Survey report

Ground Penetrating Radar surveys for Archaeological Prospection at Skänninge 2005

Methodology, data acquisition, results, interpretation

Immo Trinks
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1 Introduction

In 2004 Ground Penetrating Radar (GPR) was used to survey two sites in the vicinity of the medieval St Olof’s monastery in Skänninge, Östergötland (Sweden). These investigations were conducted by a group of specialists from Austria within a framework designed to test the applicability of the GPR method for archaeological prospection in Sweden. Archaeological excavations in relation to construction work along the existing railway track in Skänninge had revealed foundations of the medieval friary. At the test site next to the excavation (site A in Figure 1.1) the GPR method led to the delineation of the foundations of a large part of the monastery, including its assumed church. The high quality of the GPR data is shown in slices of constant depth taken from the geo-radar data volume (Figure 1.2). The linear structures visible through darker colour are caused by reflections of the electro-magnetic GPR signal from stone and brick foundations and other subterranean structures.

An additional survey conducted in 2004 on a second site nearby on top of a small hill with the field name “Bishopsholmen” (site B in Figure 1.1) uncovered structures in the subsurface belonging to several buildings. The data obtained from the measurements at site B shows weaker anomalies and less coherent structures, indicating thinner walls of smaller extend. Both surveys on site A and B were conducted with a spacing of 50cm between the parallel GPR profiles. A smaller line spacing of 25cm would result in an even clearer image and higher resolution of the archaeological structures.

In regard to the construction of a noise attenuation wall alongside the railway track in the vicinity of St Olof’s friary the archaeological prospection of four additional areas using the GPR method (plus one possible test area) was suggested in 2005.

During the week of June 27th to July 1st 2005 GPR measurements have been conducted at the new survey areas 1, 2, 3, 4, 5 and 6 along the railway track north-east of the town centre of Skänninge (Figure 1.1). Areas 1 and 3 were surveyed with a profile spacing of 50cm, similar to the measurements conducted in 2004. All other areas were surveyed with 25cm profile spacing in order to achieve a higher data density and thereby higher resolution. The sizes of the surveyed areas in 2004 and 2005 are listed below.

<table>
<thead>
<tr>
<th>Area name</th>
<th>Area [m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4305</td>
</tr>
<tr>
<td>B</td>
<td>2693</td>
</tr>
<tr>
<td><strong>Total area 2004</strong></td>
<td><strong>6998</strong></td>
</tr>
<tr>
<td>1</td>
<td>1226</td>
</tr>
<tr>
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<tr>
<td>5</td>
<td>989</td>
</tr>
<tr>
<td>6</td>
<td>198</td>
</tr>
<tr>
<td><strong>Total area 2005</strong></td>
<td><strong>5664</strong></td>
</tr>
</tbody>
</table>

The total measured GPR profile length was 13,996m in 2004 compared to 19,708m in 2005.

The data measured in 2005 have to be seen in the context of the results obtained through excavations and the earlier GPR measurements.

The data processing was conducted by Alois Eder-Hinterleitner (Central Institute for Meteorology and Geodynamics, Vienna). The interpretation of the data was done by Dr. Wolfgang Neubauer (Vienna Institute for Archaeological Science).

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Figure 1.1: Ortho-photo of the north-eastern region of Skänninge, Östergötland. The GPR survey sites A and B were measured in 2004 and are marked in yellow. In 2005 the blue marked areas 1, 2, 3, 4, 5 and 6 were surveyed. Areas 1 and 3 were measured with 50cm profile spacing, while areas 2, 4, 5 and 6 were surveyed with 25cm profile spacing. Site 1 is located west of the railway line opposite the excavation of S:t Olof's monastery on a hill that is sloping to the north-west. Site 2 is located north of the river. In the nearby excavation site C a historic road and pits have been excavated, while in excavation D several pit houses, post holes of a longhouse and drainage dikes have been found. Site 3 is a small strip of lawn between a house and the railway line. Site 4 is a garden in the vicinity of S:t Olof's monastery. Area 5 is located east of the hill called "Bishopsholmen", on which survey area B had been located. Area 5 had been surveyed in order to test whether the location and context of wooden structures that were found in this area could be detected. Area 6 is a repeated measurement of a small section of area A with higher spatial sampling.
Figure 1.2: GPR depth-slices from the survey conducted by Wolfgang Neubauer and Sirri Seren at site A of the St Olof’s monastery at Skänninge, Östergötland in 2004. A 500MHz antenna (Malå Geosciences) was used with 50cm cross-line profile spacing. The slices represent a depth range of 10cm each. They cover from top left to bottom right in rows the depth range between 0cm and 240cm. The data was processed by Alois Eder-Hinterleitner.
1.1 How to use this report

The first part of this report provides an introduction to the GPR method. The second part explains the data acquisition for each of the sites, the resulting data and interesting structures. An interpretation of the structures is given in the text.

A DVD is included in this report containing the report in electronic form in Microsoft Word (.doc) and PDF format. Furthermore, the original GPR data is included in the folder "Original Data". The result of the GPR data processing is contained as GPR depth-slices in the folder “Processed Data” in form of geo-referenced TIFF images.

Further data analysis and use of the data is possible within a Geographical Information System (GIS). The data is made available for use with ArcGIS (ArcView, ArcExplorer).

To this purpose, create a folder called “Gisdata” on the partition “D” of the hard-disk of your computer, if no such folder exists.

Then, copy from the DVD the folder Skaenninge, which is placed in the folder “GIS Data”, to “D:\Gisdata\”.

Change to “D:\Gisdata\Skaenninge\” and open “Skaenninge.apr” with ArcView GIS 3.2, or alternatively open “Skaenninge.aep” with ArcExplorer. The folder "GIS Data\Skaenninge\ShapeFiles” contains the geo-referenced data in form of TIFF images, maps, an ortho-photo and further shape files such as historical maps, the GPR depth slices and the interpretation of the data in ArcView format. The freeware GIS viewer software ArcExplorer for viewing and printing of the data is contained in the subfolder ArcExplorer Software. The ArcExplorer software is as well available from http://www.esri.com/software/arcexplorer for Windows 98/2000/NT/XP, Macintosh, Solaris, AIX, HP-UX and Linux operating systems. On Windows operating systems run the ae2setup.exe program to install ArcExplorer2. On all other systems choose the Java Edition.

In order to obtain the exact coordinates or dimensions of structures and anomalies of interest it is recommended to load the data into ArcView or ArcExplorer and to use the cursor and the measuring tool. To display the coordinates in ArcExplorer at the bottom left corner of the main-frame choose View/Display Scale Bar.

Attention:
The nomenclature used for the individual survey sites of the raw data contained in the folder Original Data does not correspond to the nomenclature used in this report. The descriptive file Survey_Skaenninge_2005.pdf in the folder Original Data uses the original notation.

In the folder Original Data the original data of each survey site is located in the subfolder original_area_#, with # substituting the site number according to original nomenclature. The second subfolder Area_#_for_AP_soft contains the original data with file-names modified for use with the processing software APsoft, developed by Alois Eder-Hinterleitner. The files in these subfolders are using the letters a,b,c,d,e,f,g,h for the areas 1,2,3,4,5,6,7,8. The lowest profile number is 0. For all areas the internally used x-coordinate is assumed to be the cross-line coordinate, while the internal y-coordinate is assumed to be the inline coordinate.

A .bes file describing the geometry of each survey for the APsoft software can be found in the subfolders Area_#_for_AP_soft.
2 Description of the Ground Penetrating Radar method

Ground Penetrating Radar, Ground Probing Radar (GPR) or Georadar is a geophysical measurement method that allows the investigation of the shallow subsurface. A GPR antenna is used to send electromagnetic waves into the subsurface. These waves are reflected from structures such as large stones, old foundations of buildings, pits, ditches or interfaces of geological layers. The reflected radar waves that are returning to the surface like an echo are recorded with the GPR antenna and used to generate an image of the subsurface.

The GPR technique

GPR antennas used for archaeological prospection typically emit an electromagnetic signal with an average frequency between 100 and 1000 Megahertz (MHz), similar to radio stations. In general, it can be said that the higher the frequency, the shorter the wave-length of the electromagnetic wave. The wave-length is defining how well we can resolve structures in the subsurface: a shorter wave-length of higher frequency is able to “see” smaller objects. On the other hand, high frequency electromagnetic waves suffer more from damping of the signal, compared to electro-magnetic waves with longer-wave lengths and lower frequency.

The frequency dependent damping has the effect that the amplitude of the electromagnetic signal decreases, the further the signal travels through the ground. Low frequency signals are better suited to look deeper into the ground than high frequency signals. Thus, for the selection of the antenna with the right frequency for our survey we need to make a compromise between penetration depth and desired resolution. Antennas with different frequencies are available (e.g. 100, 200, 250, 300, 500, 800, 900, 1000 MHz), and a 500 MHz antenna is often a good choice for archaeological investigations down to a depth of about 2 to 3 metres with 15cm to 20cm resolution.

The penetration depth and resolution of the georadar method does not only depend on the frequency of the antenna used, but as well on the soil properties at the measurement location. The physical properties of the ground determine the velocity and attenuation of the electromagnetic waves. In particular, the electrical conductivity of the soil can have a great effect on the radar waves.

Soils with high clay content, or soils that contain a large amount of conductive water, are difficult to investigate with georadar. The uppermost layers of such soils soak up the energy of the electro-magnetic waves and prevent the energy to travel deeper. Sandy soils allow much better depth penetration. Fresh-water in itself poses no problem to GPR investigations. It is possible to conduct a radar survey from a boat, by suspending the antennas into the water of a lake or by placing them on the floor of a rubber-boat. In that case the electromagnetic waves penetrate through the water into the sediment underneath. Similarly, it would be possible to measure on the frozen surface of lakes in winter time, for example to search for harbour constructions or wrecks in shallow water regions, that are inaccessible during summer due to reeds or other seasonal plants.
How is a GPR survey conducted?
Before a georadar survey is undertaken it is important to determine the specific conditions of the measurements site. Each project is different and requires the use of an antenna of suitable frequency and a carefully designed measurement grid. If linear structures, such as walls or ditches, are the target, it is best to measure perpendicular to the expected structure. Regular survey areas with equally long profiles allow faster, cheaper measurements, while survey areas that contain obstacles, such as trees, bushes, walls or fences, cause delays.

While the GPR antenna is pulled over the surface an electromagnetic source signal is emitted into the ground. The antenna will then “listen” for fractions of a second and record the returning signal which has been reflected or refracted in the subsurface. For each measurement position along the profile line a time-series of amplitude values (“GPR trace”) is recorded. It is important that the data is measured with very dense trace spacing (3cm in profile direction; 25 cm profile spacing).

How does GPR data look like?
Each GPR trace is a time-series of amplitude values of the reflections of the electromagnetic GPR signal, recorded with the receiver antenna, some time after emittance of the source signal from the source antenna, at a specific antenna location.
Fig. 2.5: Set of parallel GPR sections. This set of two-dimensional (2D) GPR sections can be merged into a three-dimensional (3D) data volume through interpolation between the sections. Normally, the sections are measured in zig-zag mode by pulling or pushing a GPR antenna back and forth over the survey area along parallel, equally long profile lines.

Such a 3D data volume can be cut like a cake in all directions. Slices of equal recording time, so called time-slices, can be generated by cutting the 3D data volume horizontally (Figures 2.6, 2.7).

Fig. 2.6: A horizontal slice cut through the 3D data volume with travel-time as vertical axis is called a time-slice, since all data values have the same two-way travel-time value.

If the velocity of the electromagnetic waves in the subsurface is known, the 3D data volume can be converted into a 3D block with depth as the vertical axis. Then it is possible to generate depth-slices, which show the reflecting structures at a certain depth or within a certain depth range. Often an average velocity is used for the time-to-depth-conversion (e.g. 10cm/ns). It should be noted that in the case of an average velocity used, depth variations of up to 50%, compared to the real depth, can remain present in the data.

Fig. 2.7: A time-slice showing cables, or pipes, and the foundation walls of medieval buildings.

Structures in depth are best recognizable by analyzing a series of depth-slices. From a series of depth-slice images an animation (simple movie) can be generated. Then the viewer can observe the emergence and change of different structures with increasing, or decreasing depth.

Fig. 2.5: GPR profile before (top) and after average trace removal (below). This process suppresses the direct-wave and reveals the reflections in the uppermost section. Furthermore, signal-ringing is removed from the data.
Other common GPR data processing steps are the removal of the average trace, or background removal. This process removes signal-ringing in the data and allows to image the uppermost region of the data, which otherwise would be hidden by the high amplitudes of the direct-wave. The direct-wave is the wave that travels directly from the source antenna to the receiver antenna, which are often located both inside the same GPR antenna box. The direct-wave is the first signal that is recorded by the receiver antenna. Since the direct-wave is of several ns length, it covers the reflections that occur in the uppermost layers of the subsurface.

What objects can GPR detect?
Under the right conditions georadar can be used to detect the foundations of buildings, canalisation pipes, pits, ditches, graves, cavities and geological structures such as layer interfaces and faults. It is important to realize that the GPR method cannot guarantee the detection of objects or structures, particularly if they are small in size (relative to the wave-length used), if their physical properties do not differentiate them from the surrounding material or if the soil conditions are adverse.

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Under the right conditions GPR measurements allow the archaeologist to obtain an image of structures that are hidden in the subsurface without digging. GPR surveying, similar to magnetic prospection, is a non-destructive method. In addition to the structural information obtained through magnetic prospection, GPR measurements provide information about the relative depth of the structures. If the velocity of the radar waves in the subsurface is known, the absolute depth of structures seen in the GPR data can be determined.

The results of georadar measurements can be used to plan excavation activities efficiently in regard of costs and time. GPR measurements make it possible to target interesting structures and to excavate selectively with the benefit of prior knowledge.

Suggested reading


3 Description of GPR measurements and obtained results

This section describes the technical details of the GPR survey as well as the exact location of the individual survey areas. For each survey area the data interpretation is presented and the results are discussed. An archaeological interpretation is suggested wherever possible. An overview of the survey areas is given in Figure 3.1.

The survey was conducted using a manually pulled Malå Geosciences 500MHz antenna with an X3M electronic unit and the RAMAC Monitor for data logging. A large distance wheel attached to the antenna was used for accurate positioning of the data. This system was similar to the system used by Sirri Seren during the survey at Skänninge in 2004. The antenna was pulled along 50m long profile lines that where marked every meter. If the geometry of the survey area required shorter profile length than 50m, the length of the profiles was reduced and measured to the nearest meter marking. Prior to the measurements the distance wheel was calibrated along a 50m profile.

The survey areas had been prepared through mowing of the grass. The survey areas were staked out using three 50m long measuring tapes and a robotic total station. For each survey area at least two reference points were measured with a geo-referenced total station.

For all measurements the data recording length was set to 98ns at 512 samples. The inline trace interval was set to 3cm and the cross-line profile distance was 50cm for survey areas 1 and 3, and 25cm for survey areas 2, 4, 5 and 6. The internal trace stacking was set to a value of 4.

The weather remained dry throughout the entire period of field work.

Data processing was conducted by Alois Eder-Hinterleitner (Institute for Meteorology and Geodynamics Vienna). The time-to-depth conversion of the GPR data was performed with a constant velocity of 10cm/ns for all survey areas.

![Figure 3.1: Photograph showing the survey areas alongside the railway north-east of the town centre of Skänninge. The blue arrows indicate the position and direction of the first GPR profiles of each survey area. Area 2 was measured during two successive days, therefore two start positions and directions are shown. Area 4 consists of a 98 GPR profiles perpendicular to the railway and three profiles parallel to the railway.](image)
3.1 Survey area 1

Survey area 1 is located opposite the excavation site where remains of S:t Olof’s monastery have been discovered. The survey site covers the slope of a hill (Figure 3.1.1). It is bounded in the east by the railway embankment and in the south by a hedge bordering a private garden, which contains survey site 4 (Figure 3.1.2).

Figure 3.1.1: Photograph showing survey site 1 located on a hill slope with the railway embankment in the east and the hedge of a garden in the south. The pump station is located in the north of the survey site and the excavation is located next to the large barn, visible in the left part of the photo.

Figure 3.1.2: Survey site 1 is located opposite site A and in continuation of site 4. Surveying with GPR between the fence and the railway track was not likely to result in any useful data due to buried pipes, cables and an uneven surface.

The survey was conducted by measuring parallel to the railway in zig-zag mode with 50cm profile spacing. The ground was relatively uneven, hampering the data acquisition.

Printouts of the individual GPR depth-slices can be found enclosed in the Appendix. The interpretation of site 1 is shown together with sites 3, 4 and 6 in Figure 3.14.
Figure 3.1.4: Interpretation of survey areas 1, 3, 4 and 6. The structures visible in the GPR data recorded at site 1 are little coherent due to the uneven ground and the relatively wide profile spacing of 50cm. Regions of high amplitude reflections are visible in the north and south of this area. The northern high amplitude region, marked grey in this Figure, is possibly caused by the gravel way of the pump house. The ground appears to be heaped up artificially at this location. The southern region of high amplitude reflection in site 1 is likely to be related to rubble in the ground: pieces of clay bricks protrude at the surface. Some linear features can be seen in the data that are parallel aligned to the excavated walls at the eastern side of the rail track, suggesting a continuation of the foundations of the monastery buildings on this side of the railway track. The western part of this area, which is coinciding with the slope of the hill, is relatively empty of strong reflections. This indicates a subsurface that is not disturbed from walls, pits or other larger artificial structures and traces of cultural activity.

The long linear structure that is indicated in light blue in area A appears to continue into the northern part of area 1. This continuation appears visible in the data but was omitted from the interpretation since it is likely to be a more recent pipeline or cable.

The clear structure of a house visible in area 4 does not continue into area 1.
3.2 Survey area 2

Survey area 2 is a larger strip of grassland parallel to and west of the railway line north of the river (Figures 1.1, 3.1). The sketch in Figure 3.2.1 gives the exact location of the survey area in local and global coordinates. Area 2 is bordering to the east to the railway embankment while it is bounded to the west by the hedge of a private garden and thick bushes. East of area 2, on the other side of the railway, an earlier excavation had resulted in the discovery of an old road and several pits (Figure 3.2.2). The entire area 2 was surveyed within two days (areas 2a and 2b in Figure 3.2.1) with a cross-line profile spacing of 25cm and an inline trace spacing of 3cm.

GPR depth-slices were generated with 10cm and 5cm thickness for this area assuming a constant velocity of 10cm/ns for the depth conversion.

The interpretation of the measured GPR data is shown in Figures 3.2.3 to 3.2.7. The main features seen in the data are an about 6-7m wide modern trench that is running parallel to the railway line, modern pipes or cables that are crossing the area, the continuation of the old road seen on Figure 3.2.2, a number of pits with up to 3m diameter, a well, agglomerations of stones and linear features attributable to artificial structures of historic or prehistoric origin.
Figure 3.2.3: Overview of GPR survey site 2 including the excavation results of the excavation east of the railway line and the excavation 2005 north of Motalagatan superimposed onto the orthophoto. The course of the river Skena is marked in blue. In the lower left part of the image the location of St. Ingrid’s monastery is shown as a light grey coloured rectangle. The two parallel black lines connecting site 2 and St. Ingrid’s monastery are the extrapolation of the course of the historic road that was discovered in the excavation east of the railway line and in the GPR data of site 2. This extrapolation is speculative and shall merely illustrate the possibility that the old road north of the river probably has been leading to the monastery, a site of historic importance. The old road and the bend in its course are likely to coincide with the road shown in the map of the year 1712 (Figures 3.2.4 and 3.2.5).
Figure 3.2.4: Map of Skänninge form the year 1712. The red circle shows a road that branches of Motalagatan and that matches well with the course of the road discovered in the excavation east of the railway line, as well as with the structures that were interpreted as road in the GPR data. The bend appears to be located exactly where it would be expected from the excavation and GPR measurement results (Figure 3.2.5).
Figure 3.2.5: The same map as shown in Figure 3.2.4 with the GPR interpretation and the course of the modern river superimposed. The historic road branching into Motalagatan shows a bend where as well the excavation and GPR results would suggest a change in direction. This bend is located at the location of the modern railway track. In order to achieve the alignment between the map from 1712 and the modern map in GIS a shift to the south-east and a minor clockwise rotation of the historic map is required, if the alignment of the map had been based on structures in the town centre of Skänninge.
Figure 3.2.6: Interpretation of the GPR data measured at site 2. The colour legend in the lower left corner refers only to the GPR interpretation. The colours used for the drawing of the excavated areas follow a different colour scheme. The most striking feature in the GPR data and interpretation is the recent anomaly caused by an about 6m wide, filled trench that has been dug parallel to the railway line and that is running along the entire length of area 2 (marked in yellow with a pattern of diagonal black lines). The map in the background shows three parallel lines indicating the pipelines or cables that have been buried in this trench. The grey areas indicate structures of higher reflectivity that could be caused by the local geology (e.g. layers of clay) or by artificial horizons of stone accumulations. In green and olive colour are pits and possible pit houses indicated. Single anomalies caused by large single stones or by accumulations of several stones are indicated as separate shapes while linear structures are marked with black thick lines. In the central part a strong and clear GPR anomaly with corresponding enclosure is interpreted as well and marked in blue colour. A presumable recent pipeline or cable is indicated in light blue in the northern part of area 2.
Figure 3.2.6: Close-up of area 2 showing all interpreted structures.
Figure 3.2.7: Central part of area 2 showing in detail the structure that has been interpreted as well (dark blue) as well as pits (green and olive) that have been dug into a layer of increased reflectivity (grey with black dots). This grey area is likely to be caused by a layer of geologic origin, e.g. a clay layer, marking the rim of the higher, flat area north of the river. South of this area the land slopes towards the river. Under the assumption that this layer is actually a clay layer the present pits can be clay pits of undetermined age or older pit houses. The nature of the region marked in grey, and of the content of the pits, could be easily investigated through augering by hand.
3.3 Survey area 3

Survey area 3 is located west of the railway line just south of Vistena gatan (Munka gatan) next to the pedestrian railway crossing. The area is quite small and its proximity to the house and the rail track suggest that the ground has been disturbed in this area through recent excavation for the foundations of the house, the laying of the rail track and related cable and pipeline works (Figure 3.3.2).

The exact location of the survey area 3 can be seen in Figures 3.3.1, 3.3.2 and 3.3.3. The interpretation of area 3 and its relation to the structures seen in areas 1, 4, 6, and A is shown in Figure 3.3.4.

**Figure 3.3.1:** Area 3 with survey lines shown and the first profile and grid points in local coordinates indicated.

**Figure 3.3.2:** Southern end of area 3 showing a manhole related to pipelines or cables that belong either to the building or to the railway track.

**Figure 3.3.3:** Sketch showing the survey geometry of site 3 with local and global coordinates and location and orientation of the first and second GPR profile.
Figure 3.3.3: Interpretation of area 1, 3, 4, 6 and A. The course of Vistena gatan is marked as yellow band. The areas measured with GPR are coloured pink. The excavated areas alongside the railway track are marked light brown, the interpreted walls seen in the radar data of areas 3 and A are drawn in dark grey while their assumed extrapolation is plotted in green. Due to the small size of area 3 it is difficult to interpret its structures in connection with the structures seen in data from areas 4 and A. The anomalies visible in the GPR depth-slice data of area 3 indicate several recent pipes or cables. It is currently not possible to address any of these anomalies as structures of archaeological interest.
3.4 Survey area 4

Survey area 4 is located in a private garden next to the railway line and opposite to the excavation of St. Olofs monastery. Figure 3.4.1 shows an extrapolation of the excavated walls across the railway line and into site 4.

![Figure 3.4.1: Aerial view of the excavation site (site A) east of the railway line and site 1 and 4 west of the railway line. This image shows the extrapolation of excavated walls across the railway into the north-east corner of the private garden (site 4). The shown extrapolations were drawn prior to the GPR measurements made in 2005.](image)

The survey geometry of site 4 is irregular and complicated due to the presence of bushes, trees and a workshop/garage building. Two perpendicular sets of GPR profiles were measured, the first consisting of 98 profiles oriented perpendicular to the railway track (Figure 3.4.2) and the second consisting of three GPR profiles measured parallel to the railway track (Figure 3.4.3). All profiles were recorded with 25cm profile spacing. Photographs of site 4 are shown in Figures 3.4.4 and 3.4.5. The GPR depth-slices of 5cm thickness and at 5cm intervals between 0m and 1m depth are displayed in Figure 3.4.6. **Attention:** the time to depth conversion was performed with a constant velocity of 10cm/ns. Therefore the depth-slices may be affected with a local depth error that may vary across the area. The depth-slices shall be regarded as showing locally the relative depth. Depth deviations of up to 50% are possible in the data. The interpretation of the data is presented in Figures 3.4.11 and 3.4.12.

![Figure 3.4.2: Sketch showing survey geometry of 98 GPR profiles measured perpendicular to the railway track at site 4.](image)

![Figure 3.4.3: Sketch showing survey geometry of 3 GPR profiles measured parallel to the railway track of site 4.](image)
Figure 3.4.4: View of area 4 from south towards north. The red barn in the background is located next to the railway line and marks the site of St. Olof’s monastery. The electricity masts of the railway can be seen in behind the hedge. The barn at the left is a workshop and garage.

Figure 3.4.5: View of area 4 from north-west, looking towards the hidden pedestrian railway crossing of Vidstena gatan between the pink and yellow houses. The barn at the right houses the garage and workshop.
Several anomalies can be seen in the GPR depth-slice data (Figure 3.4.6). The most striking features are the dark, linear anomalies at the northern corner of the survey area, clearly visible between 25cm and 65cm depth (Figures 3.4.6 and 3.4.7). The three walls of a building meet at right angles. The south facing front wall has a width of about 7.4m. According to the unmigrated GPR data the wall thickness at approximately 45cm depth is about 40cm. Specialized data processing (migration) would collapse the reflection hyperbolae in the data and result in more focused, even thinner structures.

Figure 3.4.7: Depth-slice at 40-45cm depth. An anomaly of three walls meeting at right angles is clearly visible. The front wall is facing south. The structure appears to be well preserved.
The well preserved walls of this building indicate that the garden has not been subjected to agricultural plowing, such as the neighbouring area just north to the garden.

![50 cm profile spacing](image1.png) ![25 cm profile spacing](image2.png)

**Fig. 3.4.8:** Comparison between 500MHz GPR data surveyed with 25cm profile spacing (right) and simulated 50cm profile spacing (left) through removal of every other profile. This example shows only the data measured at site 4 perpendicular to the railway track. It is obvious that a measurement with 50cm profile spacing would be insufficient to sample the thin wall of the building in the north correctly. This wall could be wrongly interpreted as a row of columns if measured with 50cm profile spacing.

Between 15cm and 45cm depth a bend structure is visible in the GPR data, resembling the shape of the mirrored letter "S". This structure has a width of between 80cm and 1.35m. This structure could possibly be interpreted as a way. The animation of the depth-slices between 20cm and 45cm depth generates the impression of cart traces in form of darker edges of this anomaly.

![25-30cm](image3.png) ![25-30cm](image4.png)

**Figure 3.4.9:** Depth-slice at 25-30cm depth with (right) and without (left) interpretation showing a structure which resembles the mirrored letter "S". This structure is about 1m wide and could be interpreted as a way. It appears as if cart tracks are visible in form of a darkening of the anomaly to its sides.
The third obvious structure is a dark anomaly in the centre of the survey area, clearly visible at depths below 60cm (Figure 3.4.10). This anomaly is interpreted as a well. The reduction in amplitude with increasing depth visible in Figure 3.4.6 is due to the reduced amount of GPR energy reflected from greater depths, since more energy is lost when the length of the travel path increases.

**Figure 3.4.10**: Depth-slice at 60-65cm depth showing a structure of high amplitude with a diameter of about 90cm. This anomaly is visible till 1.30m depth. At greater depths the amount of reflected energy is generally low and the foot-print of the radar antenna becomes too wide for clear focusing of structures of this size.

**Figure 3.4.11**: Interpretation of the GPR data measured at sites 1, 4 and 6 as well as the interpretation of the data measured at site A in 2004.
Figure 3.4.12: Close-up of the interpretation of area 4. The building in the northern part of area 4 is clearly visible and possible additional structures inside the building are indicated. The orientation of this building is similar to the structures excavated and prospected east of the railway line, indicating that this structure existed at the same time and in context to St. Olof’s monastery. Just south of the clearly visible building further structures with right angles and similar orientation are indicated using black lines. These structures are weaker expressed in the data. Central in area 4 a strong GPR anomaly is interpreted as well with possible enclosing structures visible in the data. The southern part of area 4 contains further interesting linear structures, indicating possibly the presence of remains of one or more additional buildings.
3.5 Survey area 5

Survey area 5 is located east of the hill with the field name “Biskopsholmen”, between site 1 in the south and the river in the north (Figures 1.1 & 3.1). The sketch shown in Figure 3.5.1 displays the exact location of measurement area 5.

Area 5 is of interest since canalization works between the pump house and the two gullies shown in Figure 3.5.1 revealed wooden planks shown in Figure 3.5.2. Furthermore, on the eastern side of the railway line a wood and stone construction has been excavated in 2005 (Figure 3.5.3).

Photographs of survey area 5 are shown in Figure 3.5.4 a-c. The interpretation and the results are presented in Figure 3.5.5. Due to the relatively low elevation the soil has higher soil water content and presumably as well higher clay content at site 5. Therefore the penetration depth is lower and the resolution of the GPR data is less than at sites that are located higher.
Figure 3.5.4: Overlapping views of survey area 5: (a) View to the north with railway embankment and overhead contact wire in the right part of the image. The line of trees indicates the location of the river. The slightly higher ground with the two gullies is marked by the higher grass. (b) View to the east. (c) View to the south showing the pump house. In the background the large horse stable of area A can be seen. Area 1 is located behind the pump house. The way shown in (a) and (c) can be clearly identified in the GPR data.
Figure 3.5.5: Interpretation of the GPR measurements undertaken at area 5 combined with the results of the measurements from area B. The course of the river is indicated in blue and the background image is the orthophoto. East of area 5 on the other side of the railway line the wood and stone construction excavated in 2005 is shown (see Figure 3.5.3). These constructions are located on either side of a drainage ditch that is running towards the north east and that is clearly visible in the orthophoto. Therefore these constructions could be related to this drainage ditch or possibly belong to a river embankment of a time when the Skena river was running around the southern side of the hill Biskopsholmen. The interpretation of area 5 shows that structures visible in area B continue into area 5. Only little structures can be seen in the data, which may be due to less favorable soil conditions (clay, high soil humidity) compared to regions that are located higher and on more sandy soil.
3.6 Survey area 6

Survey area 6 is a repeated survey covering a 13m by 15m rectangular area at the location of survey area A. The survey of site 6 was conducted with twice as dense profile spacing as the survey of area A (25cm versus 50cm).

The location of survey area 6 is illustrated in a sketch in Figure 3.6.1. A photograph of the site is shown in Figure 3.6.2. The purpose of the repeated measurement at site 6 was the attempt to image better a structure discovered during the excavation.

Figure 3.6.1: Sketch showing survey geometry of site 6.

Figure 3.6.2: Photograph showing survey area 6.

Figure 3.6.3: Excavation next to survey area 6. The determination of the course of the field stone wall shown in this picture was the goal of the survey at area 6. This wall has a slightly different orientation compared to the structures seen in the GPR data measured at site A in 2004. The cement wall left in the picture is of more recent origin.

Figure 3.4.11 shows the interpretation of the structures in the data measured at site 6. Three linear features at right angle can be seen with a slightly different orientation than the main complex of the monastery buildings.
## 4 Ground Penetration Radar Survey Documentation

<table>
<thead>
<tr>
<th>Survey name</th>
<th>Skänninge S:t Olofs monastery 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey index</td>
<td></td>
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<tr>
<td>Survey purpose</td>
<td>Detection of archaeological structures along railway line north east of the town centre of Skänninge, with particular interest in the areas close to the excavation site of S:t Olofs monastery and the area between Motalagatan and Skenaån</td>
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<tr>
<td>Bibliographic references</td>
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</tr>
<tr>
<td>Survey keywords</td>
<td>GPR, monastery</td>
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<tr>
<td>Spatial coverage</td>
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<tr>
<td>Administrative area</td>
<td>Östergötland, Sweden</td>
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<tr>
<td>Country</td>
<td>Östergötland, Sweden</td>
</tr>
<tr>
<td>Solid geology</td>
<td></td>
</tr>
<tr>
<td>Drift geology</td>
<td>Sandy clay</td>
</tr>
<tr>
<td>Duration</td>
<td>Morning Monday June 27th 2005 until evening Friday July 1st 2005</td>
</tr>
<tr>
<td>Weather</td>
<td>Dry. The weeks prior to the survey have been quite wet</td>
</tr>
<tr>
<td>Soil condition</td>
<td>Dry</td>
</tr>
<tr>
<td>Land-use</td>
<td>Mowed grassland in case of areas 1 and 5; Mowed grass in private garden in case of area 3 and 4; Clear ground previously covered with dung pile in case of area 6</td>
</tr>
<tr>
<td>Monument type</td>
<td>Medieval monastery; Viking age settlement; historic road</td>
</tr>
<tr>
<td>Monument period</td>
<td>1237; Stone-, Bronze-, Iron-, Viking-age</td>
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<tr>
<td>Scheduled Ancient Monument (SAM) number</td>
<td></td>
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<tr>
<td>Surveyor</td>
<td>2005: Immo Trinks, Swedish National Heritage Board, UV Teknik, Box 5404, 114 84 Stockholm, Sweden E-mail: <a href="mailto:immo.trinks@raa.se">immo.trinks@raa.se</a></td>
</tr>
<tr>
<td></td>
<td>2004: Sirri Seren, Central Institute for Meteorology and Geodynamics, Geophysics Dept., Hohe Warte 38, A-1190 Wien, Austria; E-mail: <a href="mailto:sirri.seren@zamg.ac.at">sirri.seren@zamg.ac.at</a></td>
</tr>
<tr>
<td></td>
<td>Wolfgang Neubauer, VIAS-Vienna Institute for Archaeological Science, Geophysical Prospection, Franz Kleingasse 1, A-1190 Vienna, Austria E-mail: <a href="mailto:Wolfgang.Neubauer@univie.ac.at">Wolfgang.Neubauer@univie.ac.at</a></td>
</tr>
<tr>
<td>Depositor</td>
<td>Immo Trinks, Swedish National Heritage Board, UV Teknik, Box 5404, 114 84 Stockholm, Sweden E-mail: <a href="mailto:immo.trinks@raa.se">immo.trinks@raa.se</a></td>
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<tr>
<td>Primary archive</td>
<td>Swedish National Heritage Board, UV Teknik, Box 5404, 114 84 Stockholm, Sweden</td>
</tr>
<tr>
<td>Related archive</td>
<td></td>
</tr>
<tr>
<td>Copyright</td>
<td>Riksantikvarieämbetet</td>
</tr>
<tr>
<td>Geophysical coordinate system</td>
<td>Up to 50m profile lines oriented perpendicular (area 2) and parallel (areas 1, 3, 5 and 6) to railway line. Area 4 was surveyed mostly perpendicular to railway line, with 3 profiles parallel to railway line. Detailed survey grids and coordinates are shown in separate sketches for each survey area.</td>
</tr>
<tr>
<td><strong>Georeferencing</strong></td>
<td>All survey areas were geo-referenced using a total station from the excavation at S:t Olofs monastery and from the excavation north of Motalagatan.</td>
</tr>
<tr>
<td>--------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------</td>
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<tr>
<td><strong>Coregistration with site grid</strong></td>
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<tr>
<td><strong>Survey type</strong></td>
<td>Ground Penetrating Radar</td>
</tr>
<tr>
<td><strong>Instrumentation</strong></td>
<td>One single manually towed Malå Geosciences 500MHz antenna, X3M electronic unit, RAMAC Monitor, large (100MHz) survey-wheel, tow-bar</td>
</tr>
</tbody>
</table>
| **Area surveyed**        | Area 1: 1226 m²  
Area 2: 2624 m²  
Area 3: 248 m²  
Area 4: 379 m²  
Area 5: 989 m²  
Area 6: 198 m²  
Total: 5664 m² |
| **Method of coverage**   | Regular grid of parallel profile lines, Zigzag                                                                                                                                          |
| **Traverse separation**  | 50cm crossline in case of areas 1 and 3, 25cm in case of area 2, 4, 5 and 6                                                                                                               |
| **Reading interval**     | 3cm inline                                                                                                                                                                                 |
| **Grid size**            | Maximum profile length: 50m                                                                                                                                                                |

This documentation is based on the guide: *Geophysical Data in Archaeology: Guide to Good Practice* by Armin Schmidt, Arts and Humanities Data Service (http://ads.ahds.ac.uk/project/goodguides/geophys/).
5 Appendix

The Appendix contains printouts of depth-slices of the measured areas.