Materiały Zachodniopomorskie
Nowa Seria, t. XVII: 2021, s. 691–705
ISSN 0076-5236

Rainer Komp

Entering the era of landscape-scale geomagnetic surveys – technological advancements

Postęp technologiczny w badaniach geomagnetycznych nad dawnym krajobrazem

Abstract: Recent development of geomagnetic devices for non-destructive landscape-scale surveys has responded to the challenge of actual archaeological research agenda and international regulations for the protection of cultural heritage.

Keywords: geomagnetic, remote sensing, non-invasive prospection, cultural heritage, data analysis, GIS

Abstrakt: Obecny rozwój urządzeń do nieinwazyjnych badań geomagnetycznych krajobrazu odpowiada celom i wyzwaniom współczesnej archeologii oraz międzynarodowym ustaleniom dotyczącym ochrony dziedzictwa kulturowego.

Słowa kluczowe: geomagnetyka, teledetekcja archeologiczna, prospekcja nieinwazyjna, dziedzictwo kulturowe, analiza danych, GIS

Looking at pieces of antique artwork or (pre-) historic monuments is impressive – though, we know that by means of single artefacts only we can barely conceive past cultures and societies in their manifold aspects. The ambition of archaeological science is to discover as many features as possible to re-join single pieces (literally and figuratively), and this includes the context as well as immediate and larger surroundings of monuments that finally contribute to our understanding of their purpose.

Research has shown that people have not just built monumental architecture at isolated points in the landscape, but have used vast areas of the landscape as living space and ritual sites. We have only recently discovered that e.g. Neolithic Stonehenge was not an isolated monument, but in fact only a single component of a spaciously site consisting at least of more henges, a cursus and mounds (Darvill *et al.* 2013); ongoing investigation suggests the same for Avebury (Darvill, Lüth 2016). Geophysical research at Göbekli Tepe has proven that hitherto only 1.5% of the astonishing extensive Epipaleolithic site is known by excavation (Schmidt 2009; Notroff 2018).

Questions of continuity and discontinuity in land use appear and one of the most important questions is: what kind of use was made of the land between the monuments we know? Are there empty spaces and were these empty spaces part of the design concept? Settlements have been covered by desert and prosperous urban areas are sunken deeply below volcanic ashes. Numerous superstructures like monumental stone settings, embankments, earthworks or ditch-systems remain visible until today. On the other side, monuments have been stripped for reuse of building material; more inconspicuous structures eroded in time, have not been recognized or rather ignored and finally ploughed down by modern land use. The loss of monuments throughout the recent era of industrialization by land seizure and agriculture is tremendous. However, while not visible any more above ground, somewhat distinct or even only subtle traces of our ancestors have survived buried in the subsoil.

Preserving historical monuments needs sustainable efforts in order to counteract their accidental or unconcerned destruction. First step is to get knowledge of hidden sites and have them registered. Second, we have to learn about extent and condition. Furthermore, a scientific research agenda will distinguish and document its cultural significance. And finally, a management and preservation plan will assure protection in the long term. To fulfil these perceptions of research needs and cultural heritage protection new methodological approaches and technologies have constantly to be developed and applied.

Furthermore, international legal guidelines encouraged the new approaches. Forty-six member States of the Council of Europe have signed and ratified the European Convention on the Protection of the Archaeological Heritage (Revised), La Valetta 1992; as one of many concerns the State parties agreed in Article 3 to give non-invasive methods preference: “To preserve the archaeological heritage and guarantee the scientific significance of archaeological research work, each Party undertakes: to apply procedures for the authorisation and supervision of excavation and other archaeological activities in such a way as: “[…] to ensure that archaeological excavations and prospecting are undertaken in a scientific manner and provided that: non-destructive methods of investigation are applied wherever possible […]” (European Convention 1992). Hence, all states having approved the convention are committed to act accordingly. Fulfilling all these tasks will also be premises to protect extraordinary cultural sites being acknowledged as world heritage by the UNESCO.

While archaeology back in the 19th and early 20th century often was designed as large-scale excavations employing hundreds of workmen and implementing trackways for the ‘rubble’, the present-day paradigm is to preserve historical substance and to open sections only as large as necessary but as small as possible. Investigating prehistoric and historical landscapes in high resolution and in a cost-effective way requires a combination of methodologies and analytical tools. Modern technologies are part of the portfolio of archaeological investigation methods: aerial photography is frequently used since the 1920s, followed by satellite imaging since the 1970s and LIDAR since the 1990s; each of these methods has contributed to an overall insight of large prehistoric sites and monuments. It was not only the overview of still-visible structures and their settings in the landscape that made the difference, it was the discovery of hidden structures in the subsoil that helped to complete the picture and better understand the complexity of (pre-) historic monuments. Each method has its pros and cons; interpretation of aerial imaging e.g. is highly dependent on actual climatic and soil conditions.

In addition, different geophysical methods (see Clark 1990; Zickgraf 1999; Neubauer 2001; Jones 2008; Becker 2016) have been successfully used on archaeological sites and contributed even deeper insights into the (internal) structure of monuments. Geomagnetic survey is a well-established, rapid and non-destructive method for detecting archaeological features. Magnetometers combine speed with high spatial resolution, and their measurements are largely independent of the current soil water content (in contrast to geoelectrics). Human activity can modify the magnetic signature of the soil. Only slight deviations of soil magnetic susceptibility distinguish natural soil from human intervention. Due to the necessity of an adequate magnetic contrast, it is not always easy to recognize features clearly. Moreover, iron-bearing material, e.g., some bedrock like basalt, can in effect blind the magnetometer to the subtler magnetic signatures of archaeological features. In general, pits and ditches, refilled with organic-rich material, are detectable as positive anomalies; deposits of stone that displace magnetic sediments appear as negative anomalies. Iron objects, igneous rocks, and intensely burned features create magnetic dipoles, which are related to permanently magnetized, or thermoremanent, features. Modern waste dumps are a common source of dipolar anomalies in agricultural fields. (Cf. Berghausen 2013; Fassbinder 2015; Hahn, Fassbinder 2021)

Until recently, the use of geomagnetic appliances was restricted to small sites compared to aerial or satellite surveys. It seemed impossible to survey large prehistoric and historical regions by means of magnetometry. Accordingly, it was applied in particular in the interior of enclosed sites, from which the existence of archaeological remains was basically known; but the surroundings have rarely been investigated – the cost expenses and requirements for man power were intolerable for external areas that might not bear any additional information. Magnetometry, hence, to large extent was wrongly reduced to acknowledge mostly already known facts. Pretended limitations of this technique lead to restricted utilization.

The need for landscape-scale investigations inspired a team at the German Archaeological Institute, led by Friedrich Lüth, to develop a geomagnetic device for large scale archaeological surveys. The approach, indeed, needs large scale findings but key-hole like examples of details. Another essential requirement was to engineer a user-friendly appliance that could be assembled and operated easily by archaeologists, who should also be provided with software to process the high resolution data in order to visualise and interpret archaeological findings on their own. Finally, the resulting data should be sustainable and reusable in other contexts.

In order to achieve these goals, the German Archaeological Institute entered a joint venture with SENSYS, a German company specialized in magnetic and electromagnetic survey systems and components. The project initially was generously funded from 2009 to 2011 and again from 2014 to 2016 by a special economic development scheme through the German Federal Ministry for Economic Affairs and Energy[1], and continued in the long term.

The cooperation resulted, first of all, in a carrier Magneto® MX designed for surveying large areas (Fig. 1). It is set up as a towed array of up to 16 fluxgate gradiometers attached to a non-magnetic frame at usually 25 cm intervals, producing at the most a 4-meter swath of data with each pass of the system. Four wheels joined by brackets with efficient suspension provide mobility to the whole frame. By adjusting the suspension, the height of the sensors above the ground can be managed between 10 and 40 cm – according to the roughness of the terrain.

The first version of the carrier came with a robust glass fibre frame, weighing 130 kg and a 7 m long drawbar; this is still advised for use in heavy terrain. The second version Magneto® MX V3 is designed as a completely modular system, which can be configured as a 1 or 2 m push variant or 2 to 4 m towed rig as needed. The rather small fibre reinforced components, resulting in an overall weight of only 45 kg, can easily be stowed e.g. in two bicycle cases; the drawbar was reduced to 5 m. Though lightweight and flexible, the appliance is still very sturdy; the connections between the components using plastic bolts, in our experience, serve as a kind of predetermined breaking points in the event of cracks in unforeseen heavy terrain – which can be repaired immediately.

The fluxgate sensors in the SENSYS model FGM650/3 have a standard measurement range of ±8,000 Nanotesla (nT, unit of magnetic field strength). In each probe, or gradiometer, the sensors are spaced 65 cm apart, one atop the other, and provide measurements of the difference between the top and bottom sensor to within 0.1 nT.

---

[1] “ZIM” – Zentrales Innovationsprogramm Mittelstand, which means “Central Innovation Programme for small and medium-sized enterprises”

A central unit called MX-box bundles and digitizes the analogue data signals from the sensors. While the original unit operated with a sampling rate of 20 Hz and a 16-bit digitization (resulting in a measurement range restricted to ±3,000 Nanotesla), the newer MXcompact unit processes sampling rates in grades up to 200 Hz and the full 24-bit range of ±8,000 Nanotesla. The experience shows that the magnetic measurements in each probe are taken ideally at a 100 Hz frequency configuration; therefore, and depending on the driving speed, the fully equipped system records 16 evenly spaced measurements every 3 to 4 cm in driving direction. This produces data density of about 100 measurements per square meter.

The digitizer transmits the data to the control device, usually a notebook or tablet in the operator's view field, for immediate track control and storage by a single LAN-cable or even W-LAN (compared to a wire bundle that had to be conducted to the former unit version).

The system is equipped with a high level (Survey Grade), Real-time Kinematic (RTK) global positioning system (GPS) to provide exact coordinates for each magnetic reading. While the GPS antenna of the moving device (the rover) is fixed on the frame holding the magnetometers, a nearby reference station, ideally positioned on top of a calibrated geodetic point, steadily transmits correction values to the rover by radio. To apply the coordinates to the collected magnetometry values, the data values are matched using timestamps; therefore, the clocks of the GPS and the magnetometer's data logger are synchronized at the beginning of each session. Magnetic readings recorded between GPS positions are assigned evenly spaced positions between the GPS readings. The GPS coordinates are originally recorded one per second, but actual GPS-appliances even provide rates of up to 10 Hz; therefore the reduced distance for interpolation makes the data clearly more precise. Interruptions in GPS data and radio signal transmission between the rover and the base station, which usually can be as far as 3 km apart, might be a problem, so attention should be given to terrain conditions in advance.

The complete system is powered by a common car battery that lasts for a day surveying; it is recommended to use AGM or lead-gel batteries in order to accommodate the necessary continuous charging and discharging cycles.

Beside the smaller push variant, an off-road vehicle is used to tow the array, as well as carry the electronics, power supply, control unit, and the system operator. Especially for the light rig, a quad bike is the best solution. An appropriate driving speed considering the terrain and technical limits of the frame is about 15 km/h.

A consistent survey method should be used while collecting the magnetic data. In principle, following the farmers' strategy to till the field is a good idea: first, because they know best how to treat the field's shape efficiently;

second, carrying the sensors along with seed rows and furrows avoids disturbance of the sensors through vibration. It is advisable to divide very large areas up into smaller areas, e.g. the size of football fields. Within these smaller areas, the survey ideally starts with 4–5 tracks/swaths circling around the border of the area. Once the area is outlined, the system continues to be run in loops, but without collecting data in the outlined ends. In this way most tracks of data are collected with the system pointing in the same direction as neighbouring tracks, which reduces changes in the magnetic readings related to the driving direction and the angle of the earth's magnetic field. For the same reason curves must be avoided; instead tracks can be interrupted and started again. Sensor and position data are recorded in a live stream by the control unit mentioned above so that tracks can readily be seen on the fly on the control monitor; this, and being able to see the previous tracks' tire marks in the grass, helps ensure even coverage over the survey area. Following the tracks in the given speed as straight as possible, and in the same time avoiding overlaps with previous tracks as well as gaps between them is the most challenging task for the system operator.

The entire development cycles were conducted by intense exchange of ideas, specifying requirements and feedback between partners from field experience and failures, resulting in optimizing and testing again. Finally, a reasonable survey management and excellent terrain conditions provided the daily teamwork-performance results in up to 25 ha of prospected area in high resolution, which can easily be multiplied operating several devices at once.

Having developed the large landscape scale capable carrier in the first place, secondly the data processing was another urgent mission within the project. The software for assessment of data was split into a commercial and an open source branch. While SENSYS serves the former exclusively for archaeological as well as for other exploitation methods like surveying unexploded ordinance (UXO), the German Archaeological Institute engaged in an alternative processing pipeline for archaeological needs based on open source modules.

Using the new high performant system has drastically increased in recent years: earlier surveys using single-sensor systems produced a relatively manageable amount of data of about 0.5 ha per day under favourable conditions (Cf. Aitken 1974, 234 f.), today a single person using a high-resolution multi-sensor system can cover 15 or more hectares per day, generating approx. one million readings per hectare plus geodetic information. While this growing capacity allows for applying this type of survey for landscape-scale research objectives effectively, the tremendous amount of data exceeds the capacities of manual interpretation by far. The German Archaeological Institute now operates two 16-sensor fluxgate-magnetometer rigs simultaneously, resulting e.g. in about 7 km^2 coverage of a single site within one season only.

Beside the exhaustive time requirement, manual interpretative vectorisation is always subjective and rather inaccurate. To analyse and interpret this amount of data in a reproducible and more efficient way, new tools and workflows had to be developed.

Instead of creating completely new, proprietary software, the German Archaeological Institute decided to make use of the tools (binarisation, vectorisation, interpolation, cleaning and smoothing) already available in open-source GIS libraries, such as GRASS or SAGA. Using java programming and the ready-to-use QGIS graphical modeller, the team developed scripts to automatize this process (Komp, Goldmann 2021).

The first and main task was to handle and integrate the raw data into GIS. This allows for selection of data and removing failed readings, if necessary, as well as fast visualization of the survey results. One of the first processing steps is the removal of striping from the data. Since the sensors cannot be calibrated to exactly the same base level in the field, the values of each sensor row are shifted somewhat compared to the other rows. Hence, a stripe effect occurs when values are illustrated as grey shades. A compensation function is applied to the data with the software and this sets all lines of data to the same background level. Interpolation is used to fill small spaces in case of missing data. The resulting magnetogram shows the magnetic data e.g. as a greyscale map, where lower values are light and higher values are dark. It is possible to enhance the picture by emphasizing a tight range of values, since archaeological features usually only show very slight deviations from the general magnetic background. Therefore, setting a range typically between -7 nT and +7 nT focuses on details of archaeological interest for further analysis. GIS allows the referenced magnetic data to be integrated with other survey or excavation data.

The next step, interpreting vast amounts of data is a common challenge in remote sensing applications. In the case of traditional, single-axis geomagnetic data the interpretation is somewhat complex by the fact that only the magnetic flux density is recorded. This, apart from being affected by past anthropogenic and geological activities, can also be distorted by a number of other factors, including the location on the globe, the direction of measurement as well as disturbances caused by the vehicle or person moving the instrument. Archaeological features cannot easily be distinguished from these other anomalies (Fig. 2:a). We decided for an approach to reclassify the original measurement readings, e.g., into a binary raster containing only the number 1 coding magnetic values above a certain threshold and 0 coding values below (Fig. 2:b). A vectorization tool then traces the edge between 1 and 0 resulting in polygon-features. Since the threshold value can be set down to 0.1 nT this method is far more precise than any manual vectorisation (Fig. 3:a).

The general approach to do this for geomagnetic data has been around quite a long time (Neubauer 2001, 125–129; see also Stampolidis, Tsokas 2012; Schmidt, Tsetskhladze 2013; Hinterleitner *et al.* 2015). Although raw geomagnetic data do not provide much potential for classification, there are certain characteristics allowing for distinguishing anomalies, which can be statistically analysed and used for automatic classifications. Dopole-features, mainly representing modern iron debris, are marked by a negative minimumpaired with a positive maximum, which are, however, oftennot directly adjacent. Directly vectorising such dipoles, results in two separate polygons, whoch do not qualify immediately for statistical analysis. Therefore, single features are created through buffering and merging these parts. The rapid change from high to low values is reflected in different terrain parameters, among which especially the terrain ruggedness index ITRI) proved to be useful when screening dipoles from other features. Certain terrain parameters including measured values like maxima and minima as well as geometric inces like roundness and complexity were added to the attribute table of the vectorised features and can be used for a query-based classification (see Fig. 3:b).

The tools developed by the German Archaeological Institute facilitate the vectorisation and interpretation of large survey areas considerably. Fields covering several hectares could be analysed and visualised with an easily readable, classified vector map within minutes instead of hours. While the recognition rate for features like pits or well defined dipoles is good, linear features like long ditches or walls need more attention. Of course, these tools do not replace the human analyst, who has to set the parameters and make the decisions in the end, but it provides an effective assistance as well as enabling transparency and reproducibility of the results.

The demand for archaeological research at a landscape-scale level and the requirement for non-destructive approaches confront the archaeological community with challenges. Hence, the recent endeavours have shown exciting and successful technological advancements for the application in the context of archaeological research. The cooperation of business and science has been a win-win situation, since commercial partners could engage in specialised products for very small market segments and archaeological science benefits from applications fully adapted to its needs. Finally, all main requirements have been fulfilled: the system can be assembled and operated easily by archaeologists; the vast amount of data, presented in open format, can be handled, analysed and depicted extremely performant and successfully.

The following paragraphs will briefly reference some examples of the profitable application of such state-of-the-art research, for which the publications are in preparation.

The still ongoing magnetometry-analysis now being applied to World Heritage sites such as the landscape around Stonehenge and Avebury in England has revealed hundreds of new features around both of these iconic English sites (Darvill *et al.* 2013).

At the princely site of Mont Lassois in France the landscape surveys allowed to gain information of the surroundings based on facts for reconstruction of suburban areas instead of modelling land use following hypotheses only. The results suggest that representative apsidal buildings have not only been located in the residential area site but were built at the harbour site forming an impressive reception. (Chaume *et al.* 2020; Goldmann 2021; Goldmann *et al.* 2021)

The project ANR MONUMEN aims to explore the phenomenon of a megalithic landscape in south western France between the 5th and 3rd millennium BC (MONUMEN 2018). Large scale geomagnetic surveys now reveal giant embankments, which have yet not been detected by satellite analyses. At the same time the high resolution technique also detects buildings up to the level of postholes (MONUMEN 2020).

Landscape scale geomagnetic surveys have contributed to describe the extent and state of preservation of different Roman military sites and ancillary features of the Lower German Limes near Xanten/Vetera (Bödecker *et al.* 2018), a critical contribution for the success that the Lower German Limes has recently been appointed as a UNESCO World Heritage Site (Niedergermanischer Limes 2020; Polak *et al.* 2019).

Finally, also sites of the Hopewell culture in Ohio, USA, an ancient American Indian ceremonial complex of monumental scale and complexity, a unit of the US National Park System, are to become a candidate for serial nomination to the UNESCO World Heritage List. For this, we transferred the technology to the New World and proved that traces of vast earthworks known from early investigators still remain underground – and large areas in between these monuments contain features like mounds and post circles (Komp *et al.* 2020).

While optimisation and further development never ends, actual research questions focus on the applicability of geomagnetic surveys on the African continent, where the different settings of the magnetic field of the earth near the equator poses special challenges.

Fig. 1. Sensys MX V2 and V3 multi-sensor magnetometers in front of Mont Lassois. Photograph by DAI / E. Runge
Ryc. 1. Magnetometry wieloczujnikowe Sensys MX V2 i V3 na tle Mons Lassois. Fot. DAI / E. Runge

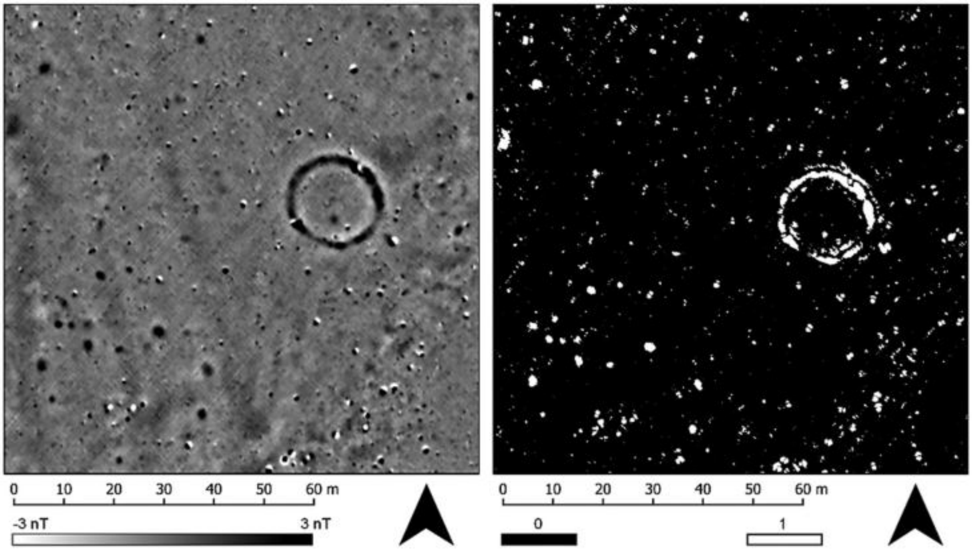

Fig. 2. From left to right: a – original magnetogram; b – binary raster created using a threshold of 2 nT. Prepared by DAI / L. Goldmann
Ryc. 2. Od lewej do prawej: a – oryginalny magnetogram; b – binarny raster wygenerowany przy pomocy progu 2 nT. Wyk. DAI / L. Goldmann

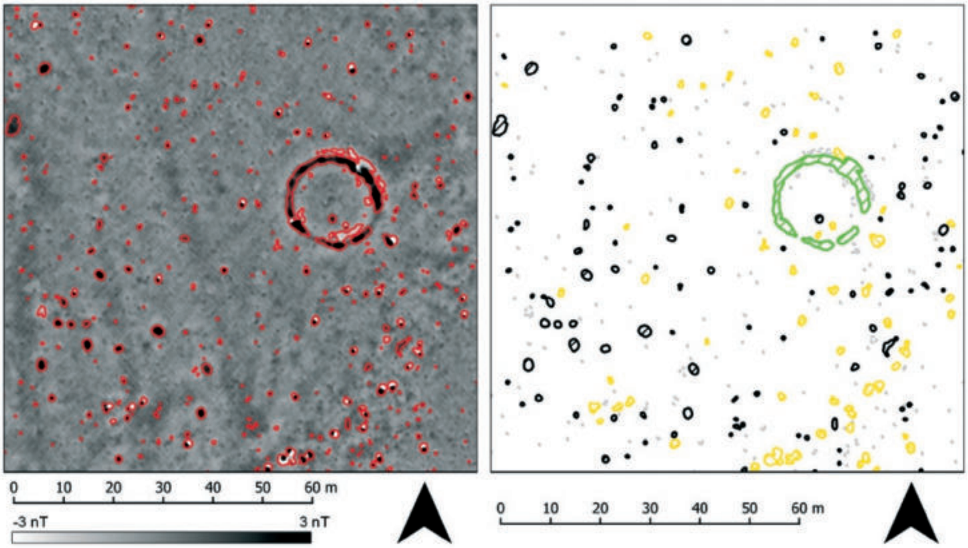

Fig. 3. From left to right: a – magnetogram with vectorized anomalies; b – anomalies semi -automatically classified as dipoles, pits, noise and a ditch feature. Prepared by DAI / L. Goldmann
Ryc. 3. Od lewej do prawej: a – magnetogram ze zwektoryzowanymi anomaliami; b – anomalie automatycznie zaklasyfikowane jako dipole, jamy, szum i rów. Wyk. DAI / L. Goldmann

Literature

Aitken M.J. 1974. *Physics and Arcaeology*.

Becker H. 2016. *Magnetische Prospektion in der Archäologie*.

Berghausen K. 2013. *Magnetometrische Untersuchungen an spätkeltischen Viereckschanzen in Bayern*. DOI: 10.5282/edoc.16615.

Bödecker St., Lüth F., Berger L., Rung E. 2018. „Wie eine aus dem Stegreif hingeworfene Stadt“ (Flavius Josephus). Erschließung militärischer Raumnutzungskonzepte durch großflächige Magnetome-terprospektionen am Niedergermanischen Limes. In: M. Aufleger, P. Tutlies (eds.), *Das Ganze ist mehr als die Summe seiner Teile. Festschrift für Jürgen Kunow anlässlich seines Eintritts in den Ruhestand*. Bonn, 277–282. Materialien zur Bodendenkmalpflege im Rheinland 27.

Chaume B., Cheetham P., Komp R., Lüth, F., Pertlwieser Th., Reinhard W., Urban O., Weissl M. 2020. Vix (Côte-d’Or) et l’émergence des principautés celtiques: l’hypothèse portuaire et le concept de port of trade. *Gallia* 77/1, 435–452.

Clark A. 1990. *Seeing beneath the soil – prospecting methods in archaeology*. Routledge.

Darvill T., Lüth F., Rassmann K., Fischer A., Winkelmann K. 2013. Stonehenge, Wiltshire, UK: High Resolution Geophysical Surveys in the Surrounding Landscape 2011. *European Journal of Archaeology* 16/1, 1–30.

Darvill T., Lüth F. 2016. Avebury, Großbritannien: Landschaftsarchäologische Betrachtungen. *e-Forschungsberichte* 1.2016, 42–45. <urn:nbn:de:0048-journals.efb-2016-1-p42-45-v450>.

European Convention 1992 – *European Convention on the Protection of the Archaeological Heritage (Revised). La Valetta 1992*. <https://rm.coe.int/CoERMPublicCommonSearchServices/DisplayDCTMContent?documentId=090000168007bd25> [accessed: 13 VIII 2021].

Fassbinder J.W.E. 2015. Seeing beneath the farmland, steppe and desert soil: magnetic prospecting and soil magnetism. *Journal of Archaeological Science* 56, 85–95. DOI: 10.1016/j.jas.2015.02.023.

Goldmann L. 2021. *New glimpses of a hidden landscape in the surroundings of Mont Lassois. Analyses of survey data in the proximity of the Iron Age sites at Vix with special consideration of the geomagnetic surveys of the German Archaeological Institute 2013–2016*. Drémil-Lafage. Archéologie du Paysage 4.

Goldmann L., Komp R., Lüth F. 2021. The large scale geomagnetic survery at Mont Lassois (2013–2017). In: P. Brun, B. Chaume, F. Sacchetti (eds.), *Vix et le phénomène princier, Actes du colloque de Châtillon-sur-Seine, 2016, Pessac, Ausonius éditions, collection DAN@* 5, 39–58, <https://una-editions.fr/geomagnetic-survey-at-mont-lassois/> [accessed: 23 VII 2021].

Hahn S., Fassbinder J.W.E. 2021. The Effect of Remanence in Magnetometer Prospection. *Archeo Sciences* 45/1, 71–74. DOI: 10.4000/archeosciences.8580.

Hinterleitner A., Löcker K., Neubauer W., Trinks I., Sandici V., Wallner M., Pregesbauer M., Kastowsky-Priglinger K. 2015. Automatic detection, outlining and classification of magnetic anomalies in large-scale archaeological magnetic prospection data. *Archaeologia Polona* 53, 296–299.

Jones D.M. 2008 (ed.), *Geophysical Survey in Archaeological Field Evaluation*. Swindon.

Komp R., Lüth F., Ruby B., Burks J., Darvill T. 2020. Between the Monuments: Landscape-Scale Geophysical Surveys at Hopewell Culture National Historical Park-Seip Earthworks. In: B. Redmond, B. Ruby, J. Burks (eds.), *Encountering Hopewell in the Twenty-first Century: Ohio and Beyond 1: Monuments and Ceremony*. Akron, 50–78.

Komp R., Goldmann L. 2021. Lifeguard for large-scale geophysical surveys. Automated anomaly-analysis of geomagnetic data using open-source GIS-tools. In: W. Börner, C. Kral-Börner, H. Rohland (eds.), *Monumental Computations: Digital Archaeology of Large Urban and Underground Infrastructures. Proceedings of the 24th International Conference on Cultural Heritage and New Technologies. Vienna, Austria, November 2019*. Heidelberg, 117–120. DOI: 10.11588/propylaeum.747.

MONUMEN 2018. <http://monumen.huma-num.fr> [accessed: 3 XI 2021].

MONUMEN 2020. <https://www.meganeo.fr/redessiner-le-paysage-neolithique-grace-a-la-prospection-magnetique/> [accessed: 3 XI 2021].

Neubauer W. 2001. *Magnetische Prospektion in der Archäologie*. Wien.

Niedergermanischer Limes (2020). *Welterbe in Deutschland: Niedergermanischer Limes: nasse Grenze von Rheinland-Pfalz bis zur Nordsee*. <https://www.unesco.de/kultur-und-natur/welterbe/welterbe-deutschland/niedergermanischer-limes> [accessed: 17 IX 2021].

Notroff J. 2018. *Looking beneath the surface: Geophysical surveys at Göbekli Tepe*. <https://www.dainst.blog/the-tepe-telegrams/2018/07/18/looking-beneath-the-surface-geophysical-surveys-at-gobekli-tepe/> [accessed: 3 XI 2021].

Polak M., Bödecker St., Berger L., Zandstra, M., Leene T. 2019. *Frontiers of the Roman Empire – The Lower German Limes. Nomination File for Inscription on the World Heritage List. Part I – Nomination File*. <https://whc.unesco.org/document/181026> [accessed: 3 XI 2021].

Schmidt A., Tsetskhladze G. 2013. Raster was yesterday: using vector engines to process geophysical data. *Archaeological Prospection* 20/1, 59–65. DOI: 10.1002/arp.1443.

Schmidt K. 2009. Göbekli Tepe. Eine Beschreibung der wichtigsten Befunde, erstellt nach den Arbeiten der Grabungsteams der Jahre 1995–2007. In: K. Schmidt (ed.), *Erste Tempel – Frühe Siedlungen. 12000 Jahre Kunst und Kultur. Ausgrabungen und Forschungen zwischen Donau und Euphrat*. Oldenburg, 187–223.

Stampolidis A., Tsokas G. 2012. Use of Edge Delineating Methods in Interpreting Magnetic Archaeological Prospection Data. *Archaeological Prospection* 19/2, 123–140. DOI: 10.1002/arp.1424.

Zickgraf B. 1999. *Geomagnetische und geoelektrische Prospektion in der Archäologie. Systematik, Geschichte, Anwendung*. Rahden/Westfalen. Internationale Archäologie – Naturwissenschaft und Technologie 2.

Entering the era of landscape-scale geomagnetic surveys – technological advancements

Summary

To fulfil perceptions of actual research agenda and cultural heritage protection, new methodological approaches and technologies using geomagnetic devices for non-destructive landscape-scale surveys, have responded to this challenge.

While geomagnetic appliances since then were restricted to small sites only, the need for landscape-scale investigations inspired a team at the German Archaeological Institute (Deutsches Archäologisches Institut), led by Friedrich Lüth, to develop a geomagnetic device for large scale archaeological surveys.

In a government-funded co-operation the German Archaeological Institute and SENSYS, a German company specialized in magnetic and electromagnetic survey systems and components, engineered a vehicle-towed rig carrying up to 16 sensors at 4 m width. The GPS-referenced lightweight device is fully flexible and user friendly; it can be assembled and operated by archaeologists at low-threshold. Open source-software allows the data to be treated in GIS for visualization and integration with other sources. Additional approaches address classification and assisted automatic recognition of archaeological features.

Postęp technologiczny w badaniach geomagnetycznych nad dawnym krajobrazem

Streszczenie

Nowe metodologie i technologie geomagnetyczne, pozwalające na nieinwazyjne badania dawnego krajobrazu, odpowiadają celom i zadaniom stawianym współczesnej archeologii oraz ochronie dziedzictwa archeologicznego.

Dotychczasowe zastosowania metody geomagnetycznej ograniczały się do badania pojedynczych stanowisk. Potrzeba szerszych badań, obejmujących większe przestrzenie, stała się impulsem dla zespołu z Niemieckiego Instytutu Archeologicznego (Deutsches Archäologisches Institut) pod kierunkiem Friedricha Lütha do modernizacji odpowiedniego sprzętu badawczego.

Finansowana przez źródła rządowe współpraca z niemiecką firmą SENSYS, wyspecjalizowaną w systemach i komponentach stosowanych w prospekcji magnetycznej i elektromagnetycznej, zaowocowała skonstruowaniem przyczepy (o szerokości 4 m), na której można umieścić i przewozić do 16 czujników. Sprzęt jest lekki i łatwy w obsłudze, może być używany przez archeologów z minimalnym przeszkoleniem. Swoją pozycję weryfikuje poprzez GPS. Oprogramowanie open source umożliwia wizualizację i integrację danych pozyskanych z różnych źródeł. Dodatkowo możliwa jest klasyfikacja i zautomatyzowana identyfikacja struktur archeologicznych.

Rainer Komp
Deutsches Archäologisches Institut
Berlin
rainer.komp@dainst.de