Survey report

Ground Penetrating Radar survey for Archaeological Prospection at Mälsåker Slott 2006

Methodology, data acquisition, results, interpretation

Immo Trinks
Photo title-page: Immo Trinks
Mälsåker Slott seen from the south with Sjögården in the foreground.

Contact information:
Riksantikvarieämbetet
UV Teknik
Instrumentvägen 19
126 53 Hägersten

© Riksantikvarieämbetet, UV Teknik 2006
Table of contents

1 Introduction ..............................................................................................................................................................................5
2 Description of the Ground Penetrating Radar method .................................................................................................11
3 Description of GPR survey and discussion of the results .................................................................................................17
   3.1 Survey site *Entréträdgården* ...............................................................................................................................................17
   3.2 Survey site Sjögården .........................................................................................................................................................45
   3.3 Survey site Formträdgården..............................................................................................................................................53
4 Description of the geodetic survey .........................................................................................................................................55
5 Appendix ................................................................................................................................................................................59
   5.1 GPR depth-slices for survey site *Entréträdgården* ..............................................................................................................60
   5.2 GPR depth-slices for survey site Sjögården .......................................................................................................................90
6 Survey Documentation.........................................................................................................................................................103
1 Introduction

In August 2006 the Archaeological Excavation Department of the Swedish National Heritage Board conducted Ground Penetrating Radar (GPR) measurements in the grounds of Mälsåker Slott in order to investigate the presence of historic and archaeological structures in the subsurface. The survey was commissioned in order to probe the existence and location of traces of historic park and garden architecture, in particular the layout of gravel paths and green areas, as well as to detect remains of buildings and walls in the ground.

During one day of field work two areas were surveyed extensively: The so called Entréträdgården located north of Mälsåker Slott and the Sjögården south of it (Figure 1.3). A third area, the Formträdgården east of Mälsåker Slott, was briefly scanned in order to test the suitability of the GPR method for a future survey at this site in terms of signal penetration depth and presence of detectable anomalies.

The processing of the GPR data was performed by Alois Eder-Hinterleitner (Central Institute for Meteorology and Geodynamics, Vienna) using specialized software. The analysis and interpretation of the geo-referenced GPR data was conducted within the Geographical Information System (GIS) ArcView and ArcMap.

The exact location of the survey areas was measured using Real-Time-Kinematic Network Global Positioning System (RTK-GPS) with centimeter accuracy. In addition, the position of Mälsåker Slott and nearby points was topographically surveyed to allow for the geo-referencing of existing recent and historic maps.

Historical maps (Figures 1.4 to 1.7) of the area were rectified and geo-referenced and used together with the GPR data for the identification and interpretation of anomalies. The maps in Figures 1.3 to 1.7 show the same area at the same scale.

Section 2 provides a short introduction to the methodology of archaeological prospection using the GPR method. In Section 3 the measured data for the different survey areas and their interpretation are presented and discussed separately. Section 4 describes the geodetic survey. The Abstract contains depth-slices of the data from both survey areas. The depth information of each depth-slice is approximate, since only an approximate constant velocity of 10cm/ns was used in the time-to-depth conversion of the data. The actual depth can vary by up to 50%. However, the relative depth of structures is correctly imaged in subsequent depth-slices.

The help offered by Viveka Hoff and the trainees of the Mälsåker Slott Parkhytta during the field work permitted the survey of both Entréträdgården and Sjögården in time and was greatly appreciated.
Figure 1.1: Undated photograph showing Mälsåker Slott and the Entréträdgården seen from the north. The central gravel pathway is flanked by two symmetric circular path formations located approximately in the centre of the park.
Photo source: Nordiska museum. Courtesy of Viveka Hoff (Institutionen för landskapsplanering SLU Ultuna).

Figure 1.2: Photograph of the western part of the Entréträdgården taken from the upper floor of Mälsåker Slott. Crop marks in form of yellow structures in the lawn indicate dry soil due to remains of gravel paths. The semi-circular shape in the centre resembles part of the circular path shown in Figure 1.1.
Photo: Viveka Hoff (Institutionen för landskapsplanering SLU Ultuna).
Figure 1.3: Map from the year 2000 showing an inventory of the vegetation (Elg R., Lagerström T. & Suneson T., Institutionen för landskapsplanering, Uppsala). Trees and bushes are marked with blue circles. Målsåker Slott is shown in the centre left as blue filled polygon. The grass areas in the Sjögården are as well marked as blue shapes. The small crosses in the Formträdgården indicate the location of former fruit trees.
Image source: Viveka Hoff (Institutionen för landskapsplanering SLU Ultuna).

Figure 1.4: Section from map of Målsåker Slott by Nils Nelien 1947/1948. The design of the Entréträdgården shows two circular pathways and adjoining grass or green areas. This layout appears similar to the design shown in the photo of Figure 1.1
Image source: Viveka Hoff (Institutionen för landskapsplanering SLU Ultuna).
Figure 1.5: Map from 1853-1855 showing a cross-shaped layout of paths in the Entréträdgården with a central circular walkway. In the Formträdgården a symmetric design of flower beds or lawn intersected by gravel or sand path can be seen. The Sjögården does not show any green areas.
Image source: Viveka Hoff (Institutionen för landskapsplanering SLU Ultuna).

Figure 1.6: Map from the year 1800 (LMV Nyköpings lantmäteri). In the southern part if the Sjögården two minor buildings are shown arranged symmetric to the side wings of Mälsåker Slott. No structures are mapped in either the Formträdgården or the Entréträdgården.
Image source: Viveka Hoff (Institutionen för landskapsplanering SLU Ultuna).
Figure 1.7: Undated old map of Mälsåker Slott showing in red colour a number of buildings surrounding the area that is now known as Sjögården. The Formträdgården appears to be surrounded by a wall or ditch. In comparison with the maps in Figures 1.3 to 1.6 it is obvious that the pier into lake Mälaren is shown shorter on this map. If the length of the pier is correctly mapped this could be explained with a relative higher water level or lower land level (possibly explainable with the postglacial land-rise) at the time of the creation of this map.

Image source: Viveka Hoff (Institutionen för landskapsplanering SLU Ultuna).

How to use this report

The data presented in this report is best viewed by opening the PDF file in Acrobat Reader and displaying one page at a time or using the full-screen display mode. Then it is possible to flip between subsequent depth-slices and depth-slices and corresponding interpretations using the up and down arrow, or “Page Up”, “Page Down” keys. Thus anomalies in the data become easier visible and coherent structures located at different depth can be seen interconnected.

The paper copy of this report contains a DVD including the report in electronic form in PDF format in the folder “Report”.

The original GPR data and its geometry information are included in the folder “Original Data”.

The result of the GPR data processing is contained as GPR depth-slices of 5cm and 10cm thickness in form of geo-referenced TIFF images in the folder “Processed Data” and corresponding sub-folders “5cm” and “10cm” for each of the two survey sites Entréträdgården and Sjögården, with and without filters applied.

The folder “GIS Data” contains the geo-referenced GPR data and its interpretation in form of depth-slice TIFF images, maps, and shape-files in ArcGIS format. The project file “Georadar_Mälsåker_2006.mxd” can be opened with ArcMap 9.1 software. The path to the shape-files used by this project file are set relative to the location of the project file.
Further data analysis and use of the data is possible within a Geographical Information System (GIS), e.g. *ArcView*, *ArcMap* or *ArcExplorer*.

The freely available 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 *ArcExplorer 2*. On all other systems choose the Java Edition *ArcExplorer 9.1*.

In order to obtain the exact coordinates or dimensions of structures and anomalies of interest it is recommended to load the data into *ArcView*, *ArcMap* 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.
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 electro-magnetic 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 electro-magnetic 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 electro-magnetic 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 electro-magnetic 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 electro-magnetic 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 electro-magnetic 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 electro-magnetic 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.

![Figure 2.2: Lars-Inge Larsson operating the Sensors & Software Noggin Plus 500 MHz antenna mounted in the SmartCart. The data logger with integrated monitor is fastened in a carrier frame in front of the operator. Profile lines with 1m separation distance are visible on the ground. The antenna is pushed along these lines and in between them with a GPR profile spacing of 25cm. Every 5cm along the profile a GPR trace is recorded.](image)

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 (5cm 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.

Each GPR profile consists of a large number of GPR traces. These traces can be plotted as an image with the profile distance as horizontal axis and the recording (“listening”) time as vertical axis (Figures 2.3, 2.4). Such an image is called a "GPR section" or "GPR profile".

![Figure 2.3: A GPR section consisting of many GPR traces. The vertical axis is showing the two-way travel time of the GPR signal, and the horizontal axis denotes the distance along the profile.](image)
It is common to record many parallel GPR sections by measuring with the GPR antenna in zig-zag mode along parallel profiles across the survey area. The \textit{cross-line} distance between the sections should be 25cm. The \textit{inline} distance of traces in direction of the profile should be 3cm.

The individual GPR sections are merged into a three-dimensional (3D) data volume (Figure 2.5). Data values between the profile sections are interpolated in order to obtain a comparable sample density in inline and cross-line directions.

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

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.

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.

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.

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 survey and discussion of the 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. The location of the survey areas is indicated in Figure 1.3.

The survey was conducted using a manually operated Sensors & Software 500MHz Noggin Plus antenna mounted together with a DVLIII data logger onto a SmartCart. An odometer (distance measuring wheel) attached to one of the cart wheels was used for accurate positioning of the data along the profile line. The antenna was pulled along up to 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 odometer was calibrated along a known distance. The exact position of the GPR survey areas was measured using a network RTK-GPS (see Section 4).

3.1 Survey site Entréträdgården

In case of survey site Entréträdgården the recording time of the GPR system was set to 60ns at 512 samples. Assuming a constant velocity of 10cm/ns in the subsurface this recording time would allow for the registration of reflected signals from a maximum depth of 3m. 4-fold trace stacking was chosen for improved signal-to-noise ratio. In direction of each GPR profile traces were recorded at 5cm intervals. The cross-line profile spacing was 50cm. The dimension of the survey area was 24m times 59m. Profile direction was east-west with alternating orientation of subsequent profiles (zig-zag mode).

The days and night prior to the survey were rainy, causing the soil to be relatively humid. A light rain shower interrupted the survey.

The data processing was conducted by Alois Eder-Hinterleitner (Institute for Meteorology and Geodynamics, Vienna). Time-to-depth conversion of the GPR data was performed with a constant velocity of 10cm/ns for the entire subsurface. Since no absolute velocity values were determined the depth information of the depth-slices can vary up to 50%.

Figure 3.1.1 shows the survey area Entréträdgården as seen from the upper floor of Mälsåker Slott (see as well Figure 1.2). In the centre of the survey area a yellow structure caused by dry grass indicates varying soil humidity due to remains of old gravel paths. A circular pattern of paths in the Entréträdgården is as well shown in the map from 1947/48 (Figure 1.4). Figures 3.1.2 to 3.1.8 show depth-slices of 5cm thickness between 0m and 0.35m depth.

The interpretation of this data is shown in Figures 3.1.9a,b to 3.1.16a,b. For each discussed depth-slice structures of interest are drawn and where possible an interpretation is suggested. Each pair of Figures (a and b) should be viewed in comparison.

Figure 3.1.17 shows an overview of all major interpreted structures at the survey site Entréträdgården.

Figure 3.1.18 presents a superposition of the maps from the years 1947/48 and 2000 with the findings of GPR survey. A good agreement between the structures shown on the 1947/48 map and the garden design deducted from the GPR data can be observed.
Figure 3.1.1: The survey site Entréträdgården is located north of Mälsåker Slott. This photograph shows the western part of the Entréträdgården with the central gravel pathway at the right. On the southern area of the eastern part temporary barracks and containers obstructed a GPR survey. The parallel GPR survey lines were run in east-west orientation, starting east of the gravel path and running straight to the edge of the mowed grass in the west, which coincides with the edge in the terrain. The survey area extended up to the tall trees that can be seen in the background.

Photo: Viveka Hoff (Institutionen för landskapsplanering SLU Ultuna).

Printouts of the individual GPR depth-slices of the Entréträdgården area with 10cm thickness can be found enclosed in the Appendix 5.1.
Figure 3.1.2: Depth-slice of 5cm thickness covering the depth range 0.00 to 0.05m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 3.1.3: Depth-slice of 5cm thickness covering the depth range 0.05m to 0.10m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 3.1.4: Depth-slice of 5cm thickness covering the depth range 0.10m to 0.15m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 3.1.5: Depth-slice of 5cm thickness covering the depth range 0.15m to 0.20m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 3.1.6: Depth-slice of 5cm thickness covering the depth range 0.20m to 0.25m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 3.1.7: Depth-slice of 5cm thickness covering the depth range 0.25m to 0.30m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 3.1.8: Depth-slice of 5cm thickness covering the depth range 0.30m to 0.35m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 3.1.9a: Depth-slice (5-10cm) showing the recent gravel path.
Figure 3.1.9b: Interpretation of the recent gravel path shown in Figure 3.1.9a.
Figure 3.1.10a: Depth-slice (10-15cm) showing pattern of old gravel paths and lawn areas.
Figure 3.1.10b: Interpretation of the old gravel path and lawn areas pattern visible in Figure 3.1.10a. This interpretation is based on the analysis of several depth-slices of the depth range 0-30cm.
Figure 3.1.11a: Depth-slice (10-15cm) showing an in-filled trench in the lawn area. The trench runs from south-south-west to north-north-east and turns in the centre of the survey area towards east-south-east with an almost right angle.
Figure 3.1.11b: Interpretation of the in-filled trench visible in Figure 3.1.11a. This structure appears to be visible due to a slightly lighter colour of the grass in the photographs shown in Figures 1.2 and 3.1.1.
Figure 3.1.12a: Depth-slice (25-30cm) showing a continuation of the in-filled trench that is visible in Figure 3.1.11a to the north. The trench appears to bend eastward in the northern part of the survey area. The reflection amplitude of this structure is lower than of that shown in Figure 3.1.11a.
Figure 3.1.12b: Interpretation of the continuation of the deeper trench visible in Figure 3.1.12a (yellow). The interpretation of the shallower in-filled trench visible in Figure 3.1.11a is shown in addition.
Figure 3.1.13a: Depth-slice (25-30cm) showing a dark rectangular reflection in the centre-left region of the survey area. Furthermore, two dark linear anomalies are visible between this rectangular structure and the central gravel path that is leading to Mälssåker Slott. The rectangular structure appears to coincide with the area of bare ground visible in photographs (Figures 1.2 and 3.1.1).
Figure 3.1.13b: Interpretation of the dark rectangular reflector visible in Figure 3.1.13a. It is possible that this rectangular structure (marked in yellow colour) is located at the western end point of the horizontal cross-bar that was formed by the path shown in the map of year 1853-55 (Figure 1.5). The dark linear anomalies (orange) leading to the rectangular structure should be interpreted with caution since their orientation coincides with the direction of measurement of the GPR profiles.
Figure 3.1.14a: Depth-slice (15-20cm) showing a circular structure in the northern part of the old northern lawn area indicated in Figure 3.1.10b.
Figure 3.1.14b: Interpretation of the weak circular structure that may exist in the data of the northern part of the survey area shown in Figure 3.1.14a.
Figure 3.1.15a: Depth-slice (65-70cm) showing a dark linear structure diverging from the central gravel path that is leading to Mälsåker Slott.
Figure 3.1.15b: Interpretation of the dark linear structure that is visible in the depth-slice data shown in Figure 3.1.15a. This structure could be caused by old vehicle/cart traces.
Figure 3.1.16a: Depth-slice (125-130cm) showing some other reflective structures in the data, such as a darker region in the south-western corner of the survey area.
Figure 3.1.16b: Interpretation of other structures that are visible in the data.
Figure 3.1.17: Overview of the major interpreted structures in the GPR data surveyed in the Entréträdgården. The former lawn areas are indicated through green colouring. The green coloured area of the south-west lawn should actually extend in a rounded form to the south, as it can be seen quite clearly in the depth-slices shown in Figures 3.1.5 and 5.3.
Figure 3.1.18: Superposition of the GPR survey results, the map from 1947/48 and the vegetation inventory map from the year 2000. Good agreement can be observed between the garden layout shown in the map from 1947/48 and the observed structures. It appears as if some of the linear anomalies drawn in red even indicate the rounded southern edge of the southern lawn, as shown in the 1947/48 map. The same garden layout appears to be visible in the photograph shown in Figure 1.1.
3.2 Survey site Sjögården

This section describes the results of the GPR survey conducted south of Mälsåker Slott in the Sjögården (Figure 3.2.1). The area that was surveyed with 25cm spacing between parallel GPR profiles is shown in Figure 3.2.2. Direction of the profiles was west-north-west to east-south-east.

The uppermost depth-slice of 10cm thickness shows the current layout of grass and gravel areas (Figure 3.2.3). Dark “stains” visible as regions of higher reflectivity in the grass area are possibly caused by high soil humidity due to rain showers during the course of the survey. An interpretation of the structures seen in Figure 3.2.3 is given in Figure 3.2.4.

The depth-slice from 40-50cm depth shown in Figure 3.2.5 reveals a different layout of green areas and ways. The shape of the green areas is more curved. Figure 3.2.6 displays the interpretation of green areas and ways from several depth-slices.

A superposition of the interpretations of the recent and the older garden layout and the map from the years 1947/48 in Figure 3.2.7 shows that the garden layout has not changed dramatically during the last 59 years. In earlier times however, a different garden design was in place. The older garden layout visible in the GPR data is neither shown in the maps from the years 1853-55 (Figure 1.5) nor in the map from the year 1800 (Figures 1.6 and 3.2.9).

Figure 3.2.8 shows structures that can be seen in the GPR data. Their interpretation is more difficult. Some of these structures may be caused by cables, pipes or in-filled trenches in the subsurface. Others are caused by accumulations of stones (or possibly bricks).

The part of the map from the year 1800 shown in Figure 3.2.9 displays two buildings aligned symmetrically with the sides of Mälsåker Slott, as well as a circular structure in the central park path. In Figure 3.2.10 the GPR survey area and the structures shown in the vegetation inventory map are superimposed. A good agreement between structures in the map (trees?) with the two trees on either side of the park can be observed (see photo on title-page and Figure 4.5).

Figure 3.2.11 shows structures that are visible in the GPR depth-slices superimposed onto the map from the year 1800. An aggregation of GPR anomalies coincides with the location and orientation of the western wing building. The corresponding structures show clearest as dark anomalies in the depth-slice taken at 170-180cm depth (Figure 3.2.12). Furthermore, a region of increased reflectivity (dark grey or black colour in the depth-slice image) can be seen where the map from the year 1800 shows a circular structure in the central park path. At the same location a ring shaped structure can be seen in the depth-slice at 20-30cm depth.

Printouts of the individual GPR depth-slices of the Sjögården area with 10cm thickness can be found enclosed in the Appendix 5.2.

*Attention: As stated above, all depth information is based on a time-depth conversion of the GPR data using a constant velocity of 10cm/ns for the entire subsurface. The actual depth can vary by up to 50% up or down! Without a detailed velocity analysis only relative depth at a given location should be relied on.
Figure 3.2.1: Map showing the survey area Sjögården just south of Mälsåker Slott. The two blue circles on either side represent large trees, while the polygonal blue shapes are grass areas (see photograph on title page and Figure 4.5).

Figure 3.2.2: The GPR survey area is shown in yellow. The red dots mark topographic survey points (see Section 4).
Figure 3.2.3: Depth-slice (0-10cm) showing the recent, visible garden design with gravel paths, lawn areas and the sun dial surrounded by a piece of lawn. Some of the dark stains in the green and gravel areas may be due to rain during the survey.

Figure 3.2.4: Interpretation of structures visible in the uppermost depth-slice (0-10cm). The red lines mark boundaries between grass and gravel areas.
Figure 3.2.5: Depth-slice (40-50cm) showing an older garden design with gravel paths, lawn areas and the sundial surrounded by a piece of lawn.

Figure 3.2.6: Interpretation of structures visible in depth-slice 40-50cm and other depth-slices. The green lines mark boundaries between old grass and gravel areas.
Figure 3.2.7: Superposition if the structures shown in Figures 3.2.4 and 3.2.6 onto the map from the year 1947/48.

Figure 3.2.8: The thin blue lines mark structures seen in the data. The yellow area is the GPR survey area.
Figure 3.2.9: Section of the map from the year 1800 showing the same region as Figures 3.2.1 to 3.2.13. Note the two buildings and the circular structure in the centre.

Figure 3.2.10: Section of map from the year 1800 with the GPR survey area superimposed as white line and the structures shown in the vegetation inventory map as black lines. Note the marked black structures in the map that coincide well with the two modern trees on either side.
Figure 3.2.11: Superposition of the linear structures shown in Figure 3.2.8 onto Figure 3.2.10. Note the structures marked in blue that coincide with the circular feature in the centre, as well as the structures that coincide well in orientation and dimension with the western wing building.

Figure 3.2.12: Depth-slice (170-180cm) showing reflections from structures that are likely to originate from foundations of the western wing building shown in the map from the year 1800. Note that similar structures are not visible in case of the eastern wing building. A region of increased reflectivity can be seen where the central circular structure is shown in the map from the year 1800.
Figure 3.2.13: Shallow depth-slice (20-50cm) showing a ring-shaped structure (marked with red circle) where a circular structure is shown in the map from the year 1800.
3.3 Survey site *Formträdgården*

Using a 500 MHz GPR antenna the area of the so called *Formträdgården* was scanned with several GPR profiles running east-west and north-south. The data was visibly observed and evaluated on the screen of the data monitor and logger unit. The average penetration depth of the signal after several days with heavy rain showers was about 1m. In the eastern part of the *Formträdgården* the penetration depth was smallest, about 50cm, indicating a thin cultural, humus layer on top of underground with rich clay content.

At several spots to the centre and western part of the area penetration depth between 1.5m and 2m were observed.

It was possible to use the *SmartCart* for surveying on the surface with relatively short, mowed grass. Some small scale topography due to remains of former fruit trees may cause minor artifacts in a large spatial survey.

Particularly in the western and central part of the area, where the surface slopes towards the east, a considerable number of reflections (reflection hyperbolae, short horizontal reflectors) were observed in the data.

Similar to the results obtained through GPR survey of the *Entréträdgården* and the *Sjögården* a GPR survey (using a 500 MHz antenna) of the *Formträdgården* should be successful in revealing coherent structures of older garden designs and wall and stair constructions if present.
4 Description of the geodetic survey

The exact location and height of the GPR survey areas and of Mälsåker Slott was determined using a Network RTK-GPS (Trimble R8) with centimeter accuracy (measurement inaccuracy below 2cm). For each of the survey sites Entréträdgården and Sjögården four points where measured.

Due to the diameter of the RTK-GPS antenna (19cm) the true positions of the corner points of Mälsåker Slott (735, 736, 742) deviate by 9.5cm.

The measured points and their coordinates are listed in the table below. Their location is shown in the map in Figure 4.1.

**Point 729:** North-western corner of GPR survey site **Sjögården** with local coordinates (0/0).
**Point 730:** The centre of the southern of the two man-hole covers at the western edge of **Sjögården** (south of the west wing of the Slott).
**Point 731:** The centre of the northern of the two man-hole covers at the western edge of **Sjögården** (south of the west wing of the Slott).
**Point 732:** South-western point of GPR survey site **Sjögården** with local coordinates (22/0).
**Point 733:** South-eastern point of GPR survey site **Sjögården** with local coordinates (22/47).
**Point 734:** North-eastern point of GPR survey site **Sjögården** with local coordinates (0/50)
**Point 735:** South-western corner of east-wing of Mälsåker Slott.
**Point 736:** South-western corner of Mälsåker Slott.
**Point 738:** Local coordinate (50/24) of GPR survey site **Entréträdgården**.
**Point 739:** Local coordinate (50/0) of GPR survey site **Entréträdgården**.
**Point 740:** South-west corner of GPR survey site **Entréträdgården** (local coordinate 0/24).
**Point 741:** South-east corner of GPR survey site **Entréträdgården** (local coordinate 0/0).
**Point 742:** North-eastern corner of **Mälsåker Slott**.
**Point 747:** Metal pipe in rock outcrop on hillside north-west of Mälsåker Slott (see Figure 4.2).
**Point 748:** Most western of the four stone pillars east of the gravel path leading to the pier.
**Point 749:** Western point on pier (see Figure 4.3).
**Point 750:** Eastern point on pier (see Figure 4.4).

<table>
<thead>
<tr>
<th>Point number</th>
<th>North (x) [m]</th>
<th>East (y) [m]</th>
<th>Elevation [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>729</td>
<td>6585749.335</td>
<td>1585299.097</td>
<td>6.348</td>
</tr>
<tr>
<td>730</td>
<td>6585739.833</td>
<td>1585295.096</td>
<td>5.087</td>
</tr>
<tr>
<td>731</td>
<td>6585748.172</td>
<td>1585296.153</td>
<td>6.170</td>
</tr>
<tr>
<td>732</td>
<td>6585728.734</td>
<td>1585291.621</td>
<td>4.395</td>
</tr>
<tr>
<td>733</td>
<td>6585712.591</td>
<td>1585335.735</td>
<td>5.282</td>
</tr>
<tr>
<td>734</td>
<td>6585732.291</td>
<td>1585346.115</td>
<td>6.531</td>
</tr>
<tr>
<td>735</td>
<td>6585746.868</td>
<td>1585341.634</td>
<td>6.439</td>
</tr>
<tr>
<td>736</td>
<td>6585756.751</td>
<td>1585311.002</td>
<td>6.576</td>
</tr>
<tr>
<td>738</td>
<td>6585850.603</td>
<td>1585342.340</td>
<td>9.872</td>
</tr>
<tr>
<td>739</td>
<td>6585843.079</td>
<td>1585365.077</td>
<td>9.718</td>
</tr>
<tr>
<td>740</td>
<td>6585803.062</td>
<td>1585326.742</td>
<td>9.777</td>
</tr>
<tr>
<td>741</td>
<td>6585795.637</td>
<td>1585349.503</td>
<td>9.631</td>
</tr>
<tr>
<td>742</td>
<td>6585775.268</td>
<td>1585358.274</td>
<td>9.423</td>
</tr>
<tr>
<td>747</td>
<td>6585868.371</td>
<td>1585245.225</td>
<td>15.521</td>
</tr>
<tr>
<td>748</td>
<td>6585701.040</td>
<td>1585316.572</td>
<td>(3.857)</td>
</tr>
<tr>
<td>749</td>
<td>6585626.651</td>
<td>1585286.579</td>
<td>1.760</td>
</tr>
<tr>
<td>750</td>
<td>6585624.838</td>
<td>1585291.976</td>
<td>1.749</td>
</tr>
</tbody>
</table>
Figure 4.1: Map showing the location of the Network RTK-GPS survey points.
Figure 4.2: Metal pipe in rock outcrop located north-west of Mälsåker Slott (RTK-GPS survey point 747).

Figure 4.3: RTK-GPS survey point 749.
Figure 4.4: RTK-GPS survey point 750.

Figure 4.5: RTK-GPS survey points 729, 730, 731, 732, 748, 749 and 750.
5 Appendix

The Appendix contains printouts of 10cm thick depth-slices of the measured areas. On the enclosed DVD further depth-slices with 5cm thickness with and without filter applied can be found.
5.1 GPR depth-slices for survey site *Entréträdgården*

| Figure 5.1.1: Overview of 10cm thick depth-slices between approximately 0m and 2.9m depth from top left to bottom right. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey. |
Figure 5.1.2: Depth-slice of 10cm thickness covering the depth range 0.0m to 0.1m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.3: Depth-slice of 10cm thickness covering the depth range 0.1m to 0.2m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.4: Depth-slice of 10cm thickness covering the depth range 0.2m to 0.3m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.5: Depth-slice of 10cm thickness covering the depth range 0.3m to 0.4m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.6: Depth-slice of 10cm thickness covering the depth range 0.4m to 0.5m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.7: Depth-slice of 10cm thickness covering the depth range 0.5m to 0.6m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.8: Depth-slice of 10cm thickness covering the depth range 0.6m to 0.7m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.9: Depth-slice of 10cm thickness covering the depth range 0.7m to 0.8m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.10: Depth-slice of 10cm thickness covering the depth range 0.8m to 0.9m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.11: Depth-slice of 10cm thickness covering the depth range 0.9m to 1.0m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.12: Depth-slice of 10cm thickness covering the depth range 1.0m to 1.1m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.13: Depth-slice of 10cm thickness covering the depth range 1.1m to 1.2m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.14: Depth-slice of 10cm thickness covering the depth range 1.2m to 1.3m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.15: Depth-slice of 10cm thickness covering the depth range 1.3m to 1.4m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.16: Depth-slice of 10cm thickness covering the depth range 1.4m to 1.5m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.17: Depth-slice of 10cm thickness covering the depth range 1.5m to 1.6m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.18: Depth-slice of 10cm thickness covering the depth range 1.6m to 1.7m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.19: Depth-slice of 10cm thickness covering the depth range 1.7m to 1.8m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.20: Depth-slice of 10cm thickness covering the depth range 1.8m to 1.9m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.21: Depth-slice of 10cm thickness covering the depth range 1.9m to 2.0m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.22: Depth-slice of 10cm thickness covering the depth range 2.0m to 2.1m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.23: Depth-slice of 10cm thickness covering the depth range 2.1m to 2.2m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.24: Depth-slice of 10cm thickness covering the depth range 2.2m to 2.3m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.25: Depth-slice of 10cm thickness covering the depth range 2.3m to 2.4m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.26: Depth-slice of 10cm thickness covering the depth range 2.4m to 2.5m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.27: Depth-slice of 10cm thickness covering the depth range 2.5m to 2.6m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.28: Depth-slice of 10cm thickness covering the depth range 2.6m to 2.7m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.29: Depth-slice of 10cm thickness covering the depth range 2.7m to 2.8m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
Figure 5.1.30: Depth-slice of 10cm thickness covering the depth range 2.8m to 2.9m. The grey area is 59m long and 24m wide. Gaps in the data are due to trees obstructing the survey.
5.2 GPR depth-slices for survey site Sjögården

**Figure 5.2.1:** Overview of 10cm thick depth-slices between approximately 0m and 2.4m depth from top left to bottom right. Gaps in the data are due to trees obstructing the survey.
Figure 5.2.2: Depth-slice of 10cm thickness covering the depth range 0.0m to 0.1m. Gaps in the data are due to trees obstructing the survey.

Figure 5.2.3: Depth-slice of 10cm thickness covering the depth range 0.1m to 0.2m. Gaps in the data are due to trees obstructing the survey.
Figure 5.2.4: Depth-slice of 10cm thickness covering the depth range 0.2m to 0.3m. Gaps in the data are due to trees obstructing the survey.

Figure 5.2.5: Depth-slice of 10cm thickness covering the depth range 0.3m to 0.4m. Gaps in the data are due to trees obstructing the survey.
**Figure 5.2.6:** Depth-slice of 10cm thickness covering the depth range 0.4m to 0.5m. Gaps in the data are due to trees obstructing the survey.

**Figure 5.2.7:** Depth-slice of 10cm thickness covering the depth range 0.5m to 0.6m. Gaps in the data are due to trees obstructing the survey.
Figure 5.2.8: Depth-slice of 10cm thickness covering the depth range 0.6m to 0.7m. Gaps in the data are due to trees obstructing the survey.

Figure 5.2.9: Depth-slice of 10cm thickness covering the depth range 0.7m to 0.8m. Gaps in the data are due to trees obstructing the survey.
Figure 5.2.10: Depth-slice of 10cm thickness covering the depth range 0.8m to 0.9m. Gaps in the data are due to trees obstructing the survey.

Figure 5.2.11: Depth-slice of 10cm thickness covering the depth range 0.9m to 1.0m. Gaps in the data are due to trees obstructing the survey.
Figure 5.2.12: Depth-slice of 10cm thickness covering the depth range 1.0m to 1.1m. Gaps in the data are due to trees obstructing the survey.

Figure 5.2.13: Depth-slice of 10cm thickness covering the depth range 1.1m to 1.2m. Gaps in the data are due to trees obstructing the survey.
Figure 5.2.14: Depth-slice of 10cm thickness covering the depth range 1.2m to 1.3m. Gaps in the data are due to trees obstructing the survey.

Figure 5.2.15: Depth-slice of 10cm thickness covering the depth range 1.3m to 1.4m. Gaps in the data are due to trees obstructing the survey.
Figure 5.2.16: Depth-slice of 10cm thickness covering the depth range 1.4m to 1.5m. Gaps in the data are due to trees obstructing the survey.

Figure 5.2.17: Depth-slice of 10cm thickness covering the depth range 1.5m to 1.6m. Gaps in the data are due to trees obstructing the survey.
Figure 5.2.18: Depth-slice of 10cm thickness covering the depth range 1.6m to 1.7m. Gaps in the data are due to trees obstructing the survey.

Figure 5.2.19: Depth-slice of 10cm thickness covering the depth range 1.7m to 1.8m. Gaps in the data are due to trees obstructing the survey.
**Figure 5.2.20:** Depth-slice of 10cm thickness covering the depth range 1.8m to 1.9m. Gaps in the data are due to trees obstructing the survey.

**Figure 5.2.21:** Depth-slice of 10cm thickness covering the depth range 1.9m to 2.0m. Gaps in the data are due to trees obstructing the survey.
Figure 5.2.22: Depth-slice of 10cm thickness covering the depth range 2.0m to 2.1m. Gaps in the data are due to trees obstructing the survey.

Figure 5.2.23: Depth-slice of 10cm thickness covering the depth range 2.1m to 2.2m. Gaps in the data are due to trees obstructing the survey.
Figure 5.2.24: Depth-slice of 10cm thickness covering the depth range 2.2m to 2.3m. Gaps in the data are due to trees obstructing the survey.

Figure 5.2.25: Depth-slice of 10cm thickness covering the depth range 2.3m to 2.4m. Gaps in the data are due to trees obstructing the survey.
6 Survey Documentation

<table>
<thead>
<tr>
<th>Survey name</th>
<th>Mälsåker Slott 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey purpose</td>
<td>Detection of archaeological structures in the grounds of Mälsåker Slott with particular interest in older park/garden layout</td>
</tr>
<tr>
<td>Bibliographic references</td>
<td>GPR</td>
</tr>
<tr>
<td>Administrative area</td>
<td>Mälsåker Slott, Södermanland, Sweden</td>
</tr>
<tr>
<td>Country</td>
<td>Södermanland, Sweden</td>
</tr>
<tr>
<td>Drift geology</td>
<td>Sand, clay, silt</td>
</tr>
<tr>
<td>Duration</td>
<td>Wednesday 16th August 2006, Thursday 17th August 2006</td>
</tr>
<tr>
<td>Weather</td>
<td>Warm and rainy. The days prior to the survey wet with showers.</td>
</tr>
<tr>
<td>Soil condition</td>
<td>Humid to wet</td>
</tr>
<tr>
<td>Land-use</td>
<td>Mowed grass and gravel covered surfaces</td>
</tr>
<tr>
<td>Monument type</td>
<td>Medieval to recent park and garden architecture</td>
</tr>
<tr>
<td>Monument period</td>
<td>Medieval to modern</td>
</tr>
<tr>
<td>Surveyor</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>
</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>
</tr>
<tr>
<td>Primary archive</td>
<td>Swedish National Heritage Board, UV Teknik, Box 5404, 114 84 Stockholm, Sweden</td>
</tr>
<tr>
<td>Copyright</td>
<td>Riksantikvarieämbetet</td>
</tr>
<tr>
<td>Geophysical coordinate system</td>
<td>Up to 50m profile lines. Area Entréträdgården was surveyed with 50cm cross-line spacing, area Sjögården was surveyed with 25cm crossline spacing, area Formträdgården was scanned with single profiles.</td>
</tr>
<tr>
<td>Georeferencing</td>
<td>All survey areas were geo-referenced using a Network RTK-GPS (Trimble R8).</td>
</tr>
<tr>
<td>Survey type</td>
<td>Ground Penetrating Radar</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>One manually pushed Sensors &amp; Software Noggin Plus 500MHz antenna mounted in Noggin SmartCart with included odometer wheel and DVLIII data monitor and logger.</td>
</tr>
<tr>
<td>Method of coverage</td>
<td>Regular grid of parallel profile lines, Zigzag</td>
</tr>
<tr>
<td>Traverse separation</td>
<td>Entréträdgården: 50cm; Sjögården: 25cm</td>
</tr>
<tr>
<td>Reading interval</td>
<td>5cm inline</td>
</tr>
<tr>
<td>Grid size</td>
<td>Maximum profile length: 50m</td>
</tr>
</tbody>
</table>

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/).