Geophysical Prospection: a Powerful Non-destructive Research Method for the Detection, Mapping and Preservation of Monuments and Sites

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Abstract. Geophysical Prospection has yielded remarkable results to the research in Archaeology. Besides the recognition of places, also the earlier uses of a site can be reconstructed. Therefore, the geophysical techniques help to understand the layout of a site and raise new research questions. In this paper, we summarize the main geophysical prospection methods for archaeology: magnetic, radar and resistivity-based techniques. We also present results of combined methods that have been employed for the survey on the Bavarian sites of the "Obergermanisch-raetischer Limes", frontiers of the Roman empire.

Keywords: Geophysics, Archaeology, Bavarian Limes, Remote Sensing, Magnetometry.

1 Introduction

Geophysical science offers a large range of prospecting methods that were adapted to the detection and description of archaeological structures beneath the soil.

Three main methods are nowadays very popular and widely used for non-destructive archaeological surveys. Magnetometry, resistivity and radar prospecting allow the creation of precise and detailed, but nevertheless large scale maps of all structures that are hidden beneath the ground. The choice of technique to be used in search of the buried archaeology depends very much on the particular situation and on the different landscapes that have to be surveyed.

Magnetometry is one of the most successful methods for inexpensive but detailed survey on large sites. On nearly all archaeological sites magnetometry can successfully detect structures, regardless if there are stone walls in the adjacent soil, soil marks of wooden structures, fireplaces, pits, ditches or traces of wooden palisades. However, magnetometry is a passive method, and whenever there are some technical constructions of iron or electric power lines nearby, the application of magnetic techniques is highly disturbed or utterly impossible. In these cases active prospecting methods can overcome such problems and resistivity and radar prospecting can be more than supplementary methods. Where stone structures are present, the prospecting results of radar and resistivity will definitely surpass the quality of the magnetometer data.

2 Geophysical prospection

It is already more than 50 years ago, when resistivity and magnetic prospection were first applied to detect archaeological features beneath the ground (Atkinson, 1953; Aitken et al. 1958; Clark, 1996; Aspinal et al. 2008; Conyers, 2004).

The first results of such methods were displayed as a simple profile plot, or a contour map. A milestone in the development of geophysical data processing was the introduction of digital image processing techniques developed by Scollar and Krückeberg (1966). Since then, the application of geophysical methods and their interpretation was no longer restricted to geophysicists, but could be understood by non-specialists and archaeologists (Fassbinder & Gorka, 2009).
Today's most common geophysical prospecting techniques are:

- Magnetometry 2 – 4 ha per day, sampling rate 25x50 cm;
- Resistivity 1/4 – 1 ha per day, sampling rate 50x50 cm;
- Radar 1/4 – 1 ha per day, sampling rate 2x25 cm.

Depending on the spatial resolution such methods can cover large areas. However, the processing and interpretation of these data exceeds 10 or 20 times the time required for data collection.
The following special applications are only rarely applied for archaeological purposes:

- Magnetic susceptibility, e.g. to discriminate archaeological layers;
- Electromagnetic methods used for metal detection;
- Sonar prospecting, e.g. for underwater archaeology;
- Seismic methods, for the detection of layers in great depth;
- Gravity prospection, for the search of cavities;
- Thermal prospecting, for the detection of heat flows.

2.1 Magnetic prospection

Magnetic prospection is a passive geophysical method, which measures the anomalies of the Earth's magnetic field, based on the:
- Enrichment of magnetic minerals in the top soil and archaeological structures;
- Natural Remanent (NRM) and ThermoRemanent (TRM) magnetization of soil and archaeological features.
The signal is a magnetogram, with the relative intensity of the magnetic anomaly as a plan-view image, typically in grey-shade.

Magnetic prospection is the most widespread, successful and cheap method in Archaeology. The origin of magnetic anomalies on archaeological sites can be ascribed to two reasons. First, the enrichment of ferrimagnetic minerals such as magnetite, maghemite and greigite in top soils, and hence in all archaeological layers. Such enrichment occurs worldwide in almost all soils by pedogenic or biological processes, as well as the use of fire through ancient settlement activities (Le Borgne, 1955; Fassbinder, et al. 1990). Second, a further part of the magnetic anomalies is due to the natural remanent (NRM) or thermoremanent magnetization (TRM) of soils, sediments or archaeological layers (Le Borgne, 1960; Fassbinder & Stanjek, 1993).

Understanding the magnetic properties of minerals in the soil and rock, sometimes allow us a very detailed and fundamental interpretation of the different archaeological features.

2.2 Radar prospecting

Radar is an active geophysical method, which is based on the transmission and reflection of electromagnetic waves in the ground. Frequencies typically range from 10 MHz – 2 GHz; 400 MHz is most suitable for archaeological prospecting. Runtime is proportional to the penetration depth of the archaeological structure. The signal output is a radargram consisting of reflected signal amplitude versus runtime, forming a section view in grey-shade.

2.3 Resistivity prospecting

This is an active geophysical method, which measures the apparent resistivity of soil. It is based on the contrast of electric resistivity between the soil, the sediment and the rock. Penetration depth depends on the distance between the electrodes. The signal is a resistogram, consisting of a grey-shade image of the apparent electric resistivity.

3 Case history: the “Obergermanisch-raetischer Limes” in Bavaria by geophysical prospection

The Roman Limes with a length of 550 km is the largest archaeological site in Europe as well as the largest monument of the Roman period (Fig. 1). In July 2005 it was decided that the Limes and its interrelated archaeological sites, together with Hadrian’s Wall in England, would be a component of a "Trans-National World Heritage Site" taking the name "Frontiers of the Roman Empire". From that point, it was necessary to minimize or avoid archaeological excavations. Further research is therefore limited to the application of non-destructive techniques (Fassbinder, 2010) and geophysical prospecting methods turned out to be highly suitable. Four examples that allowed us the verification and completion of old maps of the Reichs-Limes-Kommission will be shown here; these projects exemplify the potential of geophysical prospecting on the Bavarian Limes.

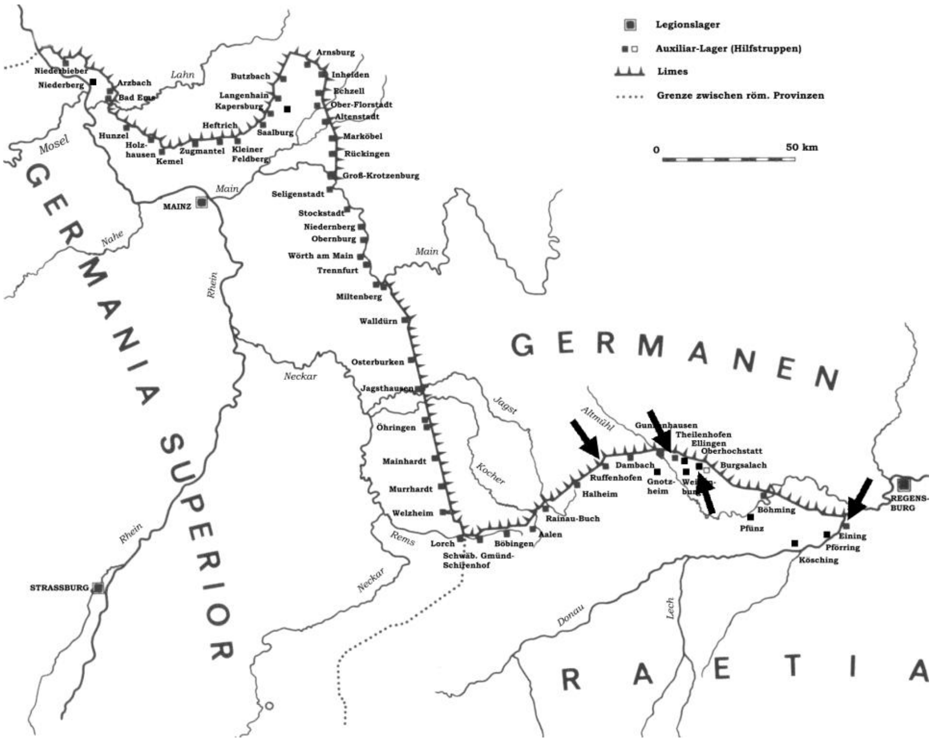

Fig. 1. Geographic map of the Obergermanisch-raetischer Limes.

3.1 The fort of Theilenhofen

At Theilenhofen we were able to complete the map of the fort with all fortification ditches and the water supply; to verify the troop level and confirm the former fort on which are superimposed the traces of the Roman vicus (Fig. 2, Fig. 3).

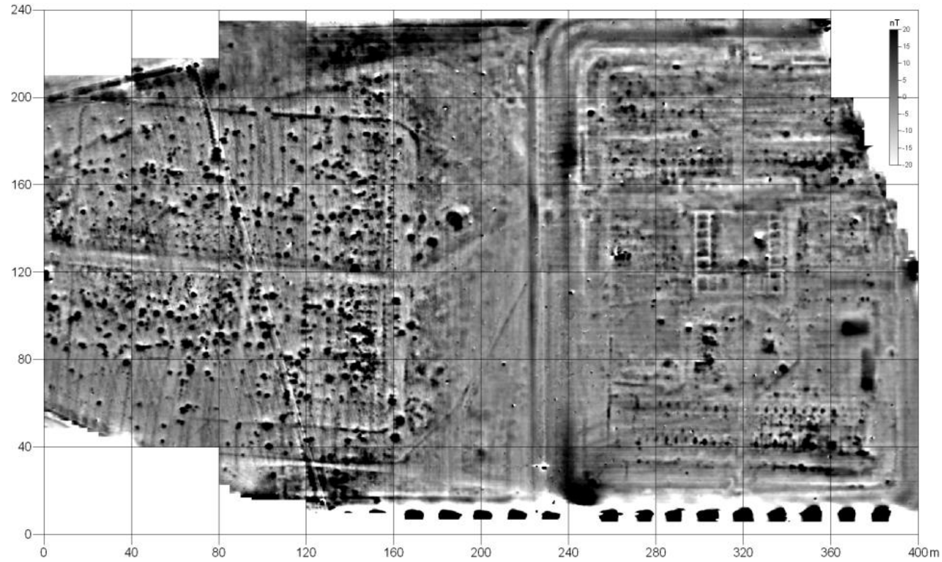

Fig. 2. Magnetogram of the Roman fort of Theilenhofen. The ground plan of the Roman fort constructed on stone foundations (right-hand side). The older fort consisting of wooden barracks, which were later overbuilt by the civil settlement (left-hand side). Dynamics +/- 20 Nanotesla, in 256 grey levels; grid size 40x40 meters, sampling rate interpolated to 25 x 25 cm.

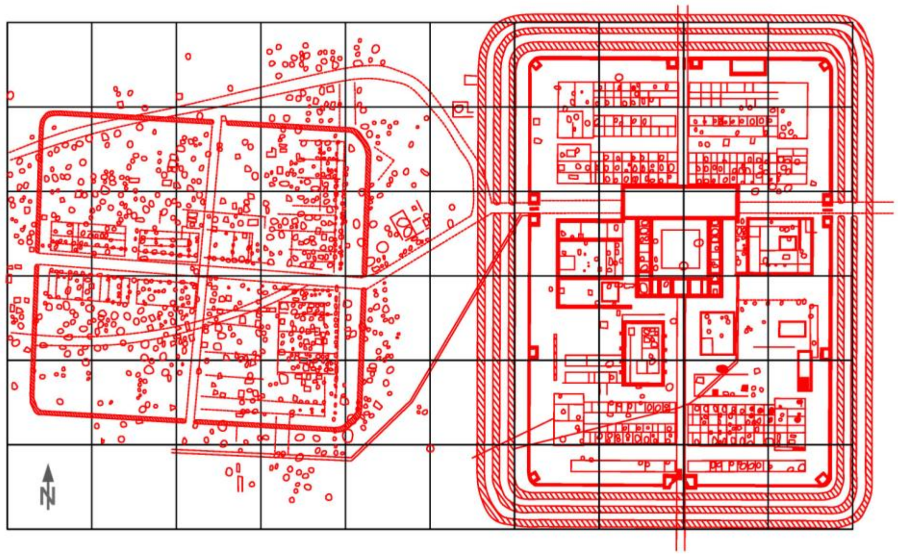

Fig. 3. Theilenhofen. Archaeological map of the magnetometer data, combined with the excavation data by the Reichs-Limes Kommission. AutoCAD-Map 6930/006.

3.2 The fort of Oberhochstatt

The fort is situated about 500 m N of the village, at the border of the Jura platform. In spite of the early reports in 1833 of a Roman fort, almost nothing was known until recently. The archaeological community first knew of the location in 1897, when a farmer reported four bronze letters found on the field. In 1920 the “Streckenkommissar” F.Winkelmann made test excavations on the site the letters had been found. Unfortunately, the trench was made in such an awkward way, that only an empty foundation ditch was found that possibly had contained an earlier wall. The construction of the highway 2228 in 1979/80 went directly through the centre of the fort, but it was never studied by the archaeologists, although farmers again reported seeing structural remains. After the misinterpretation of an aerial photo of 1983, the fort seemed to be located about 200 m from the highway. Finally, the compelling evidence of the location of the fort given by the geophysical prospection performed in 2009.

Fig. 4. Oberhochstatt. Aerial photo of the site combined with magnetic prospections; bottom is North. Archive No. 6932/119-1Ds09253, photo K. Leidorf, 19.08.2008.

3.3 The Roman camp of Eining-Unterfeld

Radar prospection. The results allowed the relief of structures down to three meters underground (Fig.5).

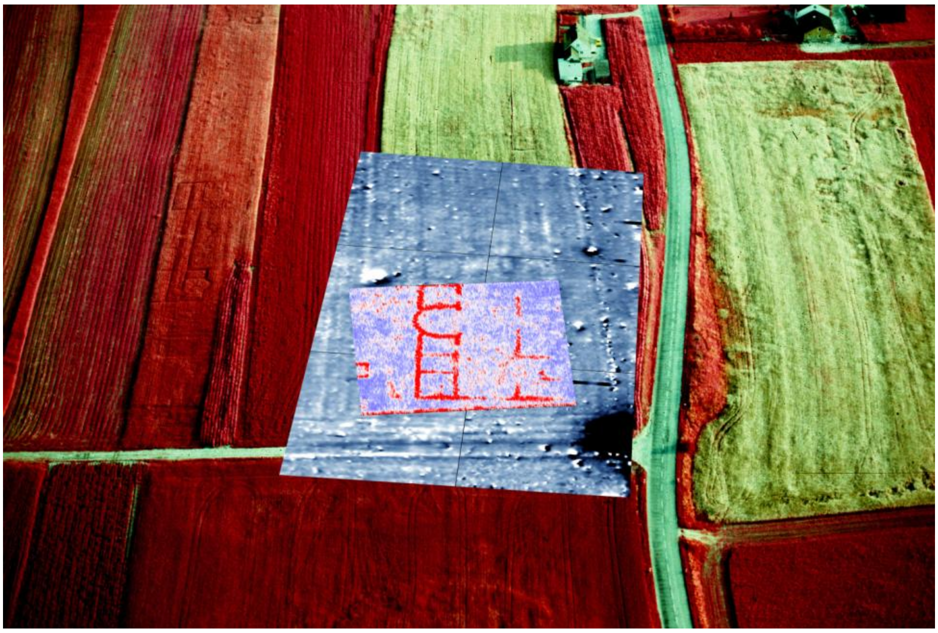

Fig.5. Eining-Unterfeld. Aerial photo of the site, combined with magnetometer and radar measurements. Archive No. 7136/075b-10i-18, photo O. Braasch.

3.4 The fort of Ruffenhofen

The resistivity survey and its potential for archaeological investigations are documented by the Roman fort of Ruffenhofen (Fig. 6). The results show a map of all the constructions that were made of stone. Even some parts of the former stone wall, that tumbled down into the fortification ditch, are visible. However, these findings also make clear that, besides the stone structures, no other traces become visible by resistivity measurements alone.

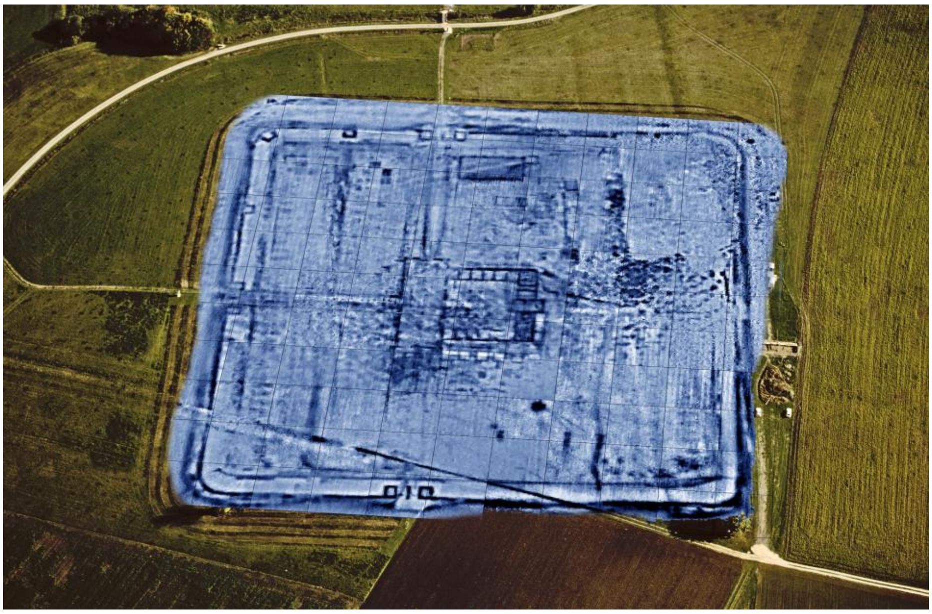

Fig. 6. Ruffenhofen. Aerial photo of the site combined with the resistivity measurements. Archive 6928/074-8941-3, photo K.Leidorf, resistogram H.Becker.

4 Conclusions

Geophysical prospection for archaeology delivers not only information about wooden and stone structures, ditches and pits, but, moreover, results in detailed archaeological maps. Besides the tracing and recognition of places, the former use of an archaeological site can be reconstructed. Therefore, the geophysical results not only help to understand the layout of a site, but also raise new research questions. In 2005 the Roman Limes and all associated constructions were declared a UNESCO World Heritage site. Therefore, archaeological excavation is no longer a suitable tool for research on these archaeological sites and monuments. Geophysical prospecting, combined with aerial archaeology and airborne laser scanning methods, remain the only effective and non-destructive techniques to recover, understand and pursue archaeological research beneath the ground.

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