Archaeologia Polona, vol. 53: 2015, pp. 368-372

SQUID-based magnetic prospection in interdisciplinary case studies at possible early and high medieval harbour sites in Germany

Michael Schneider[a,b], Sven P. Linzen[b], Markus Schiffler[b], Andreas Wunschel[c], Michael Hein[c], Christopher-Bastian Roettig[d], Stefan Dunkel[e], Ronny Stolz[b], Peter Ettel[c], Hans-Georg Meyer[b] and Daniel Baumgarten[a]

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

[a] Institute of Biomedical Engineering and Informatics, Technische Universität Ilmenau, Ilmenau, Germany
[b] Leibniz-Institute of Photonic Technology, Jena, Germany
[c] Chair of Prehistory and Early History, Friedrich-Schiller University Jena, Jena, Germany
[d] Institute of Geography, Dresden University of Technology, Dresden, Germany
[e] Supracon AG, Jena, Germany

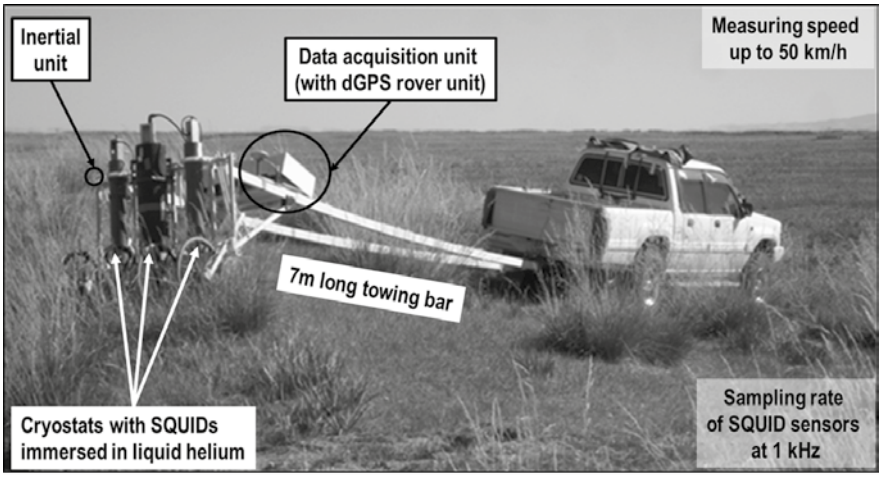

Fig. 1. Overview of the SQUID-based measurement system of IPHT Jena and Supracon AG, which is normally pulled by an all-terrain vehicle. A combination of high-sensitive magnetic sensors, precise localization and orientation reading ensures effective, high-resolution magnetic prospection measurements for archaeological inverstigations with a mapping efficiency of up to 100.000 m² per day

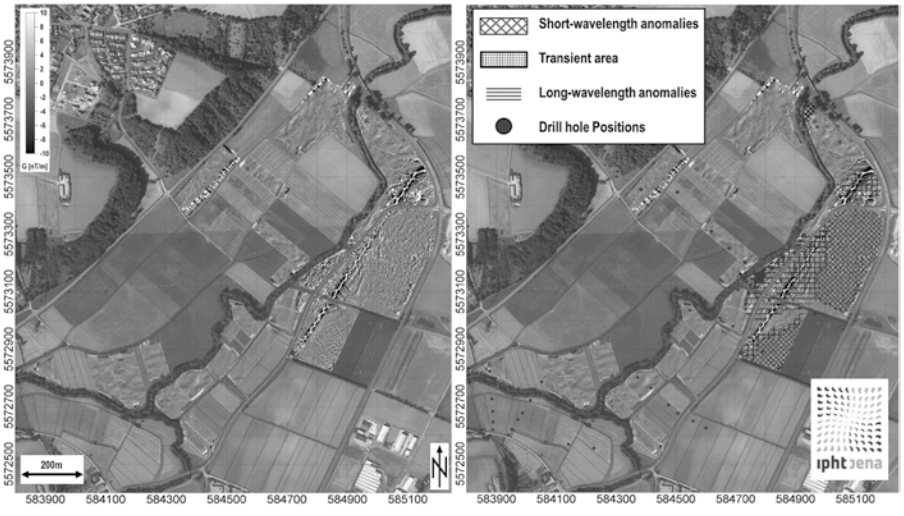

Fig. 2. Integration of georeferenced magnetic maps into an aerial photo (provided by the Bavarian State Department for Monuments and Sites) of the entire site of investigation at Mühlstatt/Bitzenhausen. The grayscale of the magnetic maps represent a vertical gradient in the range of ±10nT/m. Next to 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)

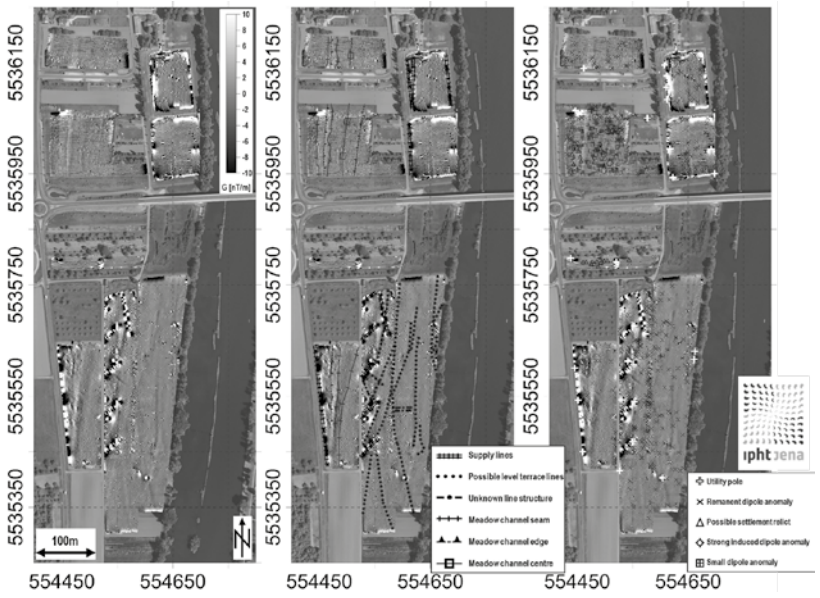

Fig. 3. Integration of georeferenced magnetic maps into an aerial photo (provided by the Bavarian State Department for Monuments and Sites) of a partial site south of Karlburg. The grayscale of the magnetic maps represent a vertical gradient in the range of ±10nT/m. Different point-shaped and linear 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 geo-archaeological 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.

ACKNOWLEDGEMENTS

This work was supported by the German Federal Ministry of Education and Research (BMBF) as part of the Innoprofile Transfer project 'MAMUD' (03IPT605X) and German Research Foundation (DFG, ET 20/8-1).

REFERENCES

Zakosarenko, V., Warzemann, L., Schambach, J., Blüthner, K., Berthel, K-H., Kirsch, G., Weber, P. and Stolz, R. 1996. Integrated LTS gradiometer SQUID systems for unshielded measurements in a disturbed environment. *Superconductor Science and Technology* 9: 112–115.

Linzen, S., Chwala, A., Schultze, V., Schulz, M., Schuler, T., Stolz, R., Bondarenko, N. and Meyer H.-G. 2007. A LTS-SQUID system for archaeological prospection and its practical test in Peru. *IEEE Transactions on Applied Superconductivity* 17: 750–755.

Schneider, M., Linzen, S., Schiffler, M., Pohl, E., Ahrens, B., Dunkel, S., Stolz, R., Bemmann, J., Meyer, H.-G. and Baumgarten, D. 2014. Inversion of Geo-Magnetic SQUID Gradiometer Prospection Data Using Polyhedral Model Interpretation of Elongated Anomalies. *IEEE Transactions on Magnetics* 50(11), Article# 6000704.

Werther, L. 2012. *Komplexe Systeme im diachronen Vergleich. Ausgewählte Aspekte der Entwicklung von drei süddeutschen Kleinräumen zwischen Früh- und Hochmittelalter.* Unpublished dissertation, Friedrich-Schiller-Universität Jena.

Ettel, P. 2001. Karlburg - Rosstal – Oberammerthal, Studien zum frühmittelalterlichen Burgenbau in Nordbayern. Frühgeschichtliche und Provinzialrömische Archäologie. *Materialien und Forschungen* 5 (Rahden/Westf): 279-301.