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Geophysical Archaeological Prospection in Rescue Archaeology: Examples from Sweden

Abstract: In Sweden, rescue archaeology is conducted through partial trenching of sites during pre-investigations, followed by complete excavations if archaeological structures are found. Geophysical prospection using magnetometer and georadar measurements can under the right conditions add valuable information to archaeological site investigations in a time- and cost-effective manner. We demonstrate the potential and pitfalls of archaeological geophysics based on two case studies: the georadar survey of a medieval convent and the magnetometer survey of an iron-age settlement and iron production site. The archaeological problem, field work and data interpretation are discussed, followed by a qualitative analysis of the results through subsequent excavation. The second example demonstrates the strength and weakness of the magnetic prospection method under challenging geological and archaeological conditions. The visibility and invisibility of archaeological structures in the magnetic data is addressed on the basis of magnetic susceptibility measurements conducted on the excavated surface.

Introduction

Rescue archaeology investigates archaeological sites prior to their destruction in the course of new road, railway or building construction and site development (Rahtz 1974). Under Swedish law, every archaeological site that is to be developed or which will be affected by construction-related earthworks must be investigated archaeologically (Kulturdepartement 1988, §11). If the presence of archaeological sites in the affected area is unknown and cannot be derived from the study of historical maps or written sources an archaeological site investigation into the existence of archaeological structures is required. These site investigations are normally conducted through limited trenching in those regions that are most likely to contain archaeological structures or remains. If the presence of an archaeological site has been established then the area has to be investigated more thoroughly. The subsequent archaeological investigation generally involves dense trenching with mechanical excavators. If this pre-investigation results in the discovery of structures of archaeological interest, the exploration of the area may either be abandoned, or a complete archaeological investigation through excavation of the affected area will be undertaken.

Large scale archaeological excavations can be time consuming and expensive for the developer. In rescue archaeology the archaeologically investigated area is normally strictly limited to the area affected by exploration. An archaeological site that extends beyond the boundaries of this area, such as a prehistoric settlement or burial ground, will not generally be investigated in its entirety due to limited funding.

Under the right conditions, geophysical archaeological methods can be used efficiently across large areas to gain knowledge about subsurface structures (e.g. Gaffney / Gater 2003). High-resolution magnetometer and georadar prospection have proven to be of great potential for archaeological site investigations (e.g. Becker et al. 1996; Neubauer 2001; Leckebusch 2003). In Scandinavia, these methods have so far been used only to a minor degree, often being limited to small areas (e.g. Alkarp / Price 2003; Grassi 2001; Lück / Callmer / Skånberg 2003; Persson / Olofsson 2004; Persson 2005). The geological conditions and expression of archaeological structures in Sweden can render large-scale magnetic prospection difficult (Gay 2004).

Since 2005, a professional archaeological prospection unit has been run by the Archaeological Excavation Department of the Swedish National Heritage Board. Over the last few years, a number of test surveys have been conducted using both magnetometer and georadar surveying methods. Here we present two case studies of archaeological surveying used in connection with rescue archaeological investigations. The first example describes the use of georadar at the site of a medieval convent that was affected by the extension of a railway line. The second case

Fig. 1. (left photo) The site of St. Olof's convent, partly covered by a large horse stable. Alongside the railway track walls of the convent came to light. In 2004, the first georadar survey was conducted east of the railway track. In 2005, an additional georadar survey was conducted west of the railway line. (right photo) Sirri Seren, Wolfgang Neubauer and Tahereh Salem surveying with the 500 MHz georadar antenna along parallel profile lines. (Photo: Lars-Inge Larsson).

illustrates the use of magnetometer prospection at an iron-age metal production and settlement site affected by housing development.

Georadar Prospection and Partial Excavation of St. Olof's Convent in Skänninge

Today, Skänninge is a small town in Östergötaland County. During medieval times, it was a clerical centre, home to two churches and two Dominican convents: the monastery St. Ingrid and the friary St. Olof's (Hasselmo 1983). The latter was founded in 1237 and existed until its closure during the church reformation under King Gustav Vasa's rule around 1540. These days, there are no traces of St. Olof's convent visible above the surface; its precise location and dimension were unknown until recently. Initial archaeological excavations in the form of small pits had been conducted in the 1930s, giving scientists a vague idea of the structure of the convent.

It was evident that the planned doubling of the single-track railway line from Motala to Mjölby would affect the site of St. Olof's convent (Kaliff 2003). Therefore, in 2004 this site was selected for a test of the georadar prospection method ahead of and complementary with a rescue archaeological excavation. An expert team from Austria consisting of Sirri Seren, Tahereh Salem, Wolfgang Neubauer and Alois Eder-Hinterleitner from Archeo Prospections® in Vienna conducted a high resolution georadar survey over the course of two days, using a towed Malå GeoSience 500 MHz antenna system with a cross-line spacing of 50 cm between the parallel georadar profile lines and an in-line trace spacing of 5cm *(Fig. 1)*, covering an area of 7000 m^2 to the east of the railway line *(Fig. 1)*. The resulting depth-slice images of the georadar data revealed in great detail the structure of the vanished convent *(Fig. 2)*. Old foundation walls, cellar rooms and stone floors as well as modern pipes and cables are visible in the data. Before the start of the actual rescue excavation, the archaeological prospection was already able to provide the archaeologists with an overview of the entire site. The excavation conducted in 2005 by the Swedish National Heritage Board (Hanna Menander, Magnus Stibéus, Rickard Hedvall) revealed thick walls of natural stone and fired clay bricks, hypocaust heating systems and fireplaces, stone floors, graves and many finds of archaeological interest (personal correspondence). By combining the findings of the archaeological excavation with the results of the georadar survey and by extrapolating the located structures, it was possible to generate a comprehensive map of St. Olof's convent *(Fig. 3)*. An inner courtyard with surrounding cloister, adjoining rooms and buildings as well as what is presumably the convent chapel were revealed. The area covered by the georadar measurements extended well beyond the excavation area, which was limited to a narrow stretch along the railway line. The excavation of the entire site covered by the georadar survey would not have been possible within the framework and budget constraints of the rescue excavation. In 2005 and 2006, additional georadar surveys were conducted with 25 cm cross-line profile spacing and a Sensors & Software 500 MHz antenna system, mapping with even higher resolu-

Fig. 2. Map showing the georadar data as depth-slice. The walls of St. Olof's convent can be seen in the depth-slice as dark anomalies. Walls excavated alongside the railway line are marked in red. Based on the results of the excavation and of the georadar prospection it was possible to reconstruct an overall image of the main buildings of the convent.

tion a building and structures in the garden west of the railway line and structures in the central area. In summer 2006, a research excavation was conducted by Hanna Menander (personal correspondence), probing structures detected with the georadar measurements. This excavation demonstrated that the excavated structures agree very well with the anomalies seen in the georadar data *(Fig. 4)*. Even the difference between walls constructed with natural stones and those built with fired clay bricks is visible in georadar data.

The cost for the initial (2004) georadar survey amounted to about 3% of the costs for the archaeological rescue excavation. In a very short time, and at comparatively low cost, the geophysical prospection contributed to the outcome of the archaeological investigation.

Magnetic Prospection of the Iron-Age Settlement and Iron Production Site Harbo-Smedsbo

The second example presented here discusses the results of a magnetometer survey conducted in August 2006 prior to an archaeological rescue excavation at Harbo-Smedsbo in Uppland, Västmanlands County. The site was to be developed as a residential area. Archaeological structures indicating an iron-age iron production and settlement site had been found in the area during the archaeological pre-investigation using test trenching. The magnetic prospection method was thought to be suitable to detect archaeological structures such as kilns, accumulations of slag, as well as larger pits and post holes and possibly ditches. An area of almost one hectare (100 m x 85 m) was surveyed using a manual Fluxgate-type Förster magnetic gradiometer system consisting of four gradiometer probes (65 cm vertical sensor spacing) mounted with 50 cm horizontal cross-line spacing on a manually operated cart *(Fig. 5)*. The lower gradiometer sensor was fixed at a height of 20 cm above the ground. The field had been mown prior to the measurements in order to improve the survey conditions. The cart was pushed along 50 m profile lines spaced at 2 m intervals and data samples were recorded with 10 cm in-line spacing. Data processing was conducted by Alois Eder-Hinterleitner using purpose-written

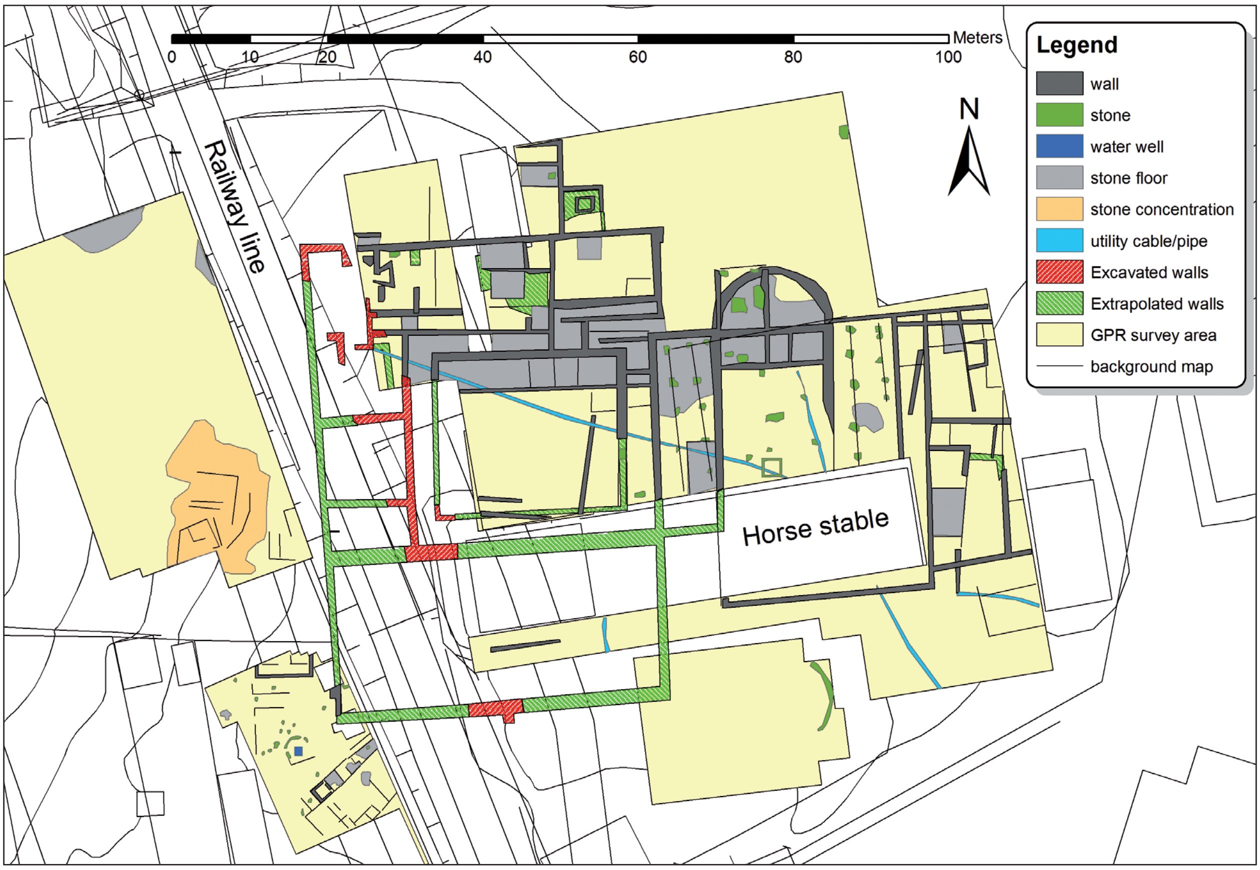

Fig. 3. Interpretation of the georadar data. The interpreted structures were derived from the analysis of a large number of depth-slices of 10 cm thickness each. Therefore more detail is visible in the interpretation compared to the single depth-slice shown in Fig. 2.

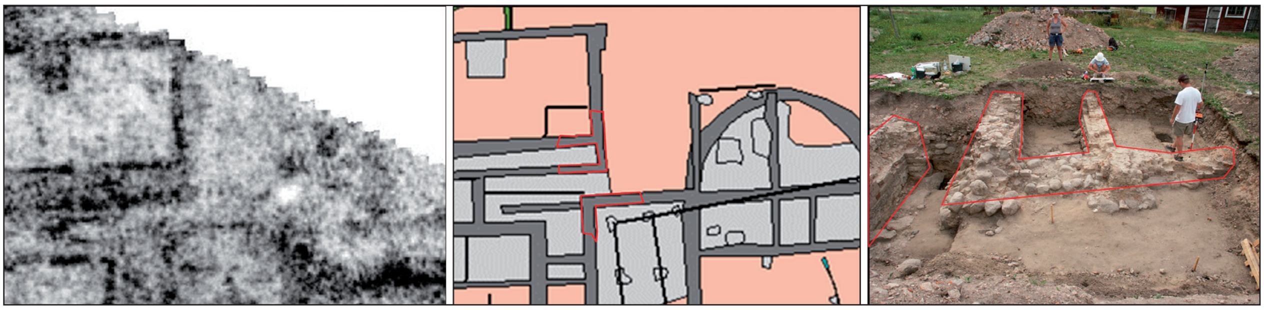

Fig. 4. (left) Georadar depth-slice of data measured in 2006 with 25 cm profile spacing. (centre) Corresponding interpretation. (right) Photo showing the excavated area. The foundation walls and their corresponding representation in the georadar data are marked with red lines. (Photo: Magnus Stibéus).

software to produce geo-referenced data images. Several images for different amplitude ranges were generated, corresponding to different contrast visualizations.

The resulting magnetograms show a large number of magnetic anomalies *(Fig. 6)*. Most prominent is a strong positive magnetic anomaly at the northern edge of the survey area. This anomaly was initially thought to have been caused by a large kiln used for iron production. Several linear anomalies can be seen in the data beside a large number of smaller, individual magnetic anomalies which do not appear to belong to coherent structures.

After the uppermost 30–40 cm of topsoil had been removed across the entire area during the subsequent archaeological rescue excavation, a considerable number of archaeological structures were found: pits, post holes, iron slag concentrations and rows of stones. A large number of boulders were found in the soil, which geologically can be described as an unsorted glacial moraine. All structures of archaeological interest were mapped and documented digitally using a total-station (robotic tachymeter) and the archaeological documentation software Intrasis, resulting in geo-referenced shape files for further analysis in GIS.

No kiln was found in the survey area. The major positive magnetic anomaly along the northern edge of the survey area originated from a large boulder which had been heated using fire, causing it to break. While several anomalies visible in the magnetic prospection data coincide clearly with archaeologically documented structures *(Fig. 6)*, the majority of archaeological structures lack a corresponding magnetic expression, and similarly, there are many magnetic anomalies without a matching archaeological structure *(Figs. 6, 7)*. The reasons for this discrepancy may be several: an object that gave rise to a magnetic anomaly may have been located in the topsoil which had been removed, or else the magnetic anomalies caused by some archaeological structures may be below the magnetic sensitivity of the used instrument. The main cause was found when magnetic susceptibility measurements were conducted on the excavated surface. The SM-30 magnetic susceptibility meter was used in interpolation mode. Readings were made on the barren ground, resulting in values of about 0.7 x 10^{-3} SI units. The filling of post holes showed readings of 10 x 10^{-3} SI units, the filling of a pit showed a value of 10.2 x 10^{-3} SI units compared to 2.5 x 10^{-3} SI units for the surrounding soil. Slag samples gave readings of above 80 x 10^{-3} SI units. These measurements indicate that in principle the archaeological structures should show in the magnetic prospection data as predicted by the theory. However, the abundance of rocks and boulders with relatively high magnetic susceptibility values complicated the picture. The present soil consists of unsorted moraine containing many diorites with large magnetic susceptibility values of 24.8 x 10^{-3} SI units, 25.1 x 10^{-3} SI units, and up to 70.9 x 10^{-3} SI units, as well as granites with relatively low magnetic susceptibilities of less than 2 x 10^{-3} SI units.

Fig. 5. Magnetometer measurements with a Förster magnetometer system. Four gradiometer probes are mounted with 50 cm horizontal spacing onto the cart. The cart is pushed in zig-zag mode along 50 m long parallel profile lines that are spaced in 2 m intervals on the ground.

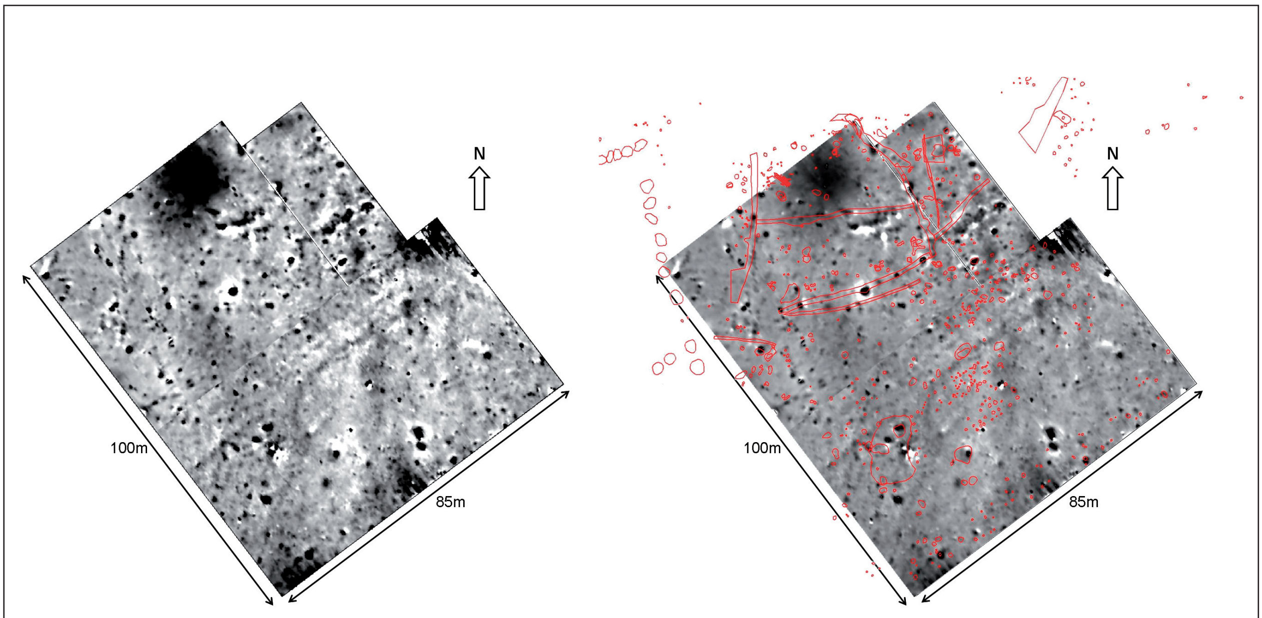

Fig. 6. (left) Magnetometer prospection results showing a large number of anomalies. The grey-scale image covers the amplitude range -8nT (white) to +18nT (black). (right) Excavated archaeological structures that were digitised in the field using a total-station are shown superimposed onto the magnetogram. While several archaeological structures coincide well with magnetic anomalies, a considerable number of archaeological structures lack a corresponding magnetic anomaly.

The magnetic prospection resulted in a distribution map of the objects with high magnetic susceptibility (i.e. mainly the diorite boulders). The rows of stones consisted predominately of granites with low magnetic susceptibility values. Thus, the use of the magnetic prospection method on unsorted moraines can lead to ambiguous results, rendering an archaeological interpretation difficult or impossible. If the site had been surveyed using high-resolution georadar prospection (25 cm cross-line spacing), the rows of stones and other stone structures would have been detected, allowing their archaeological interpretation. In this case, however, shortage of time did not permit a complementary georadar survey.

Fig. 7. Critical comparison of the magnetometer survey results with the excavated structures by the archaeologist. The magnetometer survey failed to image the row of stones visible in the foreground due to large differences in magnetic susceptibility of the individual stones.

Conclusions

The results of the two archaeological surveys presented here illustrate the strengths and weaknesses of the methods. The success of the georadar prospection of St. Olof's convent was based on the well-preserved, clearly expressed archaeological structures (stone and brick walls) in the ground. The failure to detect archaeological structures using magnetometer measurements at the second site was due to the unfavorable geological conditions and the lack of clear, coherent contrast between the archaeological structures and the background. The second example demonstrates that negative evidence does not prove the absence of archaeological structures. Geophysical survey data can show structures that are invisible in conventional archaeological excavations and vice versa (e.g. the heating of the boulder visible in the magnetic prospection data).

We have shown that digital archaeological field documentation and GIS based analysis of geophysical prospection data are of methodological importance. Finally, geophysical prospection is non-destructive, in contrast to excavations. Therefore geophysical prospection should become a standard tool prior to any rescue and research excavation wherever site conditions permit.

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