and magnetic data over this low-lying site with heavily water-saturated soils (Fig. 3). The GPR survey could also be conducted very rapidly, creating minimum interference for the landowner of this busy working stud farm.

Finally, results from a full production DXG1820 version of the antenna will be presented with a further optimisation of the individual element design to aid the recovery of weak return signals. Again, this has proved useful over sites where the presence of water-saturated soils may have compromised the use of an air-coupled antenna array or potentially restricted the depth of signal penetration. Comparison with earth resistance results over a complex of Roman buildings found close to the modern shore line at Warblington, Havant, Hampshire, UK, demonstrates the often complementary nature of the two techniques and the ability of the GPR to extract greater detail from areas of rubble destruction deposits.

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The New Archaeology. From remote sensing to archaeological digging in quasi-real time. The case of Monte Prama (Cabras, Sardinia, Italy)

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KEY-WORDS: Multichannel GPR, ARP, 3D-ERT, Sardinia, Monte Prama, Western Mediterranean, Nuragic Culture

INTRODUCTION

One of the most important archaeological sites of the western Mediterranean is located in the Sinis peninsula (Cabras, Sardinia, Italy) (Fig. 1). Archaeologists studied this site, which was discovered accidentally in 1974, in 1975, 1977 and 1979 (Bedini *et al.* 2012; Lilliu 1997). A necropolis with monumental sculptures from the early Iron Age characterizes the archaeological area of Monte Prama. Above the graves (8th/9th century BC) a large paved area was built, likely for funeral games, and statues as well as baetyls and nuraghe models were set up there.

After about forty years, new geophysical and archaeological research started in 2013, thanks to a joint project between the Universities of Sassari and Cagliari and the Archaeological Superintendency of Cagliari and Oristano. This research covers both geophysical prospecting and archaeological digs, which are still ongoing. Archaeologists have found 28 statues, measuring up to 2.20 m in height, 16 nuraghe models and 16 baetyls (Fig. 2), including finds from the 1970s.

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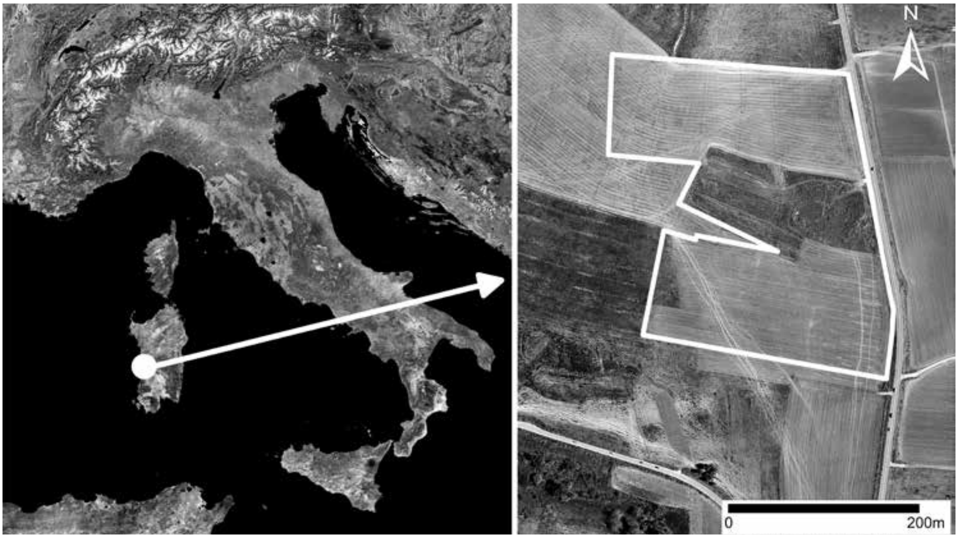

Fig. 1. Studied area. The surveyed area is outlined in white in the picture on the right

The earlier archaeological studies had left unresolved some critical questions regarding the actual extent of the archaeological site (test digs around the site revealed no further evidence of remains) and the presence of a temple and/or village. It was necessary to plan a large-scale survey, covering more than 100 ha, to answer these questions.

Taking into account that in 85% of cases finds are smaller than 25 cm, the common geophysical methods, that is, magnetic (Ciminale and Gallo 2008), electromagnetic (Ranieri *et al.* 2013), electric (Trogu *et al.* 2014; Ranieri *et al.* 2007) and single/dual channel GPR (Piga *et al.* 2014), could not be used, because they are too time-costly and have not enough spatial resolution. The methods used had to meet specific requirements of fast acquisition speed, precise positioning of anomalies, high spatial density of measured points (both vertical and horizontal), target resolution greater than 25 cm and depth of investigation (at least 1.5–2 m).

Therefore, the choice fell on a 16-channel GPR, with 200MHz antenna, that allows for the simultaneous recording of 15 parallel radargrams, spaced 12 cm from one another. Using this device (STREAM-X, by IDS), it was possible to meet all the required conditions:

– fast acquisition speed (about 10–15 km/h);
– differential GPS antenna for positioning measurements with a horizontal shift less than 5 cm;
– spatial density of measurements: horizontal, 12 cm perpendicularly to the moving direction and 9 cm along it; vertical, less than 1 cm;
– horizontal resolution of about 35 cm (due to radar frequency and EM soil velocity);
– depth of sounding, due to the good signal/noise ratio of the instrument, about 1.5–2 m.

With respect to standard single/dual channel GPR, which is frequently used in archaeology, the main advantages of this system include time efficiency, fixed distance between all 15 of the profiles (12 cm), absolute parallelism between all 15 profiles and 3D highlighting of buried targets.

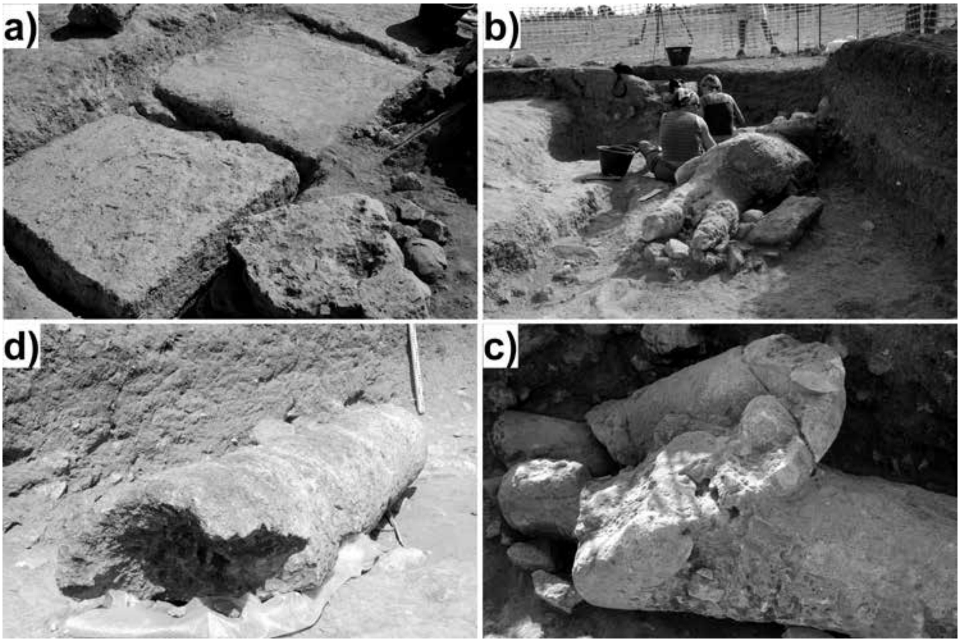

Fig. 2. Selected finds from current excavations: a) slabs; b) statues; c) the only statue to be found with the head attached; d) baetyl

At the site of Monte Prama, we also used some other unconventional methods like Three dimensional electric resistivity tomography (3DERT), continuous automated resistivity prospection (ARP), aerial thermography and aerial multispectral survey.

DISCUSSION

Data show the widespread presence of anomalies probably related to archaeological targets at a depth range between 30 cm and 160 cm. Surveys have clearly demonstrated the presence of extended anomalies far beyond the limits of the earlier excavations. Many anomalies revealed well-aligned patterns that sometimes corresponded well with finds from the 1970s archaeological excavations. The most relevant data was acquired immediately south of the area excavated in the 1970s (along a NNE–SSW direction, about 15 m long and 3 m wide) where, until now, no further extension of the necropolis had been expected.

To verify some of the anomalies, archaeologists have excavated five trenches based on the results of the GPR prospecting. The major anomalies have been clearly correlated with two statues (almost intact), three baetyls, eight square slabs overlying graves and several circular tombs. Feedback from the excavations permitted some types of anomalies clearly distinguishable in the radargrams to be classified as specific features: massive objects, slabs and fragments (Fig. 3). Other types of anomalies were linked to channels and roads on the grounds of current knowledge of the site. Thanks to the

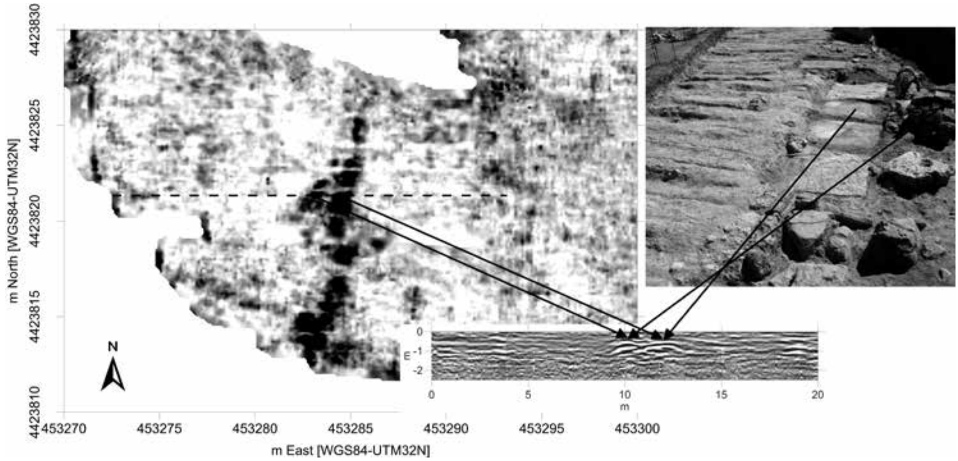

Fig. 3. Example of excavation results. The baetyl and grave were well marked by anomalies pointed out by the arrows. The dashed line corresponds to the radargram

interpretation of the digging results, we have interpreted some anomalies in the surrounding areas, like probable tombs, roads, landfills and statues or baetyls.

CONCLUSIONS

The results of geophysical surveys and excavations carried out so far have made conclusions possible regarding the unsolved questions related to the extent of the site.

1. The area of the necropolis is certainly larger than previously assumed.
2. The results of excavations in selected areas, based on GPR data, confirm the continuation of the necropolis in a southward direction.
3. Digs carried out based on geophysical results have demonstrated a strong link between location and depth of GPR anomalies and archaeological finds. In particular, two statues, almost completely intact, two baetyls and one nuraghe model, which were clearly identified and positioned by the GPR survey, were found by archaeologist in just a few days after the geophysical survey.
4. A comparison of archaeological finds and GPR anomalies made it possible to recognize at least three types of anomalies: massive objects of medium to large size, slabs and accumulations of fragments.
5. The use of fast, reliable and of high-resolution devices, like the Stream-X, open new scenarios in archaeological science. In fact, without the use of these types of tools it would not be possible to run a geophysical prospection over an area of more than 6 ha in just eight working days, obtaining raw radargrams spaced a constant 12 cm apart, giving a very accurate coverage of the area and time-slices of excellent quality. Moreover, the accurate positioning obtained by the use of differential GPS allows quick and precise location of the anomalies on the ground, permitting a careful selection of dig sites with considerable saving of time and expenditures.

Therefore, Stream-X has proved to be a very useful tool, particularly for the assessment of archaeological risk.

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Geophysical investigations of tumuli: a continuously challenging problem

Gregory N. Tsokas[a], Panagiotis Tsourlos[a] and George Vargemezis[a]

KEY-WORDS: tumulus, ERT, 2D ERT, 3D ERT

INTRODUCTION

A tumulus is a superficial hill constructed once upon a time as a burial monument and it comprises a landmark (Fig. 1). Usually, it conceals one or more tombs which may be monumental and if not looted, they may contain important finds. The bad practice of the past was to destroy the embankment in search of concealed tombs. After the destruction, despite the fact that the tumuli by themselves are monuments, the embankment was seldom restored.

By definition, geophysics is the main scientific discipline which may help in locating the concealed tombs and thus lead to excavation of a small portion of the whole structure, preventing its complete destruction. However, the geophysical investigation of a tumulus involves a difficult and occasionally challenging approach. The survey must be performed on uneven ground and the target might be small compared to the distance from the surface. Moreover, the tumulus embankment is usually inhomogeneous and it may consist of several layers. Also, in some kinds of tumuli, in particular the so-called "Macedonian" type that is very common in northern Greece, a pit was opened and a "dromos" was constructed leading to the tomb (or tombs). Then, all these structures were buried under the embankment. In these cases, the edges of the pit form an extra anomaly in the geophysical fields, tentatively confusing the interpretation of the geophysical data. Confusion may also be created by the presence of an enclosing or supporting wall.

The aforementioned reasons render the whole operation very difficult and challenging. If the operation is successful, it is rather rewarding, since it largely contributes to saving the integrity of the monument.

NON-TOMOGRAPHIC APPROACHES

Electrical mapping methods were employed to investigate Thracian tumuli in Bulgaria (Petkov and Georgiev 1988: 1095; Tonkov and Katevski 1996: 122). They conducted radial and circular profiles and then constructed apparent resistivity contour maps. Several successes were claimed, but the detected tombs were rather large compared to the size of the tumuli they were buried in and the material was rather homogeneous.

Vertical electrical soundings (VES) were used by Tsokas and Rocca (1987: 100–101) in northern Greece and Pinar and Akcig (1997) on the coast of the Marmara sea.

Several other methods have also been used with varying success and for particular types of tumuli. Indicatively, the electromagnetic method was applied in Switzerland (Frohlich Gugler, Gex 1996), mag-

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Fig. 1. Tumuli are artificial funerary hills comprising landmarks, meaning they can be seen from far distances. The tumulus shown here is in the Region of Macedonia (North Greece) and it is one of the larger ones, having a diameter of about 100 m and a height of about 19 m

netic and GPR prospecting was applied by Sarris *et al.* (2000), and Smekalova *et al.* (2005) successfully employed the magnetic method on tumuli in Denmark and Crimea (Ukraine).

The technique of seismic refraction fan shooting was employed in Greece by Tsokas *et al.* (1995: 1736–1737) and Vafidis *et al.* (1995: 120–121) to investigate the so-called "Macedonian" tumuli. In fact, seismic waves were created by a sledge hammer on the top of the tumuli and their arrivals were recorded on geophones arranged along the periphery. In this way, delayed arrivals were detected because of the presence of a "dromos" and therefore the concealed tomb was located indirectly. The technique seems to produce good results for that particular type of tumulus.

TOMOGRAPHIC METHODS

Polymenakos *et al.* (2004: 147–149) employed seismic tomography in Greece while Forte and Pipan (2008: 2615–2616) used the same method plus GPR surveying in northern Italy.

The use of electrical resistivity tomography (ERT) proved to be advantageous in investigating the interior of tumuli. Several successful examples can be found in literature including the implementations of Tonkov and Loke (2006: 133–134) and Astin *et al.* (2007: 29), which show the potential of the method.

The potential of the 3D ERT survey was shown by Papadopoulos *et al.* (2010). Further, Tsourlos *et al.* (2014) compared the relative merits and drawbacks of the regular rectangular grid against the grid of 2D radial tomographies. In both cases the data were inverted using a 3D algorithm.

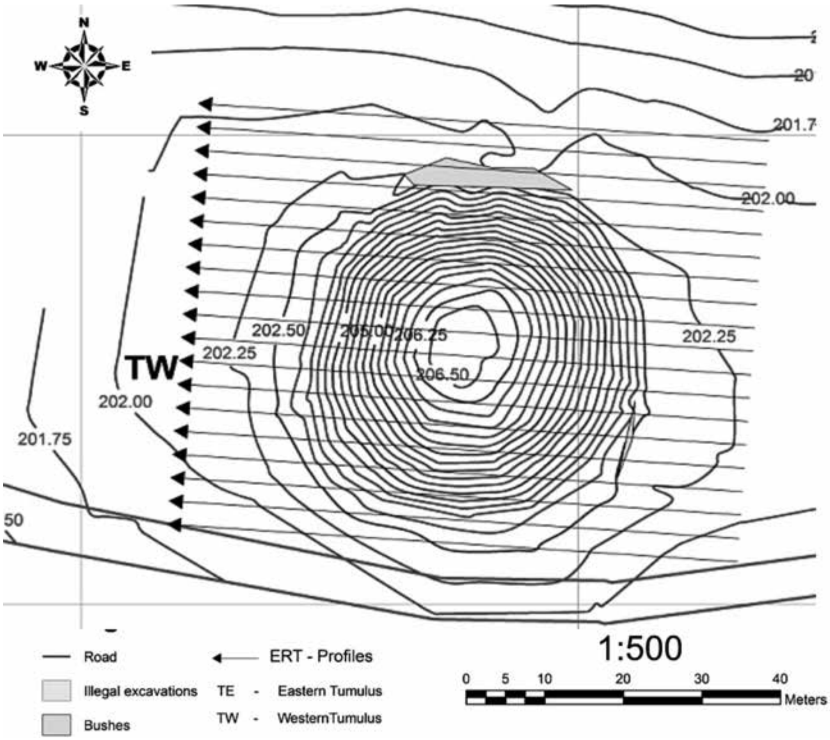

Fig. 2. The transects, along which ERTs were carried out, have been superimposed on a topographic sketch map. The tumulus shown in this example is near the village of Spilaion in Thrace (North Greece)

The example that is next demonstrated has been taken from the survey of tumuli near the village of Spilaion in the prefecture of Evros in Thrace (Northern Greece). Parallel ERTs were carried out covering the given tumulus and the surrounding ground (Fig. 2).

The data were inverted employing the 3D algorithm described by Tsourlos and Ogilvy (1999) and they were further processed using the algorithm of Yi and Kim (2003), which is of similar type. The 3D distribution of resistivities was then used to produce vertical and horizontal slices. Shown here is the horizontal resistivity distribution for the elevation 202.5 m above the mean sea level (Fig. 3). Clearly there is a high-resistivity anomaly at the center and other northwards at the periphery of the tumulus. They both comprise targets for future excavation.

CONCLUSIONS

Geophysical prospecting methods comprise the only technology to investigate the interior of tumuli without destroying them by excavation designed to search for potential concealed monuments. In this respect, geophysics act toward preserving most of the initial shape of the tumulus, which is a monument in itself.

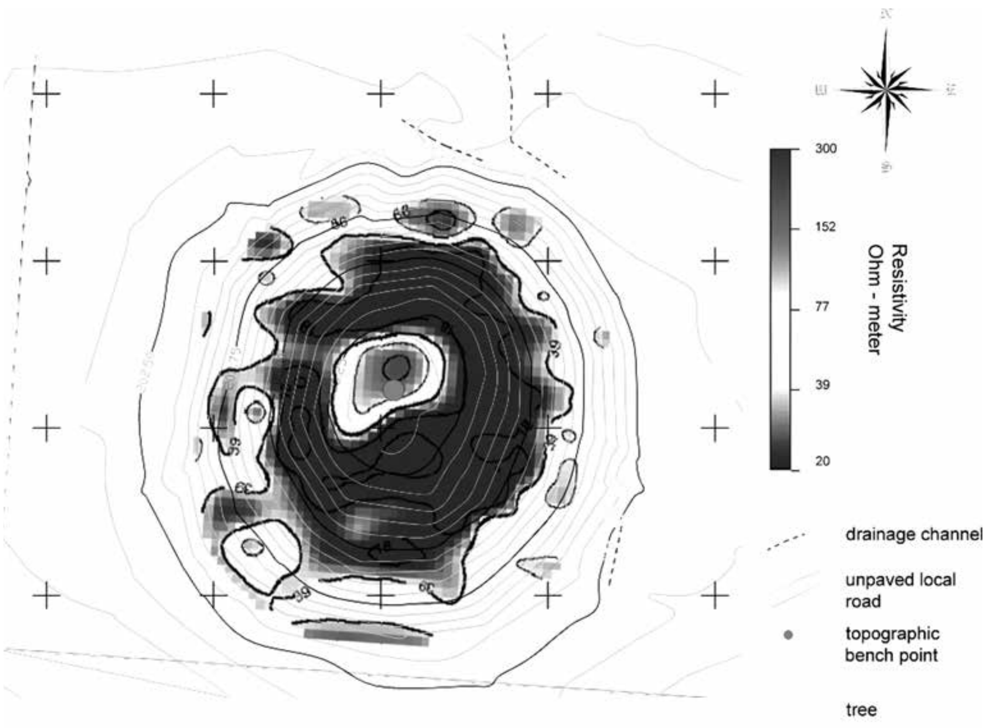

Fig. 3. Distribution of resistivity at a depth slice at 202.5 m above the mean sea level

Resistivity tomography is one of the most reliable tools for such a purpose. Moreover, it works in all environments, whereas the other methods tried so far seem to be applicable under special conditions.

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