Integrated geophysical study of the former monastic site, Rahan, Co. Offaly
Phase I and II

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Site summary sheet

Site Name:
Former monastic settlement and associated archeological features, Rahan, Co. Offaly. Irish Grid Reference approximately E 225900 N 225400.

Survey type:
Magnetometry using a Bartington 601 fluxgate gradiometer. Data collected in a zig-zag pattern at 1m traverse interval and 0.25m sample interval. Approximately 305,000 data points obtained mainly in 30 x 30m grids.
Resistance using a TRCIA twin electrode resistance meter with 0.5m electrode spacing. Data collected in a zig-zag pattern at 1m traverse interval and 1m sample interval. Approximately 33,000 data points obtained mainly in 30 x 30m grids.
Magnetic Susceptibility using a Bartington MS2B probe.
Resistivity using a multi-core Campus Geopulse. Data collected with variable electrode spacings.
Ground penetrating radar survey with PulseEkko 100 using 200 MHz antennae.

Processing software:
Data were processed using ArcheoSurveyor Surfer, Excel, Res2dinv, GPS Pathfinder and ArcMap.

Summary of results Phase I
The resistance data have shown different parts of the site have different resistances. In addition, a number of features could be observed.
A broad curvilinear low resistance feature can be observed in the eastern part of the image. It may represent an in-filled boundary ditch. Southwards it is more difficult to discern but if continued it would just enclose the small church at Rahan. (A, Figure 4). It is about 110m in length.
Very closely spaced parallel linear patterns can also be observed in the field and are also obvious on aerial photographs of the site. They relate to ploughing patterns and may be medieval in age.
Broadly spaced linear patterns with an approximate east-west trend are detected near the northern edge of the study area. These are parallel to and beside the outer enclosing northern embankment of the site and represent small embankments and ditches in this vicinity. Just to the east of these is a region with very high resistance values suggesting that stone may be present.
There are a number of other linear features most of which probably represent old field boundaries. One to the west of the small church is at least 70m in length and coincides with a linear depression on the ground.
The resistivity data generally showed non-archeological features. However, Line 1 was taken beside the large church and across where the 12th century church can be seen on the north side of the enclosure. There is a very distinctive high resistivity anomaly isolated in the section between 9-11m, which extends to a depth of at least 2m. Either side of the

anomaly there are distinctive dips in the readings. This feature is possibly archaeological and may be related to the 12th century church.
Line 2 resistivity section was taken across the front of the small 15th century church with the Romanesque doorway. Readings show a low shallow resistivity layer underlain by a deeper higher resistivity layer. The resistivity values on this section are the lowest of the 5 sections (Phase I) and confirm the resistance data which showed this church in a low resistance area. The doorway of the church is at 11-12m and this is where a low resistivity zone is observed.

The magnetic data has provided considerably more information than the resistance data.
There is a distinct magnetic zonation in the study site.
Zone A encompasses parts of the enclosing ditch on the northern edge of the study area. It covers are area of around 50m x 30m and shows clear evidence on at least 2 sides of straight linears at right angles to each other.

Zone B is NW of the small church in Rahan and is a magnetically quiet area suggesting little human activity.

Zone C is east of the large church in Rahan. It is magnetically noisy but not to the same extent as zone A. It is a very regular area and suggests a zone of linear patterns.

Zone D is magnetically quite but it is sharply defined by a curvilinear break from the magnetically noisy zones C, E and F.

Zone E occurs over the banks and ditches on the northern part of the site though there does appear to be a crude approximate E-W trend which probably reflects the different magnetic signatures for the banks and ditches.

Zone F is a regular small area of low variability, most probably bounded by ditches.

Zone G: This is quite similar to zone F and is in fact parallel to it. Again there is a magnetic zone surrounding a core of low magnetic variability.

A long curvilinear feature appears to connect the large anomalous magnetic zone which has been interpreted as a building and continues past the front of the small church. It is over 70m long and it may be a boundary or possibly a path. Part of it is quite magnetically noisy.
A band of ridges and furrows caused by ploughing are very distinctive. They terminate in the north at the possible building though continue westwards past it.
Clear evidence of part of a feature, which appears to curve around at least part of the larger church. Fences and metal made it difficult to obtain data in this area. Some other features parallel to it.

Summary of results Phase II

There is evidence of a large enclosure, which encompasses the church and graveyard. The enclosure signature consists of a dark (high) magnetic signature. It is sub-rectangular to sub-circular in shape and is approximately 190m across. The enclosure is roughly centred on Irish Grid Reference: 225943 (E) 225454 (N). The eastern boundary is parallel to the field boundary.

Immediately to the east of the graveyard, 2 sub-parallel curvilinear features can be seen. A small sub-rectangular enclosure, with its long axis orientated N-S can be seen southeast of the enclosure. The centre of this feature is located at Irish Grid Reference: 225981 (E) 225987 (N). It is about 16m long and about 12m wide. It is unlikely that this structure is a building, though if it is, it would be a large hall.

The location west of the church and graveyard consists of a number of long lineaments, one of which is 134m long and perfectly straight. Some curved features are shown in this region, mainly with a high magnetic signature.

The magnetic lineament pattern displays a range of ploughing trends in different locations of the Rahan site.

The 'magnetic' zones north of the main church were discussed in Phase 1 of the report, but there is also a large concentration of magnetic anomalies east of the main church and graveyard. A particularly large concentration of anomalies occur in the vicinity of the intersection of a number of linear features at Irish Grid Reference: 225966 (E) 225357 (N).

Resistivity Line 2 was taken over the potential enclosure boundary west of the graveyard. While there is no very prominent anomaly, there is a clear depression in the values in the middle of this traverse. This may represent the site of a former ditch, which could be the enclosure boundary

Resistivity Line 4 was taken across the enclosure boundary to the south of the cemetery. A very prominent resistivity changes occurs across this feature. Values are much higher to the north than to the south. This suggests that this was an important boundary where there were differences either side of it, perhaps in terms of habitation or cultivation.

Magnetic susceptibility values for the topsoil soil patterns which are consistent with those discovered using the magnetic gradiometer.

Ground penetrating radar Line 3 is taken near the SE corner of the new cemetery, beside old ruined church. Clear changes along this line can be seen and it shows a possible shallow trench which coincides with a dramatic change in amplitude signal. Near the

church there is very little variation suggesting a much more homogeneous shallow subsurface.

Ground penetrating radar Line 4 was obtained across the postulated boundary enclosure, south of the cemetery. The boundary coincides with a marked trough in the amplitude data. Line 6 also coincides with a marked change in signature across the location of the enclosure boundary.

Geophysical investigation around the site of the former monastic settlement, Rahan, Co. Offaly
Phase I and II

Introduction

The Environmental Geophysics Unit of the Department of Geography, National University of Maynooth was commissioned by Amanda Pedlow, Heritage Officer, Offaly County Council to undertake a geophysical survey at Rahan, Co. Offaly. Data were collected in 2 phases (2006 and 2007). Permissions to undertake the survey were obtained from the Department of the Environment, Heritage and Local Government under permit number 06R023 (extended in 2007). Data were collected by Paul Gibson, Dot George and Lorraine O'Reilly. The authors of this report would like to thank the following for supporting this research:

- Offaly County Council especially Amanda Pedlow
- Caimin O'Brien, Archaeological Survey of |Ireland.
- The Heritage Council

In addition, this work could not have been undertaken without the full co-operation of the landowner, Sean Grennan who allowed access to the relevant areas. An especial thanks goes to him.

Location

Rahan site is on the western edge of Tullamore, Co. Offaly close to the Grand Canal. It is located at Irish Grid Co-ordinates (E) 225900 (N) 225400.

Archaeological Context

Rahan has been a main ecclesiastical centre since the 6th century when it was supposedly founded by St. Carthach (Mochuda). It adopted the rules of St. Augustine around 1200. The site contains the remains of 3 churches. The Church of Ireland nave and chancel was added in1732 to a 12th century church. The former has incorporated into it a large Romanesque 12th century rose window. In the graveyard is another small church and some distance away is a small Romanesque church rebuilt in the 15th century.

Aims and Objectives

The aim of the geophysical survey was to determine if any unknown archaeological features were located at this site. Specific objectives were to:

- Determine the spatial relationship of any below ground archaeological features.
- Attempt to identify any located features.

The methodology adopted allowed a number of geophysical techniques to be employed. In Phase I of the survey, magnetic gradiometer, twin probe earth resistance and 2D resistivity techniques were employed. In Phase II of the survey, magnetic gradiometer,

2D resistivity, magnetic susceptibility and ground penetrating radar techniques were employed.

Methodology

Phase 1 of the fieldwork was carried out in early Spring 2006 and Phase 2 in late Spring - early Summer 2007 by Paul Gibson, Dot George and Lorraine O'Reilly.

The geophysical survey was carried out using a Bartington 601 fluxgate gradiometer, Campus resistivity equipment, TRCIA resistance meter and Sensors & Software ground penetrating radar system. 30 x 30m grids were laid out and GPS positions located using a Trimble XT Global Positioning System. In Phase I of the project 43 magnetic grids were obtained and in Phase II, 49 grids were investigated.

Magnetic Gradiometer Survey

A magnetometer is a device used to measure the intensity of the Earth's magnetic field at a specific location. There are various types of magnetometer, which operate using different physical principles, though the one employed in this study was a fluxgate magnetometer.

The fluxgate magnetometer consists of two short ferromagnetic bars around which identical primary coils are wound though in opposite directions. This array is surrounded by a secondary coil. An alternating current is applied to the primary coils which in the absence of an external magnetic field produces zero output in the secondary cool because the primary coils are oppositely wound. However, when positioned such that the cores are aligned with the component of the Earth's magnetic field, which is of interest, a voltage is induced in the secondary coil because the Earth's field is increased by one core and decreased by the one whose windings are in the opposite direction. This induced voltage is proportional to the strength of the component of the Earth's magnetic field to which the cores are parallel. It is possible, by changing the orientation of the fluxgate magnetometer, to measure the total field (F), the horizontal field (H) or the vertical field (Z). However, very accurate alignments are required in order to obtain accurate readings of H and Z. These high accuracies can be obtained at base stations where three fluxgate magnetometers can be permanently fixed such that one obtains values of Z and the other two measure the northerly and easterly components of the horizontal field.

When a magnetic reading is obtained using a magnetometer, this represents the resultant of the addition of the Earth's magnetic field vector and the anomaly due to all the subsurface sources. However, it is shallow sources that are of most importance in archaeological investigations but the relative contribution of shallow and deep sources cannot be determined from a single magnetic reading. However, this problem can be overcome by using the magnetometer in gradiometer mode and acquiring two simultaneous readings from two sensors located at different heights. This is accomplished by placing sensors a fixed vertical distance apart. In this study a Bartington Grad-601 gradiometer was employed with a vertical separation of 1 m between the two sensors, Figure 1.

The survey was undertaken along parallel lines, walking approximately west to east. Data were surveyed in 'zigzag' manner. Data were recorded with a spatial resolution of 1 m intervals between traverses and 0.25 m intervals along those lines with a constant walking

speed of 1 m/s. The data were logged automatically and downloaded at the end of the data for further processing. The Bartington 601 gradiometer was calibrated as instructed by manufacturers and a drift correction applied.

Data Processing of magnetic data

The data were processed in ArchaeoSurveyor by first creating a composite of all grids. High magnetic anomalies, referred to as magnetic 'spikes' were removed and a range of – 50 nT to +50 nT was initially used as archaeological features, except for iron features tend to occur within this range. The raw data were then corrected. Initially a zero mean line transform was applied in order to produce a uniform background, centred on zero (the value expected if there were no anomalies). Some linear features showed slight offsets due to the zigzag manner of acquiring data and these were fixed using the 'destagger' function. The data range was then decreased interactively in order to best display the anomalies. The data were then output to an ascii file and input into SURFER where the data were gridded. A boundary file was applied to cookie-cut the resultant images. The data were saved in Tiff format and input into ArcMap Geographical Information System and referenced to Irish grid co-ordinates.

Graphical Display of magnetic data

The data were displayed using SURFER's various colour transforms. A greyscale image was used, which tends to display best the linear features. The clipped data were employed and black represents high values and white low values. Colour coded and directional images were also employed when it as felt that they yielded more information.

Earth Resistance and Resistivity Survey

Resistance surveying has been employed for a long time in archaeological investigations because anthropogenic features are often very regular in shape and provide good resistance contrasts with the background. The variation in subsurface moisture content dictates to a large extent the changes in resistance. Infilled defensive ditches are often wetter than surrounding regions and are associated with low resistivity values whereas buried walls or foundations may appear as high resistance features. It should be stressed though that features detected by resistivity means cannot be unambiguously identified until excavated as each site is different. For example, a ditch may have been infilled with stones and it may then have a relatively high resistance and water can collect under buried walls resulting in low resistance. A TRCIA twin electrode resistance meter was employed in this study (see Figure 1).

The survey was undertaken along parallel lines, walking approximately west to east. Data were surveyed in 'zigzag' manner Data were recorded with a spatial resolution of 1 m intervals between traverses and 1 m intervals along those lines. The data were logged automatically and downloaded at the end of the data for further processing. The

Data were recorded using a TRCIA twin-probe array spaced 0.5 m apart. The remote probes were located a minimum distance of 15 m away from the mobile probes and were 1 m apart. These were moved between grids and recalibrated to match previous grids. The data were logged automatically and downloaded at the end of the data for further processing.

Data Processing

The data were processed in ArchaeoSurveyor by first creating a composite of all grids. Some grids did not match well with adjacent one due to having to move the remote electrodes. All grids were balanced and any spurious high data values removed. The data were then output to an ascii file and input into SURFER where the data were gridded. A boundary file was applied to cookie-cut the data. The data were saved in Tiff format and input into ArcMap Geographical Information System and referenced to Irish grid co-ordinates.

Graphical Display of resistance data

The data were displayed using SURFER's various colour transforms. A greyscale image was used, which tends to display best linear features. The clipped data were employed and black represents high values and white low values. Colour coded and directional images were also employed when it as felt that they yielded more information.

Resistivity surveying equipment

Resistivity surveying equipment has a number of simple components: a resistivity meter housing a source of current and a means to measure the voltage and wires connected to electrodes through which the current is injected into the ground. There are various types of resistivity meter (e.g. Campus Geopulse; IRIS Instruments SYSCAL system; ABEM TERRAMETER SAS 4000) thus details vary but they conform to a general pattern. The resistivity meter is housed in a lightweight waterproof shell, with the controls, display and connectors on the top panel. The standard type of meter has four connectors two for the two potential and two current electrodes. The operator has the option to pick the current setting from a number of preset values. A number of readings are obtained at one location and an average value obtained. The power output for most systems can be boosted using optional or external equipment which allows the delivery of larger currents. Typically, resistivity meters have power outputs of the order of 50 -100W.

Voltage is measured by a high impedance voltmeter and the output $\Delta V/I$ is displayed in ohms. The input resistance is very high (of the order of 20 MΩ in the Campus Geopulse) compared to the resistances being measured in the ground thus the voltmeter draws no current.

The electric wires connecting the electrodes to the meter are very low resistivity copper wires. Most electrodes used in resistivity surveys are metal spikes, which are generally inserted into the ground to a depth of 5 - 10 cm. The electrodes must form a good electrical contact with the ground and their resistance should be less than 2,000 Ω. The resistance may be too high in very dry conditions or in very stony ground. Increasing the contact area of the electrode may improve the situation but wetting the contact area with an electrolyte such as salt water is often sufficient. If direct current is continually input into the ground in the same direction, polarization can occur in which cations and anions accumulate around the positive and negative electrodes. This is counteracted by periodically switching the direction of current flow. Although resistivity surveys in the past were generally undertaken with four electrodes, developments over the last 15 years have led to multi-core resistivity systems. This topic is covered under electrical imaging in the next section.

2 dimensional electrical imaging

Two dimensional electrical imaging (also termed tomography) allows the acquisition of apparent resistivity variations in both the vertical and horizontal directions. It effectively produces a 2D slice which is known as a pseudosection.

To obtain 2D apparent resistivity data using only 4 electrodes is an extremely long and laborious exercise. Initially data would need to be collected along a traverse at fixed intervals with a constant electrode spacing, then the procedure would need to be repeated with a larger electrode spacing. This would involve the measurement of a large number of distances as the electrodes are moved. Electrical imaging is mainly undertaken using an insulated multi-core cable with a number of fixed interval take off points to which electrodes are connected. The length of the cable, number of take-off points and interval between them can vary. Typical cables use 25 - 50 electrodes with take off points at fixed intervals. The cable is connected to the meter which in turn is connected to a laptop computer. The operator loads a parameter file which instructs the resistivity meter which electrodes to use to obtain data. The parameter file varies with the system but typically contains a line for each data point collected. An example of the first three lines of a parameter file is:

1	2	4	1	0.5	1	2	3	4
2	2	4	1	0.5	2	3	4	5
3	2	4	1	0.5	3	4	5	6.

This file shows that for the first reading the current to be used is 2 mA, the average of 4 readings is to be taken, the current is to be switched on for 1 second and left turned off for 0.5 seconds and that electrodes 1, 2, 3 and 4 are to be used for C_1, P_1, P_2, C_2 respectively. Once the data for the first level are obtained, data for the second level are collected using different electrode combinations. For the Wenner array, the first reading for level 2 will use electrodes 1, 3. 5, 7 for C_1, P_1, P_2, C_2 respectively. Repeating this procedure for higher levels allow the production of a pseudosection which displays the apparent resistivity variations in two dimensions. The depth at which the data are plotted is generally the median depth of investigation for the particular electrode array for that specific level.

Although the pseudosection provides some information about the subsurface it is important to remember that different pseudosections would be produced for the same profile if different electrode arrays are used.

Processing the 2D resistivity data

The data must be modeled using a computer program in order to determine how the true resistivity varies with depth. One such program that is widely used in resistivity work is the inversion program RES2DINV which involves a comparison between **measured and calculated** apparent resistivity. The subsurface is divided into a number of rectangular squares which are assigned resistivity values and an initial model of the surface is formed which shows the variation in true resistivity with real depth. The apparent resistivity that this model would yield for the electrode array that is used is then **calculated** and compared to the measured apparent resistivity. The model is then progressively altered

using a least-squares optimization approach in order to reduce the Root Mean Square (RMS) error between the calculated and measured apparent resistivity. The number of iterations can be specified or the process can stop once the change between two iterations is below a specified threshold value. RMS errors were of the order of 2-4% in the Rahan survey. A Wenner-Schlumberger array was used in this survey with 25 electrodes using a Campus Geopulse Resistivity meter. Electrode spacing varied on different lines.

2D resistivity display

The resistivity models were saved as jpegs in RES2DINV and displayed using 16 colours with a logarithmic scale.

Ground penetrating radar theory

Ground penetrating radar (GPR) is an electromagnetic geophysical technique which can, under certain circumstances, provide a very detailed image of the subsurface. In essence, GPR consists of transmitting electromagnetic (EM) pulses into the ground and measuring the signals that are reflected back from subsurface interfaces or bodies and the times at which these signals are acquired at the receiver. GPR systems are designed to operate at different frequencies ranging from about 10 MHz to 1500 MHz.

The GPR data were collected with a Sensors & Software pulseEKKO 100 system. The main power supply is typically a 12 V rechargeable battery which is used to power the control console. A high voltage electrical pulse, is sent from the console to the transmitter by means of fibre optic cable and the pulse is injected into the ground via the transmitter antenna which has a designated central operating frequency. As the input energy wave travels down in encounters discontinuities in the subsurface such as changes in rock type, water content or walls and a fraction of the input energy is reflected back towards the surface. The reflected signal is recorded by the receiver and the results are shown on a display unit which is the screen of a laptop computer. The data are stored digitally on the computer which also contains the software programs used to control the collection of the data and also the processing of the radar data.

The GPR system was used in constant separation mode. In constant separation mode, the receiver and transmitter antenna are kept a fixed distance apart and an initial reading obtained. The two-antenna setup is then moved a set distance and a second reading obtained and so on. Constant separation reflection data was collected in step mode. In step mode, the antennae are physically lifted and moved along a transect with data collected at discrete intervals. The step distance varies and depends on the frequency used and the size of the subsurface target. The operator, manually using a trigger device, obtains data at each station. Such triggers are often mounted on the handle of the transmitter and connected to the control console by means of fibre optic cable.

A typical radar profile (sometimes referred to as a radargram) is composed of a number of traces which is a record of the reflections at one point. The number of traces will vary depending on the length of the traverse and how often data are recorded along the traverse. A 20 m long traverse will be composed of 201 traces, if data are obtained at 10 cm intervals in step mode. A sequence of closely spaced traces allows the continuity of reflectors to be examined. The horizontal axis shows the location along the traverse whereas the vertical axis gives the two-way transit time for the EM waves. Shallow features have shorter travel times than deeper features and consequently appear higher up

in the section. The velocity of the EM waves in the subsurface must be known, (or measured) in order to determine the true depth of features below the surface.
In order to undertake a successful GPR survey, there are a number of parameters which have to be decided on and which may need to be input into the computer program used when collecting the data. These include:

- frequency
- time window duration
- temporal and spatial sampling intervals
- antennae separation and deployment.

Frequency
GPR systems are designed to operate with antennae which transmit and receive at specific frequencies. Thus for example Sensors & Software Inc. produce antennae which operate at 12.5 MHz, 25 MHz, 50 MHz, 100 MHz and 200 MHz for the pulseEKKO 100 system. The choice of operating frequency is crucial if a project's objectives are to be achieved as it strongly controls the depth of investigation and the resolution that is obtained. Skin depth (which is inversely proportional to attenuation) depends on the operating frequency. Decreasing frequency increases the skin depth and reduces the attenuation. Therefore the lower the operating frequency of a GPR system, the deeper the depth of investigation. However, the lower the frequency the poorer the vertical resolution of the system. Data were collected on all lines using an antennae frequency of 200 MHz.

Time window duration
The time window is the temporal interval during which reflected data are measured and saved. If the time window is very short then important reflection events at depth may not be recorded. However, setting too long a time window may be inefficient as attenuation may limit the depth of investigation to only a few meters. The time window is equal to twice the depth of investigation (as the radar wave has to travel down to the reflector and the reflected wave back up to the receiver) divided by the subsurface velocity. In general, the time window for lower frequency antennae tend to be greater than for higher frequency ones as the former have a greater depth of investigation. A time window of 130 ns was employed in the survey.

Temporal and spatial sampling intervals
The returned signals are regularly sampled and should not exceed half the period of the highest frequency signal. Introducing a safety factor of two yields a maximum sampling rate that is one sixth of the period of the center frequency. Thus the maximum sampling interval for a 200 MHz system is 0.83 ns. The sampling interval increases as the center frequency decreases. This interval, combined with the time window determines how many points are recorded for each trace. 400 points per trace are recorded if the temporal interval is 0.5 ns for a time window of 200 ns.
The GPR data were being collected in step mode. The Nyquist sampling interval should not be exceeded. Typical spatial intervals provided by Sensors & Software are 10 cm for 200 MHz centre frequency antennae and this was used in the survey

Antennae separation and deployment
Systems, such as the pulseEKKO 100 obtain data in reflection mode by maintaining the transmitting and receiving antenna a fixed distance apart. This distance varies depending on the frequency of the system. The antennae should be separated by at least half a wavelength of the center frequency. Sensors & Software Inc. recommend a minimum antennae separation of 0.5 m for 200 MHz antennae and this was employed in the survey.

Processing of GPR data
Various computer programs are available to process radar data in order to maximise the amount of information that can be extracted. These programs allow the radar files to be edited e.g. datasets can be reversed, resampled or merged or they can be processed by applying gains, temporal or spatial filters.
All GPR data were 'dewowed' before being examined. Although the transmitted radar pulse is mainly at a high frequency, the low frequency component slowly decays and the reflections are superimposed on this decaying transient. GPR data are high pass filtered (dewowed) to suppress the low frequency component and to pass the antenna center frequency.
As a radio wave travels downward, the wavefront area increases, some energy is reflected at near-surface interfaces and some energy is absorbed. Thus, considerably less energy is available for reflection from deep sources and the reflectors at depth are generally associated with much weaker signals. Consequently some reflectors may not be recognised. It is usually necessary to 'gain' the data in order to account for this energy loss and boost the signal for the reflectors at depth. An autogain applies a gain that is inversely proportional to the decaying signal strength, thus reflectors near the surface are gained a little while a much greater grain is applied to deeper reflectors. This approach was employed in the survey, though the effects of some SEC gains were examined. This automatic gain attempts to equalize all the signal strengths. The software employed was Ekko-View.

(a) (b)

Figure 1: (a) Twin electrode resistance equipment; (b) Bartington magnetic gradiometer.

Results of Resistance survey at Rahan – Phase I

In all over 40 grids of data were collected at Rahan, where each grid is 30 x 30m, thus approximately 33,000 resistance data points were collected with a spacing of 1m in both the x and y directions. Figure 2 shows the location of the data collection and the northern part of the Rahan field that has been surveyed. The colour coded image shows that there is a clear patterns to the distribution of high medium and low values of resistance, Figure 3. In general the high resistance values are observed in the northwest part of the study area, the low values in the southeast with the medium values mainly around the central part. To a large extent, these variations probably represent variations in soil type and/or drainage. However, there are some sharply defined changes in resistance. Note how the small church at Rahan is enclosed within a very low resistance area, delineated in blue. This blue trends turns through a right angle and suggests that the church was once in a separate area and the soil evolved differently due to possible different agricultural practices. There are also a number of sharp changes in resistance for the high values, where the change occurs over a clearly defined linear break.

A grey tone image and interpretation are shown in Figure 4. There are clear linear features observable on this image which in all likelihood are archaeological in nature.

Feature A: This is a broad curvilinear low resistance feature in the eastern part of the image. It may represent an in-filled boundary ditch. Southwards it is more difficult to discern but if continue it would just enclose the small church at Rahan. (A, Figure 4). It is about 110m in length.

Feature B: A series of low resistance linear features can be seen to the east of feature A, i.e. they are enclosed by it. They may represent old ploughing patterns, B, Figure 4.

Feature C: Very closely spaced parallel linear patterns can also be observed in the field and are also obvious on aerial photographs of the site. They relate to ploughing patterns and may be medieval in age.

Feature D: Broadly spaced linear patterns with an approximate east-west trend are detected near the northern edge of the study area. These are parallel to and beside the outer enclosing northern embankment of the site and represent small embankments and ditches in this vicinity. Just to the east of these is a region with very high resistance values suggesting that stone may be present.

Feature E: A broad linear feature characterized by low resistance values extends across the resistance image for a distance of 80 metres.

Feature F: To the west of feature E is a number of short linears. Interestingly these tend to be concentrated within an area where resistance values are slightly lower than the surrounding areas.

Feature G: This is a curvilinear narrow high resistance boundary. It is quite close to the fence and an adjoining house so it was not possible to discern its full extent
There are a number of other linear features most of which probably represent old field boundaries. One to the west of the small church is at least 70m in length and coincides with a linear depression on the ground.

Figure 2: Location map of resistance data for Rahan.

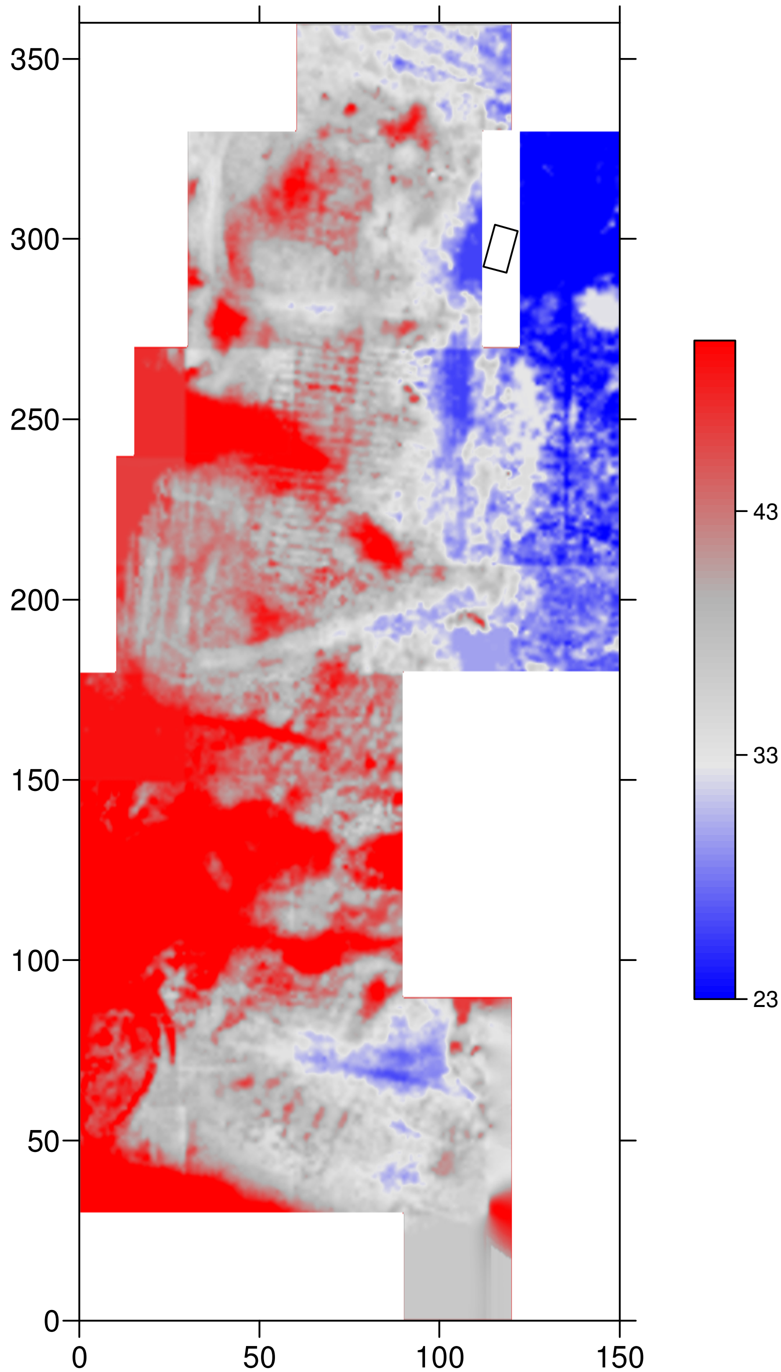

Figure 3: Plot of resistance data at Rahan, colour coded.

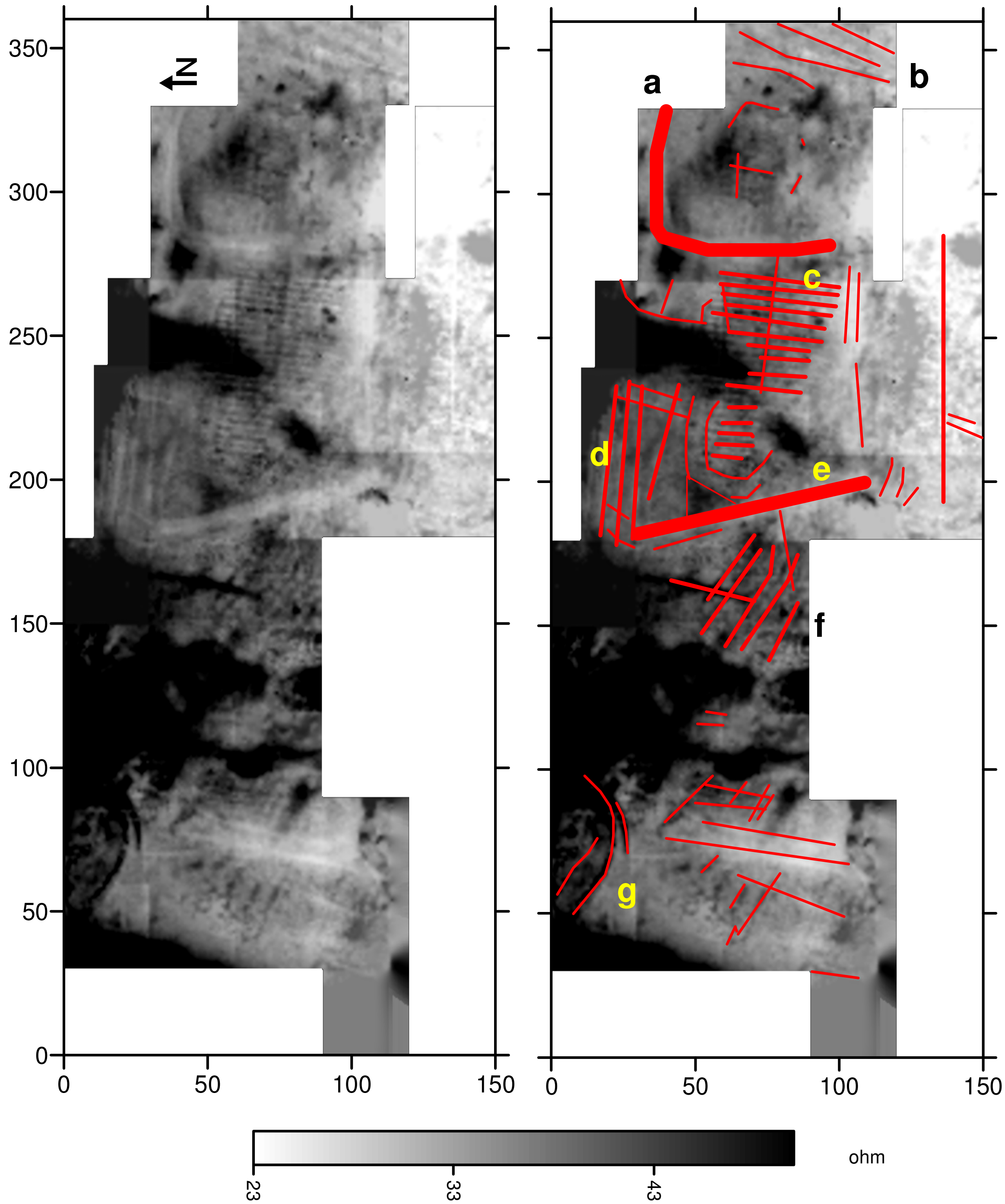

Figure 4: Plot of grey tone resistance data and interpretation.

Results of Magnetic survey at Rahan – Phase I

In all over 40 grids of magnetic data were collected at Rahan during Phase I, where each grid is 30 x 30m, thus approximately 120,000 magnetic data points were collected with a spacing of 0.25m in the y direction and 1m in the x direction. Figure 5 shows the location of the data collection and the northern part of the Rahan field that has been surveyed.

Figure 6 is a colour coded magnetic image of the study area and Figures 7 and 8 represent blow-ups of parts of the study area. These figures show Surfer grey-scale versions of the data in which deviations from the norm are show in blue or red. In theory a region which has had no anthropogenic activity should give a background value of around 0 nT. However, archaeological sites are often associated with magnetic anomalies due to the activities that occur around them and zones of activity are best observed when colour coded.

Figure 6 clearly shows there are a number of distinct zones in which there is enhanced activity and other areas which are magnetically quiet. 8 zones have been identified though it is possible that some could be further subdivided.

Zone A encompasses parts of the enclosing ditch on the northern edge of the study area. This area is shown in more detail on Figure 7. It covers are area of around 50m x 30m and shows clear evidence on at least 2 sides of straight linears at right angles to each other. Interestingly this area is also characterized by high resistance values which would also support the view that there was a building here.

Zone B is NW of the small church in Rahan and is a magnetically quiet area suggesting little human activity.

Zone C is east of the large church in Rahan. It is magnetically noisy but not to the same extent as zone A. It is a very regular area and suggests a zone of linear patterns.

Zone D is magnetically quite but it is sharply defined by a curvilinear break from the magnetically noisy zones C, E and F.

Zone E occurs over the banks and ditches on the northern part of the site though there does appear to be a crude approximate E-W trend which probably reflects the different magnetic signatures for the banks and ditches.

Zone F is a regular small area of low variability , most probably bounded by ditches.

Zone G: This is quite similar to zone F and is in fact parallel to it. Again there is a magnetic zone surrounding a core of low magnetic variability.

Zone H: This is near the entrance to Rahan field and again this zone has little magnetic variation. Its southern edge is delineated by the modern roadway to the church, though the strongest linear feature is parallel and a short distinct from the modern roadway.

Figure 5: Location map of magnetic data.

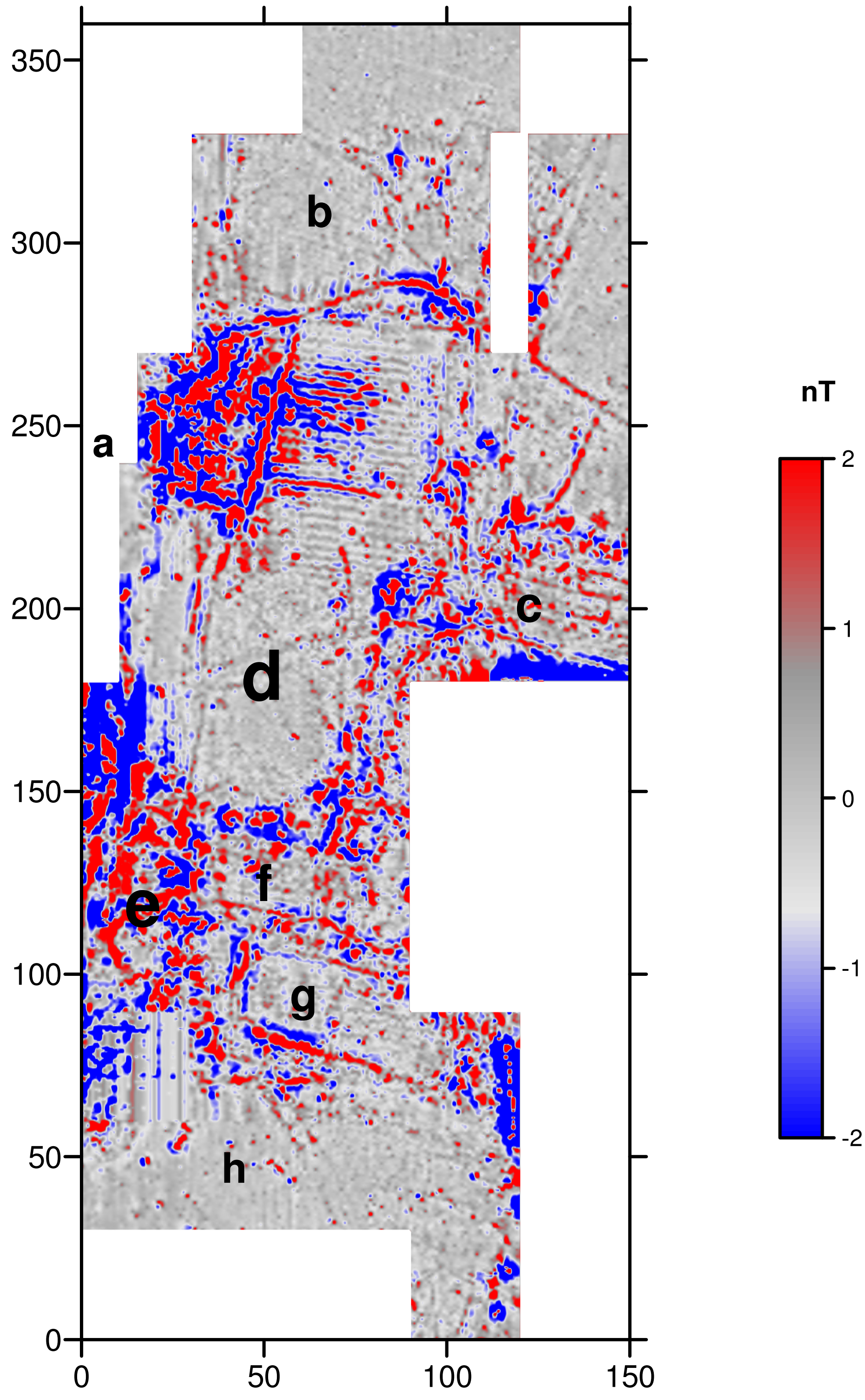

Figure 6: Colour coded magnetic data for Rahan.

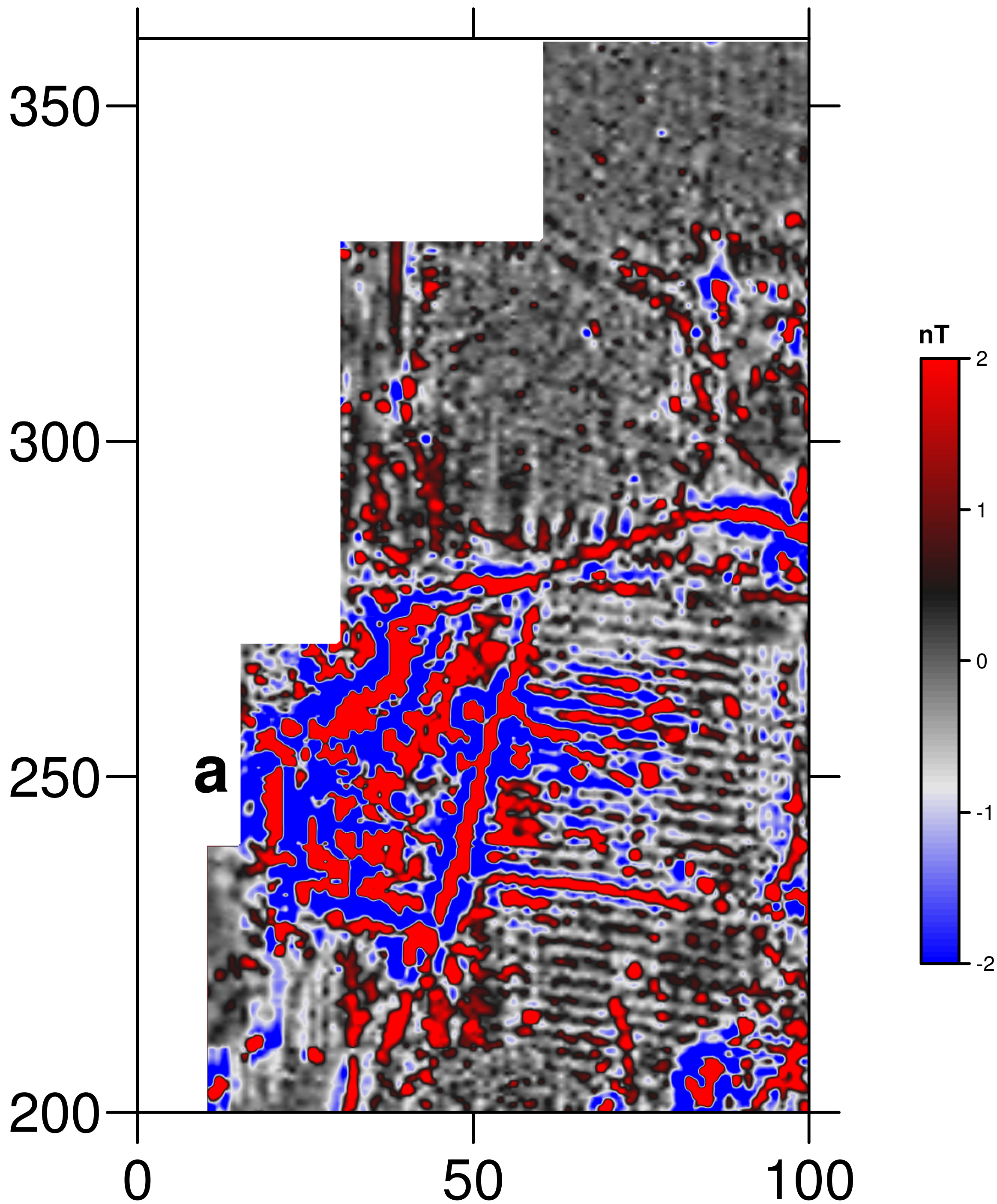

Figure 7: Detail of magnetic data at Rahan.

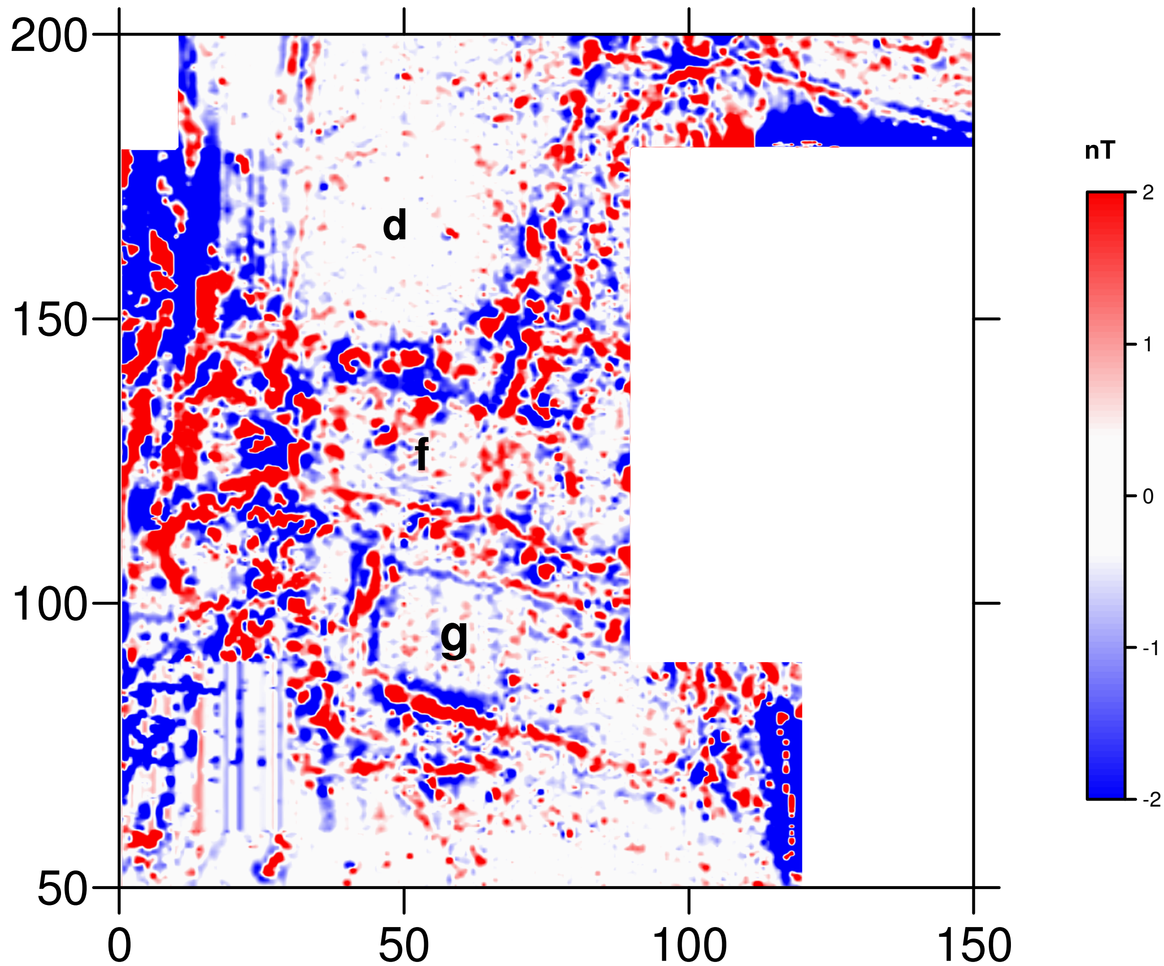

Figure 8: Detail of magnetic data at Rahan.

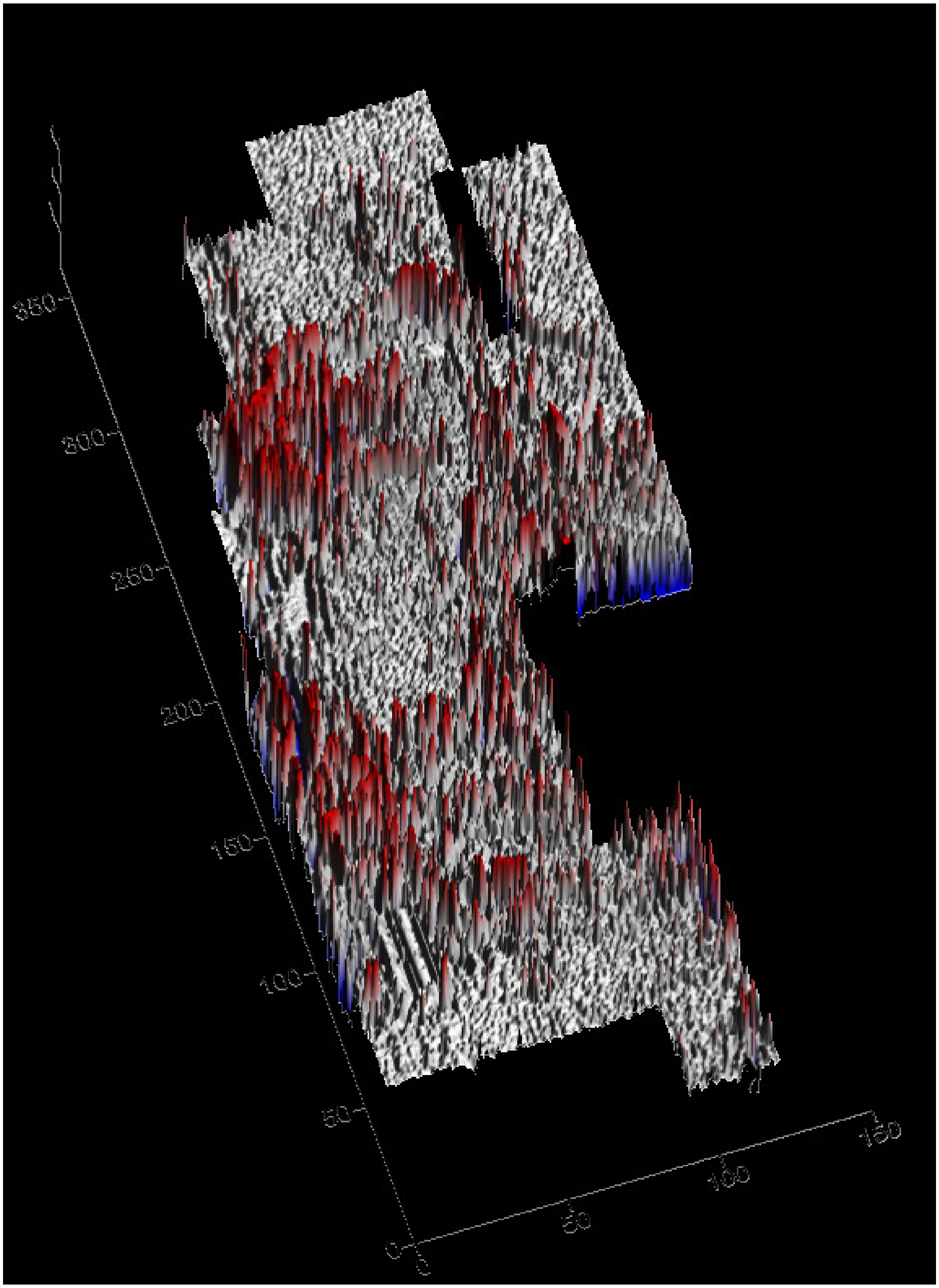

Figure 9: Perspective view of magnetic data at Rahan.

Figure 10 shows a grey tone image of the magnetic data and it is interpreted in Figure 11. Two subsets of the data are also given in Figure 12 and Figure 13. Grey tone images are particularly good for showing linear features in an area. The same zones are observable but other features are also apparent.

A: (all Figure 10). Magnetically quiet though a few diffuse linears can be observed, which were seen better on the resistance image.

B: A number of linears are observed immediately south of the small church and parallel to its long side. This is also parallel to the resistance change which again supports the idea that the church was once separated from the rest of the field.

C: A long curvilinear feature appears to connect the large anomalous magnetic zone which has been interpreted as a building and continues past the front of the small church. It is over 70m long and it may be a boundary or possibly a path. Part of it is quite magnetically noisy.

D: These are the most prominent linears on the image. They are ridge and furrows caused by ploughing. They terminate in the north at the possible building though continue westwards past it.

E: A number of linear features are observable here. Some trend parallel to the outer boundary and may represent unknown banks and ditches or possibly even a path. A subtler one cuts across the others.

F: Clear evidence of part of a feature which appears to curve around at least part of the larger church. Fences and metal made it difficult to obtain data in this area. Some other features parallel to it.

G: Very obvious enclosure type feature. Long axis is parallel to long axis of Feature F.

H. Very high anomaly linear feature adjacent to modern path. Most likely made ground.

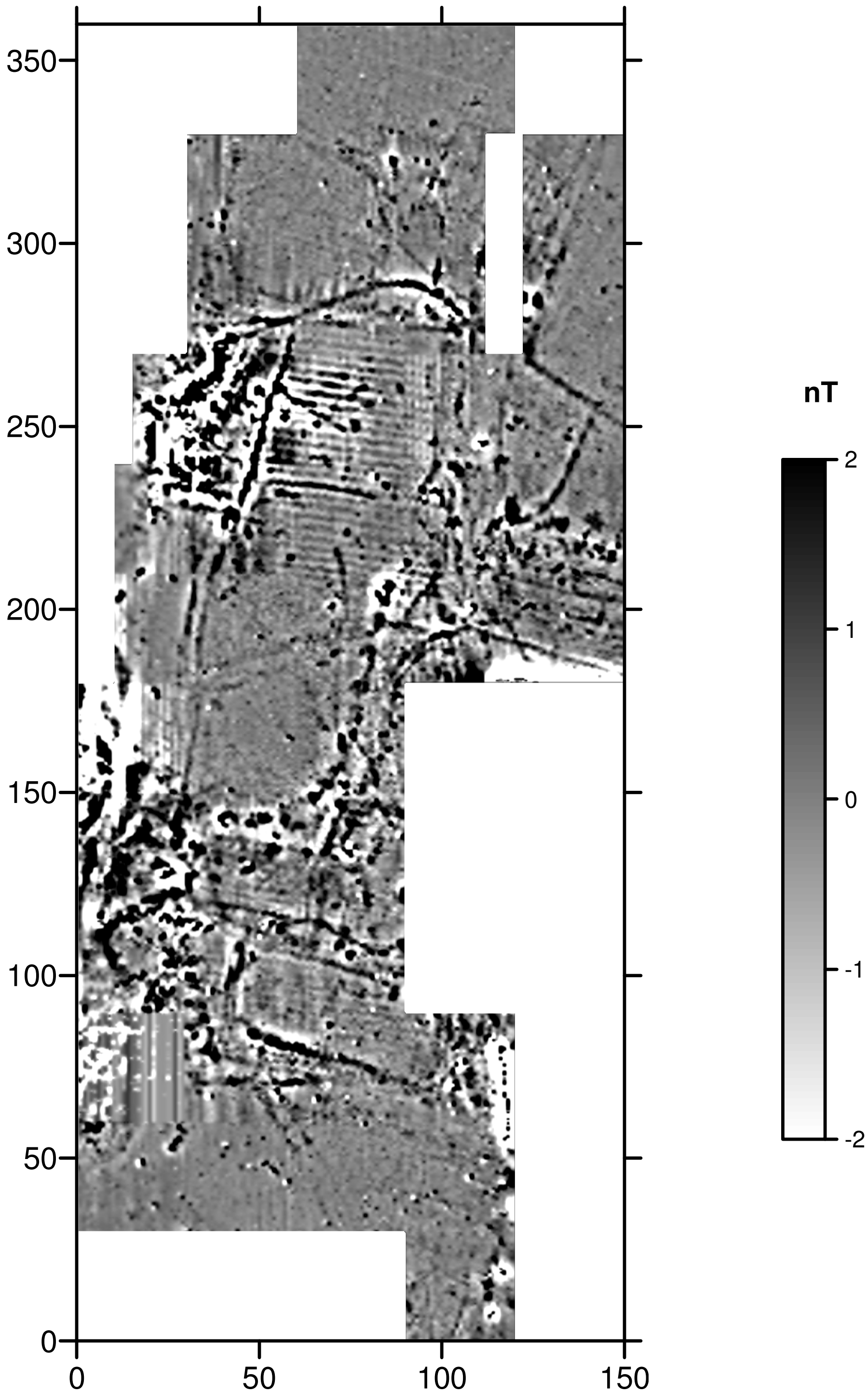

Figure 10: Grey tone magnetic data for Rahan.

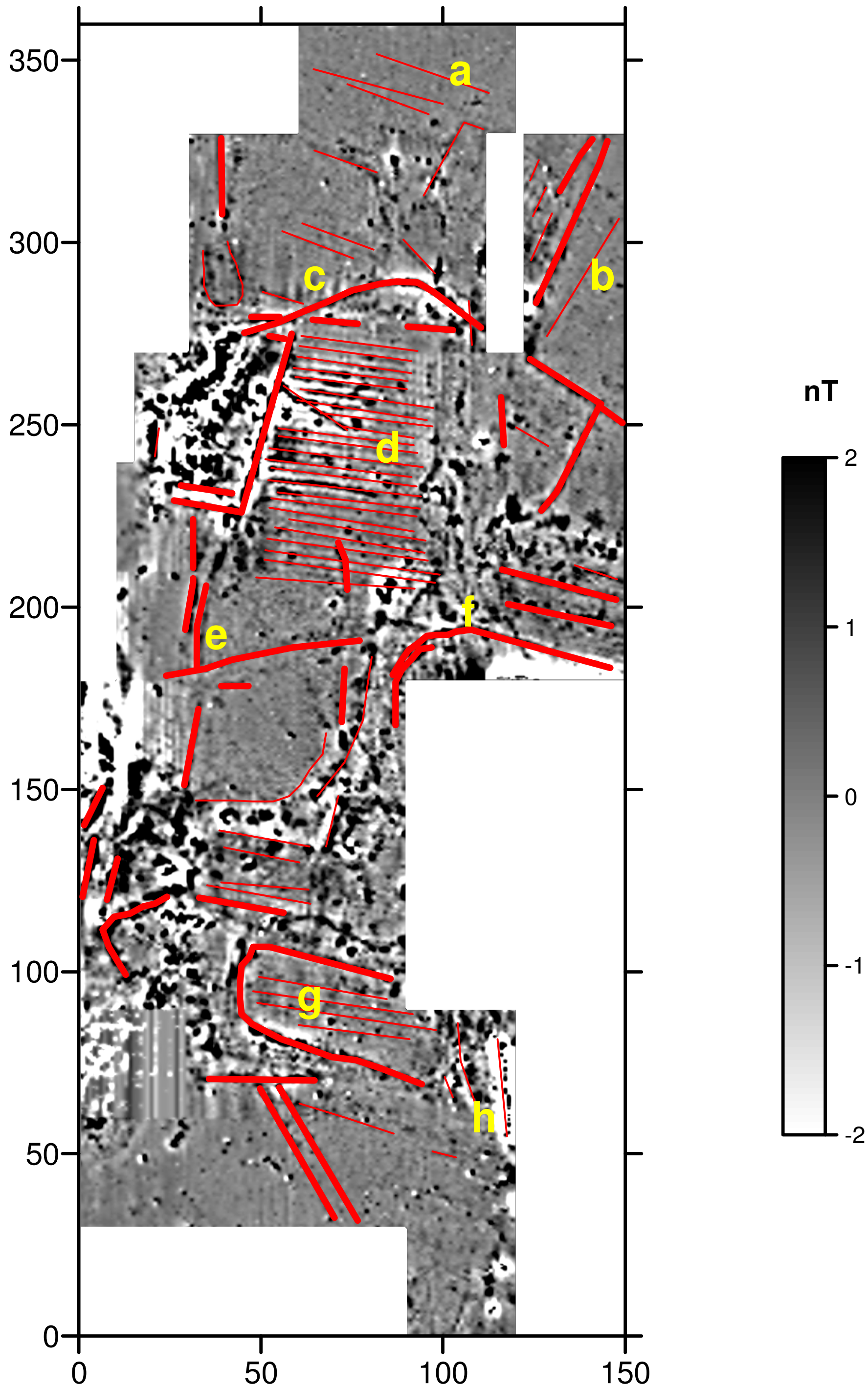

Figure 11: Interpretation of magnetic data.

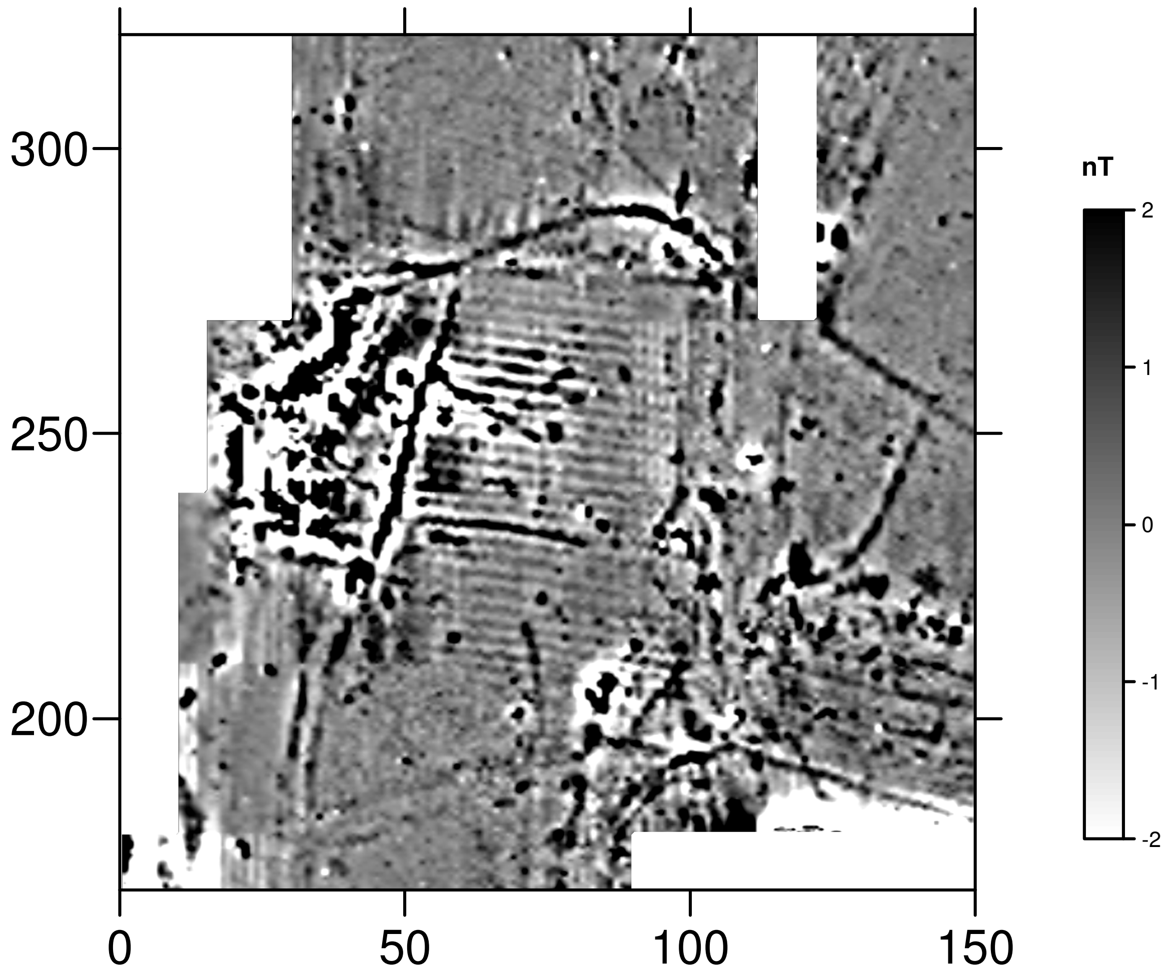

Figure 12: Detail of magnetic data.

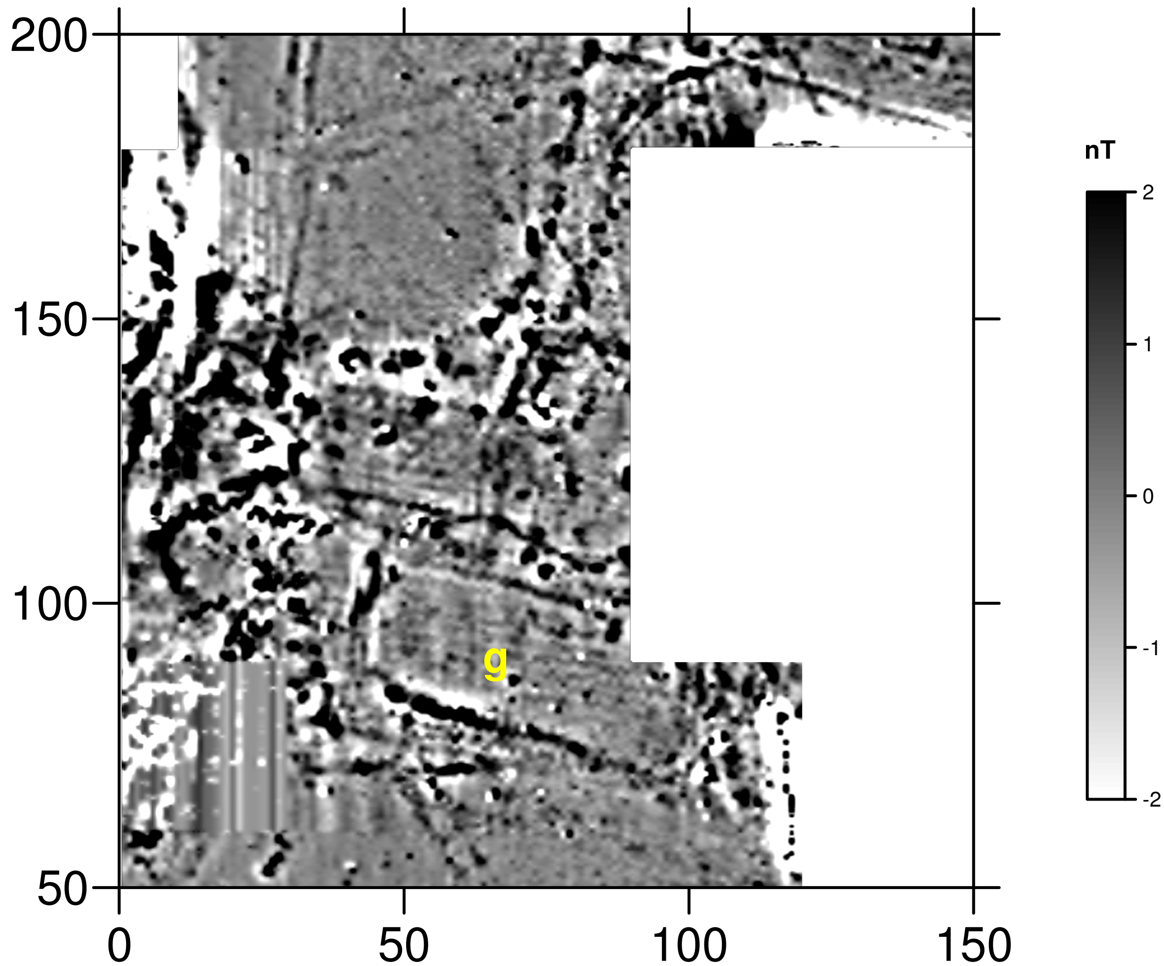

Figure 13: Detail of magnetic data.

Results of Resistivity data at Rahan Phase I

Five lines of resistivity data were collected at Rahan in 2006, during Phase I – see Figure 14 for location. Lines 1 to 4 had an electrode spacing of 1m whereas line 5 had a spacing of 1.5m. The results of the processing are shown in Figures 15-19.

Line 1: (west at left side of image). This line was taken beside the large church and across where the 12th century church can be seen on the north side of the enclosure. The mid point of the 12th century church is at 12m on Figure 15. There is a very distinctive high resistivity anomaly isolated in the section between 9-11m, which extends to a depth of at least 2m. Either side of the anomaly there are distinctive dips in the readings. This feature is possibly archaeological and may be related to the 12th century church. Reading for this section range from about 50-600 ohm m.

Line 2: (north at left). This resistivity section was taken across the front of the small 15th century church with the Romanesque doorway. Readings show a low shallow resistivity layer underlain by a deeper higher resistivity layer. The resistivity values on this section are the lowest of the 5 sections and confirm the resistance data, which showed this church in a low resistance area. The doorway of the church is at 11-12m and this is where a low resistivity zone is observed. This may have been a path to the church but it is not paved.

Line 3: (north at left). This line was taken within the high noisy magnetic zone. It appears to show mainly geology, though the slight break in resistivity, observed at 9m, is where the line crosses a very distinctive magnetic linear.

Line 4: (west at left). Again this line was taken within the noisy magnetic zone and along a prominent ridge. It appears to show, glacial rather than archaeological features.

Line 5: (north at left). This line was taken across the banks and ditches at the northern edge of the site. There is no evidence of extensive rocks within the banks, though the high resistivity zones shown in red could be rocks but most likely they are natural features.

Figure 14: Location of 5 resistivity lines at Rahan (Phase I)

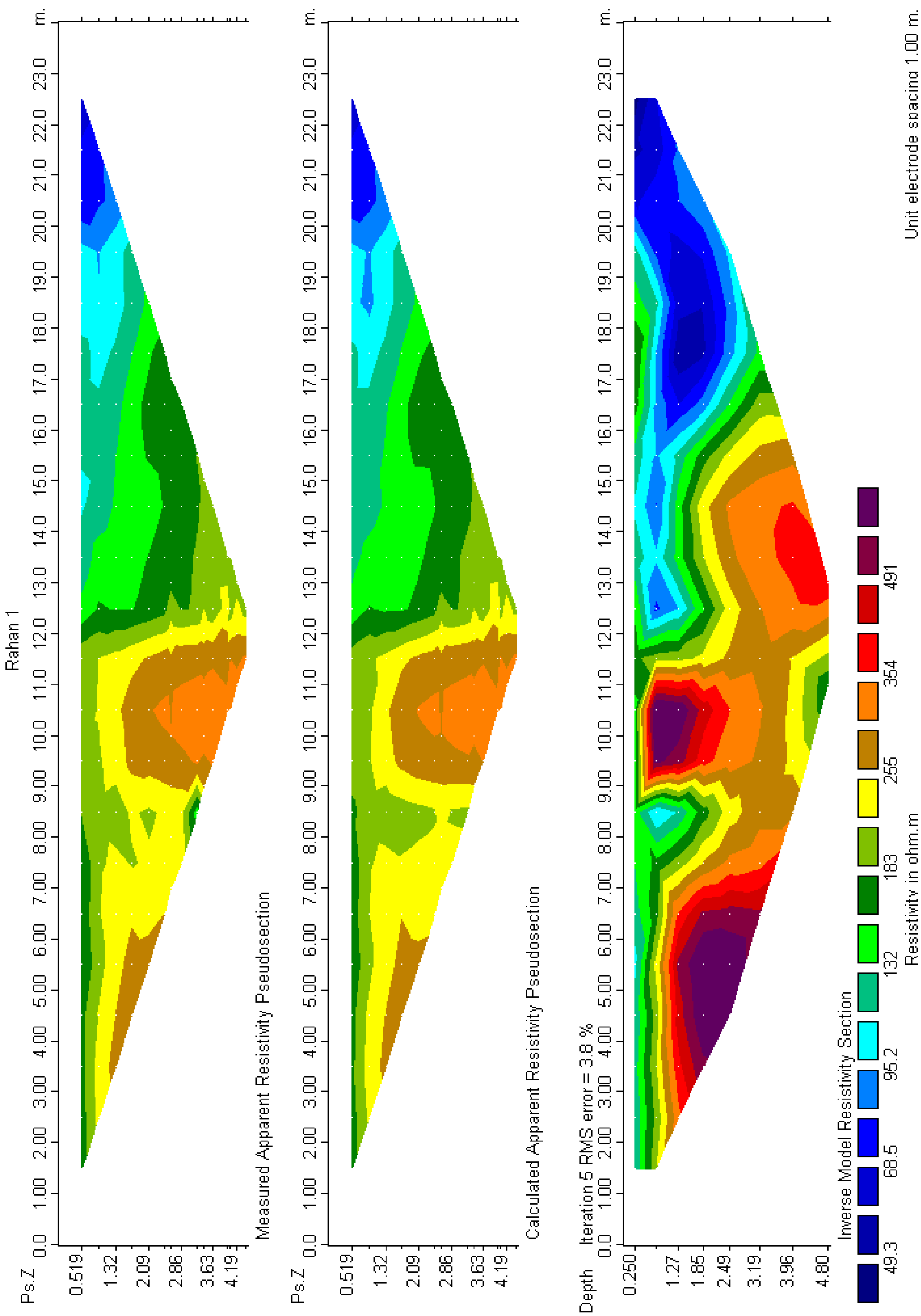

Figure 15: Resistivity line 1.

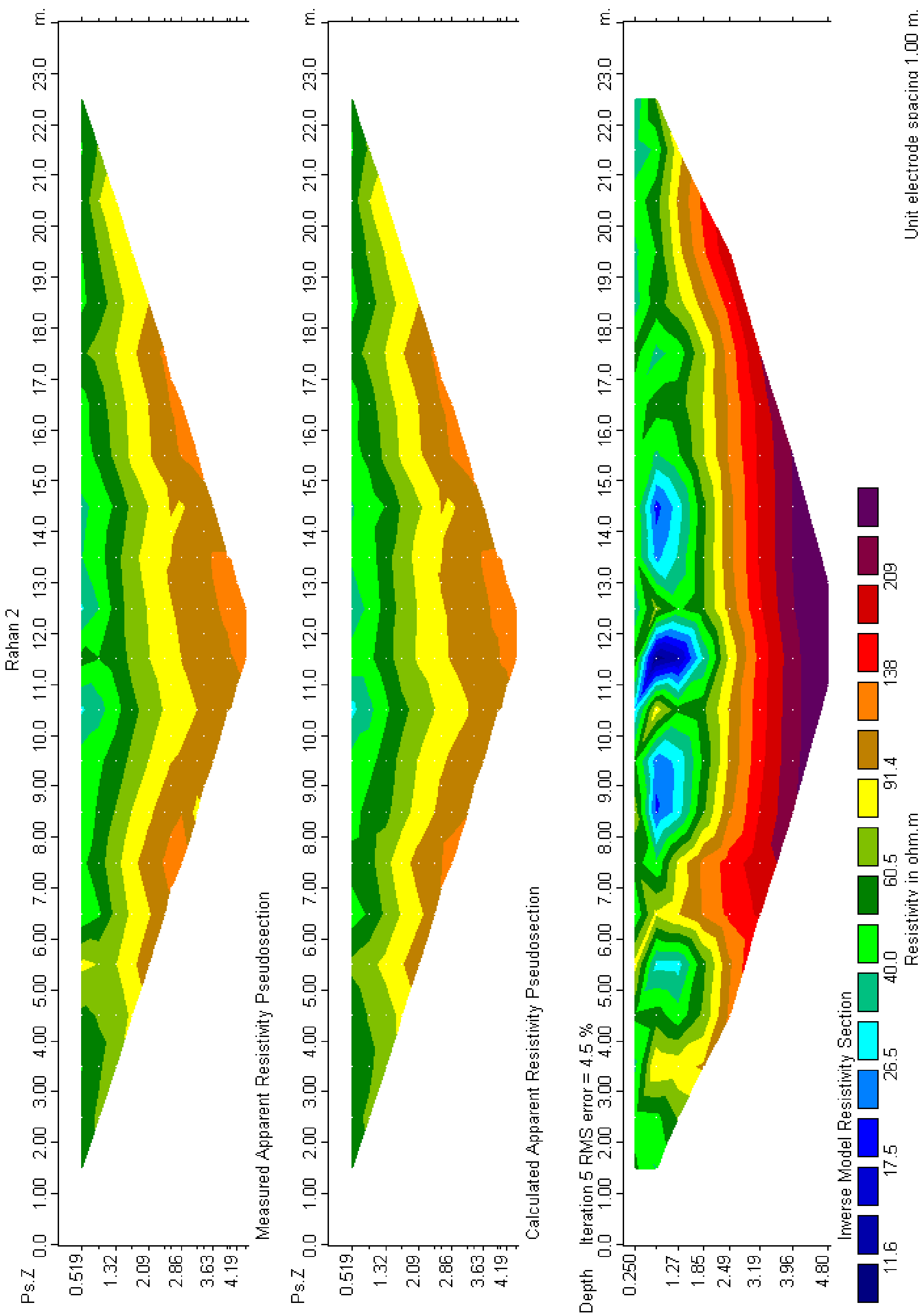

Figure 16: Resistivity line 2.

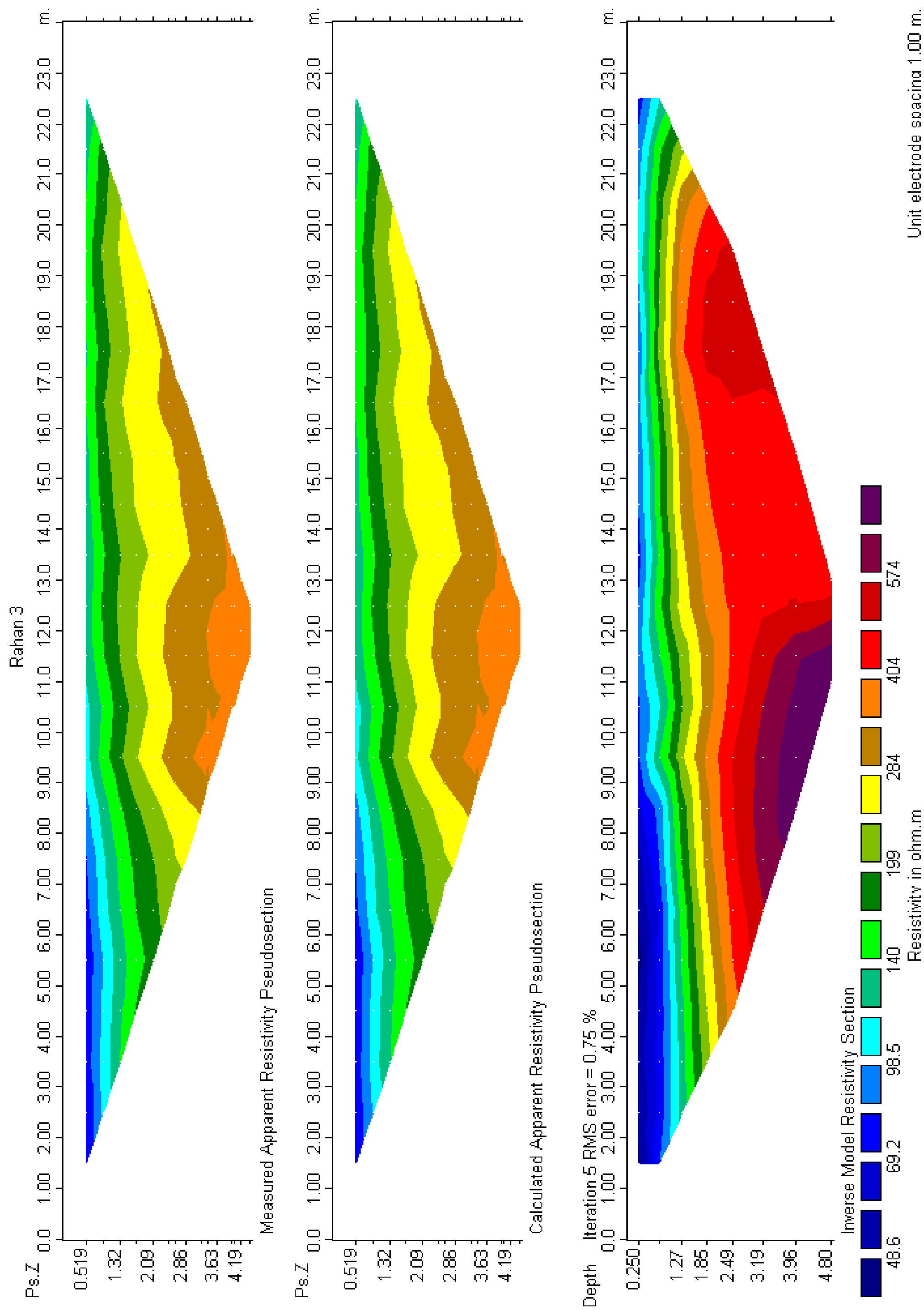

Figure 17: Resistivity line 3.

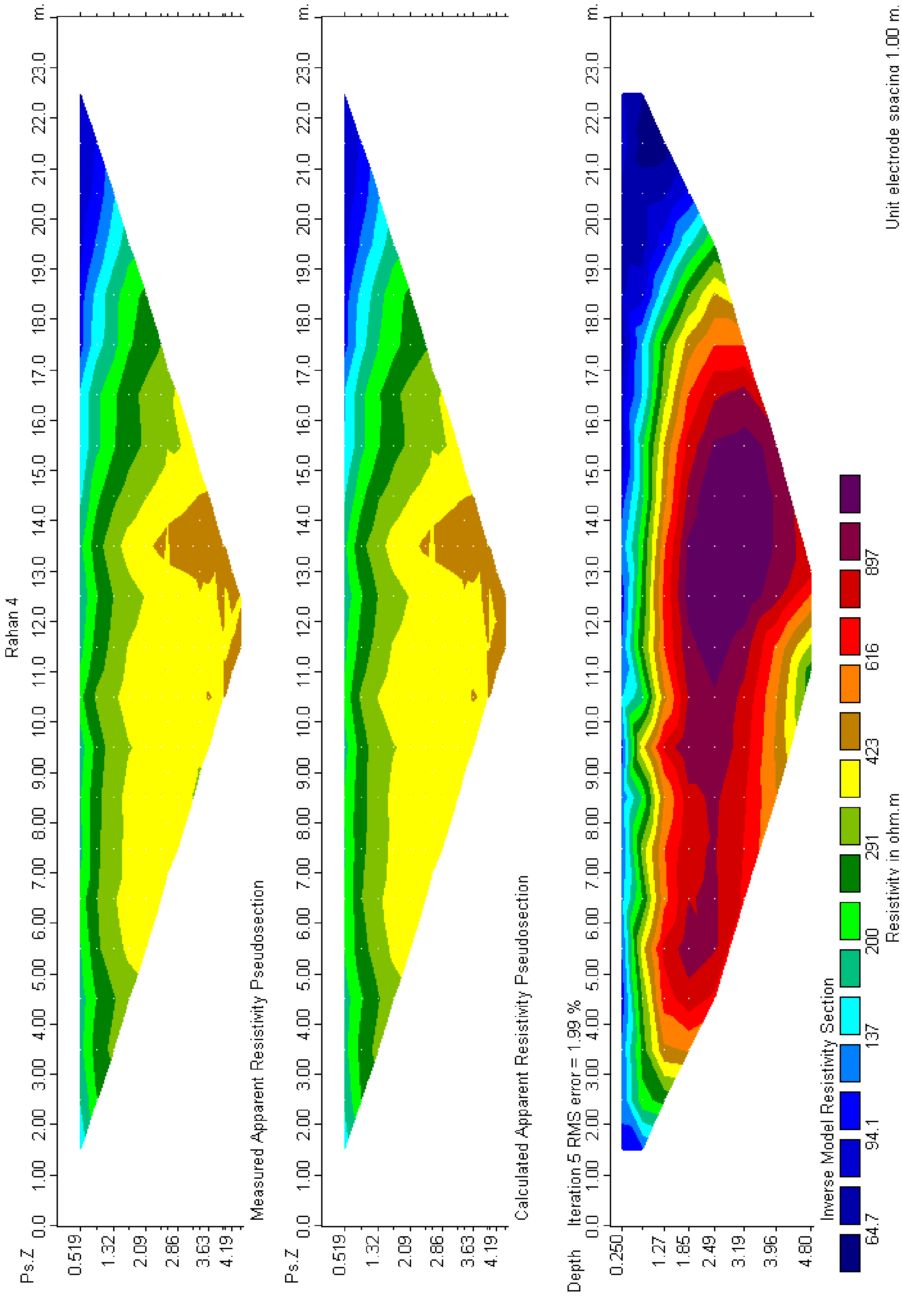

Figure 18: Resistivity line 4.

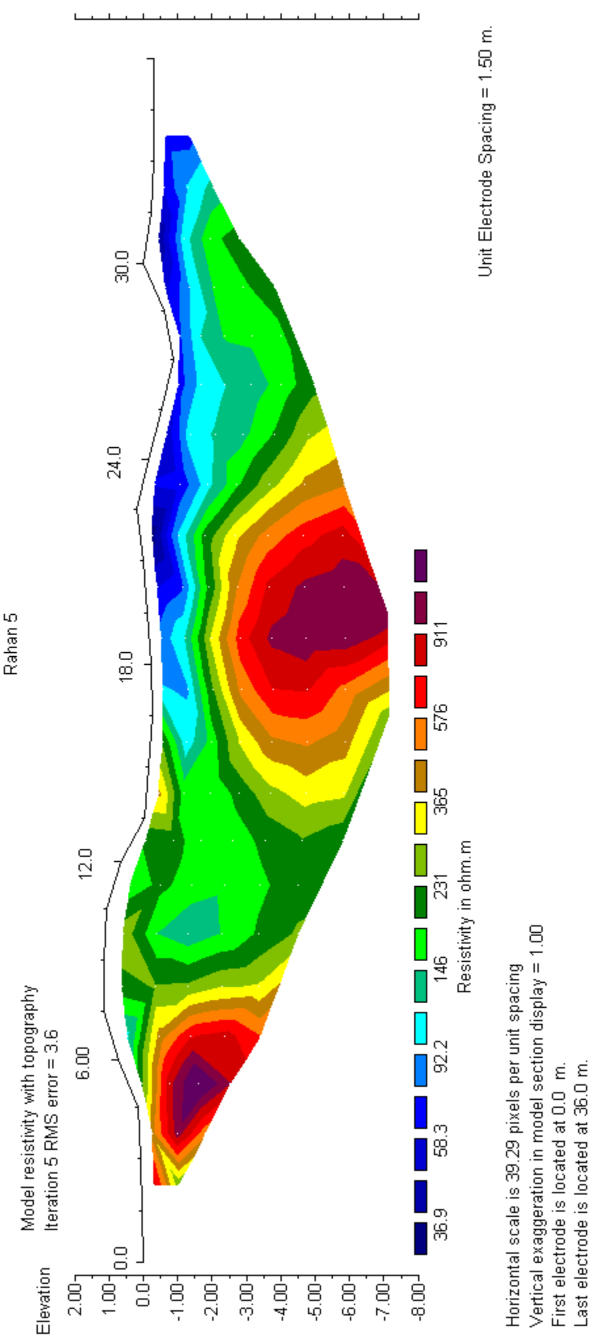

Figure 19: Resistivity line 5.

Geophysical Survey at Rahan – Phase II

Magnetic Survey at Rahan Phase II

During Phase II, 44 magnetic grids of data were collected. However, in order to put them in their proper geographical context, the Phase II magnetic data were combined with the Phase I magnetic data, resulting in 87 grids of data, which combined gave a total of c. 305,000 data points. Figure 20 shows a grey scale image of the magnetic data and its interpretation is shown in Figure 21. It is difficult to determine details at this scale; consequently subsets of the data are shown in later figures. A close-up centred on the cemetery and church grounds is shown in Figure 22 (yellow) and an interpretation in Figure 23. This shows clear evidence of a large enclosure, which encompasses the church and graveyard. The enclosure signature consists of a dark a dark (high) magnetic signature. It is sub-rectangular to sub-circular in shape and is approximately 190m across. The enclosure is roughly centred on Irish Grid Reference: 225943 (E) 225454 (N). The eastern boundary is parallel to the field boundary. Immediately to the east of the graveyard, 2 sub-parallel curvilinear features can be seen, Figure 23. It is clear from Figure 23 that any extension of the cemetery, especially to the south, would destroy this feature.

The region SE of the cemetery is shown in Figure 24 and about 55m from the graveyard boundary is a small sub-rectangular enclosure, with its long axis orientated N-S. The centre of this feature is located at Irish Grid Reference: 225981 (E) 225987 (N). It is about 16m long and about 12m wide. It is unlikely that this structure is a building, though if it is, it would be a large hall. Interestingly, within it, there is a small anomalously high zone, which if it was a hall, would probably indicate the location of the chimney.

The location west of the church and graveyard is shown in Figure 25. This region consists of a number of long lineaments, one of which is 134m long and perfectly straight. Some curved features are shown in this region, mainly with a high magnetic signature. The lineament pattern shown in Figure 21, displays a range of ploughing trends in different locations of the Rahan site.

A colour-coded image is shown in Figure 26. White areas represent 0 nT (background) whereas the reds and blues indicted where deviations from the norm occur, and which indicated where enhanced anthropogenic activity has taken place. The zones north of the main church were discussed in Phase I of the report, but there is also a large concentration east of the main church and graveyard. A particularly large concentration of anomalies occur in the vicinity of the intersection of a number of linear features at Irish Grid Reference: 225966 (E) 225357 (N). There is also a small concentration south of the small church at Rahan and in a WNW-ESE trending zone encompassing the small sub-rectangular enclosure. Figures 27 and 28 are directionally filtered magnetic images, which both show the major zones of magnetic activity but also illustrate some of the major linear trends at Rahan.

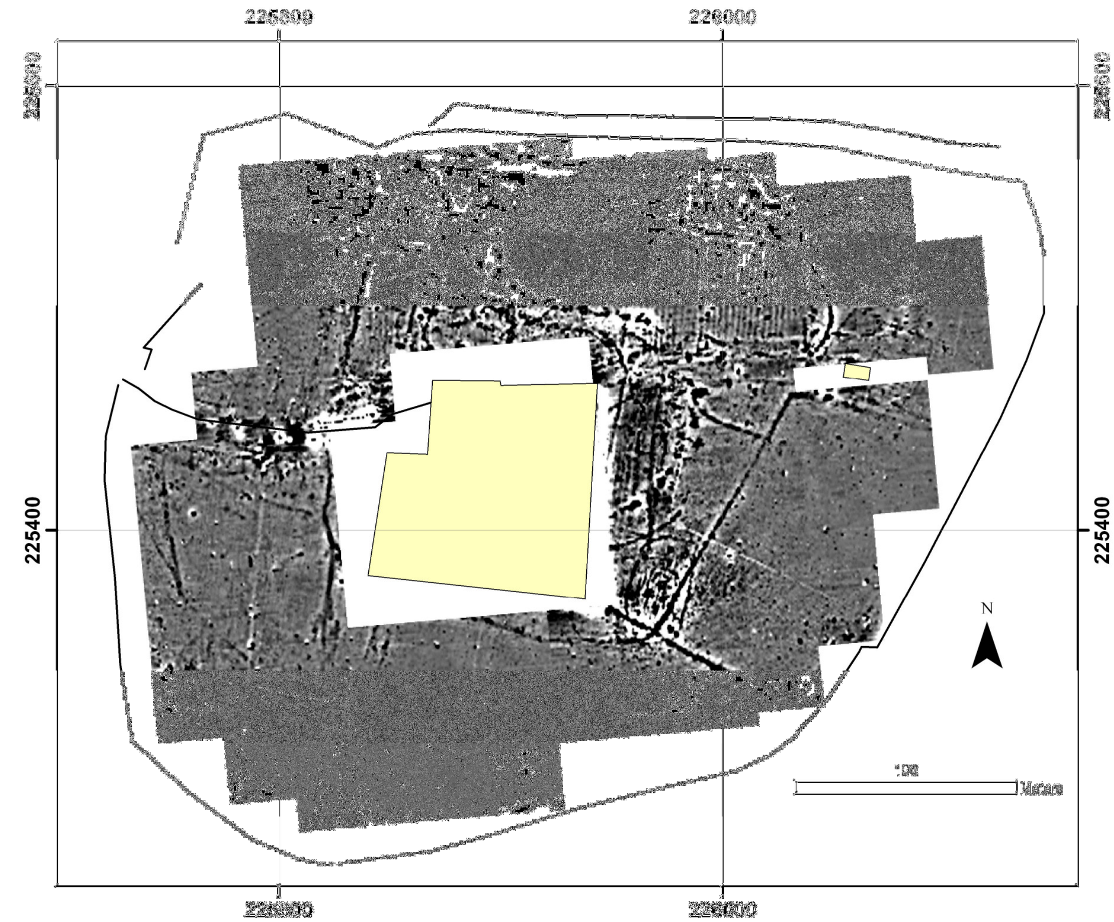

Figure 20: Magnetic data at Rahan.

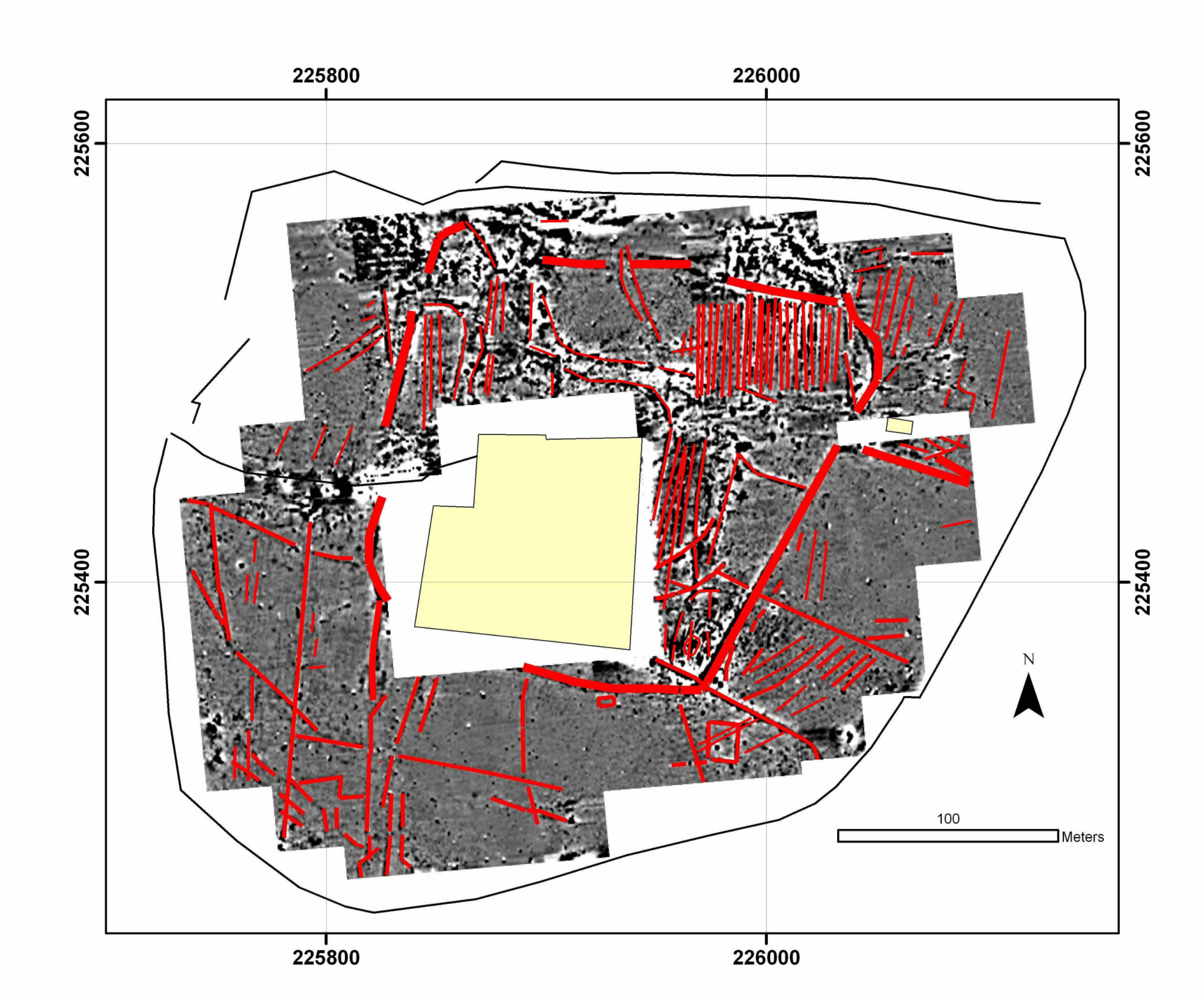

Figure 21: Interpretation of magnetic data.

Figure 22: Detail of magnetic data near cemetery, showing enclosure.

Figure 23: Interpretation of Figure 22.

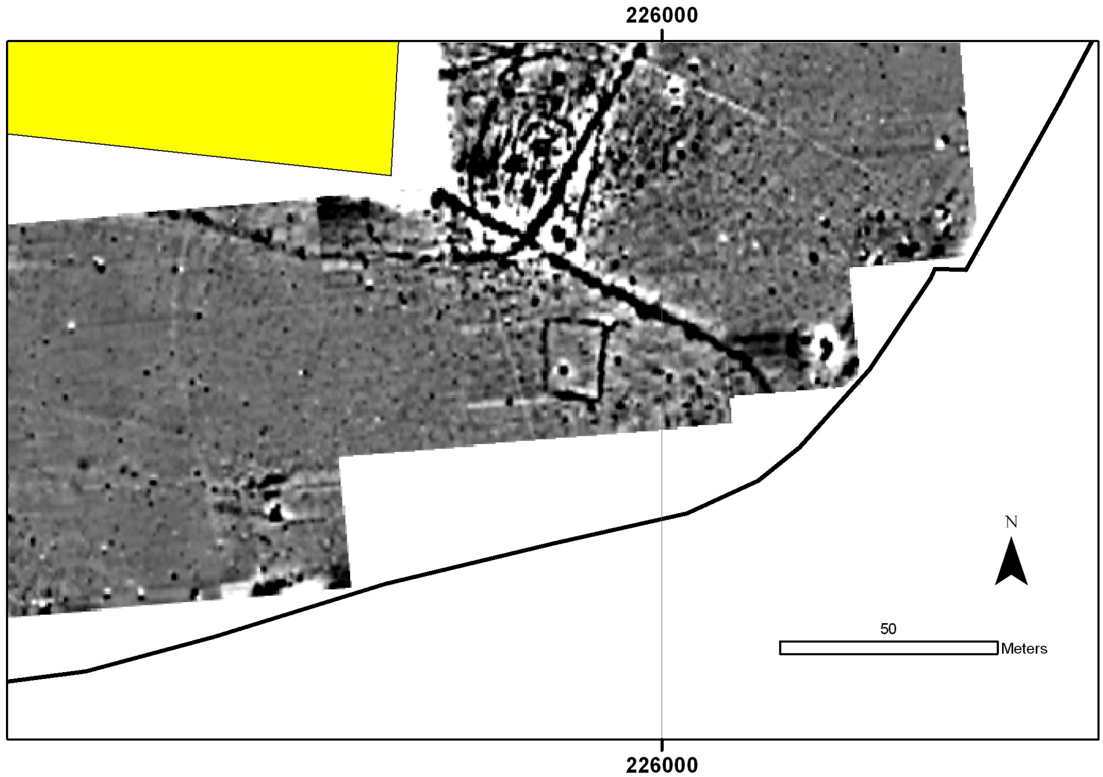

Figure 24: Detail of magnetic data southeast of cemetery showing sub-rectangular enclosure.

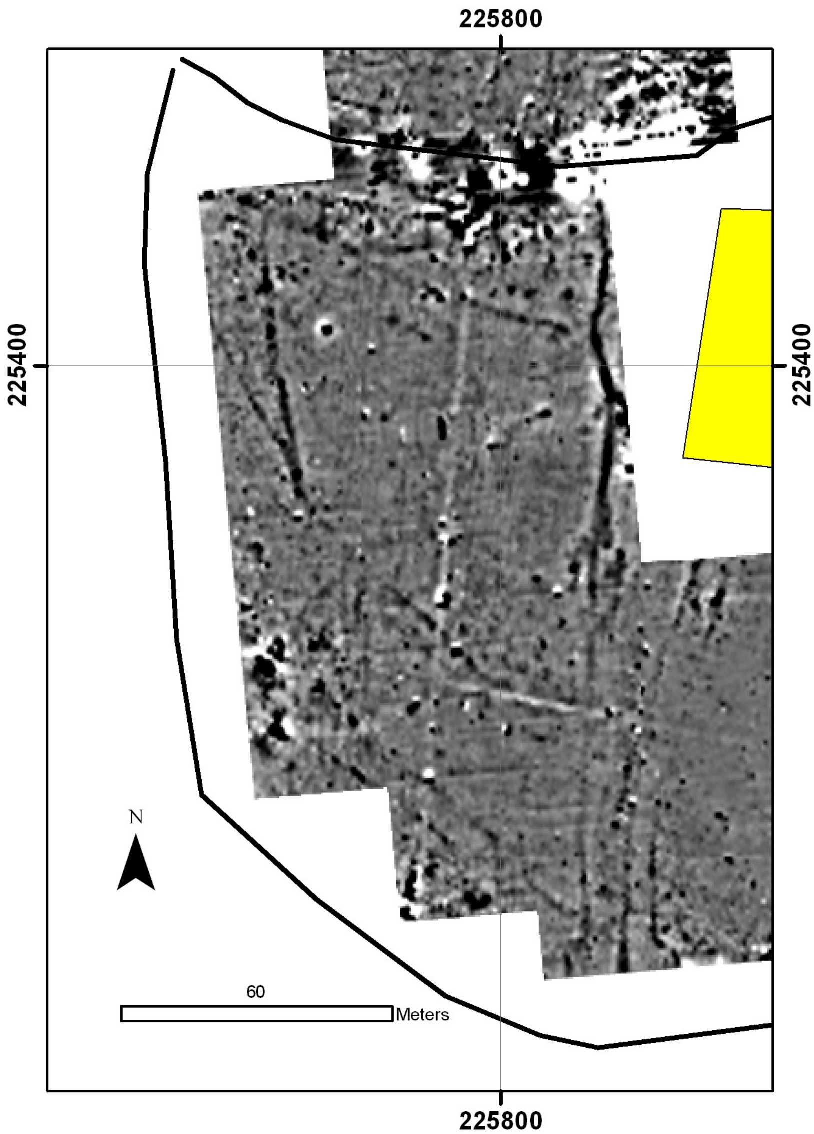

Figure 25: Detail of southwest section of field at Rahan

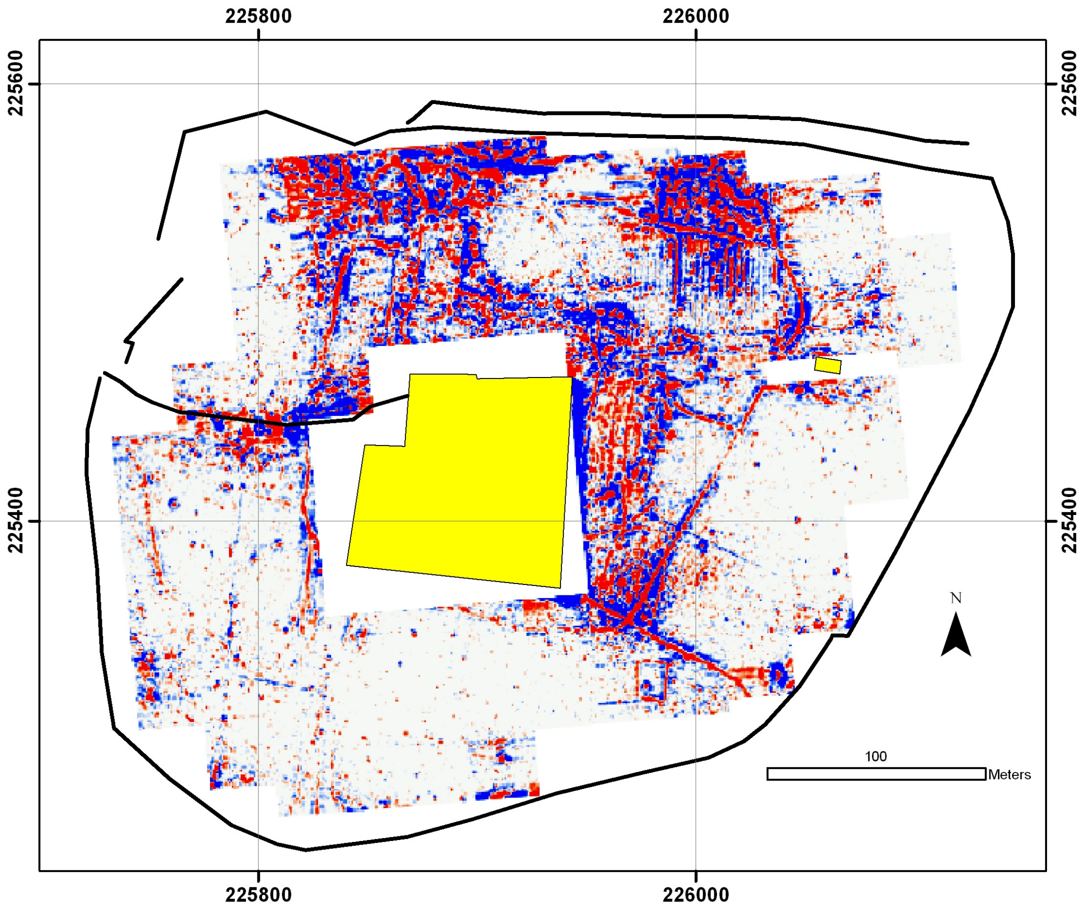

Figure 26: Colour-coded magnetic data, showing anomalous zones.

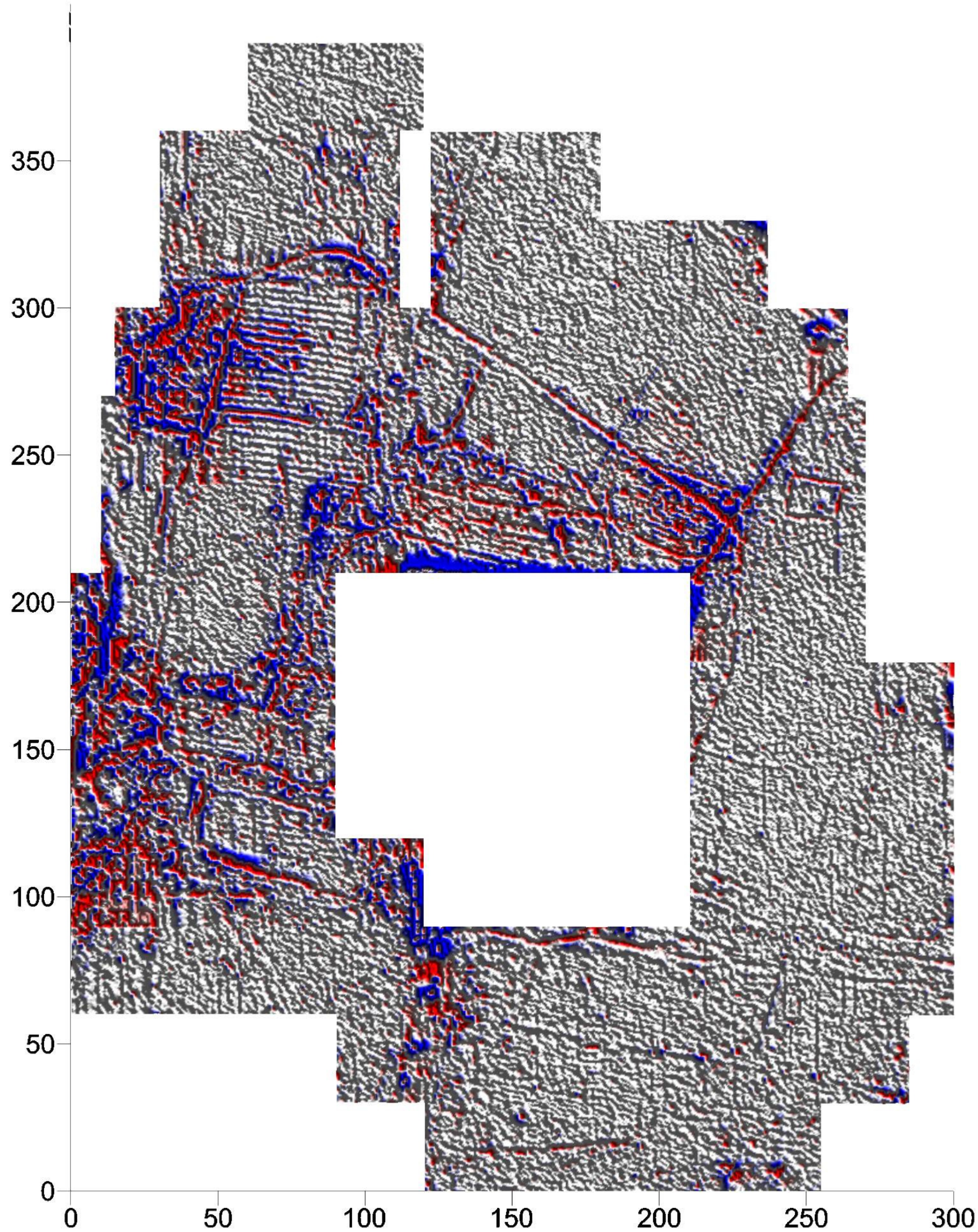

Figure 27: Surfer plot with applied directional filter.

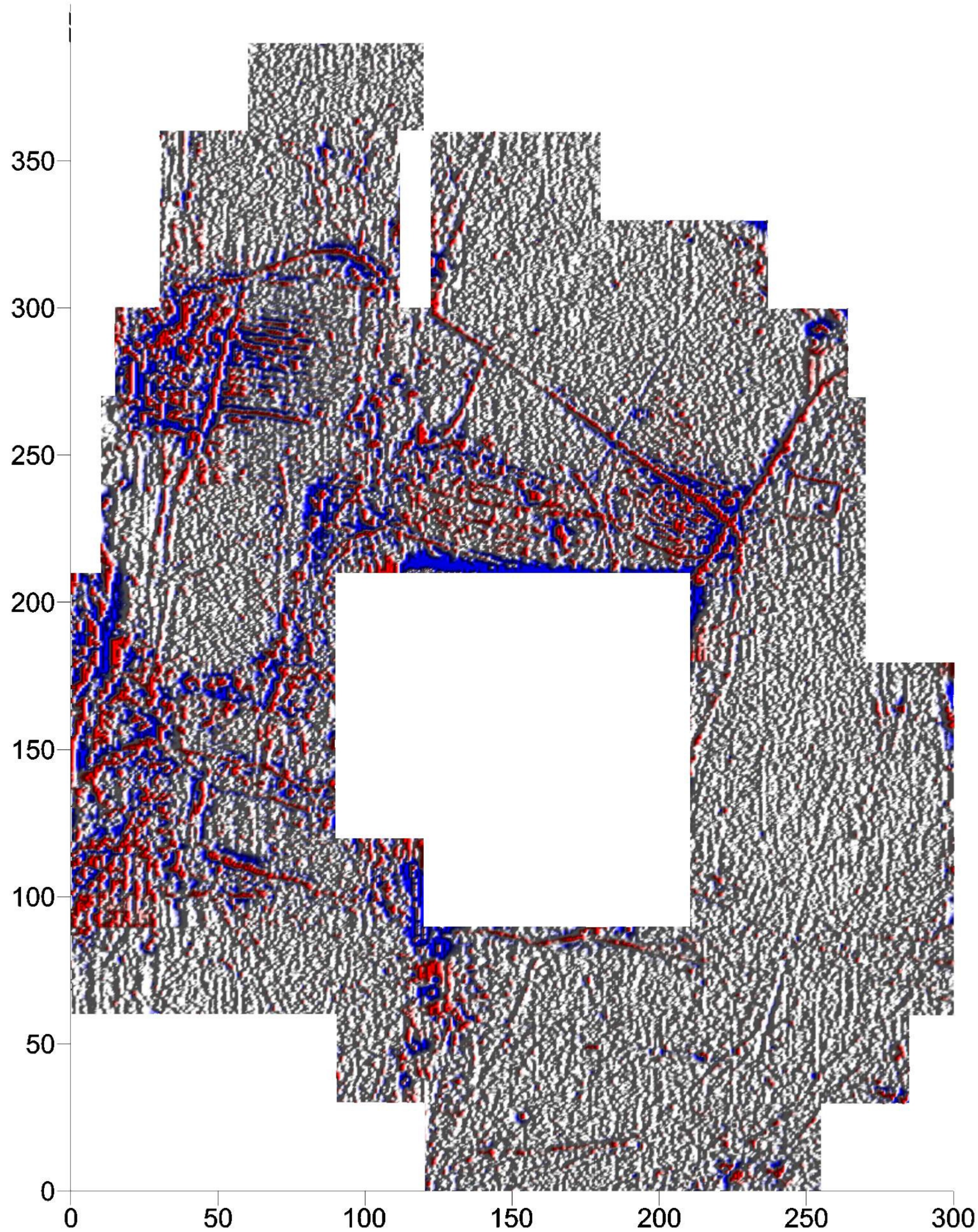

Figure 28: Surfer plot with applied directional filter.

Results of Resistivity survey at Rahan Phase II

Seven lines of resistivity data were collected at Rahan in 2007, during Phase I – see Figure 29 for location. Line 1 has an electrode spacing of 0.8m, Lines 3, 4, 6 and 7 have a spacing of 0.5m and Lines 2 and 5, a spacing of 1m.. The results of the processing are shown in Figures 30-36. West (or north) is shown at the left side of the relevant images.

Line 1: This line was taken beside the large church and inside the boundary wall. Resistivity values range from about 70 – 100 ohm metres. There is a distinctive high resistivity zone shown at depth in red, though the values suggest that it is caused by glacial sediments rather than anything archaeological.

Lines 2 and 3 were taken over the potential enclosure boundary with 2 different spacings. While there is no very prominent anomaly, there is a clear depression in the values at 15m on Figure 31. This may represent the site of a former ditch, which could be the enclosure boundary.

Line 4 was taken across the enclosure boundary to the south of the cemetery. There is a distinctive depression in the field for this section of the possible enclosure. A very prominent resistivity changes occurs across this feature. Values are much higher to the north than to the south. This suggests that this was an important boundary where there were differences either side of it, perhaps in terms of habitation or cultivation. (Figure 33).

Line 5 was taken where there was a number of intersecting linear features. These may be represented by the elongated high resistivity zones shown in red.

Lines 6 and 7 were taken across the sub-rectangular enclosure. The results show that there are no walls in this locality, thus it is likely that this feature is not a building, though the walls could conceivably have been robbed out. One boundary of the feature is associated with higher values near the surface (at 6m on Figure 36).

In conclusion, some of the resistivity lines do coincide with magnetic anomalies, most especially Line 4.

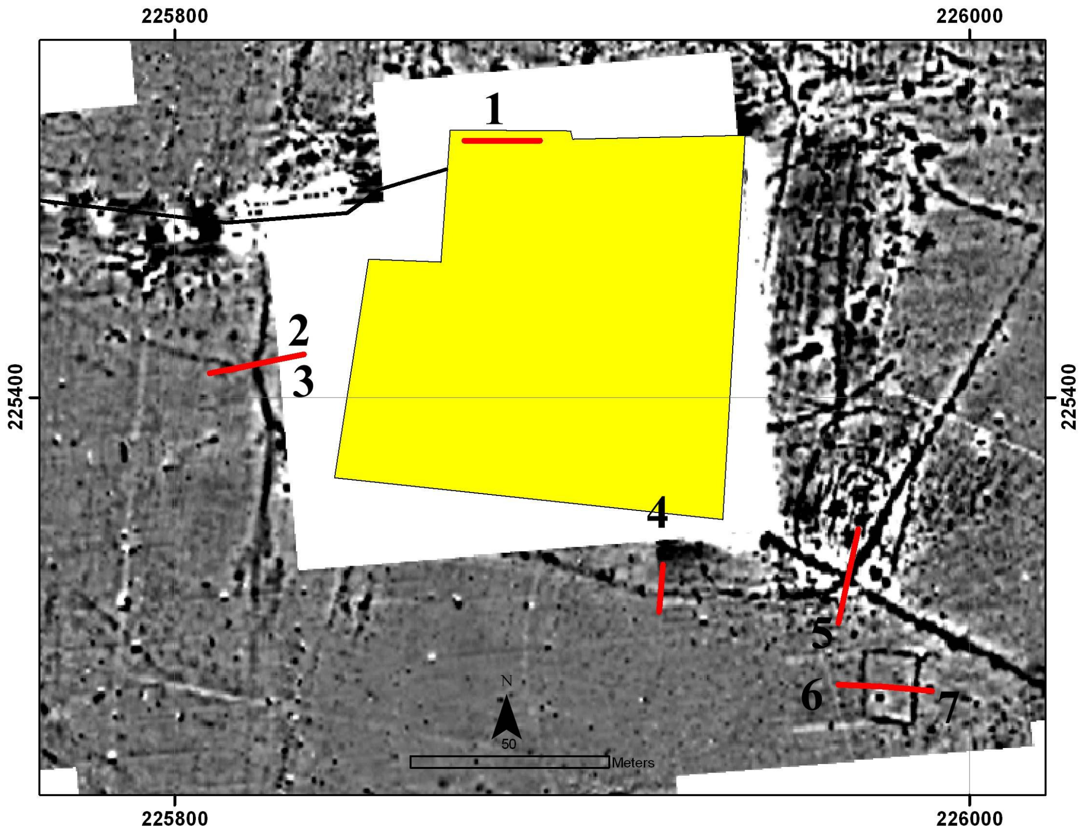

Figure 29: Location of resistivity lines during Phase II of survey.

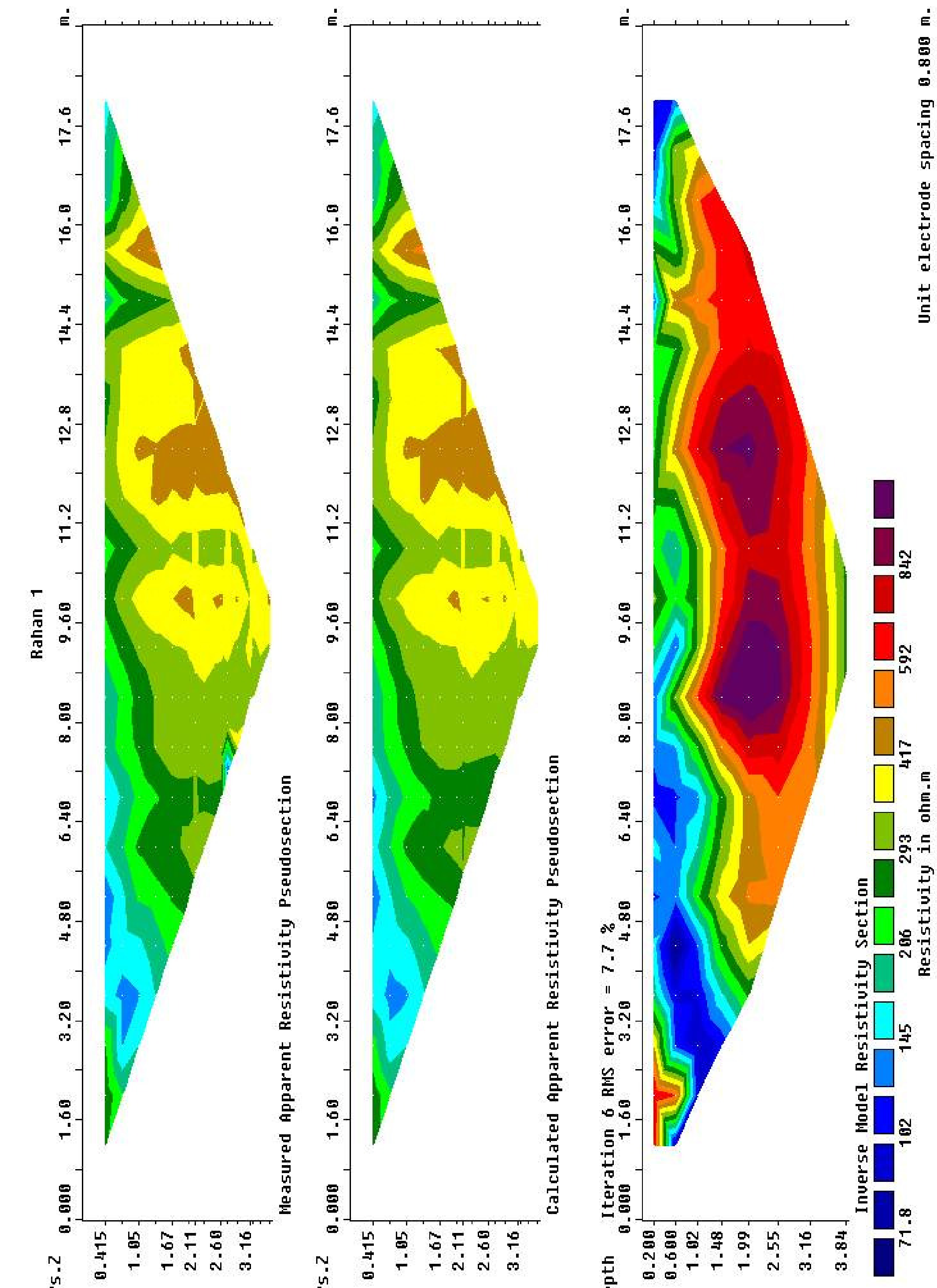

Figure 30: Resistivity line 1, Phase II.

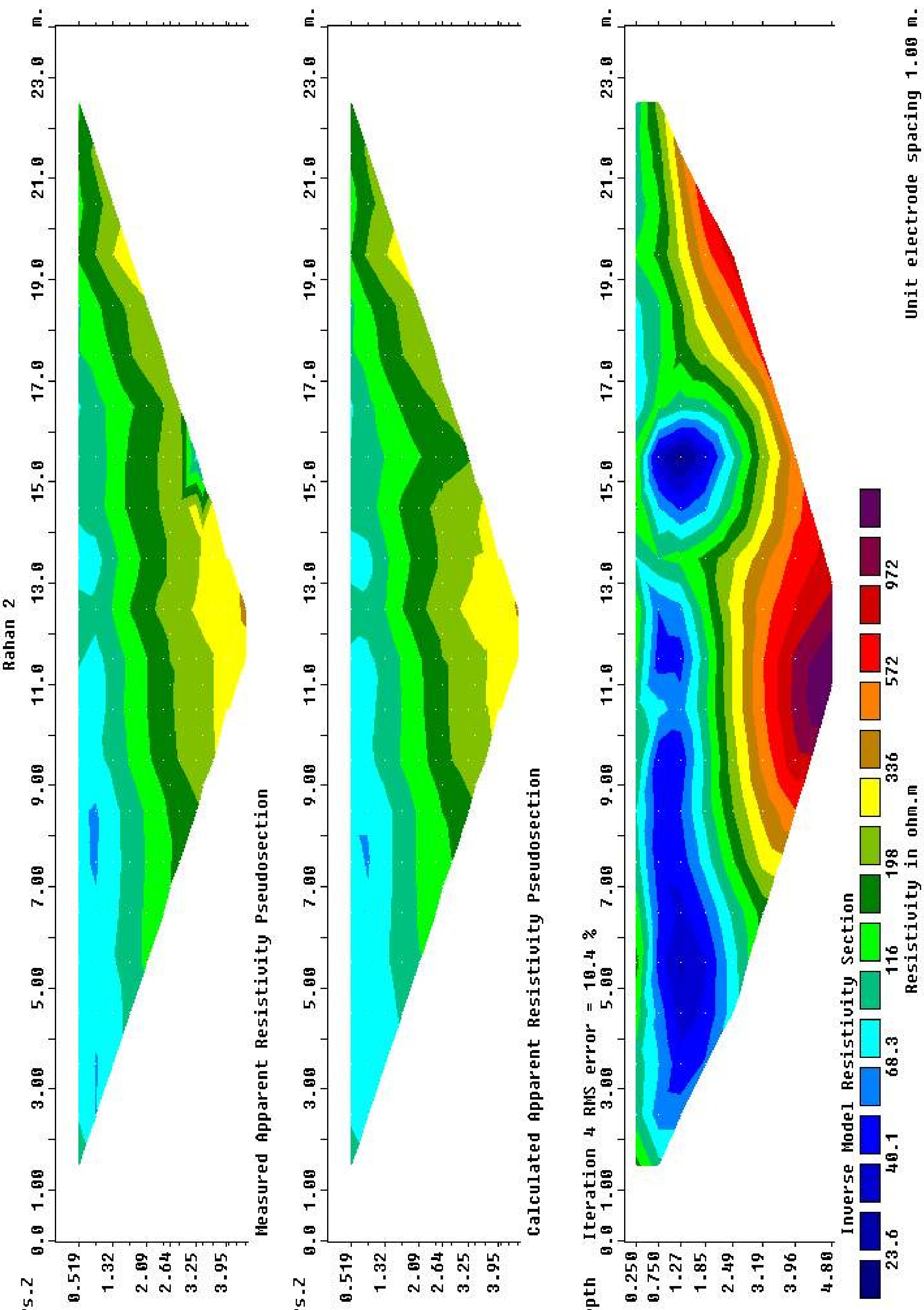

Figure 31: Resistivity line 2, Phase II.

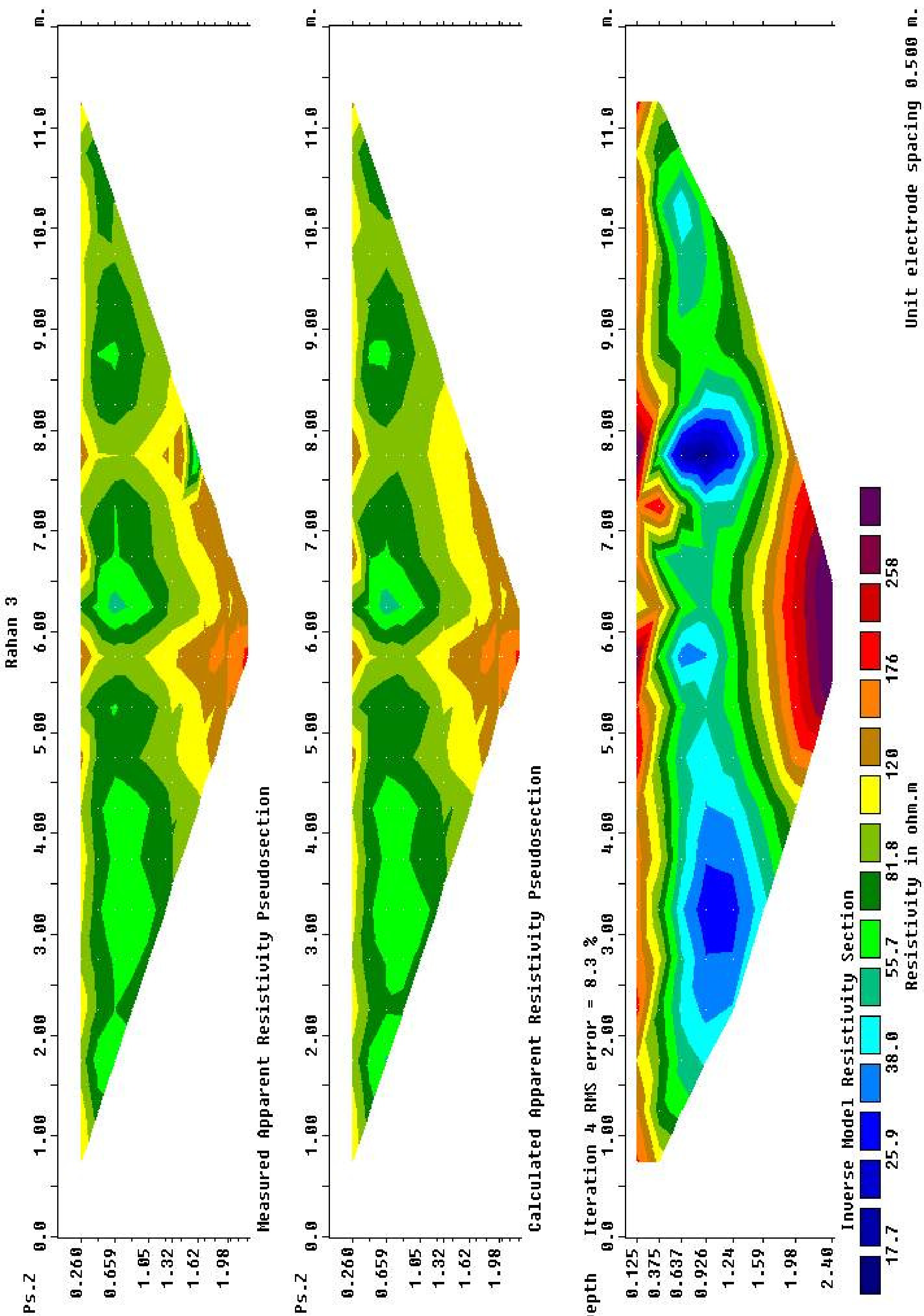

Figure 32: Resistivity line 3, Phase II.

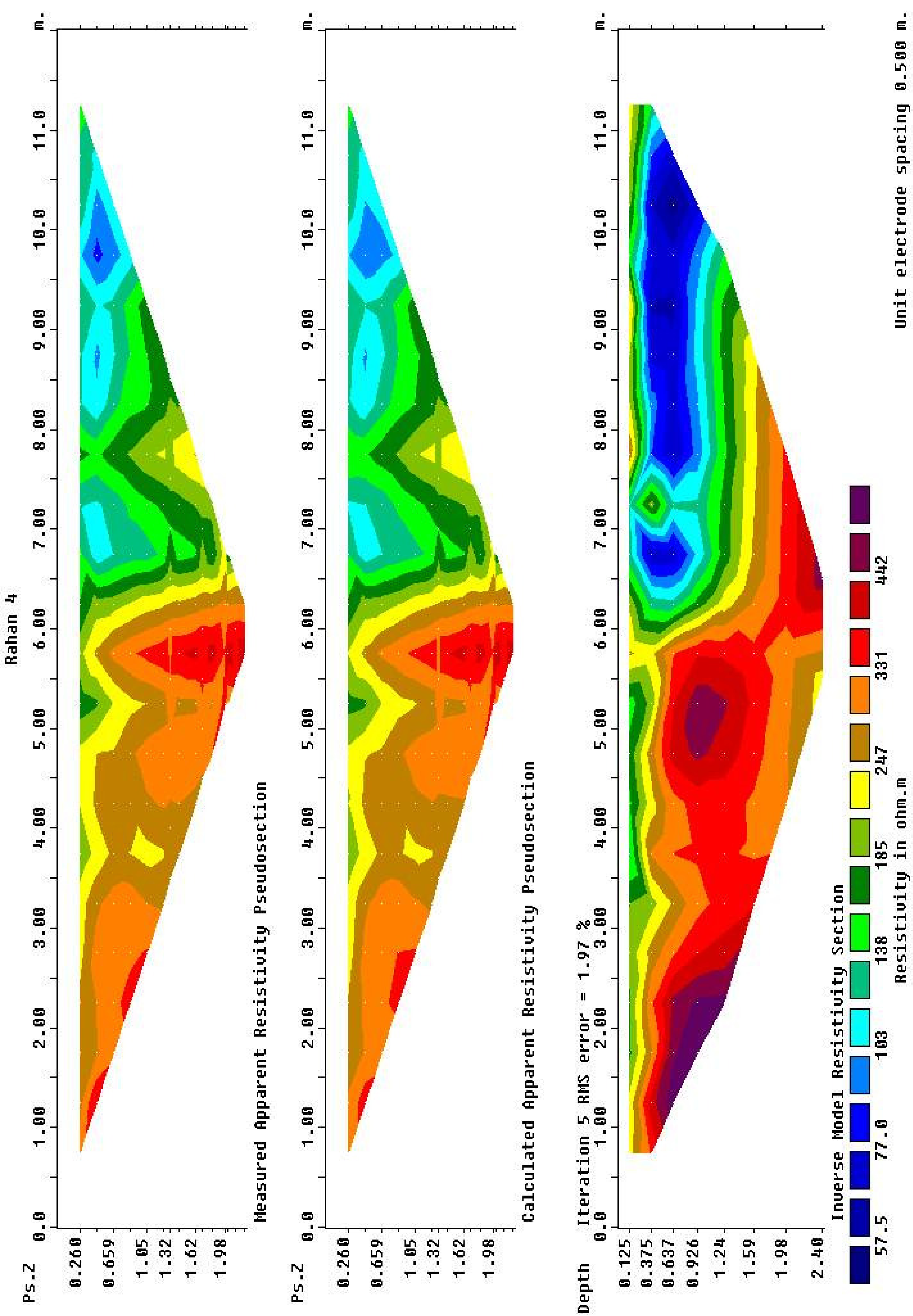

Figure 33: Resistivity line 4, Phase II.

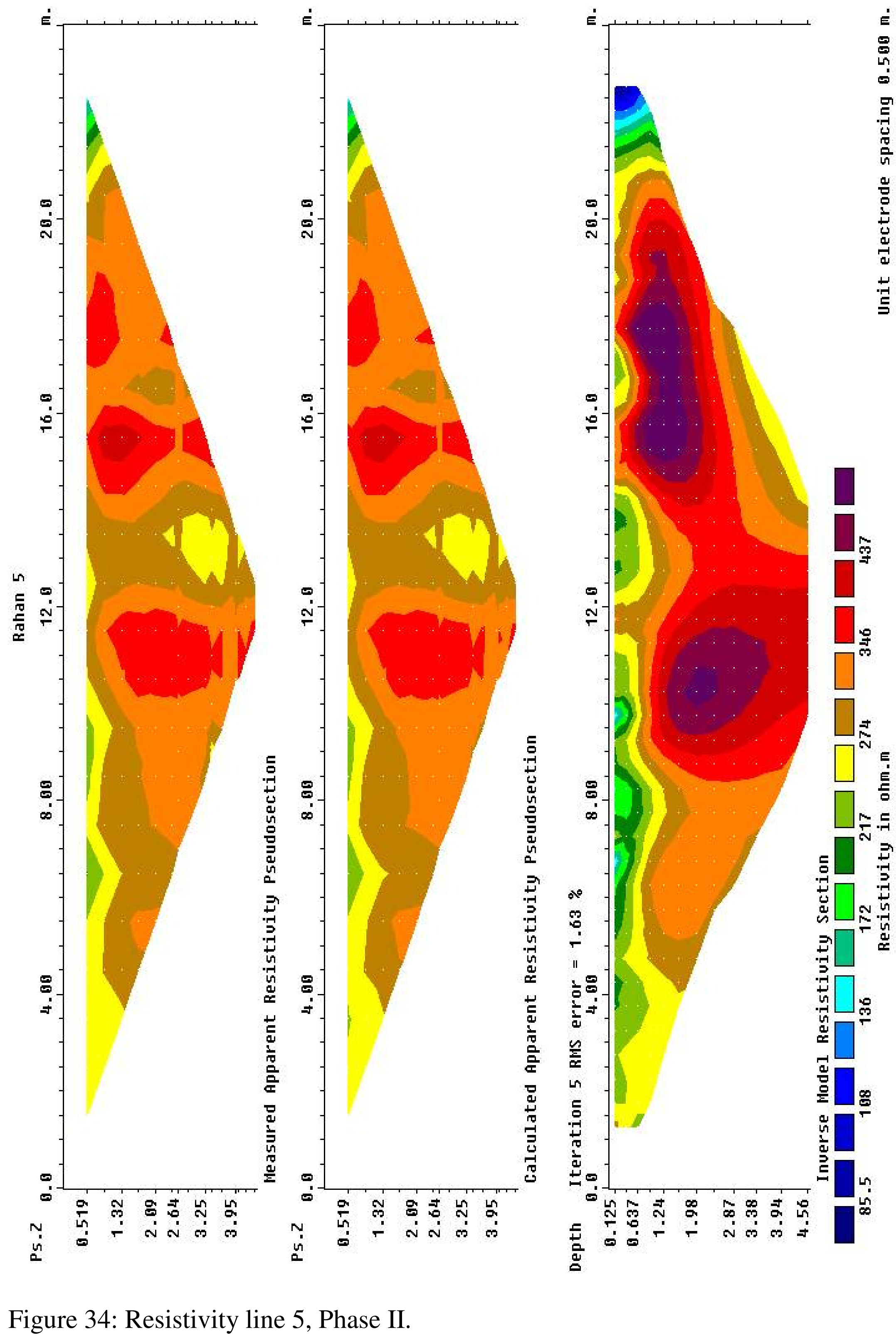

Figure 34: Resistivity line 5, Phase II.

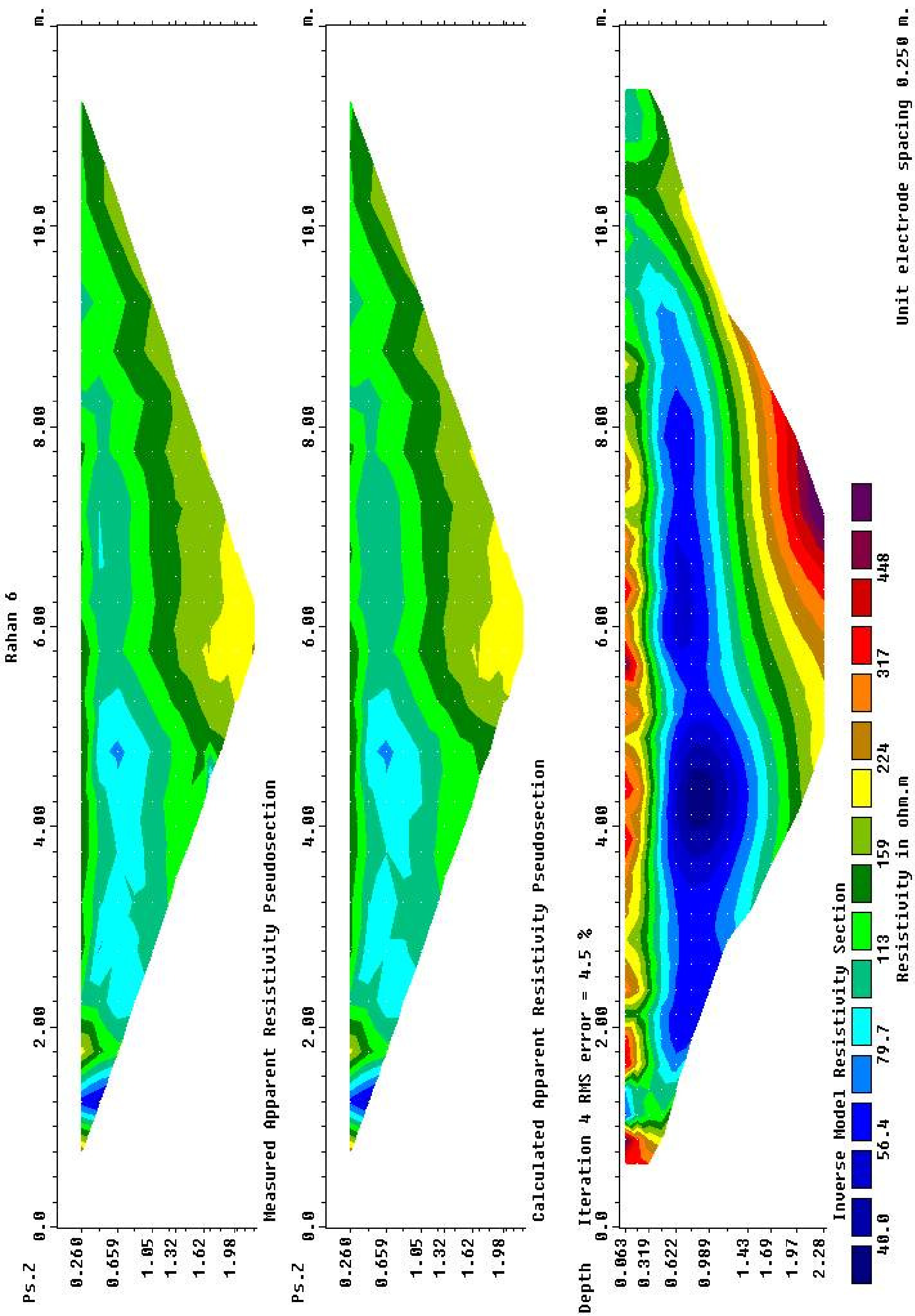

Figure 35: Resistivity line 6, Phase II.

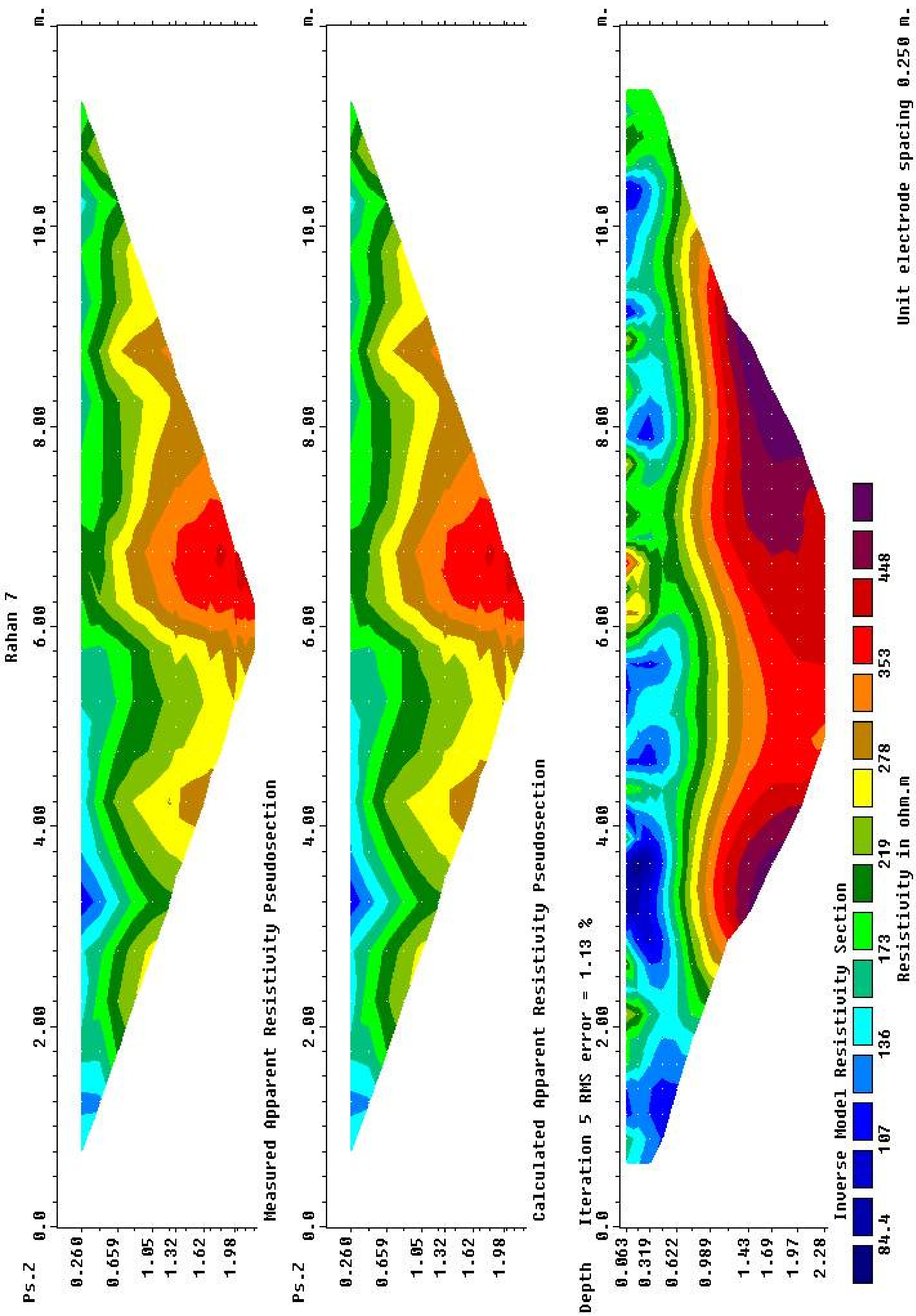

Figure 36: Resistivity line 7, Phase II.

Results of Magnetic susceptibility survey at Rahan – Phase II

Seven traverses were taken with a Bartington MS2B loop sensor in order to ascertain the magnetic susceptibility for the top 15 cm of the soil. Readings were taken at spacing of 1-5m. In general, readings were low and sometimes repeatability was poor. However, some interesting results were obtained.

Figure 37 shows the location of the magnetic susceptibility traverses and the results indicated in Figures 38-44. West (or north) is at the left of all traverses. All values quoted below are dimensionless SI units and are multiplied by 10^{-5}.

Line 1 is a 100m N-S traverse from the outer ditch to the cemetery. There is some variation in the readings. Near the outer ditch, reading tended to be slightly higher than for the central part of the traverse where readings were low (Figure 38). This central part coincides with Zone D, Figure 6 that shows a low magnetic signature. Near the church/cemetery, the values have increased greatly.

Line 2 is immediately east of the cemetery and taken southwards towards the southern boundary of Rahan, Figure 39. Again, there appears to be some zonation, with the central part being higher (and bounded by 2 peaks).

Line 3 is from the cemetery to the small church at Rahan. Very little variation is indicated except very close to the small church where a narrow zone of very high readings is observed, Figure 40.

Line 4 is 350m long and taken from the west to the east across the northern part of Rahan site. Values are higher for the first 120m and then decrease to lower values. This again is in accordance with earlier magnetic readings, Figure 41.

Line 5 is 40m in length and taken from north to south towards the small church at Rahan. Values tend to be low 2-3 (SI units), except near the small church, Figure 42.

Line 6 was taken from the small church towards the field boundary. Again, values tend to be higher near the church but there is little in the way of any distinctive pattern (Figure 43).

Line 7 from the large church eastwards towards the boundary is defined by higher values near the cemetery (Figure 44), which is similar to the pattern seen on colour coded magnetic images.

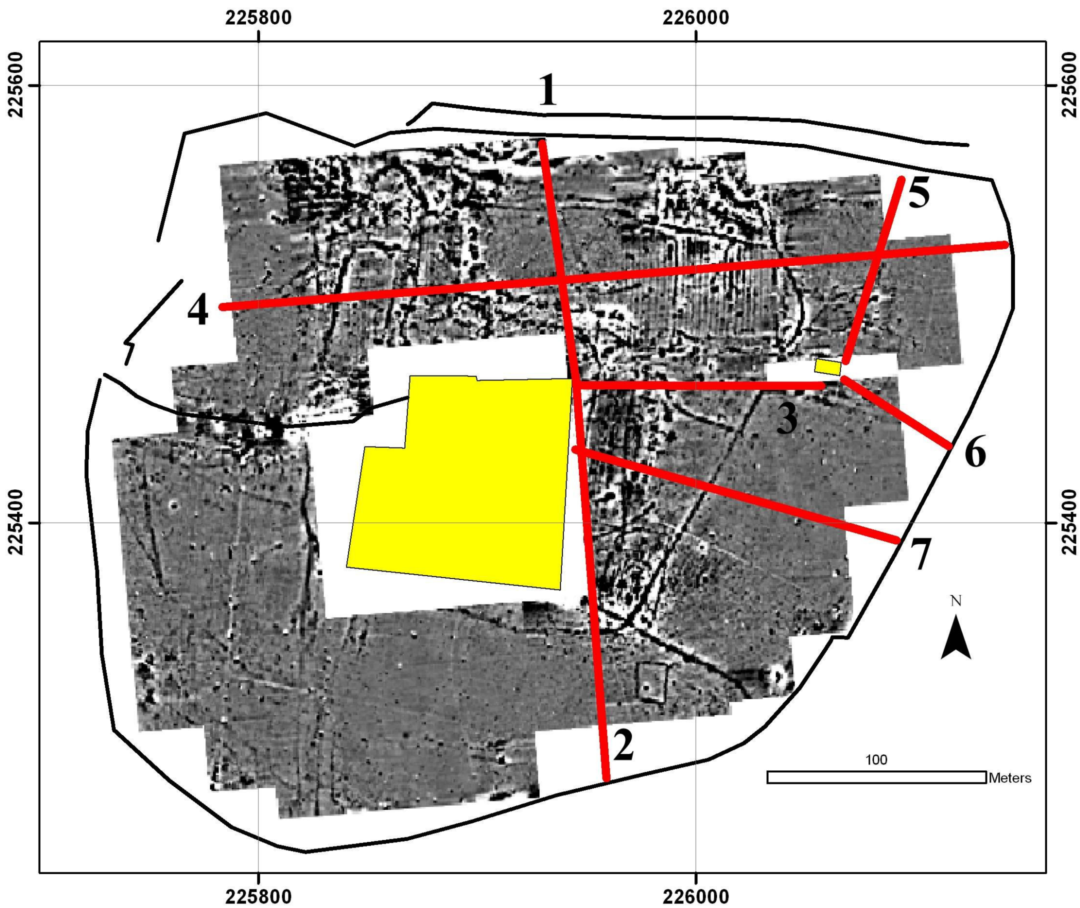

Figure 37: Location of magnetic susceptibility lines.

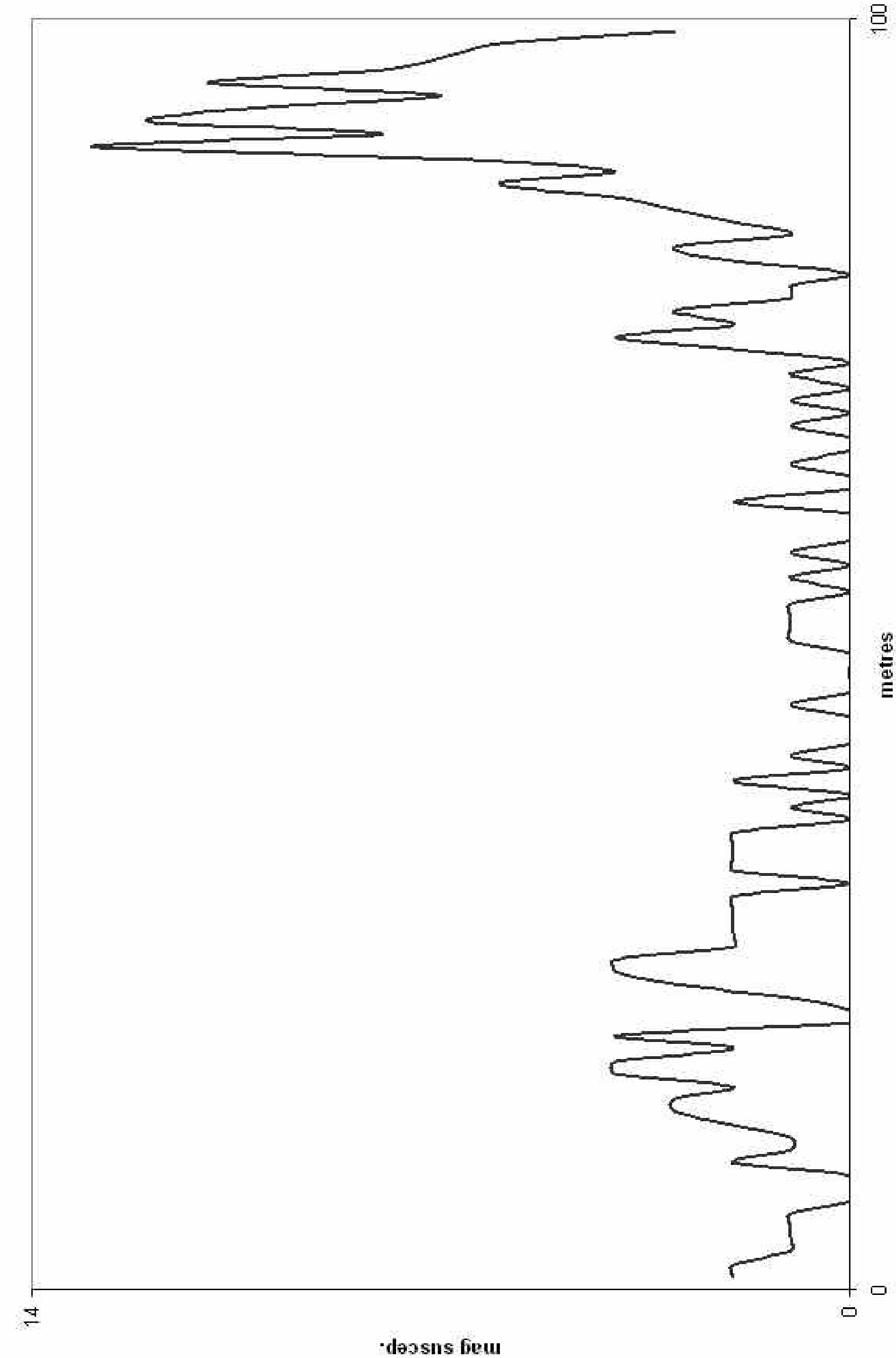

Figure 38: Magnetic Susceptibility Line 1.

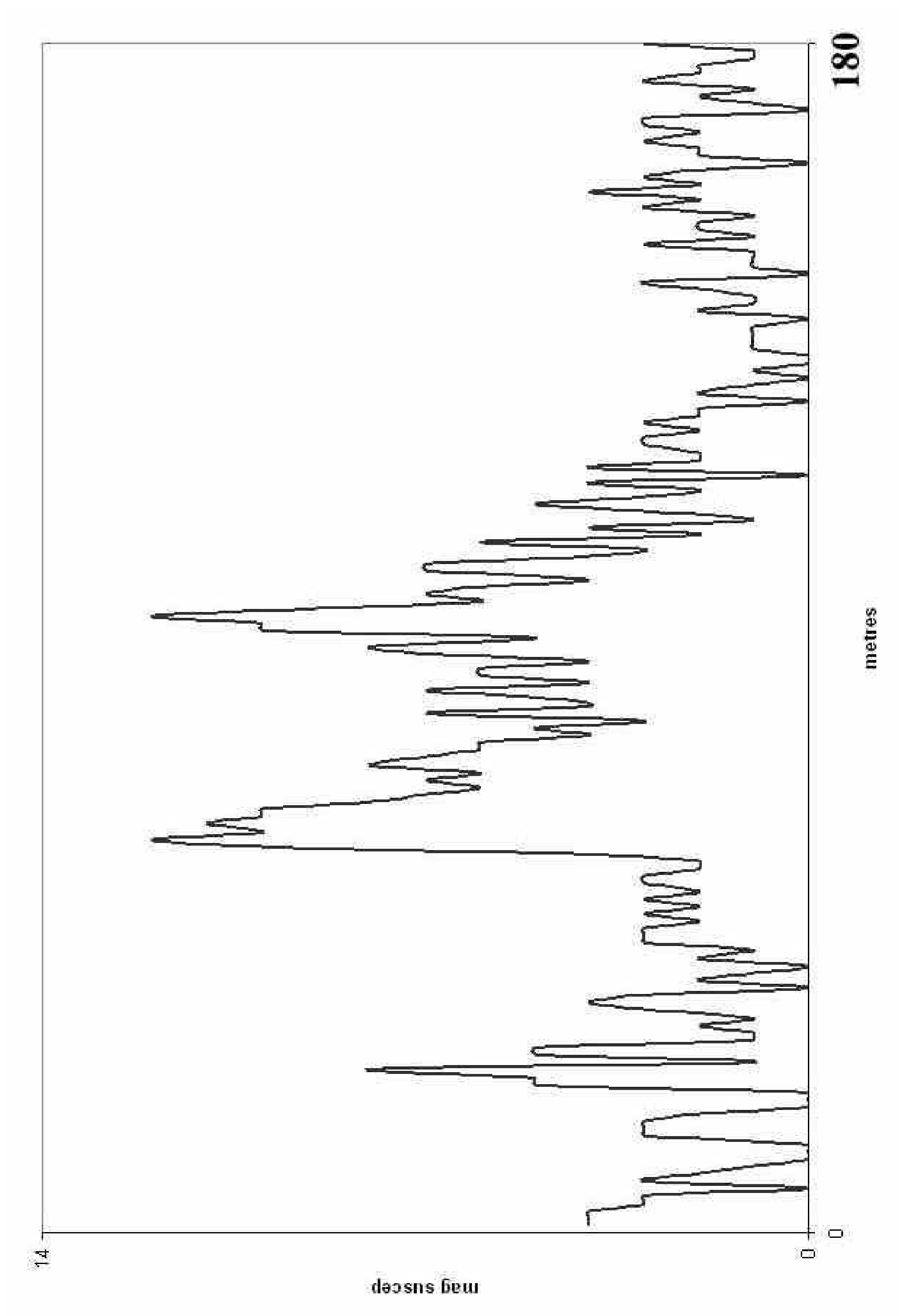

Figure 39: Magnetic Susceptibility Line 2.

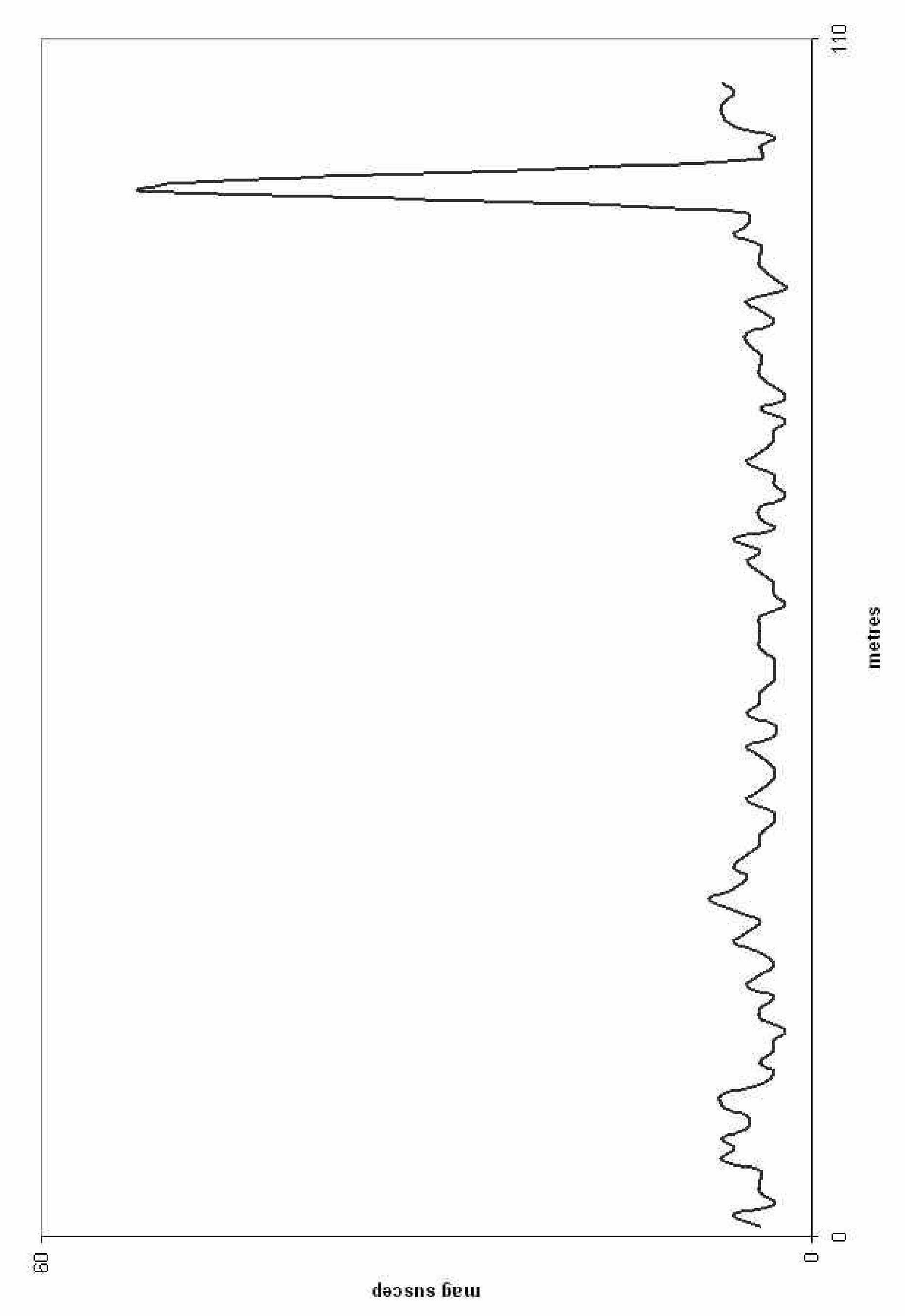

Figure 40: Magnetic Susceptibility Line 3.

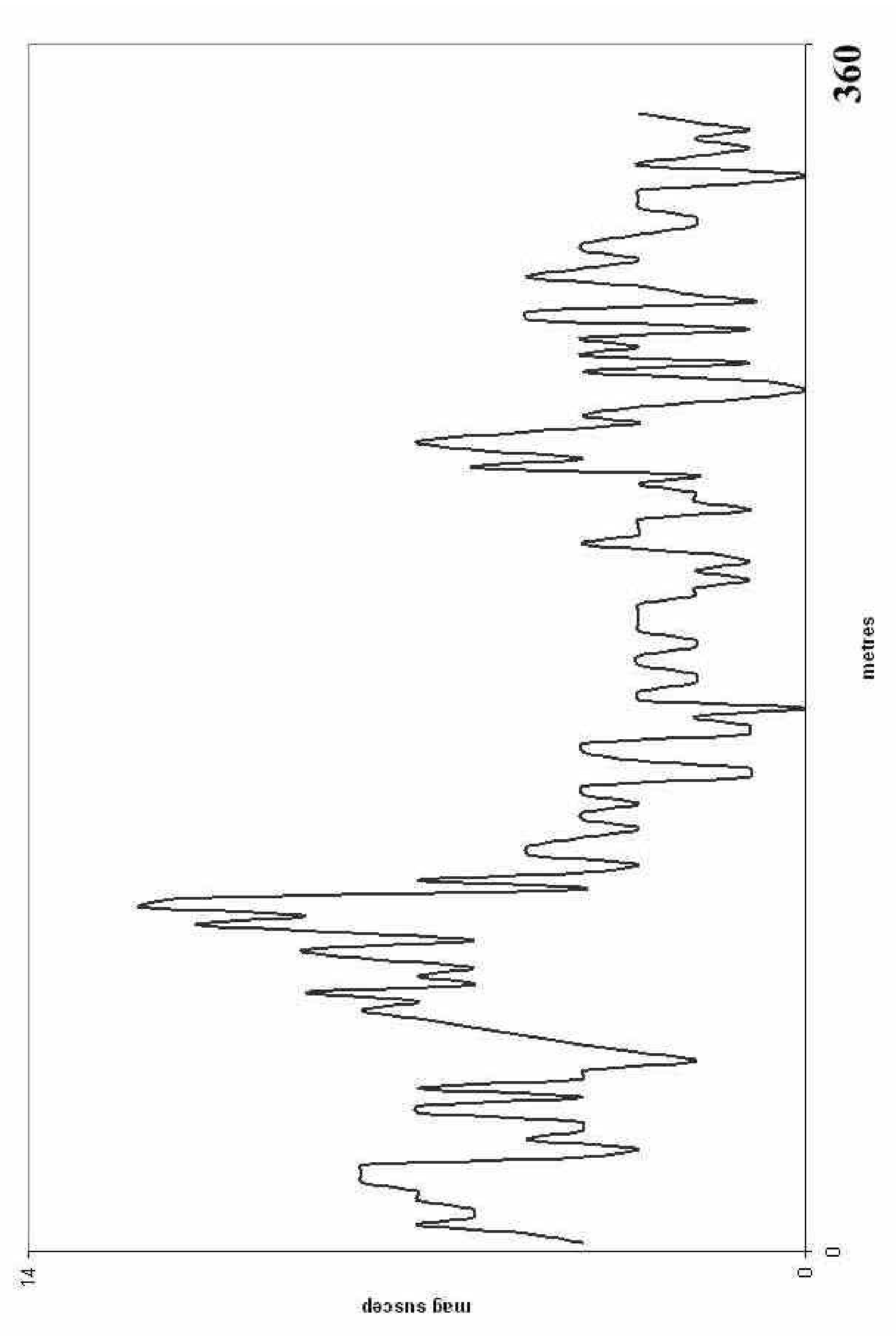

Figure 41: Magnetic Susceptibility Line 4.

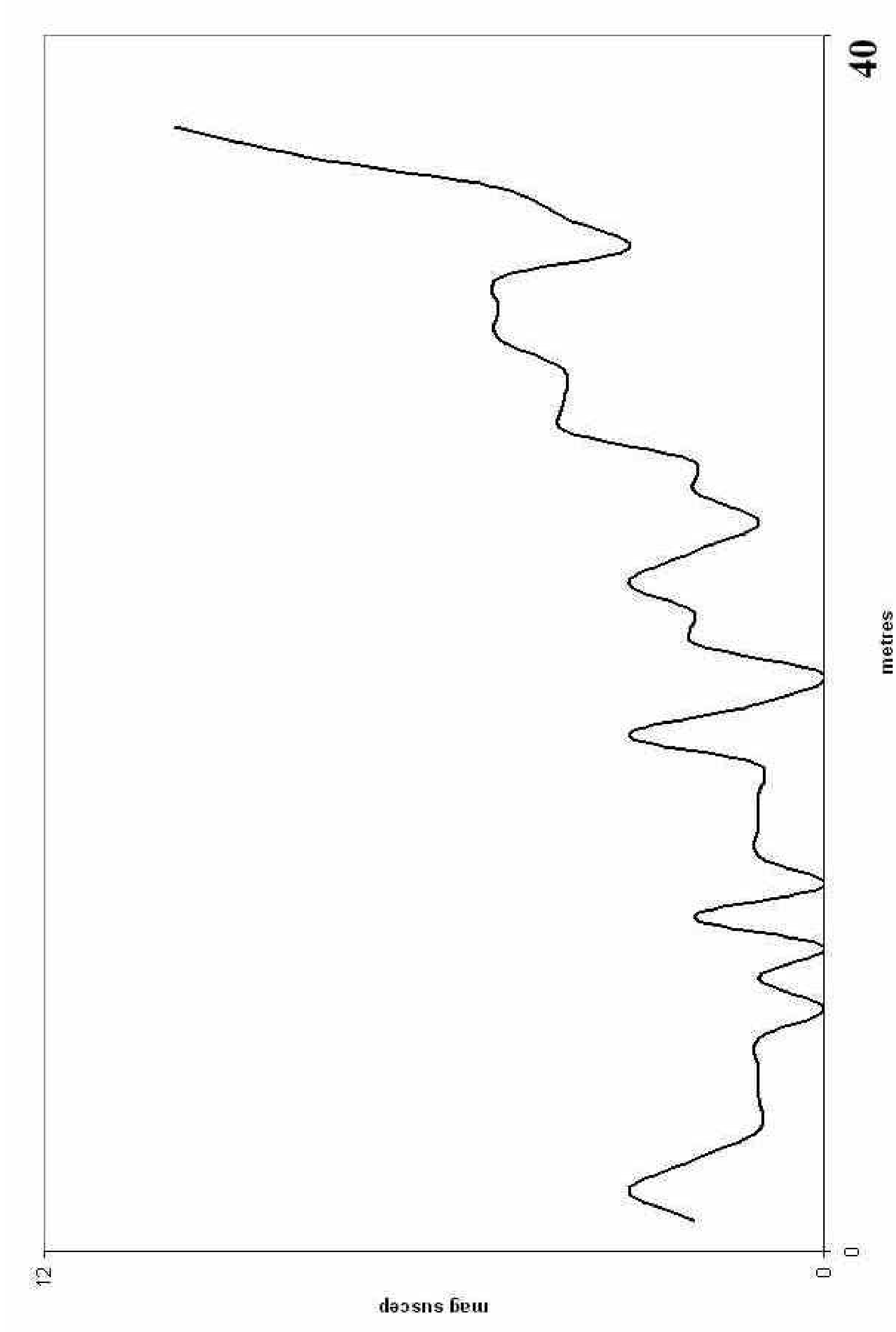

Figure 42: Magnetic Susceptibility Line 5.

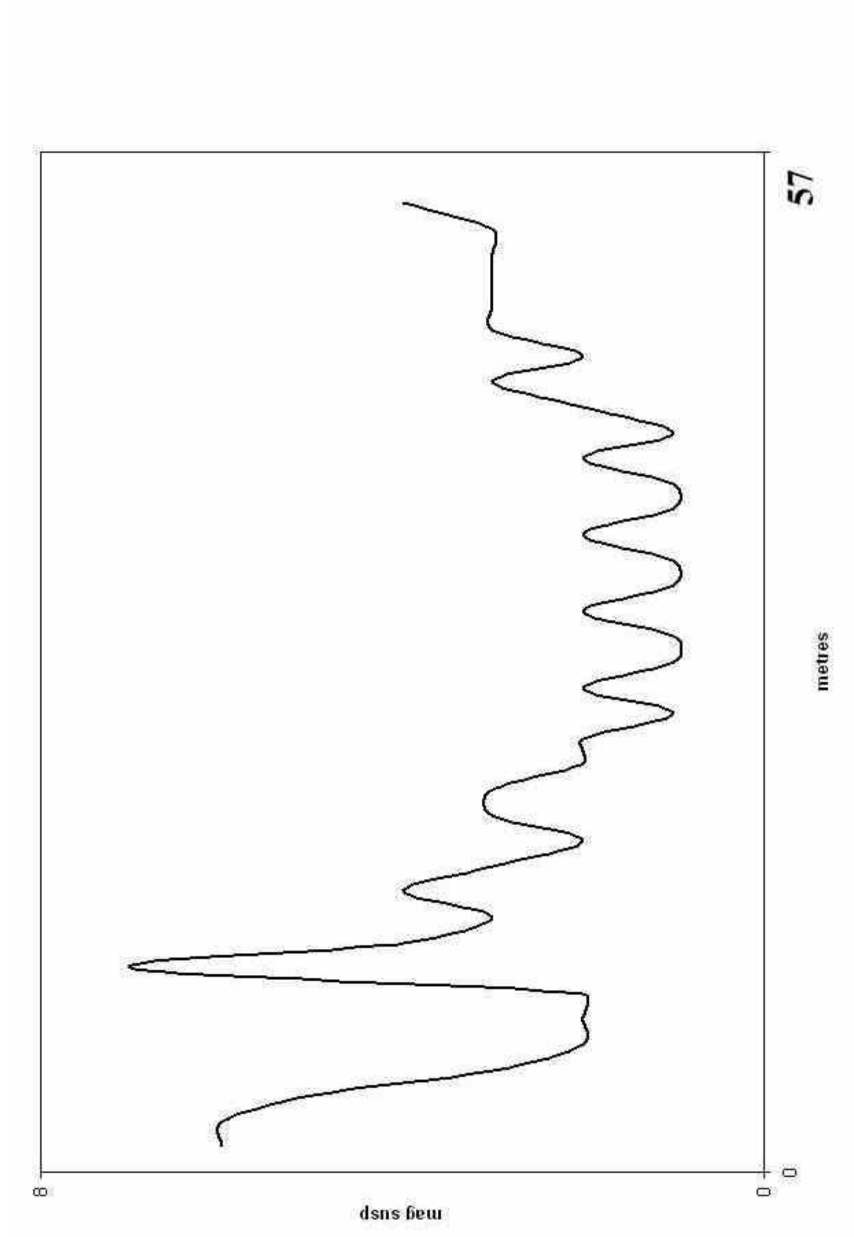

Figure 43: Magnetic Susceptibility Line 6.

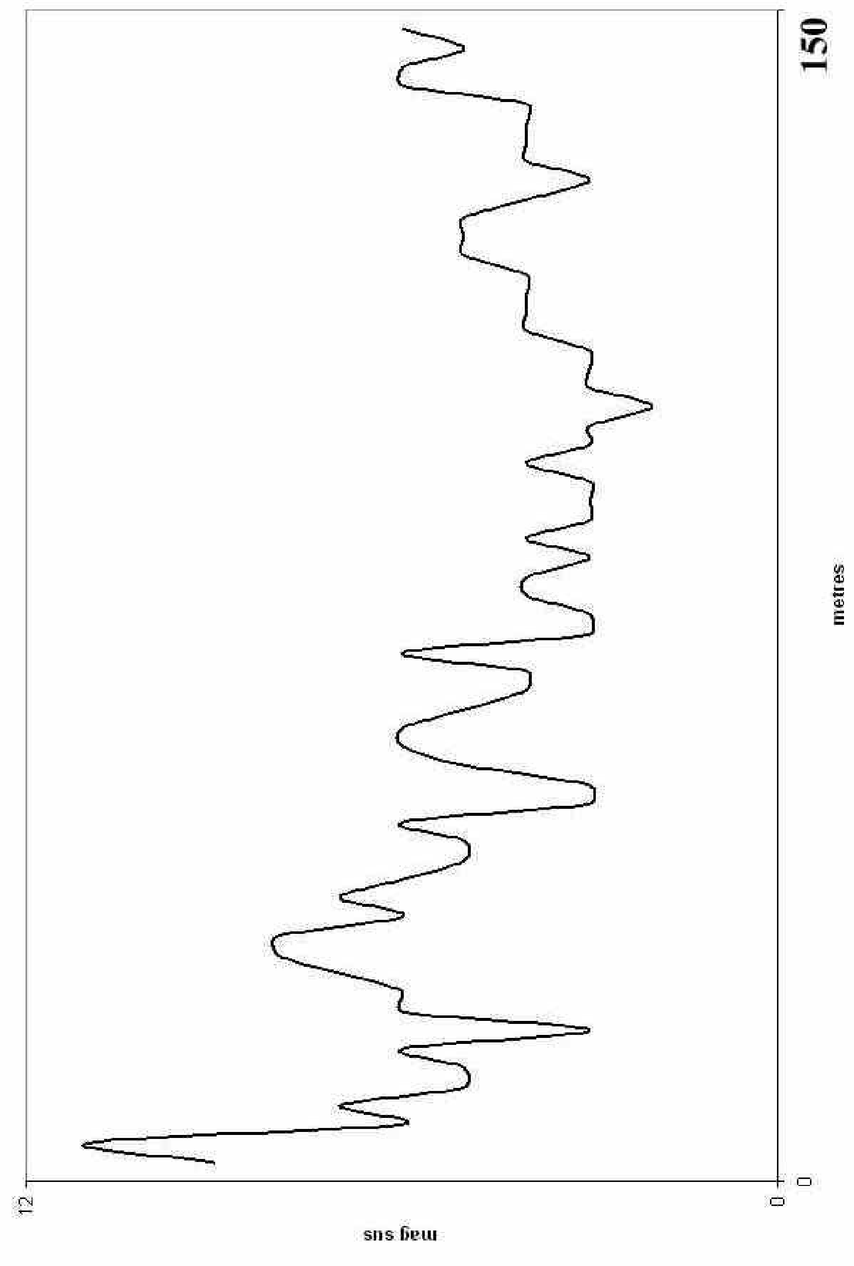

Figure 44: Magnetic Susceptibility Line 7.

Results of Ground penetrating radar survey – Phase II

Six ground penetrating radar lines of data were collected in the vicinity of the church and cemetery using a 200 MHz antenna - see Figure 45 for location. Depth of penetration varied with the subsurface but was typically of the order of a few metres. A shallow amplitude slice, showing the variation of the strength of the returned radar pulse is included for each radar profile. These amplitude slices apply to a depth of about 50 cm and variations in this shallow range are more likely to be due to features of archaeological interest. The results of the radar lines are shown on Figures 46-57. (All lines show west or north at the left except line 6, which is reversed).

Line 1: This was obtained adjacent to the 12th century church adjoined to the present 17th century one, Figure 46. There is a distinct difference in the radar returns for the first half of this profile from the second half. Penetration is considerably lower in the second half, due to attenuation of the signal, thus little information can be obtained at depth. It is possible that clays are present in this locality. (This also coincides with the low resistivity zone, shown in blue on Figure 15). Interestingly, it also coincides with the 'step' in the church wall. The amplitude data are approximately constant, though there is a prominent deviation at 17-18m. which is again beside the 12th century church, Figure 47. Note also on Figure 46, the shallow hyperbola at this location.

Line 2: This was taken in an east-west direction. Very poor penetration was obtained for this entire profile, possibly due to a highly conductive near surface clay layer; though there do appear to be a number of hyperbolas, Figure 48. Some of these are associated with prominent amplitude troughs, Figure 49, especially one at 2m, Figure 49. There is a change at the end of this profile (23m) where the signal characteristics are different – much more variable. This coincides with a linear feature on the magnetic data, see Figure 45.

Line 3: This north-south line is taken near the SE corner of the new cemetery, beside the old ruined church. Clear changes along this line can be seen, Figure 50, with what appears to be a shallow trench located at about 18m. This also coincides with a dramatic change in amplitude signal as shown in Figure 51. Near the church there is very little variation suggesting a much more homogeneous shallow subsurface.

Line 4: This traverse was obtained across the postulated boundary enclosure, south of the cemetery. It has a magnetic and a resistivity signature. The raw data do not show much (see Figure 52) though the location of the boundary at 10m is associated with a slight change in signature. However, the boundary is located at 10m on Figure 53 and this coincides with a marked trough in the amplitude.

Line 5: This was taken across the sub-rectangular feature and the results are shown in Figures 54 and 55. The boundaries of the feature are located at 10 and 22m. There is a distinct change in signature at 10m. Penetration increases and distinctive layering appears at depth. The amplitude data also shows a change around 10m and the western boundary of the features is associated with a trough. The eastern boundary of the feature is not defined on the radar images.

Line 6: This traverse was obtained across the postulated boundary enclosure, west of the cemetery. The raw data do not show much (see Figure 56). However, the boundary is located at 13m on Figure 57 and this coincides with a marked change in signature across it.

The results of the ground penetrating radar were variable. However, they do show very pronounced and abrupt changes in signature at shallow depths, which may be related to archaeological activity. In addition some boundaries, observed with magnetics, do appear to also have a radar signature. The region shown in Figures 50 and 51 look particularly interesting.

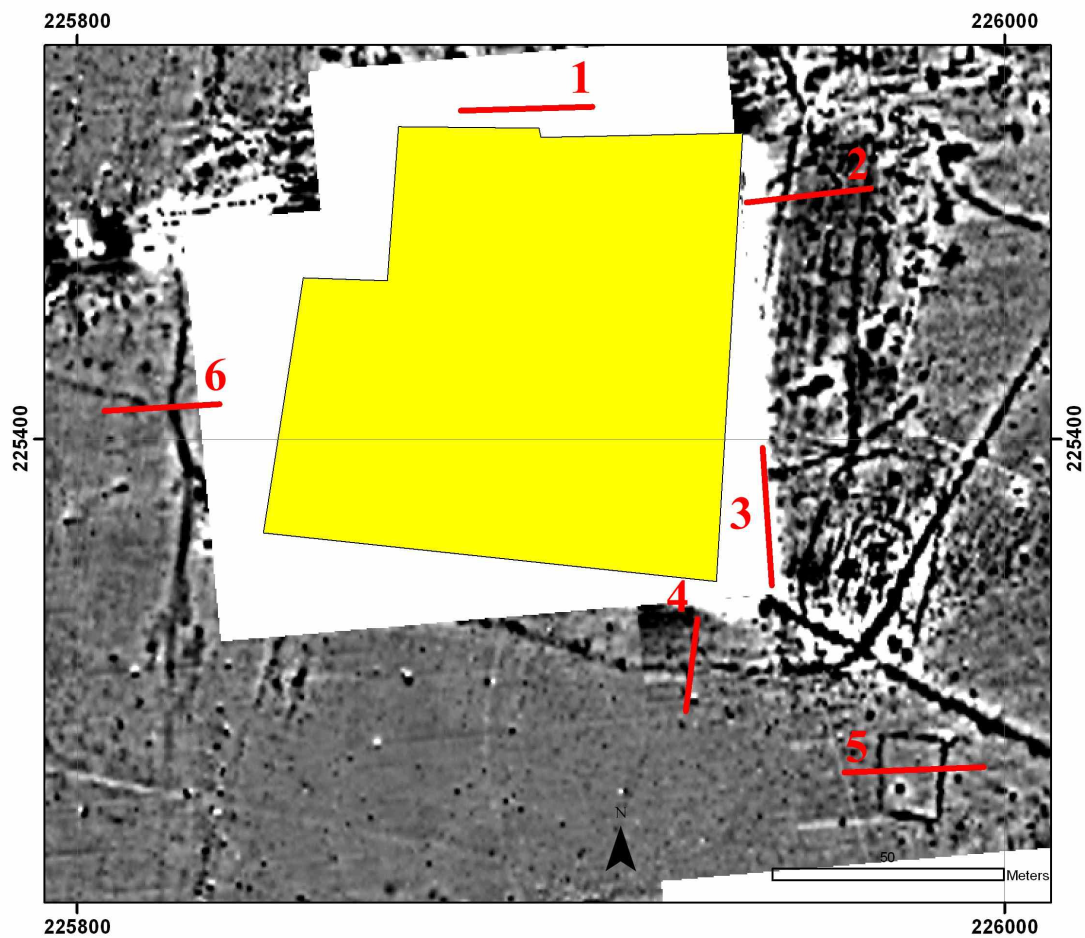

Figure 45: Location of ground penetrating radar lines.

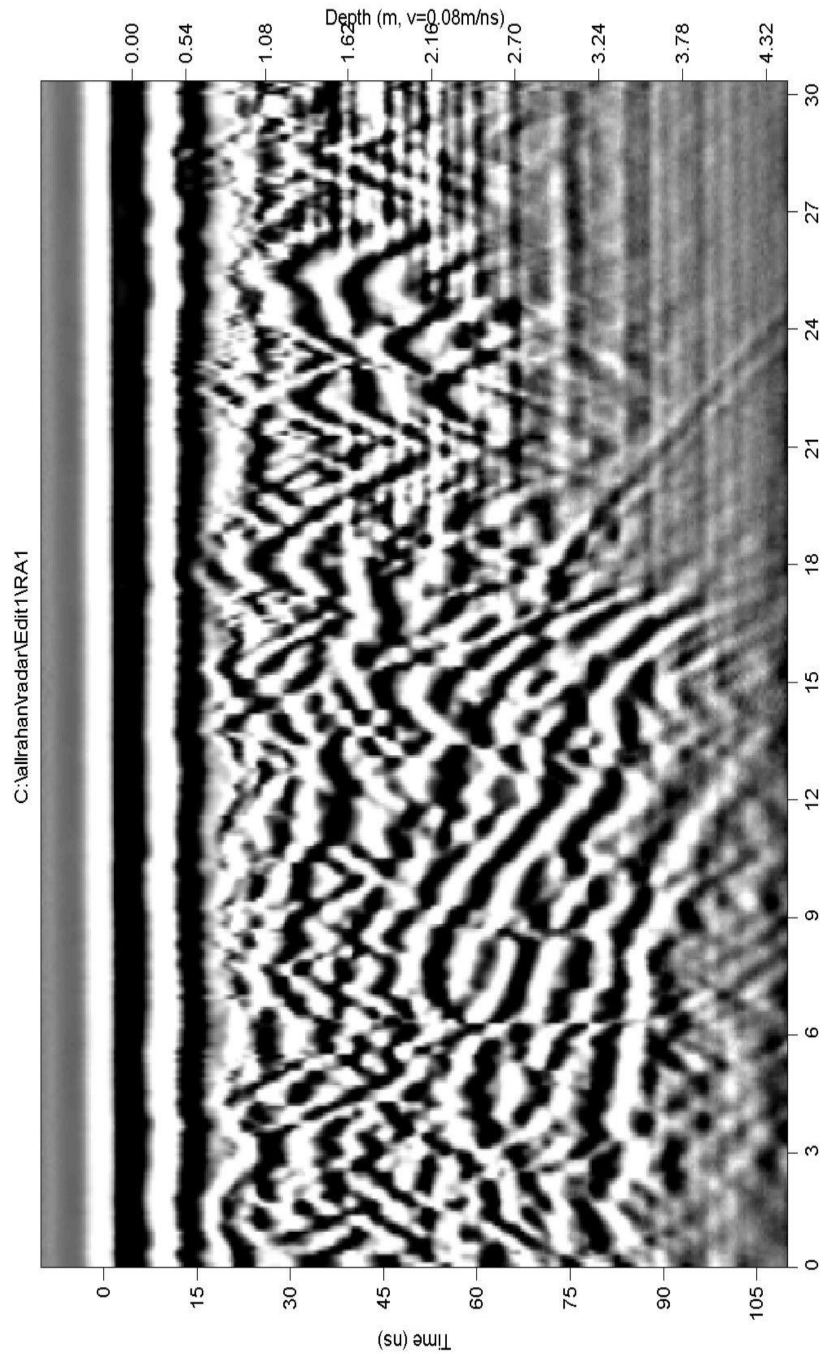

Figure 46: Ground penetrating radar Line 1.

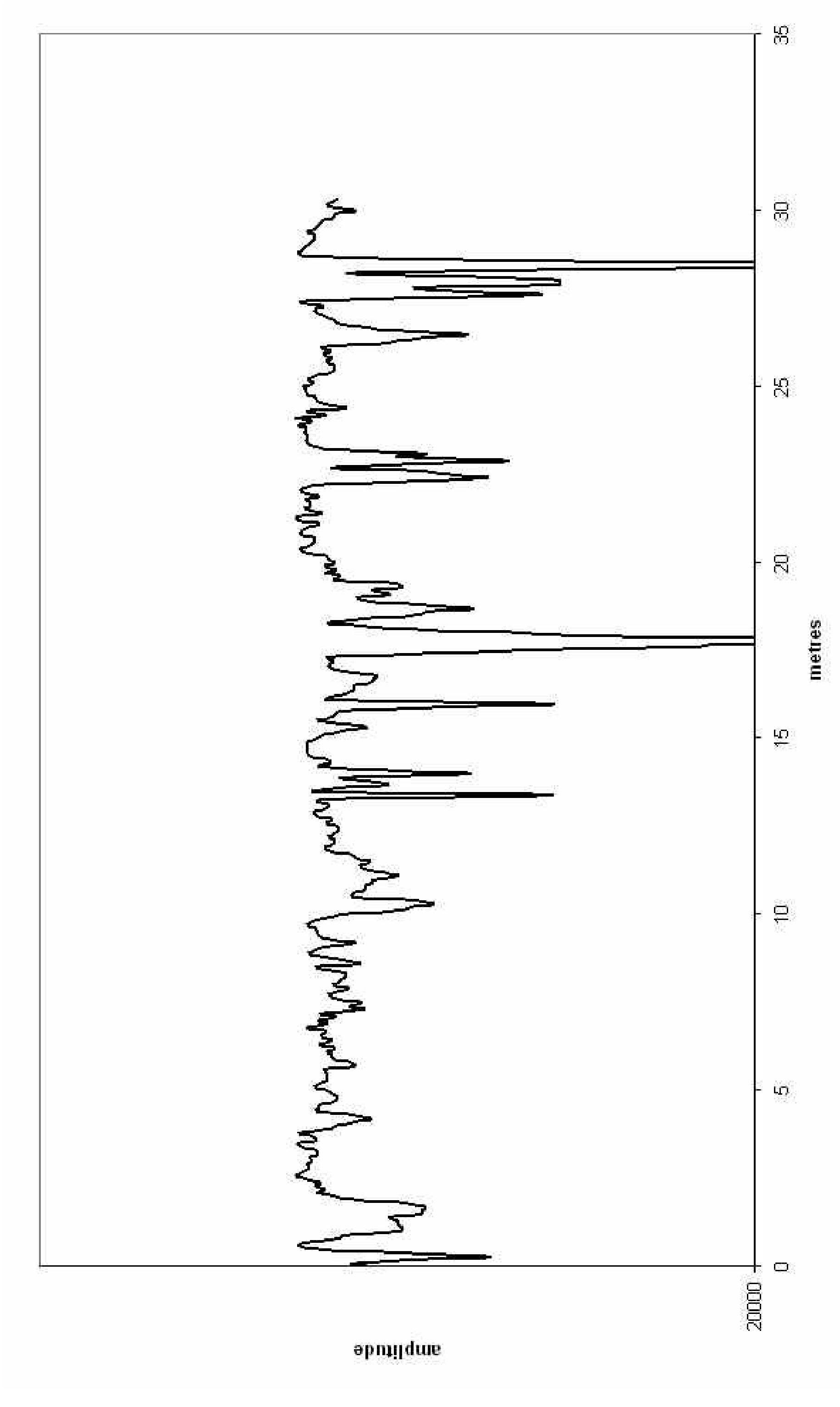

Figure 47: Amplitude data for ground penetrating radar Line 1.

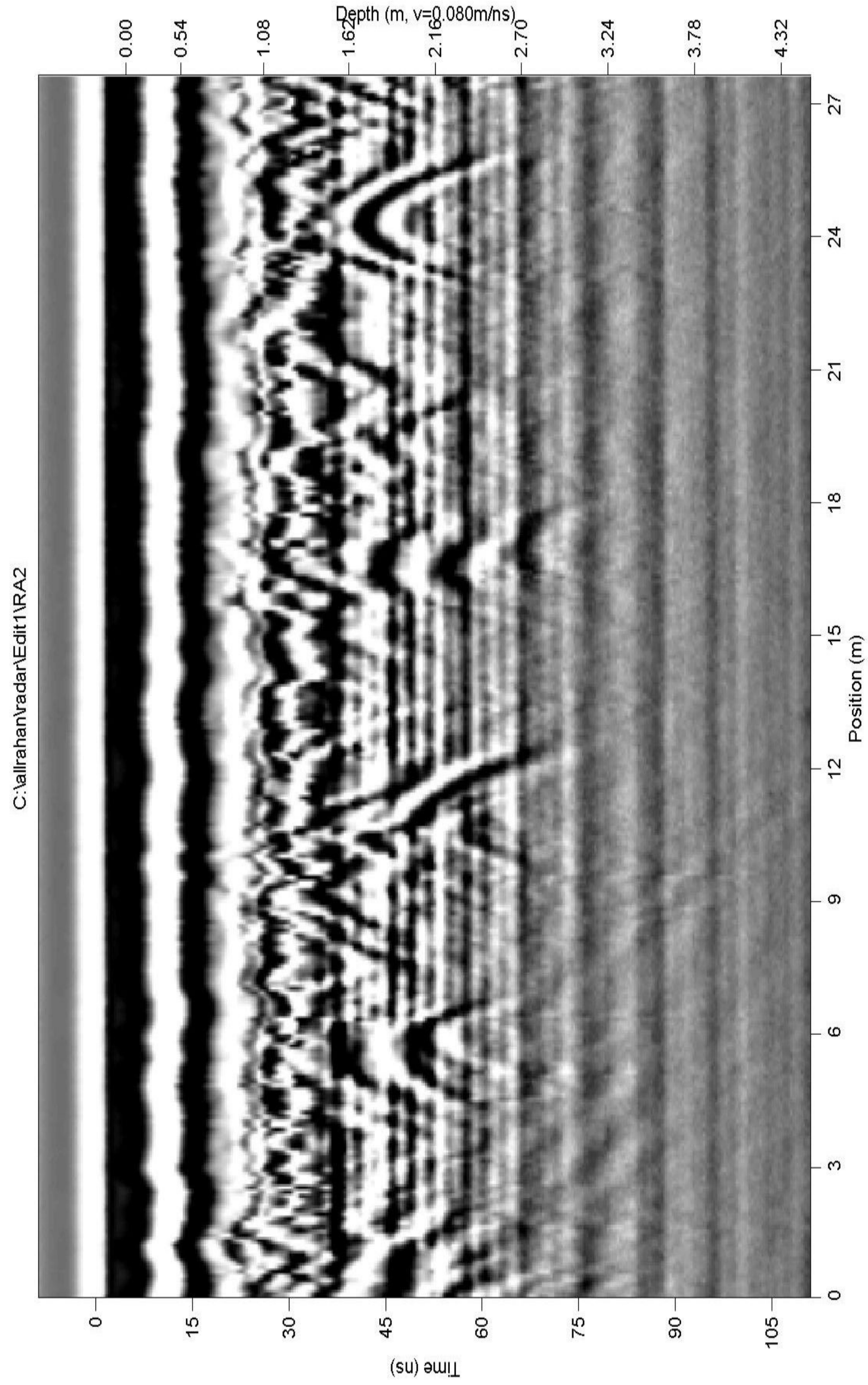

Figure 48: Ground penetrating radar Line 2.

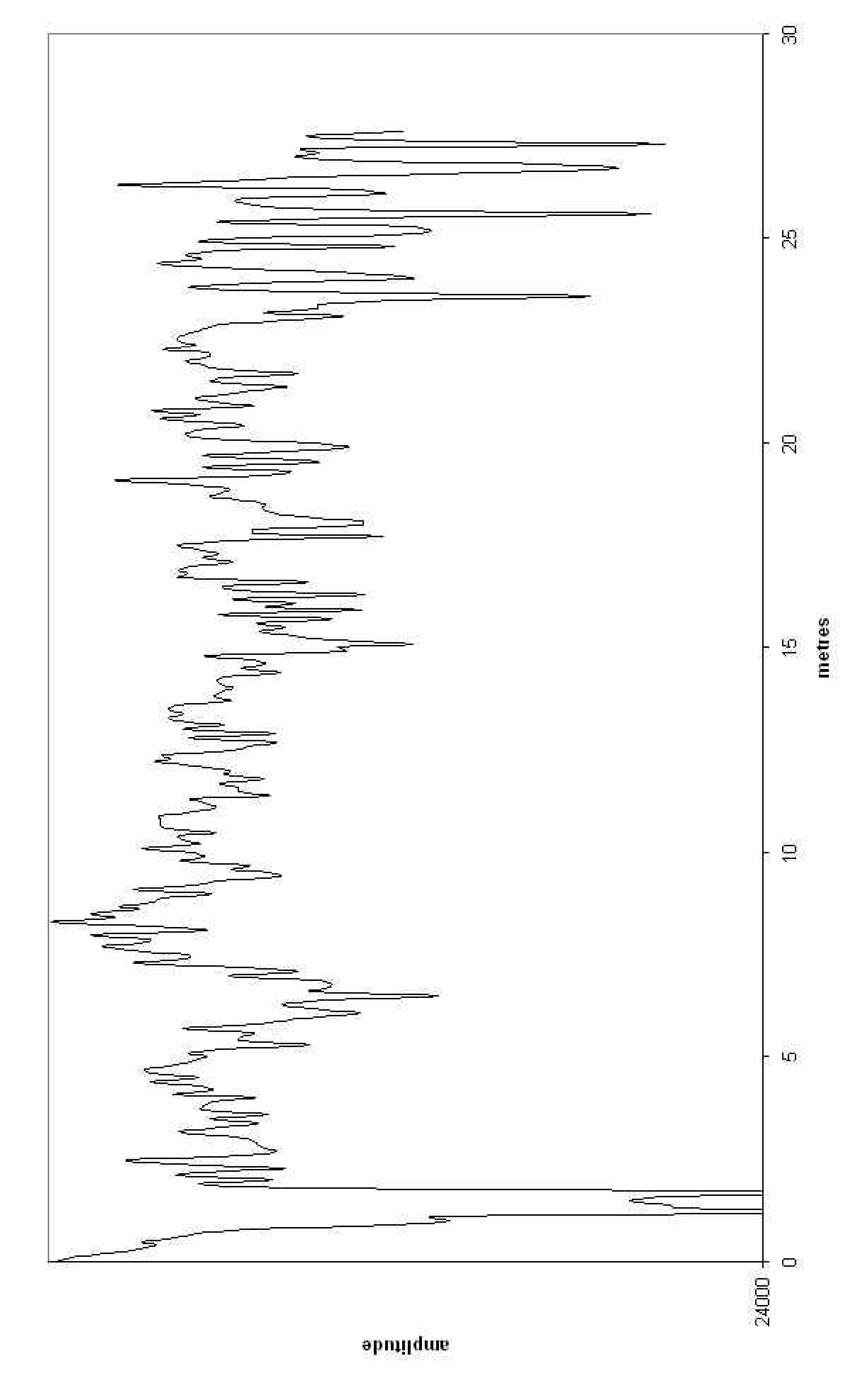

Figure 49: Amplitude data for ground penetrating radar Line 2.

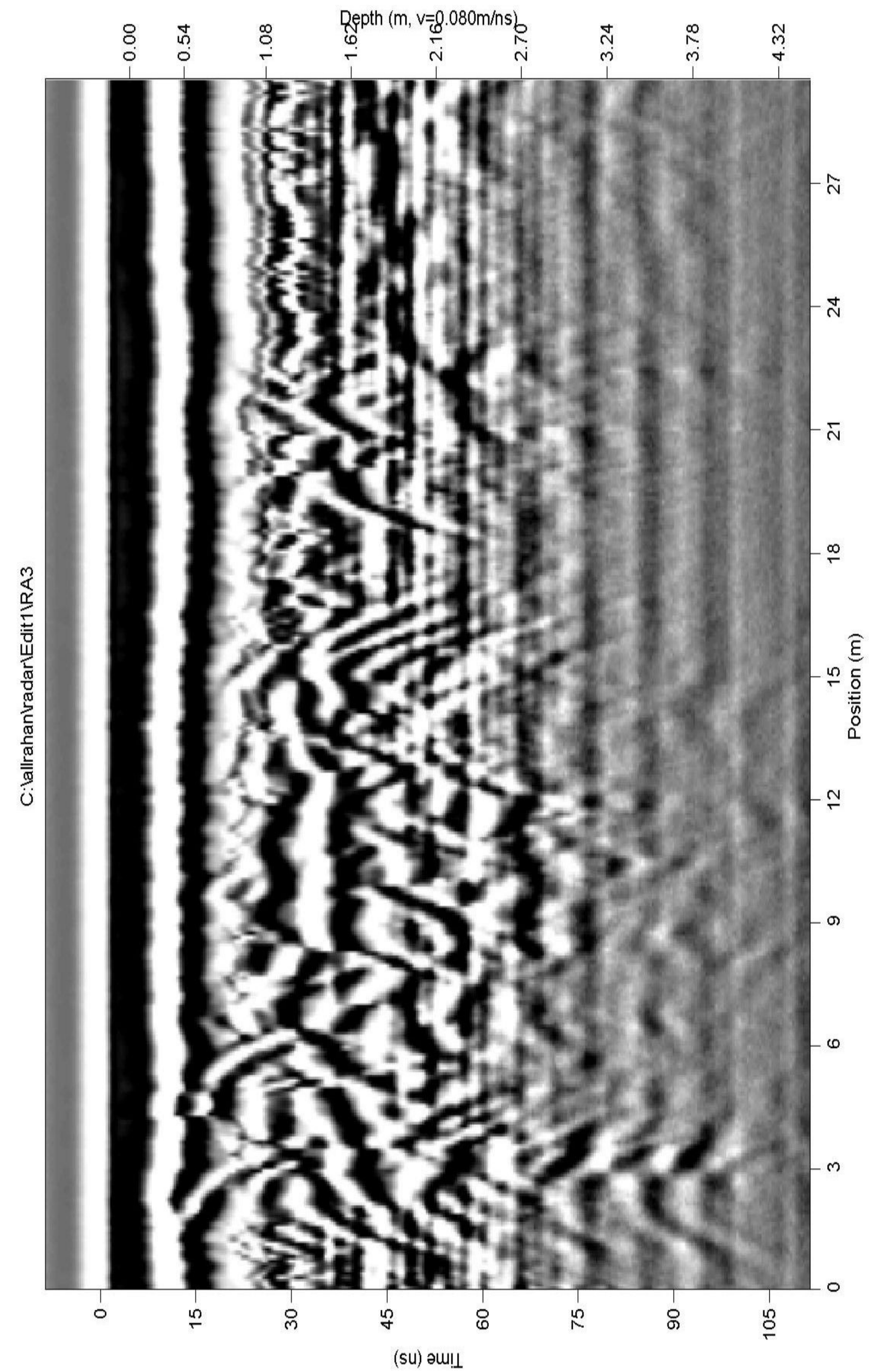

Figure 50: Ground penetrating radar Line 3.

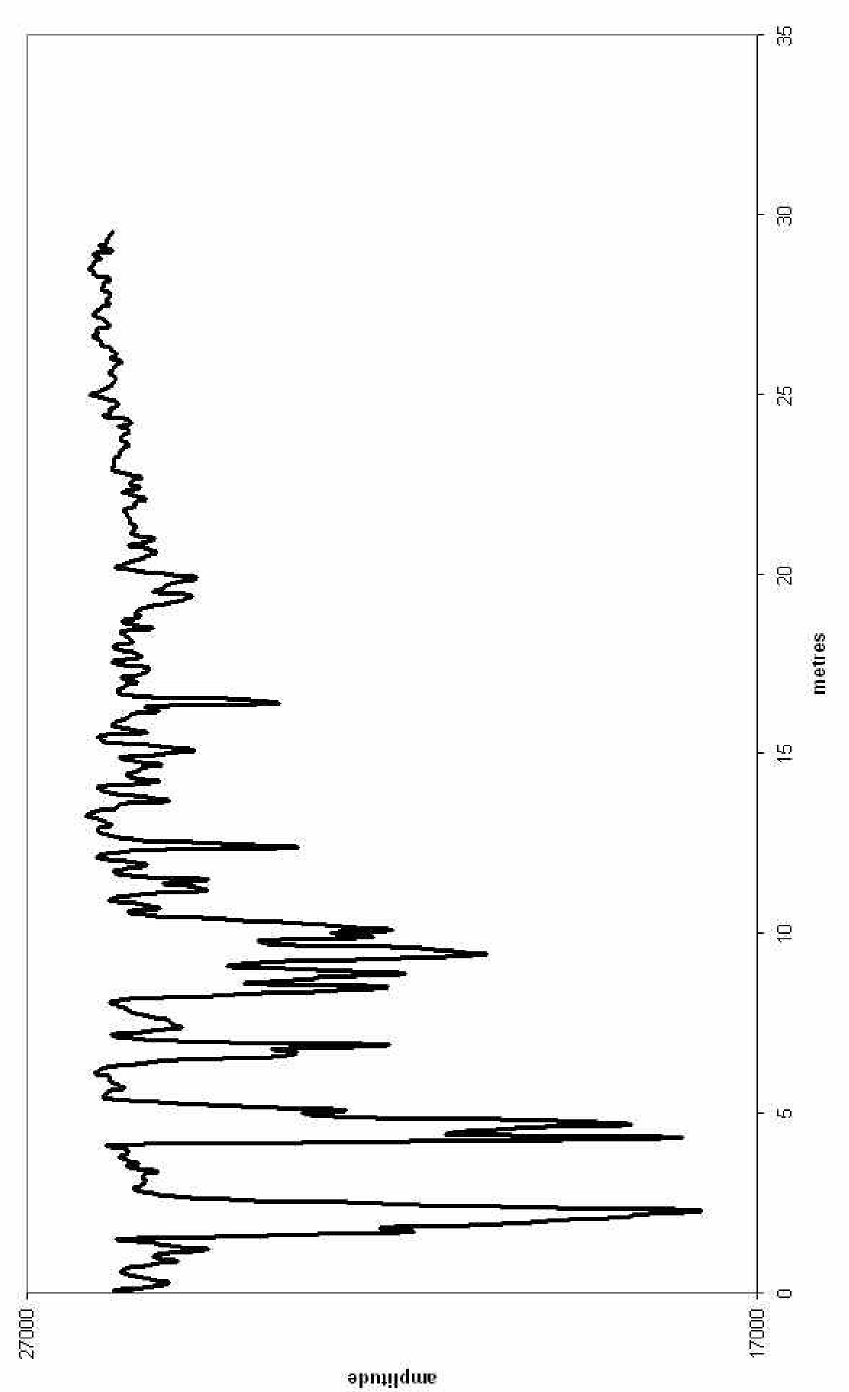

Figure 51: Amplitude data for ground penetrating radar Line 3.

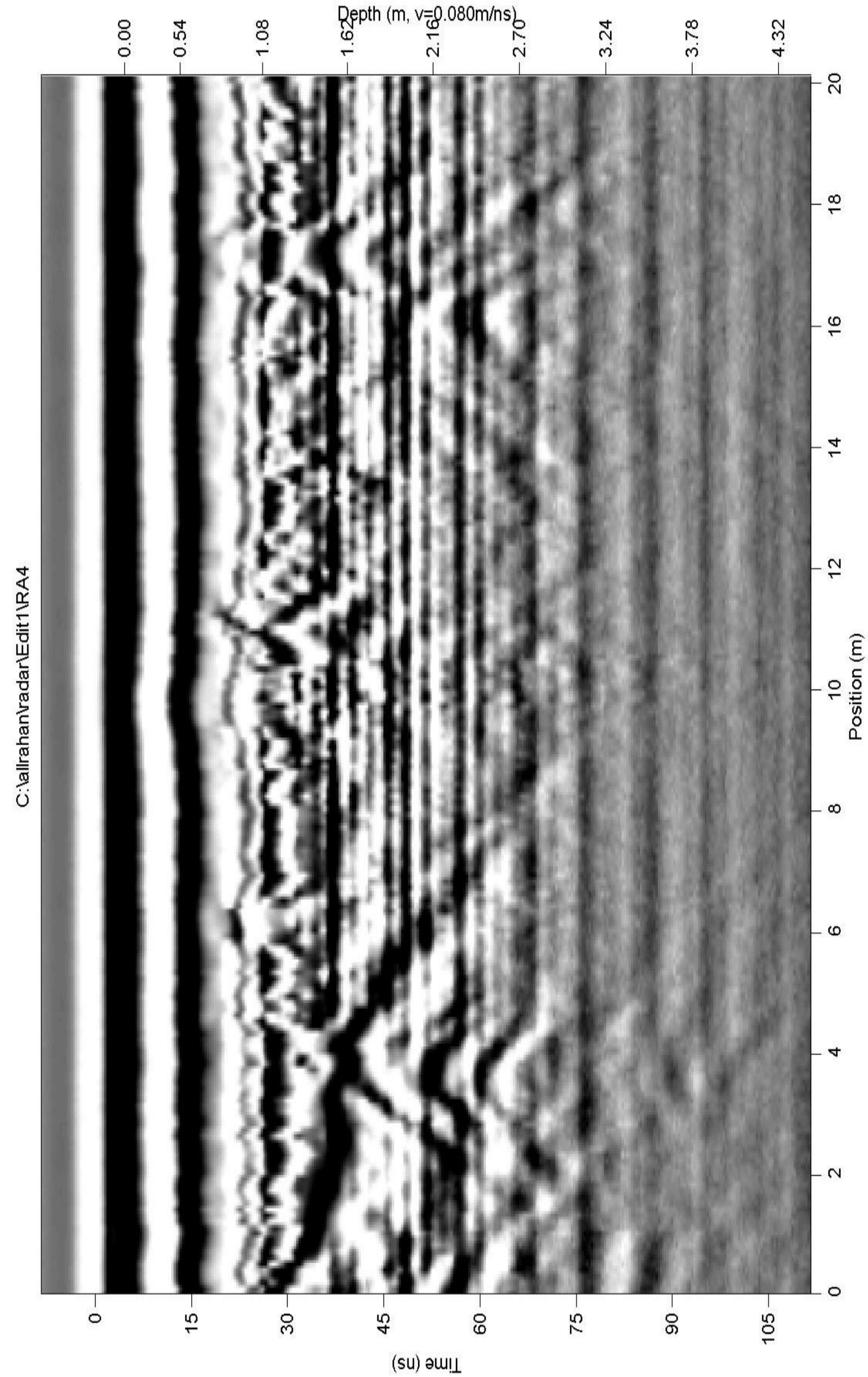

Figure 52: Ground penetrating radar Line 4.

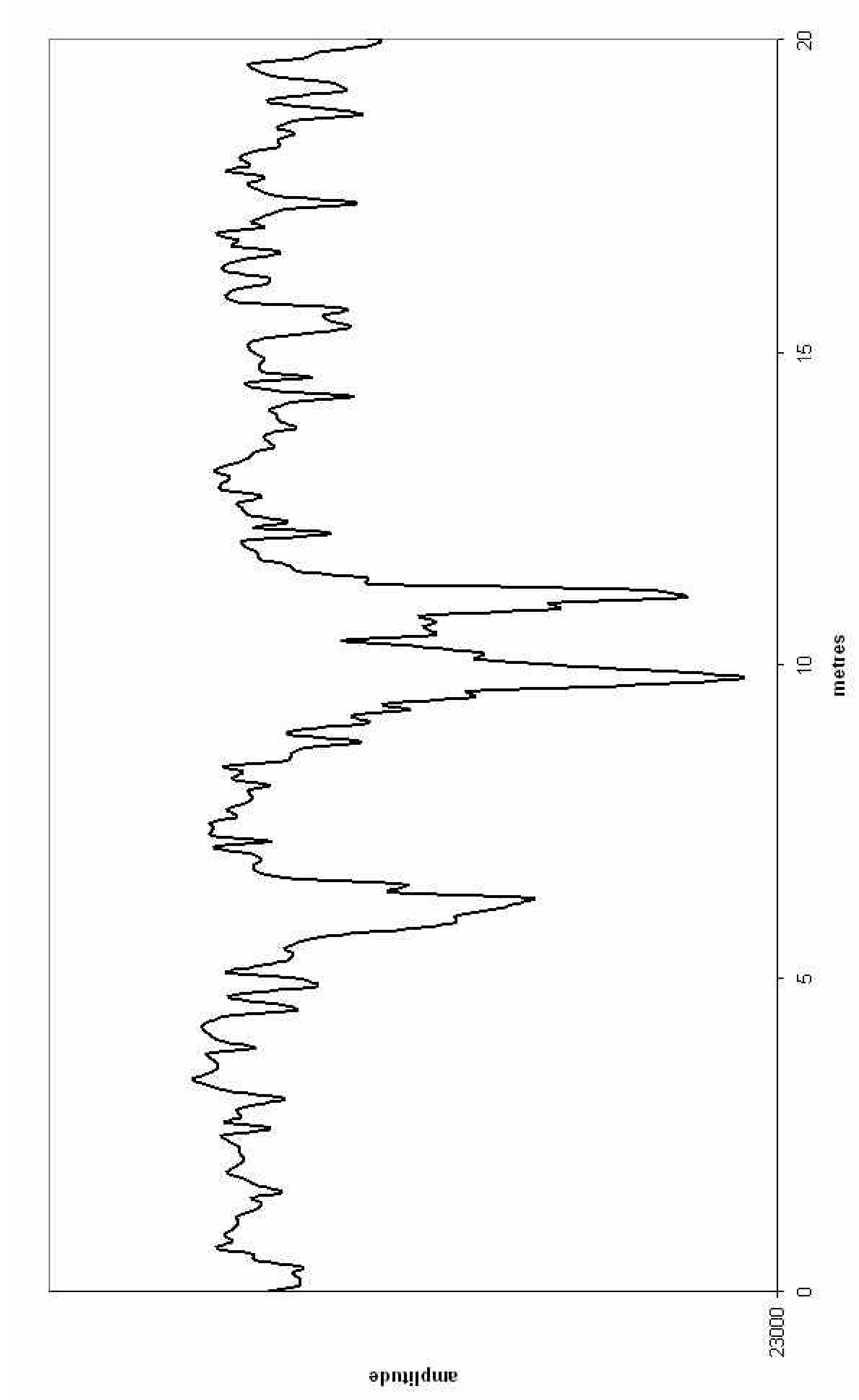

Figure 53: Amplitude data for ground penetrating radar Line 4.

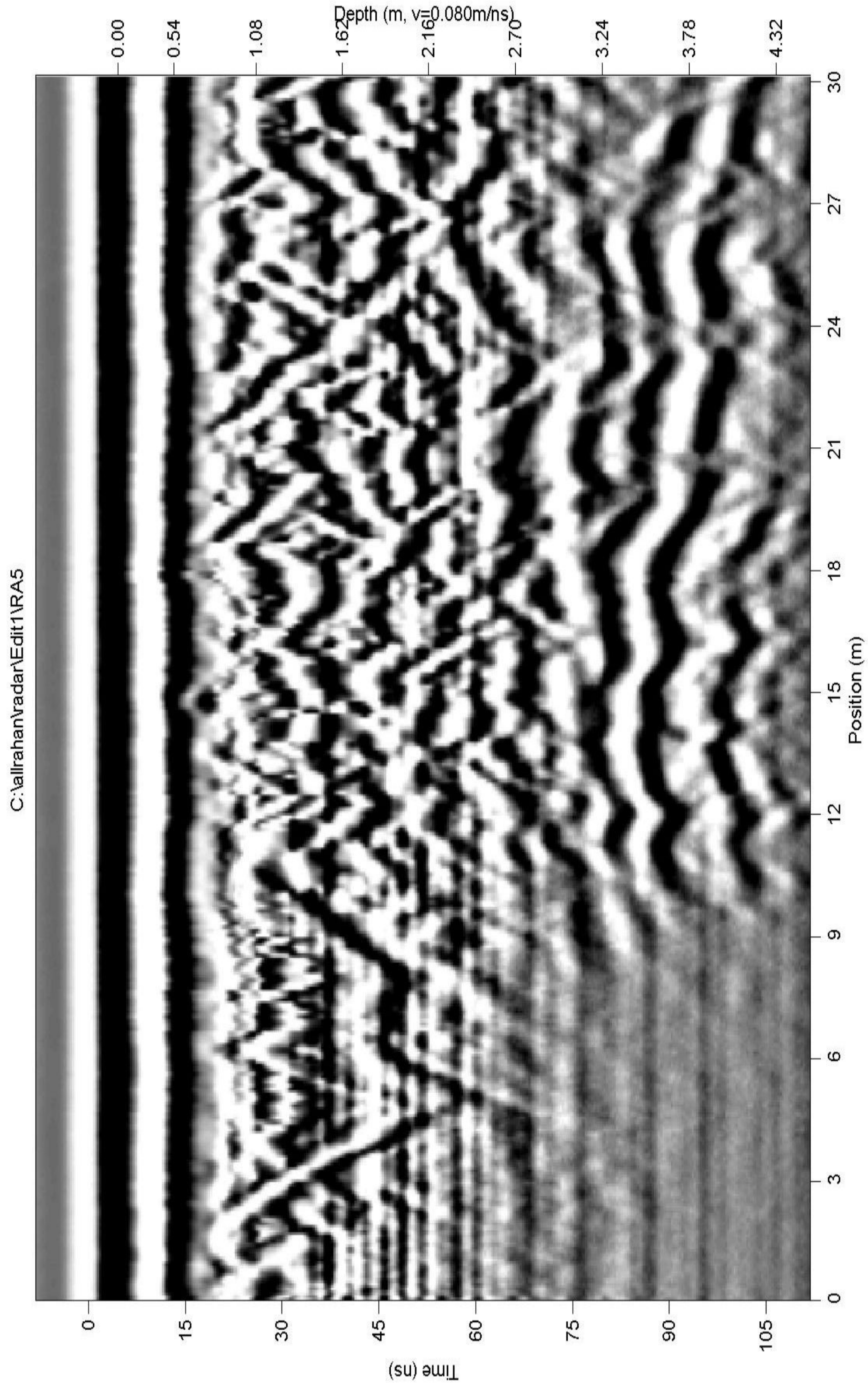

Figure 54: Ground penetrating radar Line 5.

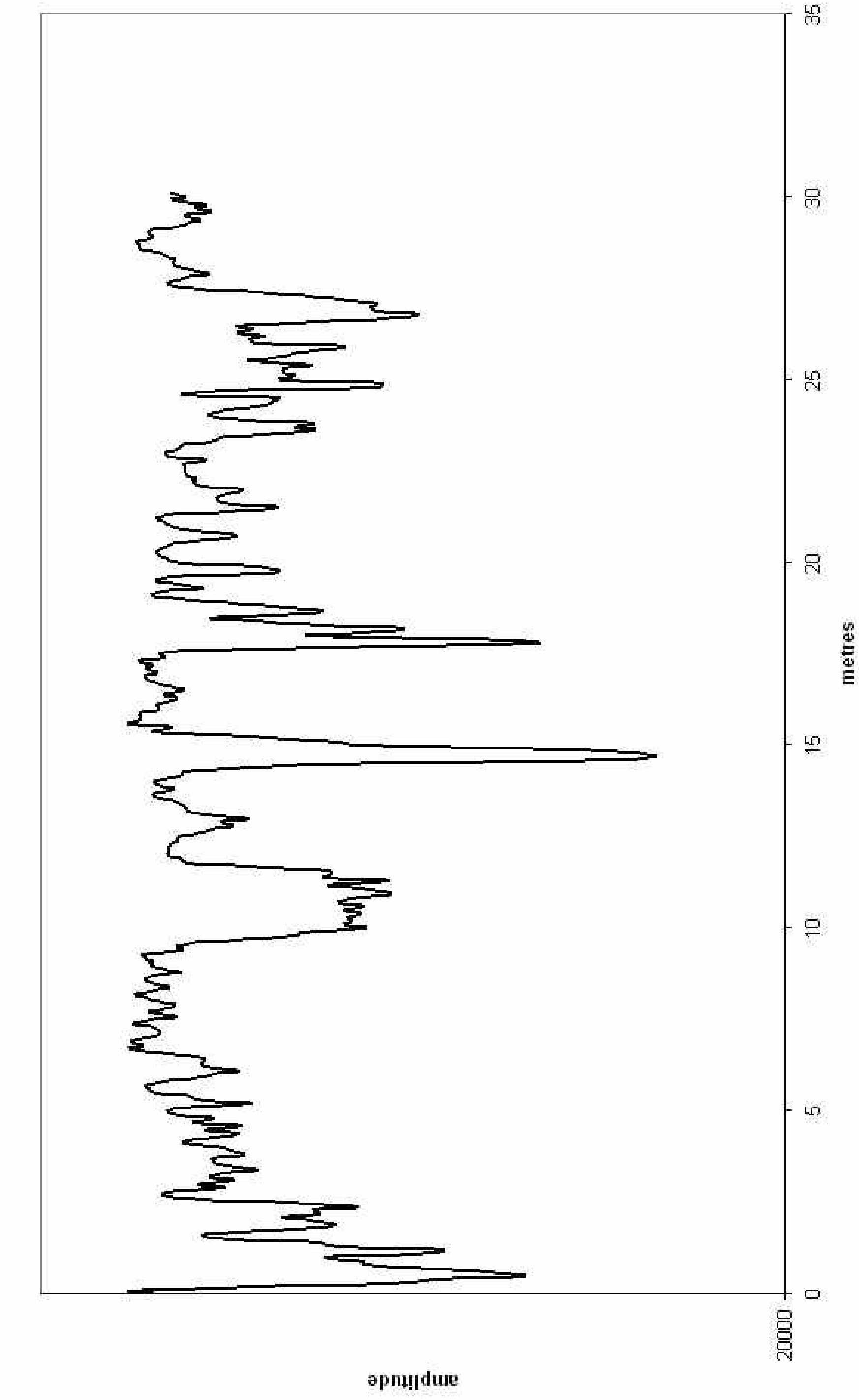

Figure 55: Amplitude data for ground penetrating radar Line 5.

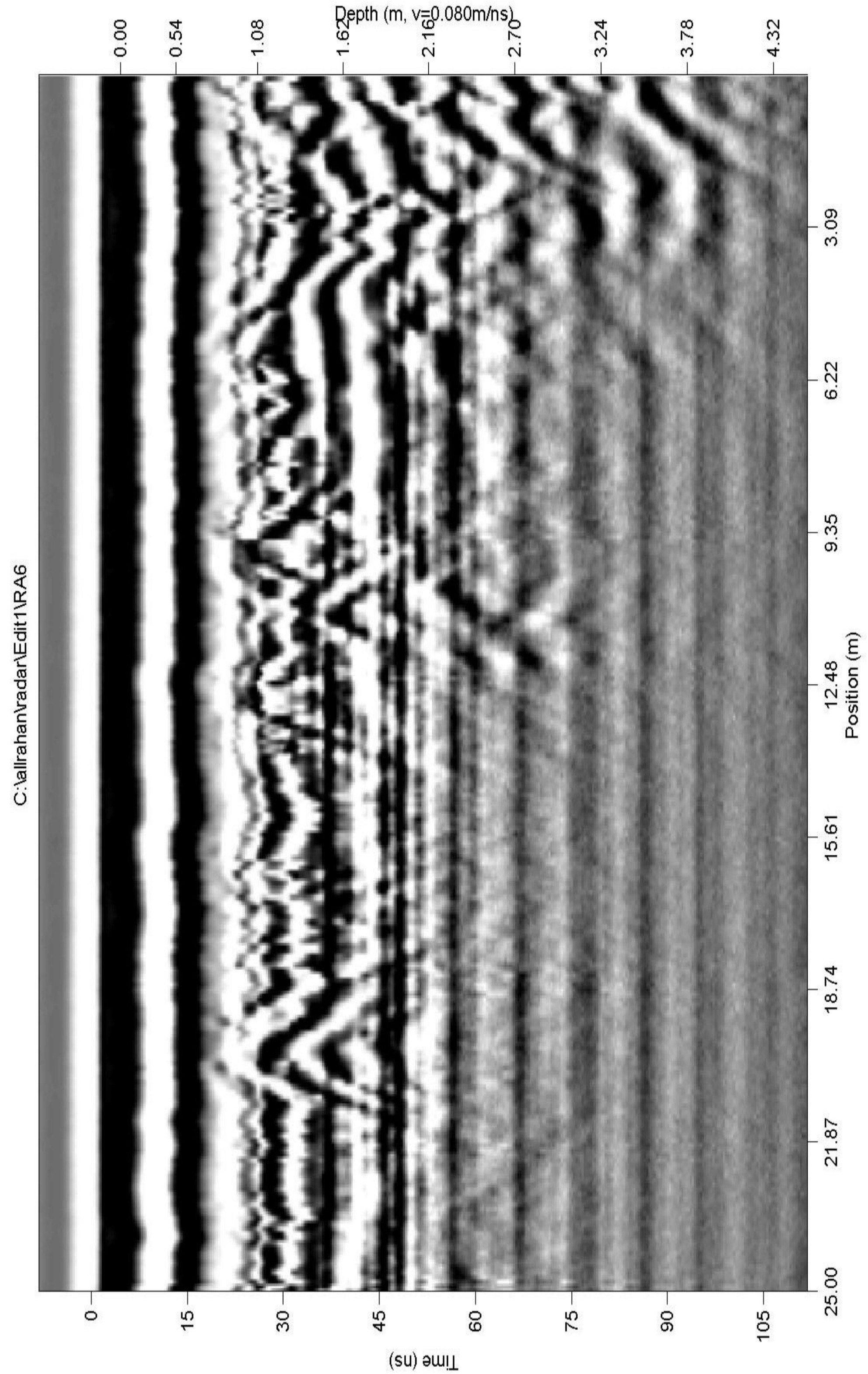

Figure 56: Ground penetrating radar Line 6.

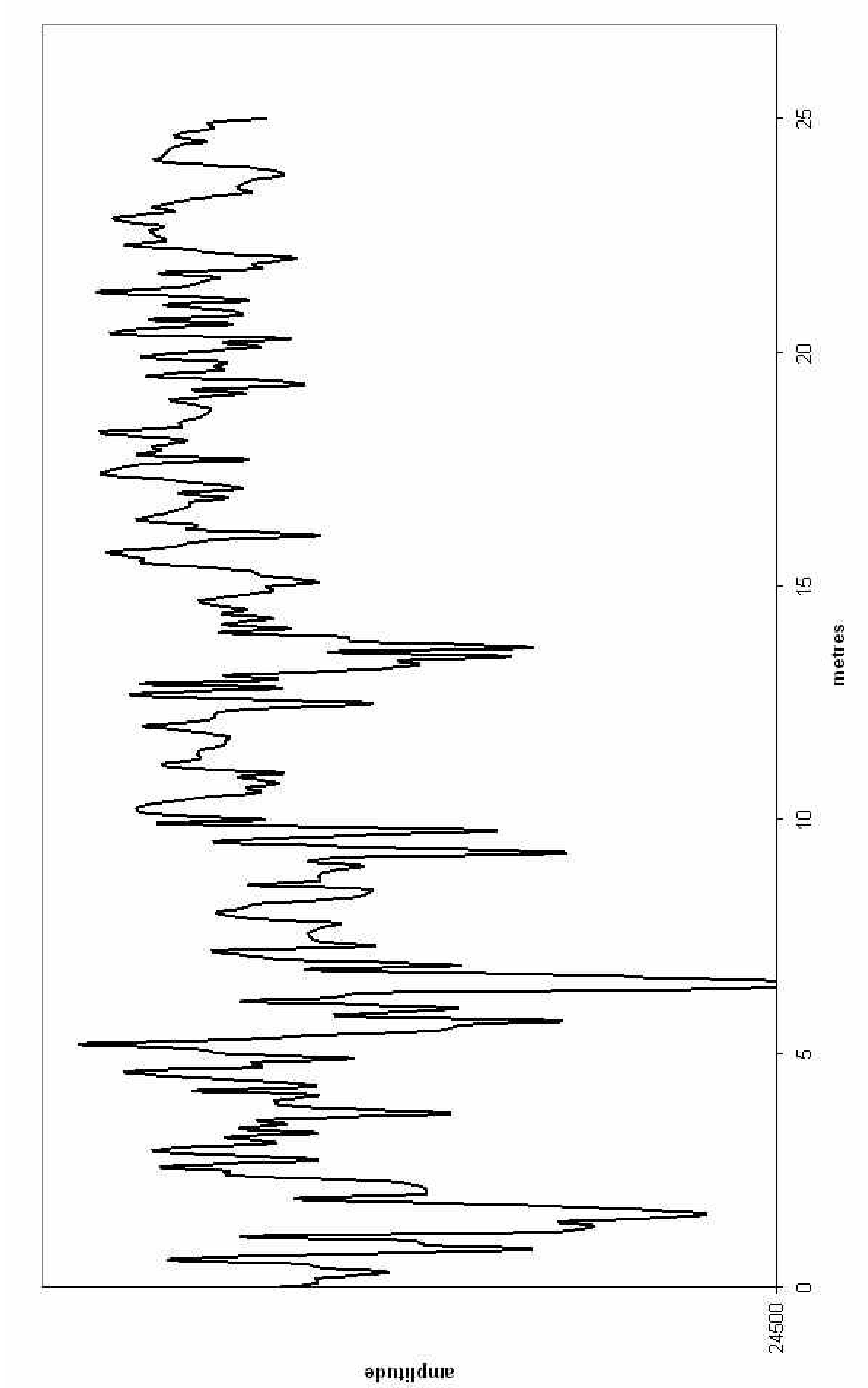

Figure 57: Amplitude data for ground penetrating radar Line 6.