Survey report

Ground Penetrating Radar survey for Archaeological Prospection in Venlo 2007

Methodology, data acquisition, results, interpretation

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Introduction

On January 25th 2007 the *Archaeological Excavation Department* of the *Swedish National Heritage Board* (UV Teknik) conducted Ground Penetrating Radar (GPR) measurements in the town centre of Venlo in The Netherlands. The survey was commissioned by *Archeologisch Diensten Centrum* (ADC) in order to probe the presence and location of historic and archaeological structures in the subsurface.

![Figure 1.1: Photograph showing the survey area Synagoge from the north-east. The white arrow indicates the building that occupies the proposed survey area shown in Figure 1.2. The yellow arrow points to the memorial for the Synagogue of Venlo. The outline of the walls of the Synagogue is marked with metal spikes spaced few decimeters apart in the tarmac and pavement. According to these markings the Synagogues south-western corner was located next to the memorial. Further structures with relevance to the georadar survey are lampposts, a sewer inlet and a large rubbish bin with underground storage.](image)

The purpose of the georadar survey at the site “Synagoge” was to locate possible historical or archaeological remains in the subsurface, with particular interest to the question whether remains of the former Synagogue of Venlo are still present in the ground.

The Synagogue of Venlo (Figures 1.8 and 1.9) had been heavily damaged in an air raid in 1944 (Figure 1.7). In 1965 it was decided to demolish the old Synagogue.

In the vicinity of the proposed survey site (Figure 1.2) today a memorial indicates the former location of the Synagogue of Venlo (Figure 1.1). The outline of the walls of the Synagogue is marked with metal spikes in the tarmac and on the pavement at the junction of the roads *Maasschriksel* and *Kwiethuvel* (Figure 1.10).
Based on the location of the memorial, the markings on the ground and an available historical map from 1842 that shows the location of the Synagogue in the old street layout (Figures 1.4, 1.6) it was decided to conduct the georadar survey over and around the street junction Maasschriksel and Kwieytheuvel (Figures 1.1, 1.2). Traffic wardens of the local road administration had kindly closed the area to traffic.

The maximum extend of the area surveyed with the georadar method was 43m by 41m. Due to the presence of many obstacles in the survey area in form of lamp posts, trees, signs, a parked car and a large rubbish bin (Figures 1.10, 1.11, 1.12 and 1.13) the profile length of the individual parallel georadar profiles had to be adjusted individually. It was attempted to cover as large an area as possible in the time available. Roy Machius’ (ADC) assistance during the survey (Figure 1.14) was very helpful and permitted the coverage of a relatively large area.

Figure 1.2: The proposed survey areas “Synagoge” and “Bij de wijnkoper” are marked with a hashed area and a star respectively. Digital data source: ADC.
Figure 1.3: Satellite photograph showing the survey areas “Synagogue” and “Bij de wijnkoper”. The white lines indicate the outlines of buildings, pavement and trees. This digital map was provided by ADC. Photo source: Google Earth.

Figure 1.4: Historical map of the year 1842 showing the same area as Figures 1.2 and 1.3. The Synagogue is visible in the centre of the map as rooftop with a round skylight in the middle. This image was scanned and geo-referenced using the digital map data which is shown in Figure 1.5. Image source: ADC.
Figure 1.5: Digital map (coloured lines) similar to the historical map of the year 1842 shown in Figure 1.4 with the modern map of Venlo as shown in Figure 1.2 superimposed (black lines). This digital map was used to geo-reference the scanned image shown in Figure 1.4. Digital data source: ADC.

Figure 1.6: Superposition of the maps shown in Figures 1.4 and 1.5. According to this map the Synagogue should be located right under the intersection of the roads Maaschriksel/Kwietenwvel (see Figure 1.2).
Figure 1.7: View towards north over the roofs of Venlo after destruction during the Second World War in the year 1944. The river Maas can be seen in the background. The synagogue is visible in the centre of the photograph with the octagonal skylight on top. Internet image source: http://historie.venlo.nl/.

The georadar survey was conducted using a Sensors & Software NogginPlus 500 MHz Ground Penetrating Radar antenna system mounted in a SmartCart (Figure 1.14). The positioning of the data was handled using tape measures and perpendicular parallel lines on the ground with a line spacing of 1m. Along each line the position of the georadar antenna was determined using a distance wheel (odometer) mounted on the SmartCart. The cross-line georadar profile spacing was 25cm and the in-line trace spacing was 5cm. Georadar trace stacking for signal-to-noise improvement was 4 fold. The recording time window chosen was 49ns, corresponding to a maximum penetration depth of 2.45m under the assumption of an average signal velocity of 10cm/ns in the subsurface.

In order to be able to geo-reference the georadar measurements several points were marked on the ground with spray paint and their absolute coordinates were measured by land surveyor Friso te Meerman on January 26th (Ron Trumpie, Fugro-Inpark B.V., R.Trumpie@fugro-inpark.nl).

The visible inspection of the survey site suggests that any possible historical or archaeological structures in the subsurface have been heavily disturbed by modern road building and house construction activities as well as by the numerous utilities in the ground. Water and sewer pipes, manhole covers (Figures 1.10, 1.12 and 1.13), metallic rings around trees, electrical cables between buildings and for the supply of street lamps, a parking ticket machine and the illumination of the Synagogue memorial (Figures 1.10, 1.11), as well as a large rubbish bin with an apparently sizeable subsurface container (Figure 1.12) present sources of disturbances for a georadar survey and indicate considerable invasive trenching and digging interference with any historical or archaeological structures in the ground.

Figures 1.10: View of the georadar survey site Synagogue showing recent structures that are likely to cause disturbances in the georadar data, or that indicate disturbing interferences in the subsurface caused by the laying of utilities. Blue arrows indicate manhole covers and sewer inlets. Green arrows cause large round metal grids surrounding the tree bases. Yellow arrows indicate lamp posts, a parking ticket machine and electrical lamps for the illumination of the Synagogue memorial. All electrical appliances indicate corresponding electrical supply cables that are buried in the subsurface.
Figures 1.11: View of the georadar survey site Synagogue. For explanation of arrows see caption of Figure 1.10. The dots highlighted in red on the pavement show the location of iron spikes that mark the former outline of the Synagogue.

Figures 1.12: View of the georadar survey site Synagogue. For explanation of arrows see caption of Figure 1.10. A large rubbish bin with a sizeable underground facility is visible left in the large photo and in the inset.
Figures 1.13: View of the georadar survey site Synagogue from the north-east. For explanation of arrows see caption of Figure 1.10.

Figures 1.14: The georadar measurements were conducted within sensible bounds as given by kerbstones, trees and other obstacles. In this photograph the georadar system is shown. Here the used 500 MHz antenna can be seen mounted in a pram like cart directly above the ground surface. The vertical profile data is visible to the operator during data recording on the screen of the data logger. Geometry information (profile length and position) is recorded manually. The parallel survey lines spaced with 1m for orientation and positioning of the georadar system can be seen.
Figures 1.15 and 1.16: View of the survey site “Bij de Wijnkoper” from the upper eastern end (left image) and from the lower western end (right image). Note the interruption of the 3m wide lane by two sets of stairs.

Figures 1.17 and 1.18: Both upper and lower areas at the survey site “Bij de Wijnkoper” have been surveyed to the maximum possible extent. Due to the georadar system configuration the first and last profiles were run with 25cm distance to the house walls on either side of the lane, resulting in a total survey width of 2.5m. Note the electrical distribution box in the upper survey area visible in the right image.

The purpose of the georadar at the second survey site “Bij de Wijnkoper” in Venlo town centre was to investigate whether any possibly existing remains of the old town wall would be detectable with the method. In general it should be possible to detect a large wall even at greater depth if a sufficiently large area on top of the assumed structure is accessible for the georadar survey. Georadar measurements with ground coupled antennas require the measurement of uninterrupted profiles that reach well beyond either side of an assumed structure, with the profile direction ideally located perpendicular to the orientation of a linear wall structure. The survey of single 2D profiles for archaeological prospection is in most cases insufficient for the safe detection and localization of an archaeological structure such as a wall, particularly if the site is surrounded by many other objects, structures and buildings that may cause disturbing reflections.
For purpose of geometry and quality control of the georadar data the data of both survey sites in Venlo was processed immediately after the fieldwork using ReflexW software using a simplified processing flow (Geometry editing, DC-shift removal, background removal, energy decay compensation, 3D data volume generation, time-slicing).

The final processing of the GPR data was performed by Alois Eder-Hinterleitner (Central Institute for Meteorology and Geodynamics, Vienna) using purpose written software for special processing of archaeological prospection GPR data. This special georadar data processing results in geo-referenced depth-slice images (greyscale TIFF) of unrivaled quality due to careful data filtering and advanced amplitude balancing.

The analysis and interpretation of the geo-referenced GPR data was conducted within the Geographical Information System (GIS) ArcMap.

Section 2 provides a short introduction to the methodology of archaeological prospection using the GPR method.

In Section 3 the measured data and its interpretation is presented in form of depth-slice images. 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 of structures visible in the data can vary by up to 50%. However, the relative depth of structures is correctly imaged in subsequent depth-slices.
1.1 Prior information available about the survey sites

The initial information provided by ADC said that the survey site “is located in a narrow street in the town of Venlo. The street is 6 m broad and 20 m long. What we expect are remnants of a stone wall at 40 to 50cm underneath the road.”

It was stated that the survey site would consist of one single area and that the terrain would be flat. Two days prior to the survey UV Teknik was informed that a second site “Synagoge” should as well be surveyed in Venlo. Both the first and the second site were marked in a map (Figure 1.2) with the names “Bij de Wijnkoper” and “Synagoge” respectively.

On arrival in Venlo it became obvious that the area that has been marked as “Synagoge” is inaccessible for georadar prospection since a building is obstructing the site (Figure 1.1). Furthermore, the site “Bij de Wijnkoper” turned out to be a 3m wide lane that is subdivided into two areas of 13m and 6m length respectively.

In case of the survey site “Bij de Wijnkoper” the declared survey area of 6m width and 20m length was at the lower end of what could be described as a sufficiently large area that may allow the detection of a town wall. The actual survey areas with a size of 3m by 13m and 3m by 6m, with a set of stairs between, are very unlikely to result in any meaningful georadar data. The conditions at the survey site “Bij de Wijnkoper” are further complicated by the fact that the narrow area is confined by high brick walls of modern buildings (with unknown structures behind the walls), large metal gates in the immediate vicinity, and an electrical distribution box with corresponding electrical wiring in the subsurface.
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.

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 2.2: Pär Karlsson 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)

![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 cross-line distance between the sections should be 25cm. The 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 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 (e.g. in case of limited signal penetration depth caused by a highly conductive soil).

GPR measurements can 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.

GPR measurements provide information about the relative depth of 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 Presentation of the georadar data

In this section the georadar data and its interpretation for each survey site are presented and the results are discussed.

3.1 Survey site Synagogue

The area covered by survey site *Synagogue* is shown in the map in Figure 3.1. From the superposition of the modern map onto the historical map in Figure 3.2 it can be seen that the former Synagogue was located precisely underneath today’s road junction. However, it is unknown how reliable the geo-referencing of the historical map is and whether there are any remains of historical or archaeological interest still present in the subsurface.

Figure 3.3 shows the extent of the area that was surveyed using the 500 MHz georadar system. In Figure 3.4 an interpretation of linear structures visible in the data at different depth is shown. Some of these linear structures can be seen for instance in Figure 3.5. Figure 3.6 shows the location of several utility and sewer inlets. These inlets are visible in the data and have been identified with the help of the photographs taken at the survey site (see Figures 1.1, 1.10, 1.11, 1.12, 1.13). Furthermore, the metal grid surrounding a tree and two distinctive manhole covers (metal plates) are marked in the interpretation. The two larger manhole covers and the metal grid around the tree foot are visible in the depth-slice shown in Figure 3.7. A dark linear anomaly coincides with the western front face of the Synagogue as mapped in the historical map. Figure 3.8 shows additionally the interpretation of kerbstones and the boundary between areas covered by tarmac and those covered with paving stones (parking places and pavement). The kerbstones show so clearly in Figure 3.9 since the antenna was tilted and lost momentarily ground coupling when passing over the gutter. In Figure 3.10 particularly strong reflections are marked as well as one reflection that is likely to be caused by the sewer pipe leading to the central manhole. The depth-slice in Figure 3.11 shows corresponding anomalies.

The linear anomaly visible in the southern part of the road *Masschriksel* (Figure 3.10) coincides with a plot boundary in the map from 1842 (see Figure 3.16 marker `f`). In Figure 3.11 a supposed trench is drawn. This structure is visible as a dark, relatively wide anomaly in the depth-slice shown in Figure 3.12. Centrally under the road junction in approximately 15-20cm depth a region can be distinguished from the surrounding areas due to its relatively homogeneous structure (Figure 3.14). This region is highlighted in Figure 3.13. South of this region we can see a dark band of unchanging width that crosses the road towards the rubbish bin shown in Figures 1.12. This band extends as well further towards west-north-west underneath the parking spaces. Finally, Figure 3.15 shows the outlines contained in the modern map superimposed onto the drawn interpretation of the georadar data. In Figure 3.16 the map from 1842 is printed in the background to allow for a comparison of the structures detected in the georadar data with historical structures. In several cases a positive correlation can be observed. Marker `c` indicates the match between the assumed location of the Synagogue’s western front face according to the historical map with reflections visible in the georadar data. Even though it is appealing to think that this match may indicate remains of the western front face of the Synagogue in the ground, it is important to consider as well the option of a coincidental more recent disturbance causing this anomaly, such as for example a modern pipe or cable at this location. The same can be said about the southern face of the Synagogue `d`. In case of the eastern `e` and northern face no clear indication for remaining structures in the ground can be found in the data. The linear structures labelled with `f` indicate a good match between detected anomalies and the historical map. However, as said above this positive correlation could as well be caused by modern utilities that coincidental follow the same direction. Markers `g` and `h` show matches between an older building and structures visible in the georadar data.
the presence of drainage pipes in the same area a safe identification of the cause of the anomalies seen in the georadar data is in this case not possible.

Figures 3.1: Map of the survey site Synagogue showing the outline of the current day roads, pavement, buildings and trees (circles). The following Figures 3.2 to 3.19 have the same extent as this map.

Figures 3.2: The map showing buildings and property boundaries from the year 1842 (background) with the modern day outline superimposed. It can be seen that the Synagogue, which is marked with the circle in the centre (representing the skylight), had been located approximately where the metal spikes mark its location on the ground.
Figures 3.3: The grey area marks the surface surveyed with the georadar method.

Figures 3.4: Linear structures that are visible in the data at various depth levels are shown in this interpretation. These linear structures can be caused by pipes, cables, trenches, edges on the surface, and foundation walls.
Figures 3.5: Map showing the interpreted linear structures together with manholes, utility outlets/inlets as well as the reflections caused by the metal grid that surrounds a tree. The reflections from utility outlets/inlets with metallic cover are recognizable in the data. The interpretation was made with help of the photographs of the survey site shown in Section 1.

Figures 3.6: This single depth-slice is an example showing clearly two manholes/manhole covers in the area of the road junction. Further data images in form of depth-slices can be found in the Appendix. The metal grid surrounding the tree can be seen. No gap in the data can be seen caused by the tree since the measurements bypassed this obstacle. A linear structure that caused a strong reflection can be seen in the northern part of the image. This anomaly agrees in location with the western front of the Synagogue as shown in the map from 1842.
Figures 3.7: Additionally to the structures shown in Figure 3.5 the georadar anomalies caused by the kerbstones and the change in surfacing between tarmac and paving stones for the parking areas are shown.

Figures 3.8: This single depth-slice is an example showing the anomalies caused by the kerbstones between the pavement and the road. Further data images in form of depth-slices can be found in the Appendix. The change of signal between the tarmac covered area and the areas covered with paving stones (parking spaces and pavement) can be seen.
Figures 3.9: Particularly strong reflections and a relatively certain water/sewer pipe are drawn.

Figures 3.10: This single depth-slice is an example showing several linear structures that are likely to be caused by utilities (cables, pipes). Further data images in form of depth-slices can be found in the Appendix. The southernmost linear structure that crosses the road *Maasschrikel* almost perpendicular agrees in location with a property boundary shown in the map from 1842.
Figures 3.11: A dark anomaly that is likely to be caused by a utility trench is drawn in brown colour. This anomaly appears to follow approximately the kerbstone and pavement.

Figures 3.12: This single depth-slice is an example showing the dark band that could be caused by a relatively recent pipe/cable trench. Further data images in form of depth-slices can be found in the Appendix.
Figures 3.13: Centred under the road junction a distinctive anomaly of darker, more homogeneous structure can be seen.

Figures 3.14: This single depth-slice is an example showing a darker, more homogeneous area underneath the junction. Further data images in form of depth-slices can be found in the Appendix. The southern boundary of this area would agree in location with the southern face of the Synagogue. The manhole with surrounding ring can be seen in the upper part of this area. A darker band can be seen running west-north-west to east-south-east, crossing the road Maaschrikel in direction of the large rubbish bin.
Figures 3.15: Outline of the modern map superimposed onto the interpreted structures shown in figure 3.13.

Figures 3.16: Several of the linear structures (blue lines) and strong linear reflectors (thick yellow lines) match well with structures visible in the historical map from 1842. The anomaly marked with $\odot$ appears to coincide with the western front face of the Synagogue. The Synagogue’s southern face $\circ$ appears to match with the southern edge of the distinctive area. However, the trench visible in Figure 3.14 renders a clear identification difficult. The location of the Synagogue’s eastern front $\oplus$ can not be seen in the data. $\odot$ marks good agreement between linear structures in the data and a plot boundary visible on the historical map. $\ominus$ and $\odot$ indicate matching anomalies and historical structures, but modern near-surface structures (boundary between tarmac and paving stones; sewer pipes) render the interpretation inconclusive.
Figures 3.17: Depth-slice showing several linear anomalies. Strongest is the sewer pipe that runs in the subsurface between the parking places and the tarmac road. Other linear structures crossing the road Maasschriksel almost perpendicularly are visible.

Figures 3.18: Depth-slice showing the supposed street water sewer pipe very clearly.
The depth-slices shown in Figures 3.17 and 3.18 illustrate further the number of structures visible in the data. Most (if not all) of these structures are likely to have been caused by the laying of modern utilities (cables, pipes). It can be assumed that during the demolition of the Synagogue in 1965 and the construction of the modern buildings most or all historical remains where removed. If coherent, intact structures would be present in the ground these would show clearly, as illustrated with the example shown in Figure 3.19. Here, a comparable georadar survey had been conducted at the site of a medieval convent. The georadar data (Figure 3.19a) clearly shows the foundation walls present in the ground, allowing for a detailed interpretation of the data (Figure 3.19b). The archaeological excavation of the site revealed great correlation between the imaged, interpreted and actually present structures in the ground (Figure 3.19c).

**Figures 3.19:** (a) Georadar depth-slice showing the foundation walls of a medieval stone building. (b) Interpretation of the georadar data shown left (and of other georadar depth-slices from this area). (c) Photo showing the excavated area. The foundation walls and their corresponding interpretation in the georadar data are marked with red lines in (b) and (c). (Photo: Magnus Stibéus)
3.2 Survey site *Bij de Wijnkoper*

The location of survey site *Bij de Wijnkoper* is shown in Figures 1.2 and 1.3. Within the 3m wide lane both the upper and the lower area were surveyed with each 11 parallel georadar profiles. The eastern, upper area has a length of approximately 13m while the western, lower area has a length of approximately 6m. Due to the width of 50cm of the georadar system the maximum extent possible to survey was 2.5m. A cross-line profile spacing of 25cm, an inline trace spacing of 5cm and a recording time-range of 99ns was used. The corresponding data images in form of depth-slices are included in the Appendix 5.2.

Figures 3.20 shows the survey site *Bij de Wijnkoper* with the historical map from 1842 in the background. It can be seen how the town wall crosses the survey area in its western half. The areas covered by the georadar survey can be seen in Figure 3.21. The interpretation of the data is shown in Figure 3.22. In the interpretation of the data linear structures are marked, as well as regions of high reflectivity. The linear structures visible in the data are most likely related to subsurface cables and/or pipes between the two buildings. The electrical distribution box in the upper part of the lane indicates the presence of cables. Several linear anomalies are leading towards this distribution box.

Figures 3.24 and 3.25 suggest that the assumed location of the former town wall of Venlo coincides with the place of the steps in the lane. Due to the limited amount of data available and the numerous external sources of interfering signals it is impossible to determine whether the anomaly shown in Figures 3.23 and 3.24 is actually caused by the possibly existing remains of the town wall at this location.

*Figures 3.20:* The small lane *Bij de Wijnkoper* is indicated by the thin lines of the digital modern map of Venlo. In the background the map from the year 1842 is plotted. The former town wall is shown to have been crossing the lane in its western half.
Figures 3.21: The georadar survey area in the lane *Bij de Wijnkoper* is indicated in grey. Due to the stairway the area had to be divided into two parts.

Figures 3.22: Interpretation of the georadar data. Linear structures and reflective areas in the data are shown.
Figures 3.23: Georadar depth-slice showing a dark wedge in the western part of the eastern (upper) area, and a low reflective eastern part of the western (lower) area. The dark wedge is directed towards the electrical distribution box and therefore may be related to modern utilities. The low reflective area coincides with the location of the outer part of the old town wall (see Figure 3.24). This match may be purely coincidental since a safe interpretation of data acquired over such a narrow area is quite unreliable, particularly when considering the numerous disturbances in the vicinity.

Figures 3.24: Georadar depth-slice with the historical map from 1842 in the background. The match between the low-reflective area and the presumed location of the town wall may be purely coincidental. The expression of this anomaly is weak and not definitive. The location of the former town wall appears to coincide with the location of the stairway.
Figures 3.25: Interpretation with the historical map from 1842 shown in the background. Some linear anomalies in the lower part could possibly be caused by remains of the former town wall.
4 Archaeological and antiquarian analysis and interpretation

Under the right conditions georadar (GPR) measurements allow the archaeologist to obtain an image of structures that are hidden in the subsurface without digging. 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.

Under the right conditions the georadar method 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.

Modern structures that are present in the subsurface can dominate the images obtained from a georadar survey. This is particularly obvious at sites located in towns such as Venlo where over a long time uncounted changes of the subsurface and the contained cultural layer have occurred.

The georadar survey in Venlo was conducted in the central part of a modern city. At the location of the survey site considerable changes of the layout of streets and buildings have occurred during the last 50 years due to extensive damage caused during the Second World War. The visible inspection of the survey site suggests that any possible historical or archaeological structures in the subsurface have been heavily disturbed by rather recent road building and house construction activities as well as by the numerous utilities laid in the ground. Water and sewer pipes, manhole covers (Figures 1.11, 1.13 and 1.15), metallic rings around trees, electrical cables between buildings and for the supply of street lamps, a parking ticket machine and the illumination of the Synagogue memorial (Figures 1.11, 1.12, 1.13, 1.14), as well as a large rubbish bin with an apparently sizeable subsurface container (Figure 1.13) present sources of disturbances for a georadar survey and indicate considerable invasive trenching and digging interference with any historical or archaeological structures in the ground.

The site can be considered quite normal from an urban archaeological perspective. From a geophysical prospection perspective the above mentioned circumstances suggest that the resulting data can be expected to be highly complex, in cases ambiguous and nontrivial to interpret.

The georadar data recorded displays numerous linear structures at different depth (Fig 3.4). Many of these can easily be attributed to the modern utilities visible at the surface, such as manhole covers, sewer inlets or the metal grid surrounding a tree. However, there exist anomalies in the data that may be related to older structures in the ground. Nevertheless it is possible that some of them may be caused by the remains of fairly modern structures that are out of use, like old electricity cables or sewer pipes.

There exist linear structures in the georadar data that deviate from the orientation of clearly modern structures. Some of them display a good match with structures that are visible in the historical map from 1842 (①, ②, ③, ④, ⑤, ⑥ in Fig. 3.17). ① and ② may be related to the western and the southern wall of the Synagogue. ⑤ and ⑥ mark good agreement with plot boundaries visible on the historical map, boundaries once that may have been marked with walls.
There is as well an area showing a distinctively different reflection pattern in the data. The area is located where the Synagogue is supposed to have been located according to the map from 1842. The homogeneous reflection pattern may be caused by remains of the floor of the Synagogue, or the foundations of the floor (under-floor).

Which archaeological and antiquarian conclusions can be drawn from the results of the Synagogue georadar survey?

First of all; the site has been heavily reshaped over the years. The orientation of plots and streets has been changed, older buildings have been demolished and new ones have been erected. The survey has shown that the ground under the tarmac has numerous times been disturbed for the purpose of electricity, water supply and garbage handling. If at all, only little intact older structures can be expected at the site. As an example, within the assumed outline of the Synagogue a manhole is located. This manhole is most certainly connected to at least one fairly large pipe.

However, the GPR survey has shown that in spite of the extensive ground works there may be older structures remaining at the site. For example, two possible walls as well as potentially the floor of the Synagogue as well as some older plot boundaries.

If detailed site information including the historical map showing the outline of the Synagogue would have been available prior to the survey a better design of the field work would have been possible. The georadar method is best suited to detect structures which are oriented perpendicular to the GPR profile direction. Thus, a survey across the assumed Synagogue location would have been conducted measuring two perpendicular sets of densely spaced georadar profiles, allowing for the improved detection of all four possibly remaining foundation walls.

The survey site Bij de Wijnkoper, located in a narrow lane with two sets of stairs, can generally be classified as unsuitable for archaeological prospection georadar measurements with the goal to detect wall structures. If the historical map and detailed information about the site conditions would have been available prior to the survey the plan to survey this site with GPR would have been abandoned. In order to be able to safely detect and identify archaeological structures in georadar data a sufficiently large survey area is required.

In the case of both the Synagogue and the Bij de Wijnkoper survey it is important to remember that there may be archaeological structures in the ground that the georadar method was unable to detect.

The georadar method was able to map and show the degree of disturbances present in the ground. Most of these disturbances are related to rather modern construction work. Several areas of possible historical interest have been detected at the Synagogue site. The results of the georadar measurements suggest that the markings made with iron nails in the tarmac closely represent the actual former outline of the Synagogue of Venlo.
5 Appendix

The Appendix contains 10cm thick depth-slice images for the measured area Synagogue and 20cm thick depth-slice images for the measured area Bij de Wijnkoper.

5.1 Depth-slice images of survey site Synagogue
Figure 5.1: Depth-slice of 10cm thickness covering the depth range 0.00 to 0.10m.
Figure 5.2: Depth-slice of 10cm thickness covering the depth range 0.10 to 0.20m.
Figure 5.3: Depth-slice of 10cm thickness covering the depth range 0.20 to 0.30m.
Figure 5.4: Depth-slice of 10cm thickness covering the depth range 0.30 to 0.40m.
Figure 5.5: Depth-slice of 10cm thickness covering the depth range 0.40 to 0.50m.
Figure 5.6: Depth-slice of 10cm thickness covering the depth range 0.50 to 0.60m.
Figure 5.7: Depth-slice of 10cm thickness covering the depth range 0.60 to 0.70m.
Figure 5.8: Depth-slice of 10cm thickness covering the depth range 0.70 to 0.80m.
Figure 5.9: Depth-slice of 10cm thickness covering the depth range 0.80 to 0.90m.
Figure 5.10: Depth-slice of 10cm thickness covering the depth range 0.90 to 1.00m.
Figure 5.11: Depth-slice of 10cm thickness covering the depth range 1.00 to 1.10m.
Figure 5.12: Depth-slice of 10cm thickness covering the depth range 1.10 to 1.20m.
Figure 5.13: Depth-slice of 10cm thickness covering the depth range 1.20 to 1.30m.
Figure 5.14: Depth-slice of 10cm thickness covering the depth range 1.30 to 1.40m.
Figure 5.15: Depth-slice of 10cm thickness covering the depth range 1.40 to 1.50m.
Figure 5.16: Depth-slice of 10cm thickness covering the depth range 1.50 to 1.60m.
Figure 5.17: Depth-slice of 10cm thickness covering the depth range 1.60 to 1.70m.
Figure 5.18: Depth-slice of 10cm thickness covering the depth range 1.70 to 1.80m.
Figure 5.19: Depth-slice of 10cm thickness covering the depth range 1.80 to 1.90m.
Figure 5.20: Map of the area shown in the Figures 6.1 to 6.19.
5.2 Depth-slice images of survey site *Bij de Wijnkoper*

*Figure 5.21:* Depth-slice of 10cm thickness covering the depth range 0 to 0.20m.

*Figure 5.22:* Depth-slice of 10cm thickness covering the depth range 0.20 to 0.40m.
Figure 5.23: Depth-slice of 10cm thickness covering the depth range 0.40 to 0.60m.

Figure 5.24: Depth-slice of 10cm thickness covering the depth range 0.60 to 0.80m.

Figure 5.25: Depth-slice of 10cm thickness covering the depth range 0.80 to 1.00m.
Figure 5.26: Depth-slice of 10cm thickness covering the depth range 1.00 to 1.20m.

Figure 5.27: Depth-slice of 10cm thickness covering the depth range 1.20 to 1.40m.

Figure 5.28: Depth-slice of 10cm thickness covering the depth range 1.40 to 1.60m.
Figure 5.29: Depth-slice of 10cm thickness covering the depth range 1.60 to 1.80m.

Figure 5.30: Depth-slice of 10cm thickness covering the depth range 1.80 to 2.00m.

Figure 5.31: Depth-slice of 10cm thickness covering the depth range 2.00 to 2.20m.
Figure 5.32: Depth-slice of 10cm thickness covering the depth range 2.20 to 2.40m.

Figure 5.33: Depth-slice of 10cm thickness covering the depth range 2.40 to 2.60m.

Figure 5.34: Depth-slice of 10cm thickness covering the depth range 2.60 to 2.80m.
Figure 5.35: Depth-slice of 10cm thickness covering the depth range 2.80 to 3.00m.

Figure 5.36: Depth-slice of 10cm thickness covering the depth range 3.00 to 3.20m.

Figure 5.37: Depth-slice of 10cm thickness covering the depth range 3.20 to 3.40m.
Figure 5.38: Depth-slice of 10cm thickness covering the depth range 3.40 to 3.60m.

Figure 5.39: Depth-slice of 10cm thickness covering the depth range 3.60 to 3.80m.

Figure 5.40: Depth-slice of 10cm thickness covering the depth range 3.80 to 4.00m.
# 6 Survey Documentation

<table>
<thead>
<tr>
<th><strong>Survey name</strong></th>
<th>Venlo Synagogue &amp; Bij de Wijnkoper, January 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Survey purpose</strong></td>
<td>Detection of historical and archaeological structures in the ground, in particular of possible traces of the Synagogue of Venlo and of the old town wall.</td>
</tr>
<tr>
<td><strong>Bibliographic references</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Survey keywords</strong></td>
<td>GPR / Georadar</td>
</tr>
<tr>
<td><strong>Administrative area</strong></td>
<td>Venlo, Limburg, The Netherlands</td>
</tr>
<tr>
<td><strong>Country</strong></td>
<td>The Netherlands</td>
</tr>
<tr>
<td><strong>Drift geology</strong></td>
<td>Sand, clay, silt</td>
</tr>
<tr>
<td><strong>Duration</strong></td>
<td>Thursday 24&lt;sup&gt;th&lt;/sup&gt; January 2007</td>
</tr>
<tr>
<td><strong>Weather</strong></td>
<td>Cold, close to freezing. No rainfall.</td>
</tr>
</tbody>
</table>
| **Soil condition** | Survey site Synagogue: Tarmac and pavement slabs.  
Survey site Bij de Wijnkoper: Red-bricks |
| **Land-use** | Road, lane, pavement, parking places |
| **Monument type** | Synagogue (damaged in 1944, demolished in 1965)  
Historical town wall |
| **Monument period** | Medieval until modern |
| **Surveyor** | Immo Trinks, Pär Karlsson |
| **Depositor** | Immo Trinks |
| **Primary archive** | Swedish National Heritage Board, UV Teknik, Box 5404, 114 84 Stockholm, Sweden |
| **Copyright** | Riksantikvarieämbetet, UV Teknik |
| **Geophysical coordinate system** | Local system. |
| **Georeferencing** | Land surveyor: Friso te Meerman, January 26<sup>th</sup> 2007  
Ron Trumpie, Fugro-Inpark B.V., R.Trumpie@fugro-inpark.nl |
| **Survey type** | Ground Penetrating Radar |
| **Instrumentation** | One manually pushed Sensors & Software Noggin Plus 500MHz antenna mounted in Noggin SmartCart with included odometer wheel and DVLIII data monitor and logger. |
| **Method of coverage** | Regular grid of parallel profile lines, Zigzag. |
| ** Traverse separation** | 25cm |
| **Reading interval** | 5cm inline |
| **Grid size** | Maximum profile length: 41m |

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/).