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Salisbury Cathedral
Salisbury, Wiltshire

Ground Penetrating Radar Survey Report

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May 2015

geoservices

Salisbury Cathedral
Salisbury, Wiltshire

Ground Penetrating Radar Survey Report

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* I = Internal Draft; E = External Draft; F = Final

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Ground Penetrating Radar Survey Report

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Summary

In April 2015, Wessex Archaeology was commissioned by Richard Wood, Salisbury Cathedral Close Surveyor, to undertake a ground penetrating radar survey on land at Salisbury Cathedral, Salisbury, Wiltshire to gain information on the extent and character of a buried water culvert. This work was undertaken by Wessex Archaeology's in-house geophysical specialists.

The high-resolution radar survey has revealed several sources of high-amplitude reflection readings of potential archaeological significance. Most relevant to this project are the clear linear high amplitude responses that represent the water culverts that are shown in historic mapping. Further responses are likely to represent past landscaping features and walls.

The survey was undertaken on the 16th April 2014 with favourable weather conditions and ground underfoot.

Salisbury Cathedral, Salisbury, Wiltshire

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Acknowledgements

The high-resolution ground penetrating radar survey was commissioned by Salisbury Cathedral Office. The assistance of Richard Wood is gratefully acknowledged in this regard.

The fieldwork was undertaken by Wessex Archaeology's in-house geophysical specialists. The data was processed and interpreted the data by Lizzie Richley who also produced this report The geophysical work was quality controlled by Lucy Learmonth. Illustrations were prepared by Lizzie Richley and Karen Nichols. The project was managed on behalf of Wessex Archaeology by Caroline Budd.

Salisbury Cathedral
Salisbury, Wiltshire

Ground Penetrating Radar Survey Report

1 INTRODUCTION

1.1 Project Background

1.1.1 Wessex Archaeology (WA) was commissioned by Salisbury Cathedral Office to carry out a ground penetrating radar (GPR) survey of land at Salisbury Cathedral, Salisbury, Wiltshire (**Figure 1**), hereafter "the Site" (centred on NGR 414360,129400).

1.1.2 The Site is located within the grounds of Salisbury Cathedral, and covers part of the grounds of the former Bishop's Palace which now houses Salisbury Cathedral School. Both the Cathedral and the Cathedral School are Grade 1 listed buildings and were constructed in the 13th century when the centre of the Diocese moved from Old Sarum to its current location.

1.1.3 The aim of the geophysical survey was to establish the presence/absence, extent and character of a buried water culvert within the survey area and other drainage features.

1.1.4 This report presents a brief description of the methodology followed, the detailed survey results and the archaeological interpretation of the geophysical data.

1.2 The Site

1.2.1 The Site consisted of an area of grass that is used for recreation to the west and south of the Cathedral school (**Figure 1**). The survey area gently slopes from the north to south with a small lake in the southern area.

1.2.2 GPR survey was undertaken over all accessible parts of the Site within the time frame allocated.

1.2.3 The Bishop's Place is situated to the southeast of the Cathedral and in The Close. It was established during the 1220s. It has undergone many phases of construction, alterations and repairs. It was restored during the mid-15th century and extended after 1568. Parts of the palace were demolished after 1648. Some rebuilding took place during the 1660s with further additions taking place during the later 17th century and early 18th century. The palace was refurbished again during the later 18th century with further additions constructed throughout the 19th century. Parts were demolished in 1931. It has been used by the Cathedral School from 1947 (Historic England Pastscape, 2015). The survey area is considered to be of high archaeological potential.

1.2.4 The geology of the Site is mapped as Newhaven Chalk Formation. This is a sedimentary bedrock formed approximately 71 to 86 million years ago in the Cretaceous Period (BGS 2015).Soils derived from such geological parent material have been shown to produce contrasts acceptable for the detection of archaeological remains through GPR radar survey.

2 METHODOLOGY

2.1 Introduction

2.1.1 The geophysical survey was undertaken on the 16th April 2015. The survey area consisted of one area of recreational lawn with some obstacles in the form of football posts, trees and garden furniture. The survey area was delimitated by the extents of the Cathedral School Boundaries.

2.1.2 The survey and report production were conducted in accordance with English Heritage guidelines (2008).

2.2 Method

2.2.1 Individual survey grid nodes were established using a RTK GPS system, which is precise to approximately 0.02m and therefore exceeds English Heritage recommendations (2008).

2.2.2 GPR data were collected using a cart-mounted GSSI GPR system consisting principally of a 400 MHz shielded antenna and a SIR-3000 control unit. Profiles were collected at a line spacing of 1m with a sample spacing of 0.02m on a tangent angle to the alignment of known buried features. Profiles were collected at 1m in order to achieve larger coverage within the survey time available, this level of resolution was deemed acceptable (alongside the angled direction of data collection) to meet the needs of the survey; to identify the location of a subterranean water culvert which is in excess of 0.5m. The location of each survey profile is shown in **Figure 2**.

2.2.3 The time window for reflection measurement was set to 90.93 nanoseconds, which corresponds to a potential penetration depth of approximately 4.9m at a radar wave propagation velocity of 0.108m/ns (**Table 1**: Time depth to metric depth relationship). Due to signal attenuation and scattering relating to conductive and heterogeneous subsurface conditions, practical penetration depth is often significantly less than this theoretical maximum.

2.2.4 The approximate depth conversion is shown in **Table 2**, assuming the velocity of the GPR pulse through the ground is c. 0.108m/ns. It is possible to determine more precisely the average velocity of the GPR pulse through the ground if excavated features at a known depth can be identified in the data. Radargrams were analysed for suitable hyperbolic reflections, which can be used to determine the velocity of the GPR pulse through the sub-surface deposits; few such hyperbolae were observed and a typical value of 0.07m/ns was used.

2.2.5 The Relative Dielectric Permittivity (RDP) of the bulk structure can be calculated using $K = \left(\frac{V_c}{V_r}\right)^2$, where K is the RDP, V_c speed of light in a vacuum and V_r the GPR pulse velocity.

Table 1 - GPR timeslice information, assuming v=0.007m/ns

Time Slice	Time depth range (n.s)	Approximate metric depth range (cm)
1	6-11	31-60
2	10-15	54-83
3	14-19	76-105
4	18-24	99-128
5	22-28	121-150
6	27-32	144-174
7	31-36	167-197
8	35-41	189-219
9	39-45	213-242
10	43-49	235-264
11	48-53	258-287
12	52-57	281-310
13	56-62	303-333
14	60-66	326-356
15	65-70	348-378
16	69-74	372-401
17	73-79	395-424
18	77-83	417-446
19	81-87	440-469
20	86-90	462-484

2.2.6 The radar profiles were put through minimal processing. DC offset correction and time gains were applied to the GPR data to correct for low frequency noise and increase mid- to late-time signal amplitudes respectively. Background and bandpass filters were also applied to remove external background noise from the data. Profiles were then stacked for feature interpretation.

2.2.7 Signal amplitudes were squared to improve signal-to-noise ratio and reduce the effect of transmitter waveform shape. The resultant profile dataset was sliced at a vertical interval of 0.2m to produce depth slices suitable for feature interpretation. Depth slices from surface to 1.4m were gridded to produce the images shown in **Figure 3** to **Figure 6**.

2.2.8 Processing was carried out using the commercially available software GPRSlice v7.

2.2.9 Further details of the geophysical and survey equipment, methods and processing are described in **Appendix 1**.

3 GEOPHYSICAL SURVEY RESULTS AND INTERPRETATION

3.1 Introduction

3.1.1 The high-resolution GPR survey has been successful in identifying anomalies of definite, probable and possible archaeological interest across the Site. The advantage of GPR over other geophysical methods is that the *spatial relationship* of individual features can be appreciated. Depth slices enable features to be studied at relative depths.

3.1.2 Results are presented as a series of greyscale plots and archaeological interpretations, at a scale of 1:1500 (**Figures 3** to **10**). Radar reflectance in these images grades from low (White) to high (Black).

3.1.3 The interpretation of the datasets highlights the presence of potential archaeological anomalies including clear evidence of the buried culvert (**Figures 3** to **6**).

3.2 Geophysical Survey Results and Interpretation

3.2.1 Several high amplitude reflection features have been identified within the survey area. In particular a planar high amplitude feature (**Figures 3** to **4; 4000** and **4002**) extends from the western edge of the survey area across to the eastern edge and can be seen from *c.* 0.3m down to an approximate depth of 3m. This feature has a further extension to the north and is understood to be the subterranean culvert that is documented on the maps from 1887.

3.2.2 The culvert is clearly visible within the radargrams (**Figure 7**) in particular a clear reflection can be seen in profile 25 at approximately 30m, this relates to the north-south section of the culvert. The east-west culvert is also visible but the shape of it is less uniform and can be seen in profiles 6, 8, 14 and 25 at approximately 27m, 33m, 25m, 35m and 15m respectively. Due to the zigzag and orientation of data collection the location of the culvert varies in each individual radargram.

3.2.3 Based upon the depth calculations done in the office the culvert is detected from a depth of *c.* 0.5m.

3.2.4 Further features are also visible across the site are likely to relate to earlier buildings and garden landscaping (**Figures 3** to **6; 4001, 4003, 4004** and **4005**).

4 CONCLUSION

4.1.1 The GPR survey carried out over land at Salisbury Cathedral adjacent to Salisbury Cathedral School identified several features of likely archaeological interest that warrant further investigation.

4.1.2 The subterranean water culvert marked on the 1887 historic maps of the water courses at the Site is clearly visible in the GPR dataset as well as several smaller anomalies of potential archaeological origin. The culvert is visible from a depth of 0.30m – 3m however depths are only approximate and based upon calculations under taken in the office. Actual depths may vary slightly.

4.1.3 It should be noted that small features may produce responses that are below the detection threshold of a 400MHz antenna. It may therefore be the case that more archaeological features may be encountered than have been identified through geophysical survey. The compaction and disturbance caused by the building of a car park and road over several parts of the Site can lead to archaeological features not being detected by geophysical methods.

5 REFERENCES

English Heritage 2008 *Geophysical Survey in Archaeological Field Evaluation*. Research and Professional Service Guideline No 1, 2nd edition.

Soil Survey of England and Wales 1983. *Sheet 6, South West England*. Ordnance Survey, Southampton.

APPENDIX 1: SURVEY EQUIPMENT AND DATA PROCESSING

Survey Methods and Equipment

The ground penetrating radar (GPR) data were collected using a cart-based 250MHz GPR system (Mala RAMAC/GPR); with a CUII control unit and XV11 monitor. This configuration consists of the antenna sat in between the four wheels of the cart, one of which has an odometer attached to measure distance travelled. The combined viewer and data logger unit is affixed to the top of the handle.

The depth of penetration of GPR systems is determined by the central frequency of the antenna and the relative dielectric permittivity (RDP) of the material through which the GPR signal passes. In general, soils in floodplain settings may have a wide range of RDPs, although around 8 may be considered average, resulting in a maximum depth of penetration c. 2.5m with the GPR signal having a velocity of approximately 0.1m/ns.

The GPR beam is conical in shape, however, and whilst most of the energy is concentrated in the centre of the cone, the GPR signal illuminates a horizontal footprint which becomes wider with increasing depth. At the maximum depth of the antenna, it becomes impossible to resolve any feature smaller than the horizontal footprint for the corresponding depth. The size of the footprint is dependent upon central frequency, and its size increases as the central frequency decreases.

The vertical resolution is similarly dependent upon the central frequency; for the 300MHz antenna, features of the order of 0.05m may be resolved vertically. Antennae with lower frequencies can therefore penetrate more deeply but are less resolute in both horizontal and vertical directions. Choice of antenna frequency is guided largely by the anticipated depth to the target and the required resolution.

GPR data for detailed surveys are collected along traverses of varying length separated by 0.5m with cross lines collected running perpendicular to these traverses at wider separations. The data sampling resolution is governed by the data logger and a minimum separation of 0.05m between traces is collected for all surveys.

Post-Processing

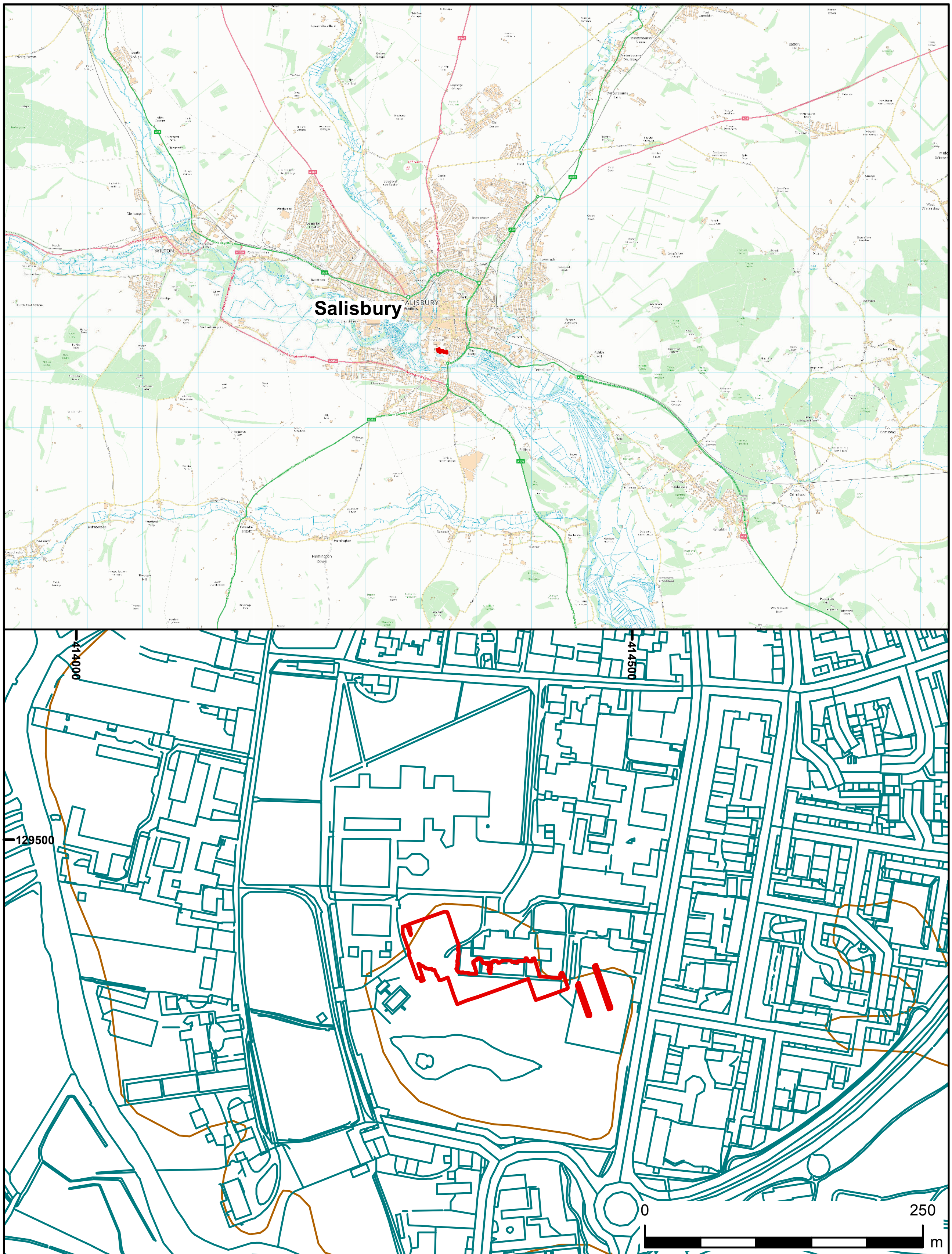
The radar data collected during the detail survey are downloaded from the GPR system for processing and analysis using commercial software (GPR Slice). This software allows for both the data and the images to be processed in order to enhance the results for analysis; however, it should be noted that minimal data processing is conducted so as not to distort the anomalies.

Typical data and image processing steps may include:

- Gain – Amplifies GPR data based upon its position in the profile, which boosts the contrast between anomalies and background. A wobble correction is also applied during this step;
- Bandpass – Removes GPR data lying outside a specified range, which removes high- and low-frequency noise.

Typical displays of the data used during processing and analysis:

- Timeslice – Presents the data as a series of successive plan views of the variation of reflector energy from the surface to the deepest recorded response. The variation in amplitude is represented using a colour scale with red indicating high amplitude and blue indicating low amplitude responses.
- Radargram – Presents each radar profile in a vertical view with distance along the profile expressed along the x axis and depth along the y axis. The amplitude variation is expressed using a greyscale.



Survey Extent

Date:	28/04/2015	Revision Number:	0
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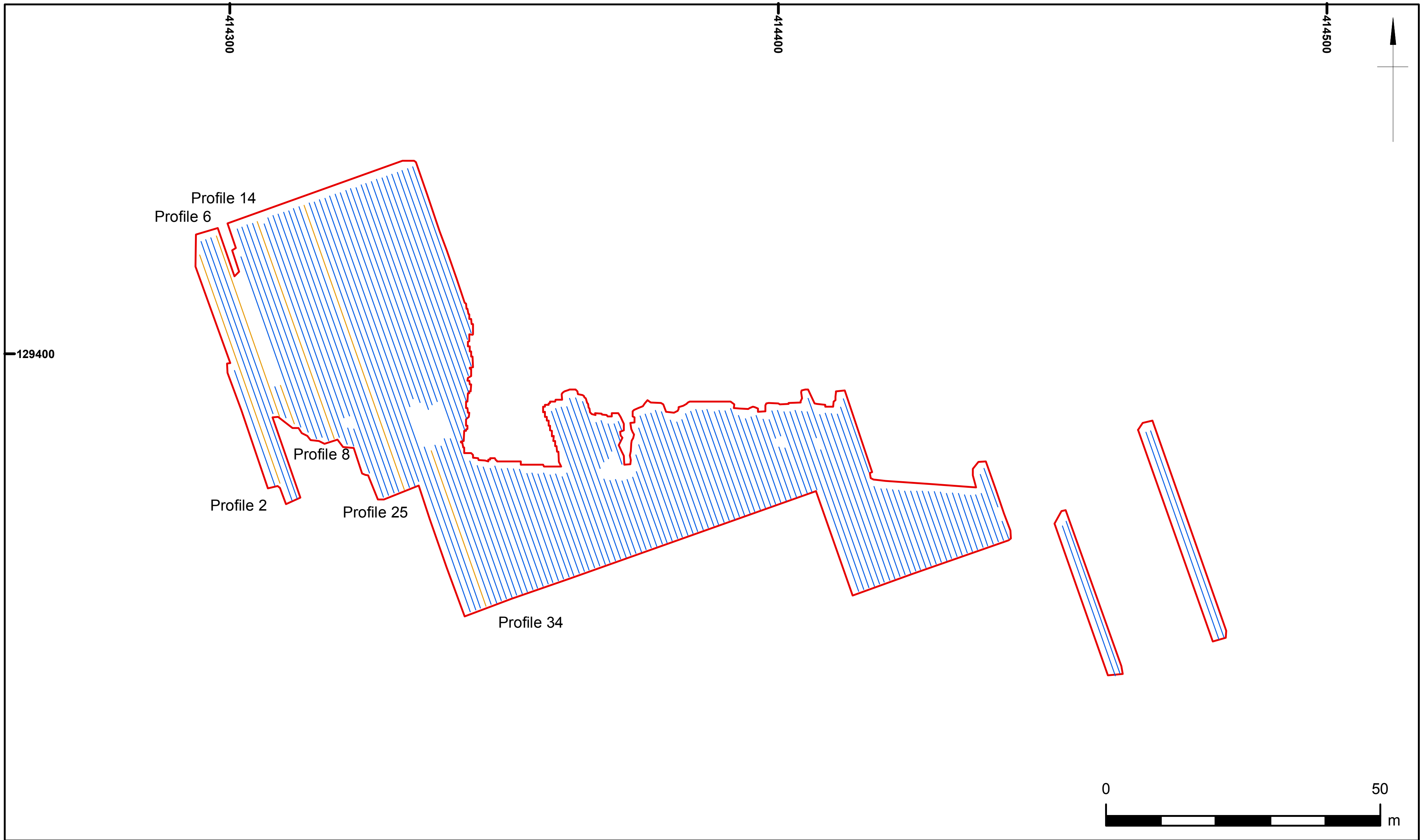
Path:	X:\PROJECTS\108881\GIS\FigsMXD		

Site Location

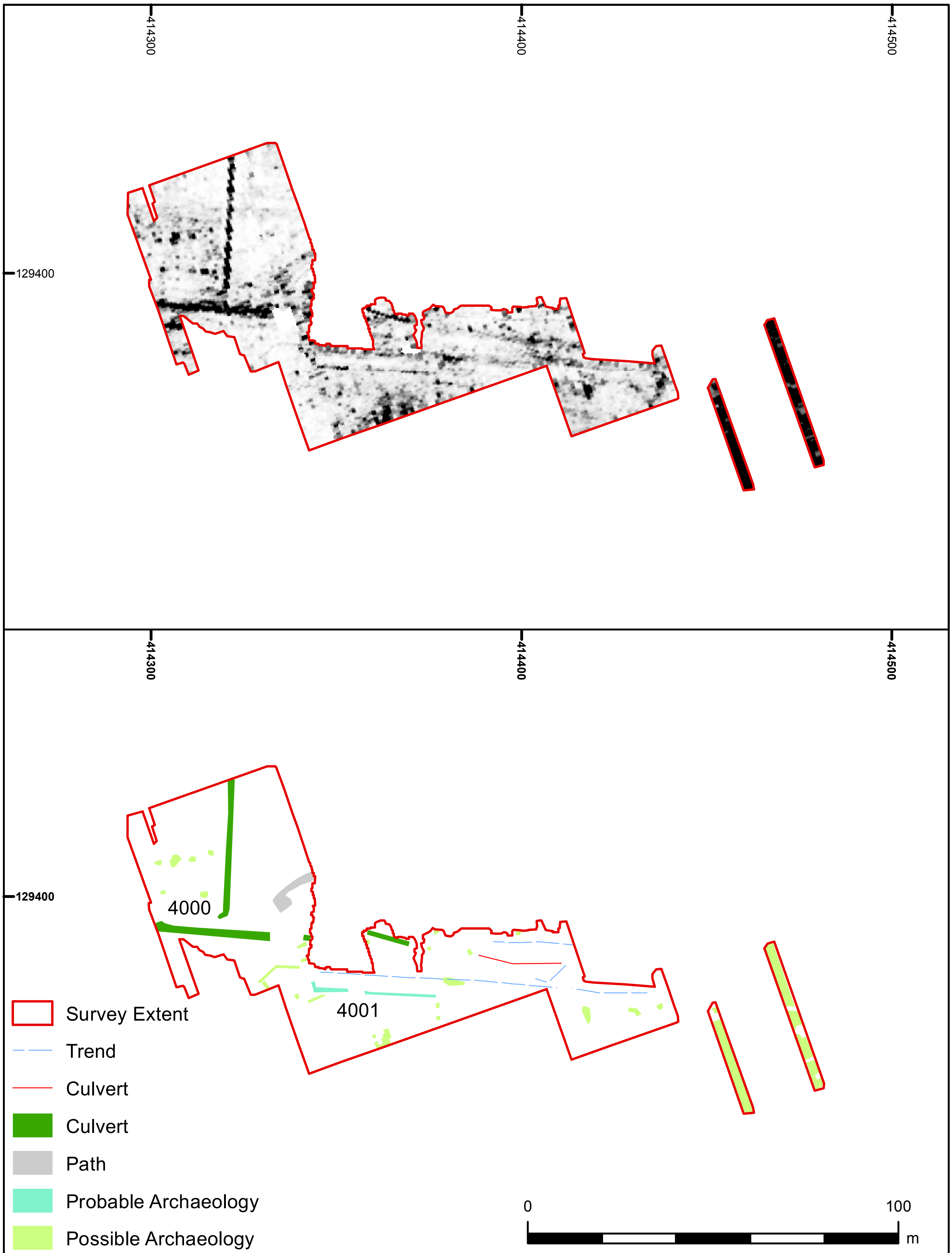
Figure 1



GPR Profiles	Survey Extent	Date:	29/04/2015	Revision Number: 0
Selected Profiles (Figure 7)		Scale:	1:1000 at A4	Illustrator: ECR
		Path:	X:\PROJECTS\108881\GIS\FigsMXD	

GPR Profile Locations

Figure 2



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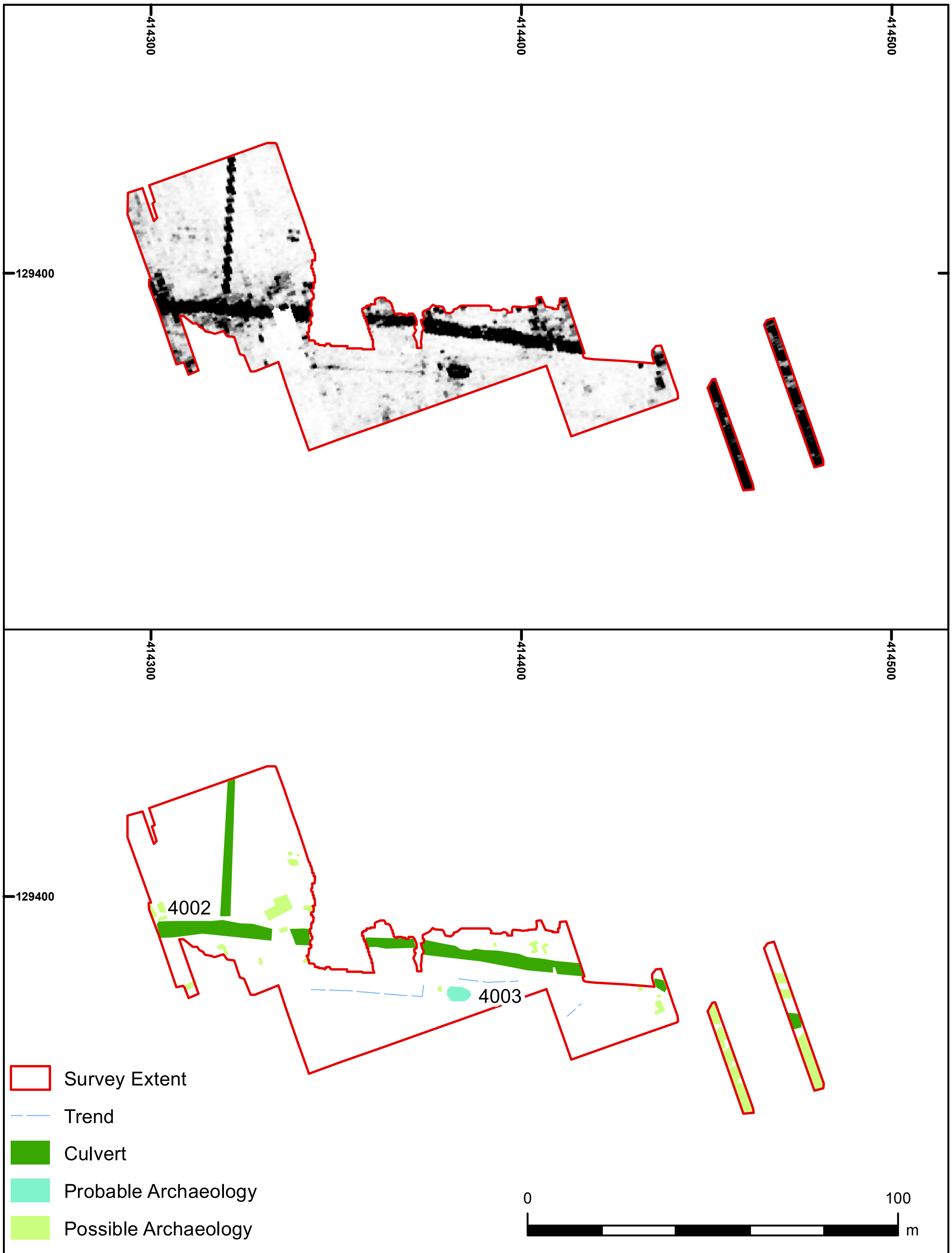
Depth Slice from 10-15ns

Figure 3



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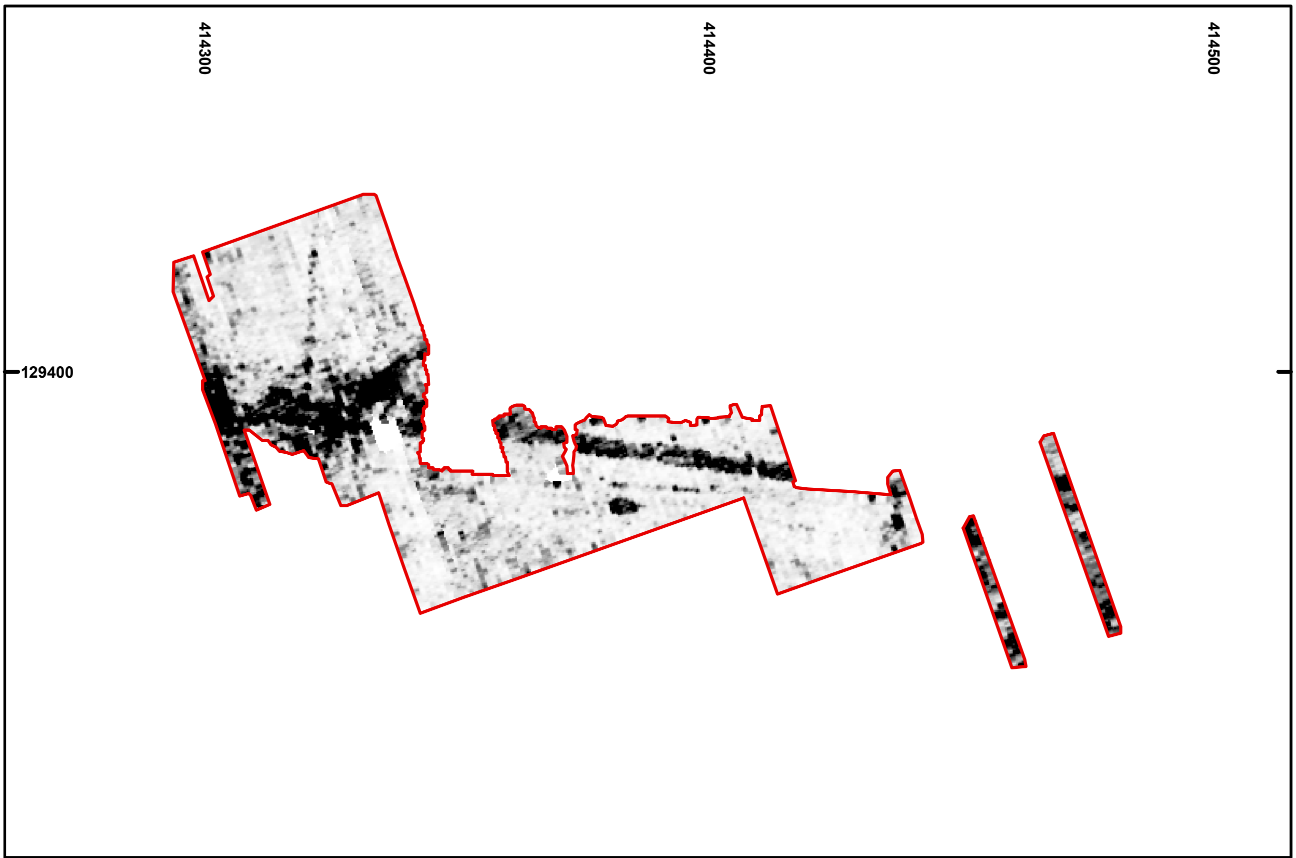
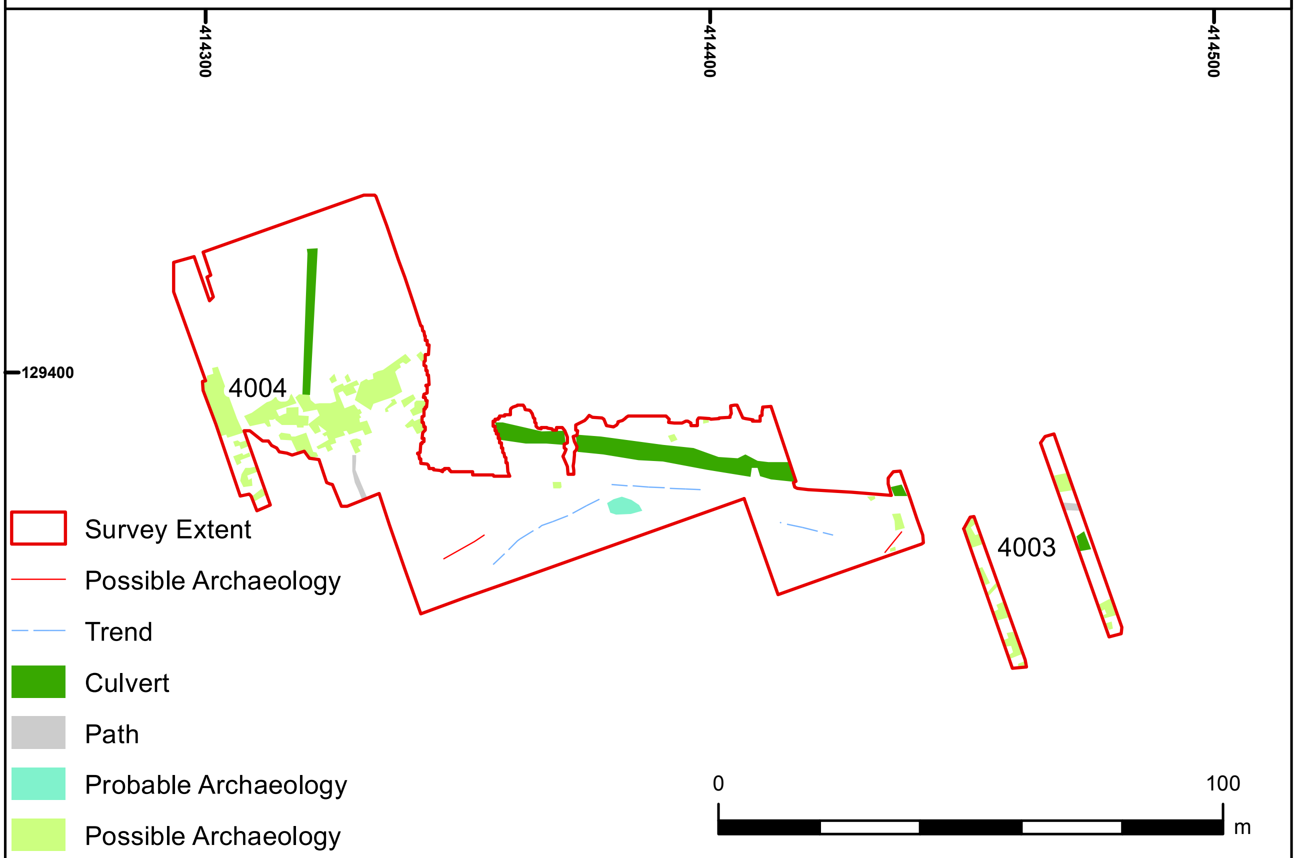
Depth Slice from 27-32ns

Figure 4





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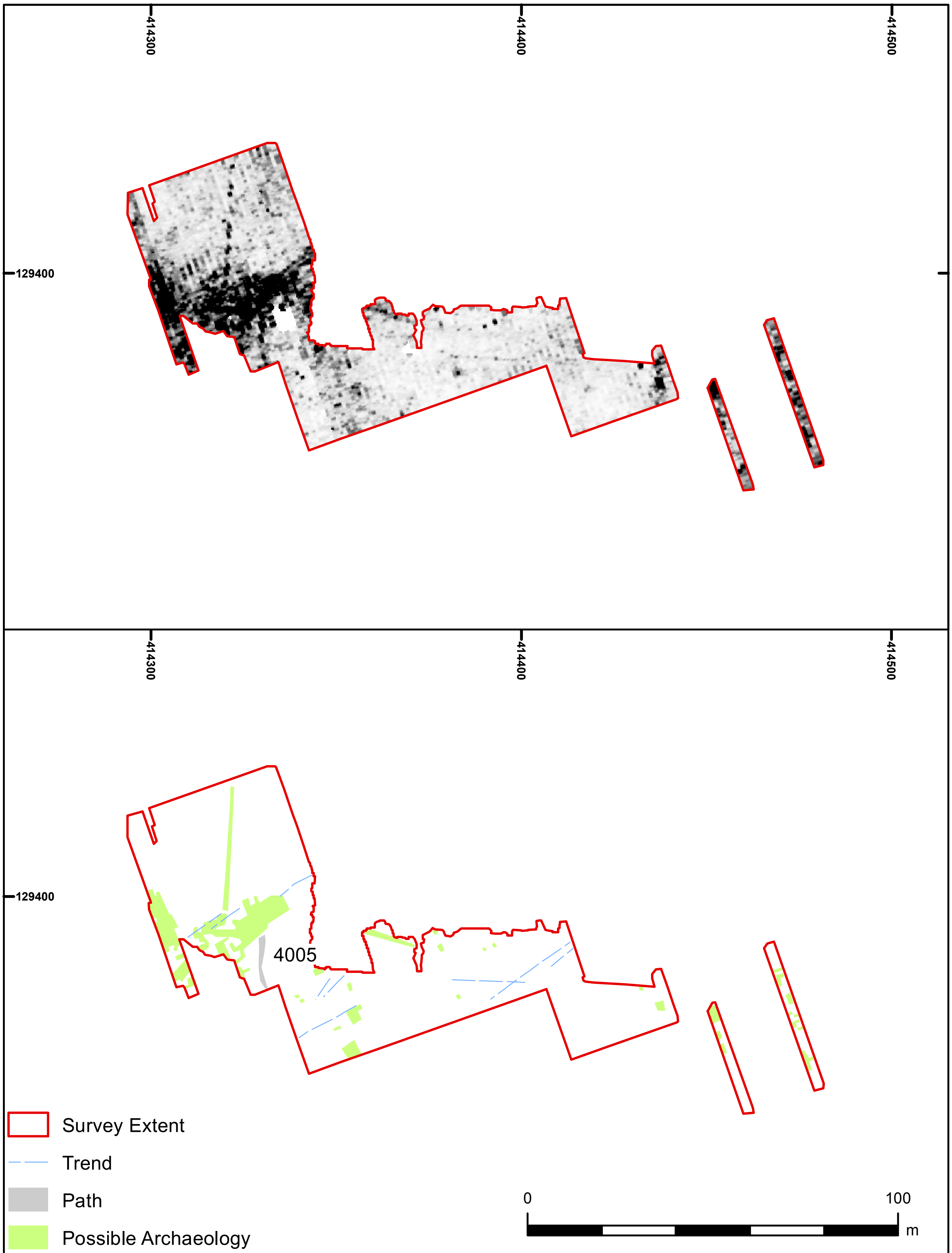
Depth Slice from 39-45ns

Figure 5



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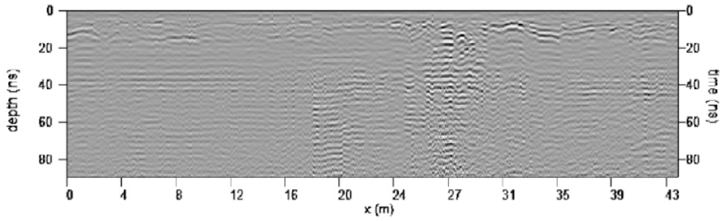
Scale:	1:1500 at A4	Illustrator:	ECR
Path:	X:\PROJECTS\108881\GIS\FigsMXD		

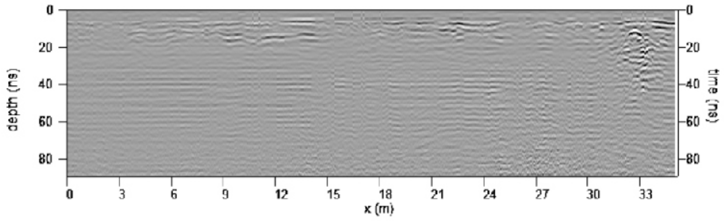
Depth Slice from 73-79ns

Figure 6

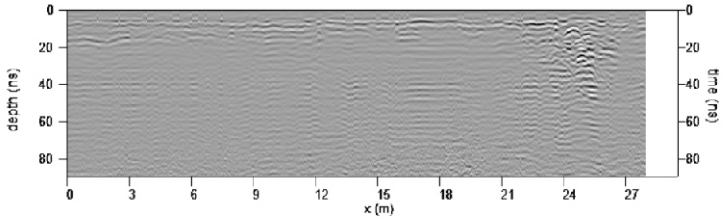
Profile 2



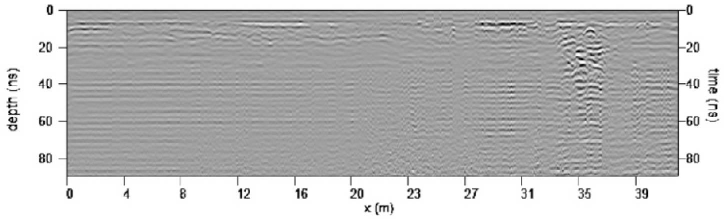
Profile 6



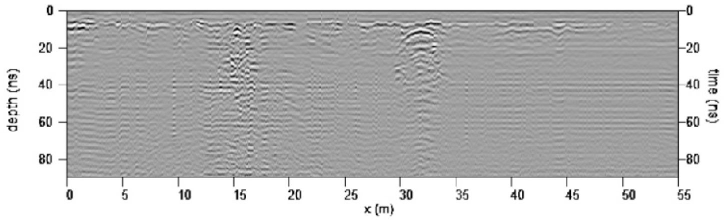
Profile 8



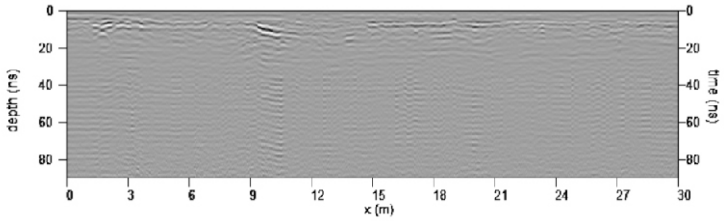
Profile 14



Profile 25



Profile 34



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Selected GPR Profiles

Figure 7