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North Walsham, Norfolk
Report on Ground Penetrating Radar survey, December 2021

Nicola Fairs

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NORTH WALSHAM, NORFOLK, REPORT ON GROUND PENETRATING RADAR SURVEY, DECEMBER 2021

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SUMMARY

Phase Site Investigations Ltd was commissioned to carry out a ground penetrating radar (GPR) survey at several locations across the town centre of North Walsham, Norfolk as part of the High Street Heritage Action Zone and the ongoing Historic England Historic Area Assessment of the town centre. The objective of the survey is to attempt to locate significant anomalies related to any surviving archaeology or historic intervention. Five survey locations were specified around the Market Place and Paston College, North Walsham. Visual analysis of the GPR profiles indicates that the effective average depth penetration of the GPR data for the majority of the survey areas was generally up to 2 m. Features located at depths greater than this are unlikely to have been identified by the GPR survey. It should be noted, however, that the majority of the GPR data was relatively 'noisy' with a disturbed and variable background, particularly in the upper 0.5 m. So, whilst penetration was generally quite good the 'noise' could mask responses from some features and so not all sub-features, even those of reasonable size and contrast to the surrounding material, will have been identified.Despite the 'noisy' data a variety of GPR anomalies have been identified across the survey areas. Anomalies indicative of basements have been identified and additional anomalies that could also be related to parts of basements are also present. In some instances, the interpretation of the cause of some anomalies was not clear and the full extents of the underlying feature may not have been determined.

CONTRIBUTORS
The survey was conducted by Phase Site Investigations Ltd. with data processing and reporting by Nicola Fairs. The final report was checked by Mark Whittingham.

ACKNOWLEDGEMENTS
We would like to offer our thanks to colleagues from North Norfolk County Council (NNCC), Paston College, North Waltham Market Traders for allowing access for the survey to take place, and to NNCC for provision of the topographic plan.

ARCHIVE LOCATION
Fort Cumberland, Portsmouth.

DATE OF SURVEY
The field work was conducted from 13th to 17th December 2021, with a small area on Market Place resurveyed on 16th February 2022 due to an equipment issue. The cover image shows the View looking east along the Market Place, North Walsham, with the early 17th-century Market Cross in the foreground (Patricia Payne © Historic England Archive, DP78210).

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CONTENTS

INTRODUCTION

Phase Site Investigations Ltd (Project No. ARC/3215/1220) was commissioned by Historic England to carry out a ground penetrating radar (GPR) survey at several locations across the town centre of North Walsham, Norfolk as part of the High Street Heritage Action Zone (HSHAZ) and to inform the ongoing Historic England Historic Area Assessment (HAA) of the town centre. A tender document for the production of a Geophysical Survey at North Walsham HSHAZ, Norfolk (Historic England, 2020) stated that,

'*The objective of the survey is to attempt to locate significant anomalies related to any surviving archaeology or historic intervention.*'

Five survey locations were specified around the Market Place and Paston College, North Walsham. Ground penetrating radar (GPR) was requested by Historic England as the preferred geophysical technique to achieve the survey objective. The general site location is shown in drawing ARC_3215_1220_01 and the approximate extents of the GPR survey areas are shown in drawing ARC_3215_1220_02. Descriptions of the areas are given below with background information taken from a tender document for the production of a geophysical survey at North Walsham HSHAZ, Norfolk (Historic England, 2020).

The Market Place area covered approximately 2250 m^2 over parts of the carriageway, footways and pedestrian areas along Market Place. This area (approximate centre at TG 28460 30206), '*is surrounded by various grade II-listed buildings, and also includes the C17 market cross, which is a scheduled monument.*'

Paston College courtyard (approximate centre at TG 28260 30190) covered an area of approximately 1320 m^2 and is located, '*to the south of Market Place is framed by a grade II-listed entrance screen to the north and a grade II-listed school block to the south'.*

Paston College front courtyard and lawned area is located to the rear of the Market Street (approximate centre at TG 28150 30244). This area included an asphalt area that was the front courtyard and an area of lawn to the south and covered an area of approximately 2250 m^2. *'The Market Street site of Paston College includes a grade II-listed block (the former girls' school), with a separately listed wall on the street (to the north).'*

The 'Shambles' (approximate centre at TG 28243 30275) covered and area of approximately 270 m^{2}and encompassed, '*a paved area of public access to the north of the Market Place between Market Street and the west entrance to St.*

Nicholas where there could be surviving cellars from the buildings previously known to have stood here.'

Black Swan Loke (approximate centre at TG 28333 30199) covered an area of 65 m^2 and encompassed a hardstanding area, '*with a concrete base where the top of a 'cellar' or underground brick structure visible*'

A brief history of North Walsham and the Market Place is provided by the North Walsham Heritage Centre online (www.northwalshamheritage.org.uk, 2022) and is summarised below.

The Market Place was issued with a charter by Henry III to hold weekly markets and has its origins dating back to the mid-13th century. A fire in 1600 destroyed much of the town centre. The Market Cross was rebuilt in 1602 by Bishop Redman and today is registered as a scheduled monument. Many of the shop fronts along market street were rebuilt following on from the great fire and occupy the same plots to this day. There is evidence of sealed cellars in the basements of these buildings. Sir William Paston founded Paston College in 1606.

METHOD

A Proceq GS8000 system, operating a stepped-frequency over a modulated frequency range of 40 – 3440 MHz was used for the ground penetrating radar survey. This system has an integral GNSS which can be used to position the data. When the GNSS was used profiles were collected at a nominal 0.5 m spacing in two, broadly perpendicular, directions.

In areas where a reliable GNSS signal could not be obtained orthogonal survey grids were established using tape measures and tied-in and referenced to Ordnance Survey National Grid using a Carlson Brx7 GNSS. Data was collected over these survey grids at 0.5 m intervals with data collected parallel with a base line and then perpendicular to it.

A reading was taken every 2.5 cm along each profile. The data was stored on an iPad and downloaded at the end of each day.

A technical summary of GPR can be found in Appendix 1.

When the data was being processed in the office it became apparent that the GNSS integral to the Proceq GS8000 was less reliable than it appeared on site and in some areas (predominantly in the Market Place) it frequently dropped out of a fix (accurate GNSS signal). Data was still collected but the positions of some profiles were not reliable. When these profiles were removed from the dataset there were areas that had gaps in the data collection. It was decided therefore to return to site and recollect data using a different system. An IDS Stream-C was selected as this is a multi-channel system and so has a very high spatial resolution and data was collected with this along the eastern part of Market Place. When the Stream-C data was processed it highlighted that the Proceq GS8000 data was actually very high quality (it was just the GNSS positioning that was an issue) as anomalies were better defined in the Proceq GS8000 data. It was therefore decided to pick and interpret the Proceq GS8000 data but use the Stream-C data to ensure that the Proceq GS8000 data was accurately located. It is thought that this approach has provided the most reliable interpretation of the data.

The Proceq GS8000 data were processed, analysed and interpreted using Geoltix (Geolitix Technologies Inc., 2022). As a minimum the data were depth corrected to allow for the gap between the antenna and the ground surface (time zero correction) and then filtered to highlight anomalies. This filtering involved performing background noise reduction to remove horizontal background noise and noise added by the GPR system. The final stage of processing was to increase the gain of responses proportional to their depth.

For data collected with GNSS positioning the 'resample traces equidistantly' function was also used. This 'rubbersheets' the profile to force a regular trace spacing which spatially corrects profiles to account for variable survey speeds.

For the orthogonal grids that were collected the co-ordinates of the origin and a base lines were recorded on site using GNSS and these were input into Geoltix to relate the grid to Ordnance Survey National Grid.

Each GPR profile was individually inspected and anomalies were 'picked' (anomalies identified and categorised). The picks were exported as a 3D dxf file. Orthogonal grids picks were exported directly to Ordnance Survey National Gird. Data collected using GNSS were exported using the OSGB36 transformation, which converts the UTM co-ordinate system that the GNSS utilises when connected to a GPR to Ordnance Survey National Grid. The pick files could then be directly overlain onto a base drawing which was in Ordnance Survey National Grid co-ordinates.

The base drawing used for this survey is a composite of a topographic survey (*NorthWalshamTownCentre2022-2D.dwg*) and an extract from Ordnance Survey map detail (provided by the client as drawing *NorthWalshamOS.dwg*).

The picks were interpreted in AutoCAD to identify anomalies and their possible cause. Anomalies have been shown with estimated depths and categorised where possible.

Ideally the data would also have been analysed and presented as timeslices but unfortunately the data that the Proceq GS8000 exports for use in other software is not the raw frequency domain data. Instead, it appears to be processed time domain data. This means that software such as Geolitix is not able to reliably produce a consistent gain curve that is applicable to multiple profiles and hence it cannot produce usable timeslices. Timeslices are a useful presentation tool and can be used to quickly identify area or linear anomalies but for the interpretation it is supplementary to analysing each radargram. Nothing has been lost, in terms of the interpretation, by not utilising radargrams.

An interpretation of the GPR data for each area alongside selected radargrams that highlight different types of anomalies present in that area are shown in drawings ARC_3215_1220_03 to ARC_3215_1220_07.

The GPR interpretation drawing must be used in conjunction with the relevant results section and appendices of this report.

RESULTS

Visual analysis of the GPR profiles indicates that the effective average depth penetration of the GPR data for the majority of the survey areas was generally up to 2 m. The majority of the data at depths below these levels showed very little variation. This may be because the ground below this level is homogenous and therefore there is nothing for the signal to reflect back from or it could be that the signal was attenuated due to site conditions. It should be noted that features located at depths greater than this are unlikely to have been identified by the GPR survey.

The penetration obtained is reasonably good for a ‘brownfield’ site where the signal is usually attenuated by the ground conditions but it should be noted that the majority of the data was ‘noisy’ with a disturbed / variable background, particularly in the upper 0.5 m. So, whilst penetration was generally quite good the noise could mask responses from features and so not all sub-features, even those that are of reasonable size and contrast to the surrounding material, will have been identified.

All depths shown are estimates based on assumptions of the sub-surface conditions. It should also be noted that some features cast a reflective ‘shadow’ in the GPR data that appears to show them extending to a greater depth than they actually are. The depths given for the area anomalies should be considered as maximum and minimum and it is probable that the feature actually lies somewhere between the two depth estimates.

The profile spacing has a major impact on the size of the feature that can be detected. Features of a similar size or smaller than the profile interval (in this instance a nominal 0.5 m) are unlikely to be detected even if they can produce a measurable response.

The shape of the anomalies shown in the interpretation are based on the observed responses and the actual shape and extent of the feature / variation causing an anomaly may differ. It is also possible that some features / variations may extend beyond a survey area and so where an anomaly is shown at the edge of the survey area the edge of the anomaly may not reflect the actual edge of the underlying feature / variation.

The categories of anomaly, and their possible causes, which have been identified by the survey are discussed below and then a discussion of the anomalies within each survey area are discussed in more detail.

Areas of high amplitude response

A high amplitude GPR anomaly is shown where the responses are stronger and more coherent compared to the background readings. Anomalies of this type are often caused by a well-defined sub-surface interface or by a 'solid' sub-surface feature / object. Anomalies caused by structural remains such as walls, foundations, concrete slabs and some types of infilled features can all produce high amplitude responses but so can a random concentration of rubble or stone, natural stones or rocks or a natural lens of more competent material (such as a patch of gravel in silts / sands). Unless a high amplitude anomaly has specific characteristics, corresponds with a known / suspected feature or forms a regular shape it can be difficult to determine its exact cause.

Areas of disturbed responses

Areas of disturbed / variable responses can have a variety of causes but they generally indicate where the sub-surface material is mixed / heterogenous. Where these areas occur near the surface, they can often indicate the presence of made ground or disturbed ground, such as may occur when buried services are installed or where relatively frequent excavations take place. Deeper areas can also be caused by made ground but they can also relate to infilled features. Concentrations of building rubble, infilled basements and infilled former foundation trenches can all potentially produce disturbed responses. Unless an area of disturbed responses corresponds with a known / suspected feature or forms a regular shape it can be difficult to determine its exact cause.

Areas of broadly horizontal or dipping reflections

Broadly horizontal or dipping reflections in the GPR data area often caused when the GPR signal reflects off a continuous surface or interface. These can be caused by previous ground surfaces, by artificial buried surfaces, such as a former building floor or courtyard area, or sometimes by cut features.

Again, the cause of these anomalies is often difficult to determine without supporting evidence.

Rebar type anomalies

'Rebar' responses are caused by reflections from regular, closely spaced objects and are usually related to rebars within reinforced concrete. Some other types of feature, such as stone or concrete setts, some cobbled surfaces or other structural features that have a regular mesh or frame can also produce 'rebar' responses.

Linear anomalies

There are a large number of 'hyperbolae' anomalies in the GPR data. These are isolated reflections that can be caused by linear features such as pipes, cables and walls. All of the linear anomalies identified in the GPR data are projected lines derived from linking hyperbolae observed in adjacent traverses. Where there is a good correlation of strong hyperbolae a probable projected feature has been interpreted and where the correlation is less certain or the anomalies are weaker a possible feature has been interpreted.

Market Place (ARC_3215_1220_03)

The carriageway and adjacent footways of Market Place. Parking bays adjacent to Market Place were also included in the survey as was a pedestrian area around a bandstand and the market cross.

There are a number of areas of high amplitude GPR responses present, where the responses are stronger and more coherent compared to the background. Some of these are typical responses from vaults and will be related to the vaulted roofs of underlying basements that extend from the adjacent buildings.

Other high amplitude response are suggestive of surfaces and could be related to flatter ceilings of underlying basements.

It is worth noting that some anomalies that are suggestive or indicative of basements do not fully extend towards an adjacent building (**Anomalies MP1**). It is reasonable to assume that the underlying basement continues towards the building but for some reason does not exhibit a clear anomaly close to the building, possibly because it is masked by disturbance or features above it (such as buried services). But it also possible that the basement may have a narrow ‘corridor’ from the building and then widen again under the street. It can be seen that the exact shape and structure of a basement, as well as its full extents, may not have been identified by the GPR survey.

There are other anomalies that could be related to parts of basements but which are localised and do not form clearly defined shapes (**Anomalies MP2**). Some responses were intermittent or had components that were suggestive of a basement but these were not consistent (**Anomaly MP3**). Other smaller high amplitude responses across the survey area could be related to parts of sub-surface features but the type of feature is not certain and some of them could be related to objects / material within made ground. It can be seen that some basements have only produced partial or not well-defined anomalies and it should be noted that additional basements may also be present which, for some reason, have not produced a clearly defined anomaly. This could be because of their structure, they may be fully infilled or because they are masked by ground conditions or features above them. This survey should not be taken as an absolute indication for the presence of absence of a basement (or other sub-surface features).

Areas of rebar anomalies suggestive of reinforced concrete are present, although as discussed in Section 4.2.4 it is possible that other types of structural features can produce this type of anomaly. In some instances, these were located above probable basements but other rebar anomalies did not have a clearly defined basement beneath them. In the latter case it is possible that a basement is present but this could not be confirmed and it is also possible that some of the rebar anomalies relate to other types of features.

Several areas of disturbed response were visible through the generally disturbed data. The broadly linear areas could be related to service trenches and there are some areas in proximity to basements that could relate to fill material or material above a basement. It is also possible that some areas could relate to parts of former structures or basements that have been infilled but there is no clear evidence for this and they could simply reflect variations in made ground.

An area of broadly horizontal reflections is present in the west of the survey area. This could be related to the top of a basement but it could also be caused by buried utility apparatus.

Probable linear and possible linear anomalies are present. Anomalies of this type can sometimes be caused by buried foundations or other linear structural features but they are usually related to buried utilities (pipes, cables, drains, ducts etc). It is thought that the majority, if not all, of the linear anomalies in this area will relate to buried utilities. It should be noted that whilst GPR is used as part of a utility tracing survey it will not detect all buried utilities and cannot, by itself, identify the type of utilities present. If this information is required at any stage then a full utility survey would need to be undertaken.

Paston College courtyard (ARC_3215_1220_04)

Hardstanding (asphalt) ground currently used as a car park.

There are a number of small areas of high amplitude GPR responses present. These are too small to reliably interpret and do not form any clear patterns or relationships that would help determine their cause. They could be related to small discrete sub-surface features, parts of larger features / structures but they could also be related to variations / material in made ground.

Several areas of disturbed response were visible through the generally disturbed data. Some of these could be related to service trenches. One area in the south has a corresponding area of high amplitude (**Anomaly PC1**) that was suggestive of an arch and it is thought that this anomaly could relate to basement. A second area also had a corresponding high amplitude response (**Anomaly PC2**) but the cause of this is less clear. It could relate to a basement but it could also be a product of some other type of feature or change in material. It is possible that some of the other areas of disturbed responses could relate to parts of former structures or basements that have been infilled but there is no clear evidence for this and they could simply reflect variations in made ground.

An area of broadly horizontal reflections is present in the east of the survey area. This could be related to a previous ground surface. The regularity of response could suggest that it could be caused by the floor of a former building or courtyard but there is no other evidence to confirm this.

Numerous probable linear and possible linear anomalies are present. Anomalies of this type can sometimes be caused by buried foundations or other linear structural features but they are usually related to buried utilities (pipes, cables, drains, ducts etc). It is thought that the majority, if not all, of the linear anomalies in this area will relate to buried utilities. It should be noted that whilst GPR is used as part of a utility tracing survey it will not detect all buried utilities and cannot, by itself, identify the type of utilities present. If this information is required at any stage then a full utility survey would need to be undertaken.

Paston College front courtyard and lawned area (ARC_3215_1220_05)

A hardstanding (asphalt) area in the north and areas of lawns. The lawns were separated by a relatively narrow path with adjacent areas of planting and was bounded by paths and some areas of planting.

There are a number of areas of high amplitude GPR responses present. In the front courtyard area there is a response that is indicative of a basement (**Anomaly PFC1**). This probably extends towards the boundary wall but this area could not be surveyed and so this could not be confirmed.

There are broadly linear areas of high amplitude responses in the lawned areas. These are probably related to utility apparatus and / or service ducts but there is a slight possibility that they could be associated with the remains of building foundations.

The remaining areas of high amplitude responses are too small to reliably interpret and do not form any clear patterns or relationships that would help determine their cause. They could be related to small discrete sub-surface features, parts of larger features / structures but they could also be related to variations / material in made ground.

Several areas of disturbed response were visible through the generally disturbed data. Some of these could be related to service trenches but it is also possible that some areas could relate to parts of former structures or basements that have been infilled, although it is likely that the majority of these areas simply reflect variations in made ground. There is a suggestion that **Anomalies PL1**, in the northern lawned area, form a return and for parts of the anomaly have a relatively regular shape. This could indicate that it is associated with a former structure but this is not clearly defined and the responses could be a product of material in made ground and the general regular shape could be a coincidence.

Areas of dipping horizons are present in the lawned area. The cause of these is not known. They could relate to previous ground surfaces, the edges of cut features that have been infilled, areas where the ground has previously slumped or have a different cause.

Numerous probable linear and possible linear anomalies are present. Anomalies of this type can sometimes be caused by buried foundations or other linear structural features but they are usually related to buried utilities (pipes, cables, drains, ducts etc). It is thought that the majority, if not all, of the linear anomalies in this area will relate to buried utilities. It should be noted that whilst GPR is used as part of a utility tracing survey it will not detect all buried utilities and cannot, by itself, identify the type of utilities present. If this information is required at any stage then a full utility survey would need to be undertaken.

The Shambles (ARC_3215_1220_06)

A hardstanding (paved) area.

There is a small area of high amplitude of unknown cause.

An area of disturbance is present that could be related to an infilled feature but there is no clear evidence for this and it could simply reflect a change in the made ground or sub-surface conditions.

An area of horizontal; reflections is present that could be related to a previous ground surface or it could be associated with some type of material change or another type of feature. There are several manhole covers in the vicinity of this anomaly and it is possible that the response is related to the underlying chambers or utility apparatus.

A number of probable linear and possible linear anomalies are present. Anomalies of this type can sometimes be caused by buried foundations or other linear structural features but they are usually related to buried utilities (pipes, cables, drains, ducts etc). It is thought that the majority, if not all, of the linear anomalies in this area will relate to buried utilities. It should be noted that whilst GPR is used as part of a utility tracing survey it will not detect all buried utilities and cannot, by itself, identify the type of utilities present. If this information is required at any stage then a full utility survey would need to be undertaken.

Black Swan Loke (ARC_3215_1220_07)

A hardstanding (concrete) area.

There are high amplitude anomalies and areas of horizontal and dipping surfaces present in the west of the area. It is possible that these could be related to basements or other structural features but the anomalies are relatively small and they are not consistent enough to determine their cause with any certainty.

A small area of disturbance and a possible linear anomaly are also present but again it is not possible to determine the cause of these.

CONCLUSIONS

Visual analysis of the GPR profiles indicates that the effective average depth penetration of the GPR data for the majority of the survey areas was generally up to 2 m. Features located at depths greater than this are unlikely to have been identified by the GPR survey. It should be noted, however, that the majority of the GPR data was relatively ‘noisy’ with a disturbed / variable background, particularly in the upper 0.5 m. So, whilst penetration was generally quite good the ‘noise’ could mask responses from some features and so not all sub-features, even those that of reasonable size and contrast to the surrounding material, will have been identified.

Despite the ‘noisy’ data a variety of GPR anomalies have been identified across the survey areas. Anomalies indicative of basements have been identified and additional anomalies that could also be related to parts of basements are also present. In some instances, the interpretation of the cause of some anomalies was not clear and the full extents of the underlying feature may not have been determined.

There are a variety of other anomalies present whose cause is not certain. Many of these could be related to changes in sub-surface material or variations in made ground but others could be associated with sub-surface features or structures, although in many cases it is not clear what type of feature may be present. Numerous linear responses are present across the survey areas and the majority of these will be related to buried utilities, such as pipes, cables, drains or ducts. It should be noted that whilst some buried utilities may have been detected this GPR survey does not constitute a full utility tracing survey and additional utility apparatus will be present that has not produced a well-defined GPR anomaly.

It should be recognised that some features, including basements, could be present that have not been identified, because they have either not produced a measureable GPR response or the response from a feature is masked / partially masked by features or material above it. Where a basement or other possible feature has been detected its exact shape and its full extents, may not have been identified by the GPR survey. This survey should not be taken as an absolute indication for the presence or absence of a basement (or other sub-surface features).

The shape of the anomalies shown in the interpretation are based on the observed responses and the actual shape and extent of the feature / variation causing an anomaly may differ. It is also possible that some features / variations may extend beyond a survey area and so where an anomaly is shown at the edge of the survey area the edge of the anomaly may not reflect the actual edge of the underlying feature / variation. Any depths shown are estimates based on assumptions on the sub-surface conditions and should not be taken as exact values.

It should be noted that a geophysical survey does not directly locate sub-surface features - it identifies variations or anomalies in the background response caused by features. The interpretation of geophysical anomalies is often subjective and it is rarely possible to identify the cause of all such anomalies. Not all features will produce a measurable anomaly and the effectiveness of a geophysical survey is also dependant on the site-specific conditions. The main factors that may limit whether a feature can be detected are the composition of a feature, its depth and size and the surrounding material. It is not possible to guarantee that a geophysical survey will identify all sub-surface features. Confirmation on the identification of anomalies and the presence or absence of sub-surface features can only be achieved by intrusive investigation.

LIST OF ENCLOSED FIGURES

REFERENCES

Historic England, 2020, Tender document for the production of a Geophysical Survey at North Walsham HSHAZ, Norfolk

North Walsham Heritage, 2022, online resource - www.northwalshamheritage.org.uk

APPENDIX 1

1. Ground penetrating radar: technical information

1.1 Theoretical background

1.1.1 GPR instruments work by transmitting electromagnetic pulses (waves) into the sub-surface at specific frequencies using an antenna. Each pulse is affected by the material that is passes through, notably its dielectric properties and conductivity, and can undergo interactions such as attenuation (signal loss), reflection and scattering.

1.1.2 How well a material conducts (its dielectric properties) determines the velocity of the wave. A change in the dielectric properties results in a concurrent change in velocity that in turn causes some of the wave's energy to be reflected. In general the ground material will have a different dielectric constant to the material of man-made objects producing an anomaly in the observed response. By measuring the travel-time and amplitude of reflected signals received back at the antenna it can be possible to obtain approximate depths to the anomaly. In cases where the target feature and the surrounding ground have matching or similar dielectric constants the target cannot be resolved.

1.1.3 A material's conductivity is the most important factor in determining a wave's rate of attenuation. A high conductivity will cause the energy to be dissipated throughout a material and so there will be a reduction in the signal strength and the distance that the wave will propagate is reduced. Signal loss is therefore greatest in conductive metals and water rich soils, such as clay. If the material through which the wave is passing is varied in its composition (heterogeneous) then this can result in scattering of the waves. As well as attenuating the signal and reducing its depth penetration the scattering of the waves can produce anomalies that do not relate to true features (phantom anomalies).

1.1.4 The antenna frequency utilised in a survey is selected based on the depth and size of a target feature. Higher frequency waves are attenuated more easily than lower frequency ones and so do not have a reduced depth penetration. Selection of antenna frequency is therefore a trade-off between depth penetration and target resolution with high frequency (greater than 1 GHz) antennae being used for shallow, high resolution surveys, such as locating reinforcement and low frequency (250 MHz or lower) antennae used for identifying deeper larger features, such as drains, buried obstructions and geological boundaries. Medium frequency antennae (400 MHz to 700 MHz) can obtain reasonable depth penetration and resolution and are often used for utility tracing. Some GPR systems, such as high dynamic range or stepped-frequency systems utilise a wide frequency band and so can provide good depth penetration and high resolution data.

1.1.5 The interpretation of GPR anomalies is often subjective and it is rarely possible to identify the cause of all such anomalies. Not all features will produce a measurable anomaly and the effectiveness of a GPR survey is also dependant on the site-specific conditions. The main factors that may limit whether a feature can be detected are the composition of a feature, its depth and size and the surrounding material. It is not possible to guarantee that a GPR survey will identify all sub-surface features.

1.1.6 There are a wide range of features that can be located using GPR including metallic and non-metallic utility apparatus, rebars in concrete, buried structures or foundations, depth or thickness of materials, archaeological features, mineshafts and depth to bedrock.

1.2 Instrumentation

1.2.1 There are a number of different types of instrument available and each one is built to a different specification. Some systems transmit energy in pulses, others in a continuous wave (CW). The form and duration of the energy, the frequency of operation, and the strength of reflected signal that can be detected, the antennae design, and whether the antennae can be moved apart or interchanged with different frequency antennae all vary from system to system. The majority of the systems that are currently on the market have digital recording facilities and a number of them have built in odometers so that data can be linked to an exact point on a traverse line. An experienced operator who has been fully briefed on the likely site conditions can best assesses whether a particular instrument and antennae frequency is suitable to achieve the desired aims of an individual project.

1.3 Survey methodology

1.3.1 A Proceq GS8000 system, operating a stepped-frequency over a modulated frequency range of 40 – 3440 MHz was used for the ground penetrating radar survey. This system has an integral GNSS which can be used to position the data. When the GNSS was used profiles were collected at a nominal 0.5 m spacing and collected in two, broadly perpendicular directions

1.3.2 In areas where a reliable GNSS signal could not be obtained survey grids were established using tape measures and tied-in and referenced to Ordnance Survey National Grid using a Carlson Brx7 GNSS. Data was collected over these survey grids at 0.5 m intervals with data collected parallel with a base line and then perpendicular to it.

1.3.3 A reading was taken every 2.5 cm along each profile. The data was stored on an IPad and downloaded at the end of each day.

1.4 Data reduction and processing

1.4.1 The GPR data were processed and analysed using Geolitix (Geolitix Technologies Inc., 2022). The data were depth corrected to allow for the gap between the antenna and the ground surface (time zero correction) and then filtered to highlight anomalies. This filtering involved performing background noise reduction to remove horizontal background noise and noise added by the GPR system. The final stage of processing was to increase the gain of responses proportional to their depth.

For data collected with GNSS positioning the 'resample traces equidistantly' function was also used. This 'rubbersheets' the profile to force a regular trace spacing which spatially corrects profiles to account for variable survey speeds.

For the orthogonal grids that were collected the co-ordinates of the origin and a base lines were recorded on site using GNSS and these were input into Geoltix to relate the grid to Ordnance Survey National Grid.

1.5 Presentation and interpretation

1.5.1 Each GPR profile was individually inspected and anomalies were 'picked' (anomalies identified and categorised). The picks were exported as a 3D dxf file. Orthogonal grids picks were exported directly to Ordnance Survey National Gird. Data collected using GNSS were exported using the OSGB36 transformation, which converts the UTM co-ordinate system that the GNSS utilises when connected to a GPR to Ordnance Survey National Grid. The pick files could then be directly overlain onto a base drawing which was in Ordnance Survey National Grid co-ordinates.

1.5.2 The base drawing used for this survey is a composite of a topographic survey (*NorthWalshamTownCentre2022-2D.dwg*) and an extract from Ordnance Survey map detail (provided by the client as drawing *NorthWalshamOS.dwg*).

1.5.3 The picks were interpreted in AutoCAD to identify anomalies and their possible cause. Anomalies have been shown with estimated depths and categorised where possible.

1.5.4 An interpretation of the GPR data for each area alongside selected radargrams that highlight different types of anomalies present in that area are shown in drawings ARC_3215_1220_03 to ARC_3215_1220_07.

1.6 Limitations of ground penetrating radar

1.6.1. The GPR survey method requires the equipment to be pushed on a cart or dragged across a site. The presence of an uneven ground surface, dense, high or mature vegetation or surface obstructions may mean that some areas cannot be surveyed.

1.6.2. The depth penetration and quality of data of a GPR survey is limited by the presence of conductive material in the sub-surface. Surface water, reinforced concrete and moisture rich soils (particularly clays) can all have a negative impact on data quality. The presence of made ground also can have a detrimental effect on the GPR data quality as this usually contains conductive material in the form of metallic scrap and brick. The effectiveness of GPR is therefore dependant on the site specific conditions.

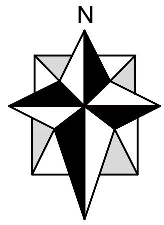
1.6.3. A GPR survey does not directly locate sub-surface features - it identifies variations or anomalies in the background response caused by features. It can be possible to interpret the cause of anomalies based on the size, shape and strength of response but the reliability of this interpretation can vary significantly from site to site.

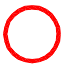
1.6.4. The profile spacing has a major impact on the size of the feature that can be detected. Features of a similar size or smaller than the profile interval are unlikely to be detected even if they can produce a measurable response.

1.6.5. Anomalies identified by a GPR survey are located on individual profiles. The location of possible features in plan is based on the extrapolation of points on adjacent profiles.

1.6.6. Approximate depth information can be obtained but it should be recognised that these values are based on average wave velocities for a given medium. Depths are therefore only estimated and the accuracy of the depth will decrease in heterogeneous materials.

1.6.7. Not all features will produce a measurable GPR response and the effectiveness of a GPR survey is also dependant on the site-specific conditions. It is not possible to guarantee that a GPR survey will identify all sub-surface features. A GPR survey is usually most-effective at identifying sub-surface features when used in conjunction with other complementary geophysical techniques.





SCALE

0m 500m 1000m

NOTE

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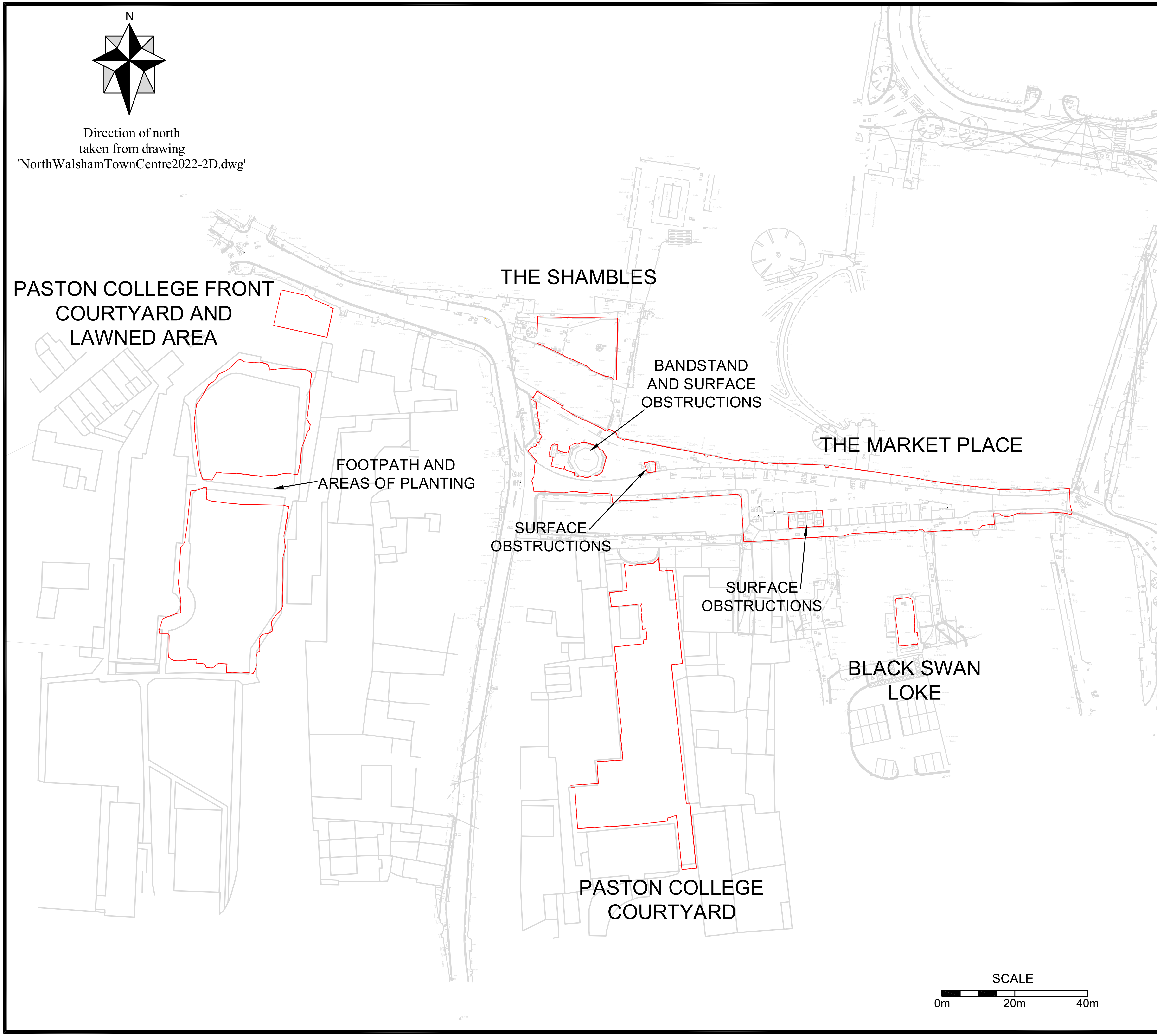
Scale [A4 Sheet]	Drawing	Status
AS SHOWN	ARC_3215_1220_01	FINAL

Client	HISTORIC ENGLAND PORTSMOUTH
Site	NORTH WALSHAM HSHAZ NORFOLK
Title	SITE LOCATION MAP
Job No	ARC_3215_1220

		Drawn	SBC
Chk.	NF	Date	22/02/2022



NOTES

1. THIS DRAWING MUST BE USED IN CONJUNCTION WITH THE ACCOMPANYING REPORT (ARC_3215_1220_RPT.PDF) WHICH PROVIDES DETAILS OF THE TECHNIQUES EMPLOYED, THEIR INHERENT LIMITATIONS AND ANY SITE SPECIFIC ISSUES.
2. PHASE SITE INVESTIGATIONS CANNOT ACCEPT RESPONSIBILITY FOR THE RELIABILITY OR ACCURACY OF ANY INFORMATION PROVIDED BY A THIRD PARTY. N OF THIS DATA WITHOUT APPROVAL IS FORBIDDEN.

ALWAYS EXERCISE CAUTION WHEN EXCAVATING

KEY

APPROXIMATE EXTENT OF GPR SURVEY AREAS

Rev	Date	Drawn	Chk.	Description
-	--/--/----	--	--	--

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Scale [A3 Sheet]	Drawing	Status
1:1000	ARC_3215_1220_02	FINAL

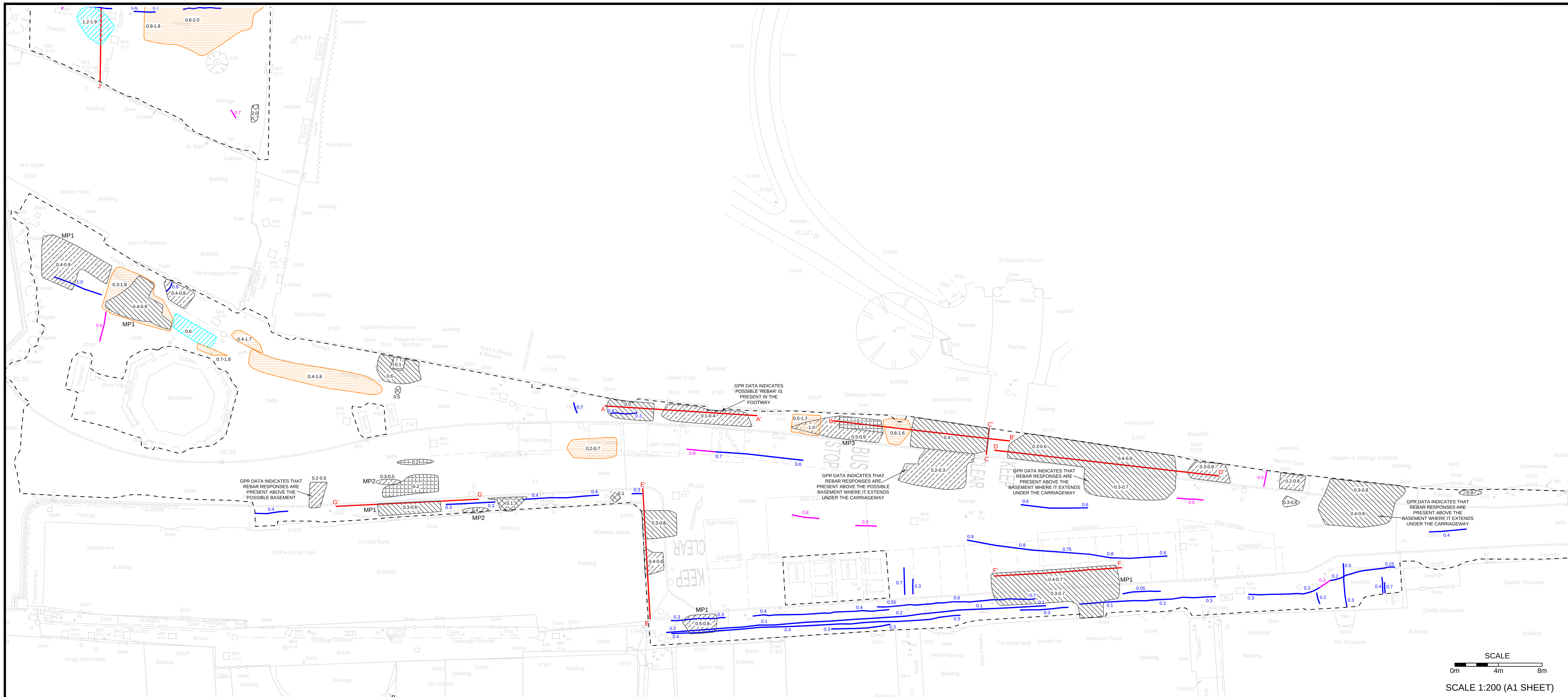
Client
HISTORIC ENGLAND
PORTSMOUTH

Site
NORTH WALSHAM HSHAZ
NORFOLK

Title
GPR SURVEY AREAS

Job No
ARC_3215_1220

Surveyed	SBC, PW	Drawn	NF
Chk.	MW	Date	17/12/2021



SCALE 1:200 (A1 SHEET)

NOTES

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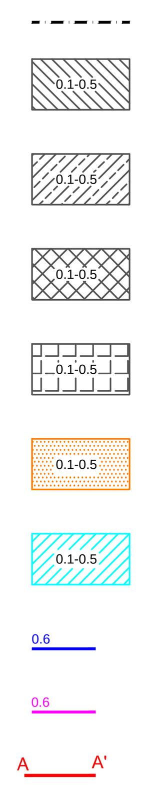
KEY



APPROXIMATE EXTENT OF GPR SURVEY AREA

AREA OF HIGH AMPLITUDE RESPONSES PROBABLY CAUSED BY BASEMENT

AREA OF HIGH AMPLITUDE RESPONSES POSSIBLY CAUSED BY BASEMENT

AREA OF HIGH AMPLITUDE RESPONSES POSSIBLY CAUSED BY SUB-SURFACE INTERFACE(S) OR FEATURE(S) OF UNKNOWN ORIGIN

AREA OF 'REBAR' RESPONSES. PROBABLY CAUSED BY REINFORCEMENT BUT COULD BE RELATED TO OTHER STRUCTURAL FEATURE

AREA OF DISTURBED RESPONSES POSSIBLY CAUSED BY SUB-SURFACE FEATURE OR DISTURBED GROUND

AREA OF HORIZONTAL REFLECTIONS POSSIBLY CAUSED BY SUB-SURFACE INTERFACE(S) OR FEATURE(S)

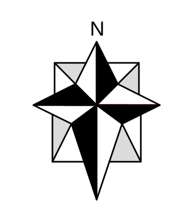
PROJECTED LINE OF PROBABLE LINEAR FEATURE DERIVED FROM HYPERBOLAE RESPONSES. APPROXIMATE DEPTH BELOW GROUND LEVEL IS GIVEN IN METRES

PROJECTED LINE OF POSSIBLE LINEAR FEATURE DERIVED FROM HYPERBOLAE RESPONSES. APPROXIMATE DEPTH BELOW GROUND LEVEL IS GIVEN IN METRES

LOCATION OF GPR RADARGRAM

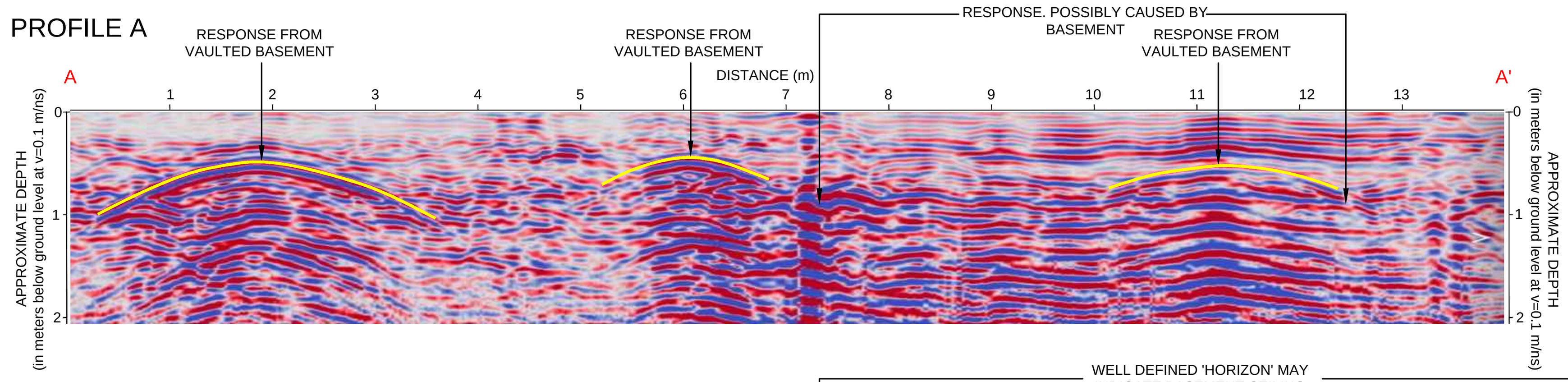
GROUND PENETRATING ANOMALY DESCRIBED IN THE ACCOMPANYING REPORT ARC_3215_1220_RPT.PDF

WHERE A DEPTH RANGE IS GIVEN THE DEPTHS INDICATED ARE MINIMUM AND MAXIMUM EXTENTS BELOW GROUND LEVEL OF THE ANOMALY. THE ASSOCIATED FEATURE MAY LIE SOMEWHERE WITHIN THIS RANGE.



Direction of north taken from drawing 'NorthWalshamTownCentre2022-2D.dwg'

PROFILE A



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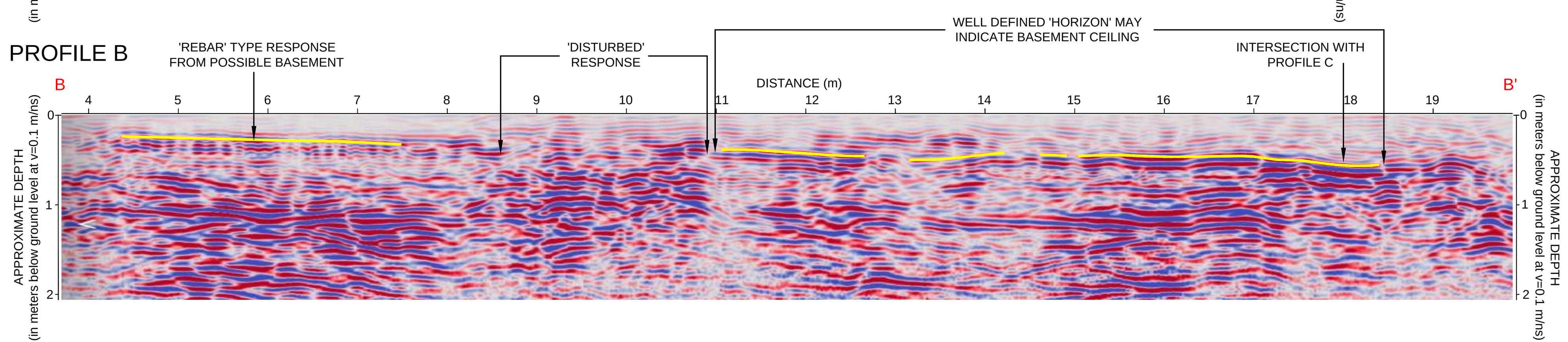

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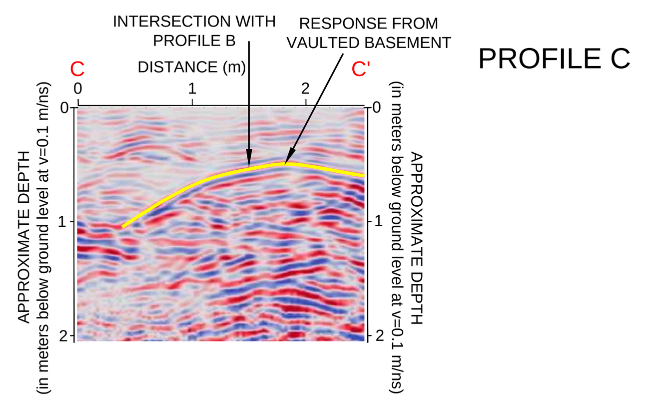

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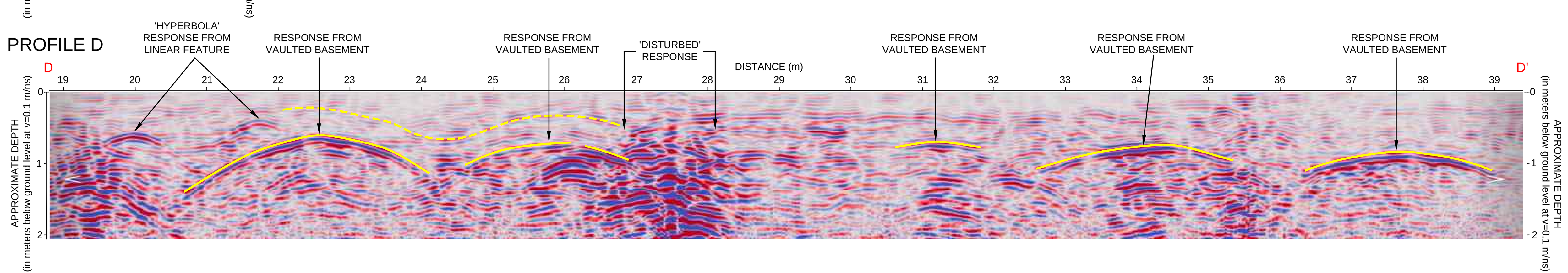

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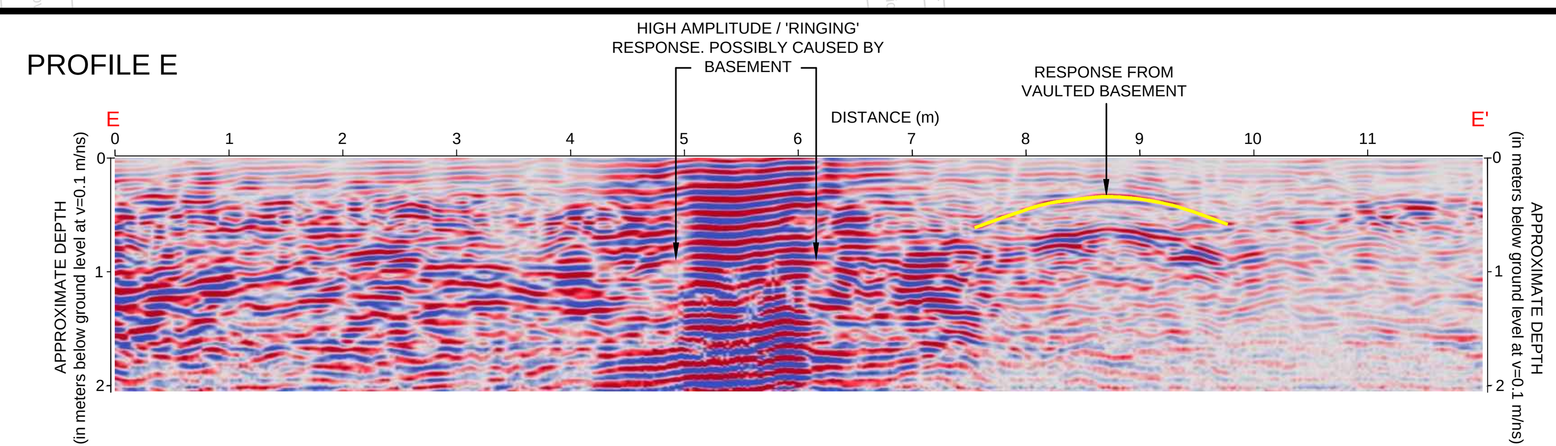

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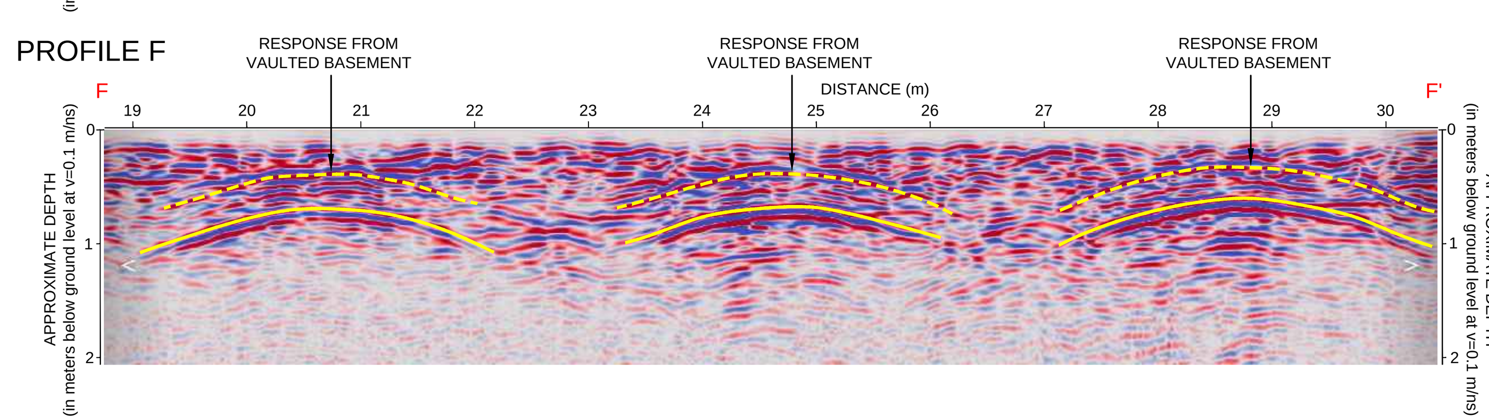
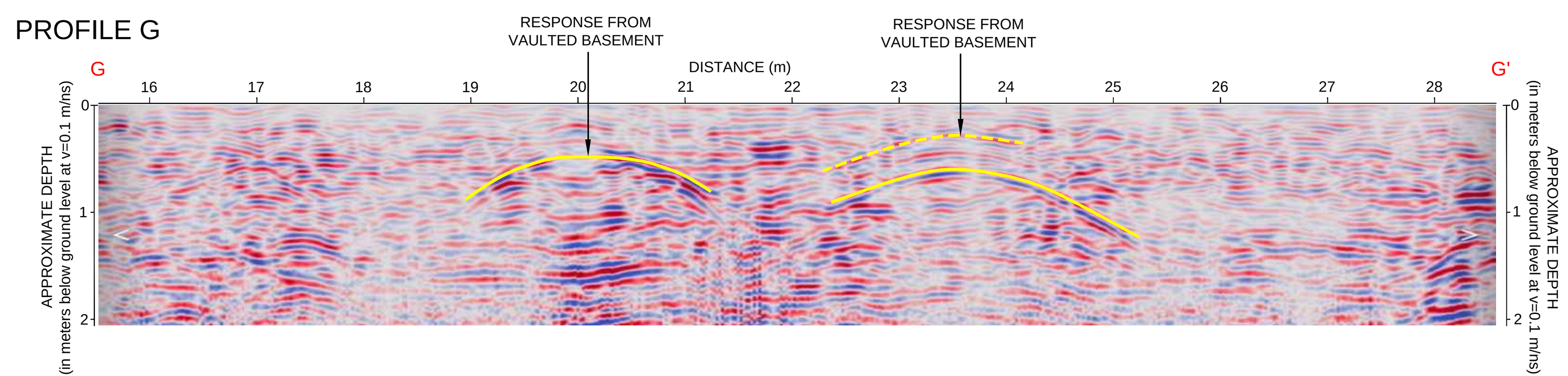
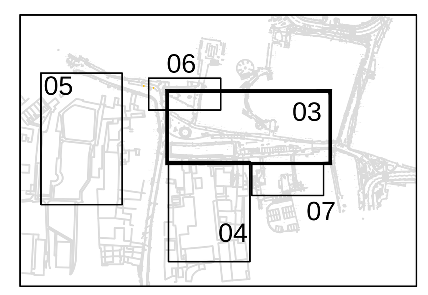


PROFILE G



THE ANOMALIES SHOWN BY THE DASHED LINES COULD INDICATE THE TOP OF AN ARCH STRUCTURE AND THOSE DEFINED BY THE SOLID LINE ITS UNDERSIDE BUT IT IS POSSIBLE THAT THE DASHED LINE ANOMALY IS RELATED TO MATERIAL ABOVE THE ARCH AND THE SOLID BY THE ARCH ITSELF

DRAWING LAYOUTS



Rev	Date	Drawn	Chk.	Description
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Scale [A1 Sheet]	Drawing	Status
AS SHOWN	ARC_3215_1220_03	FINAL

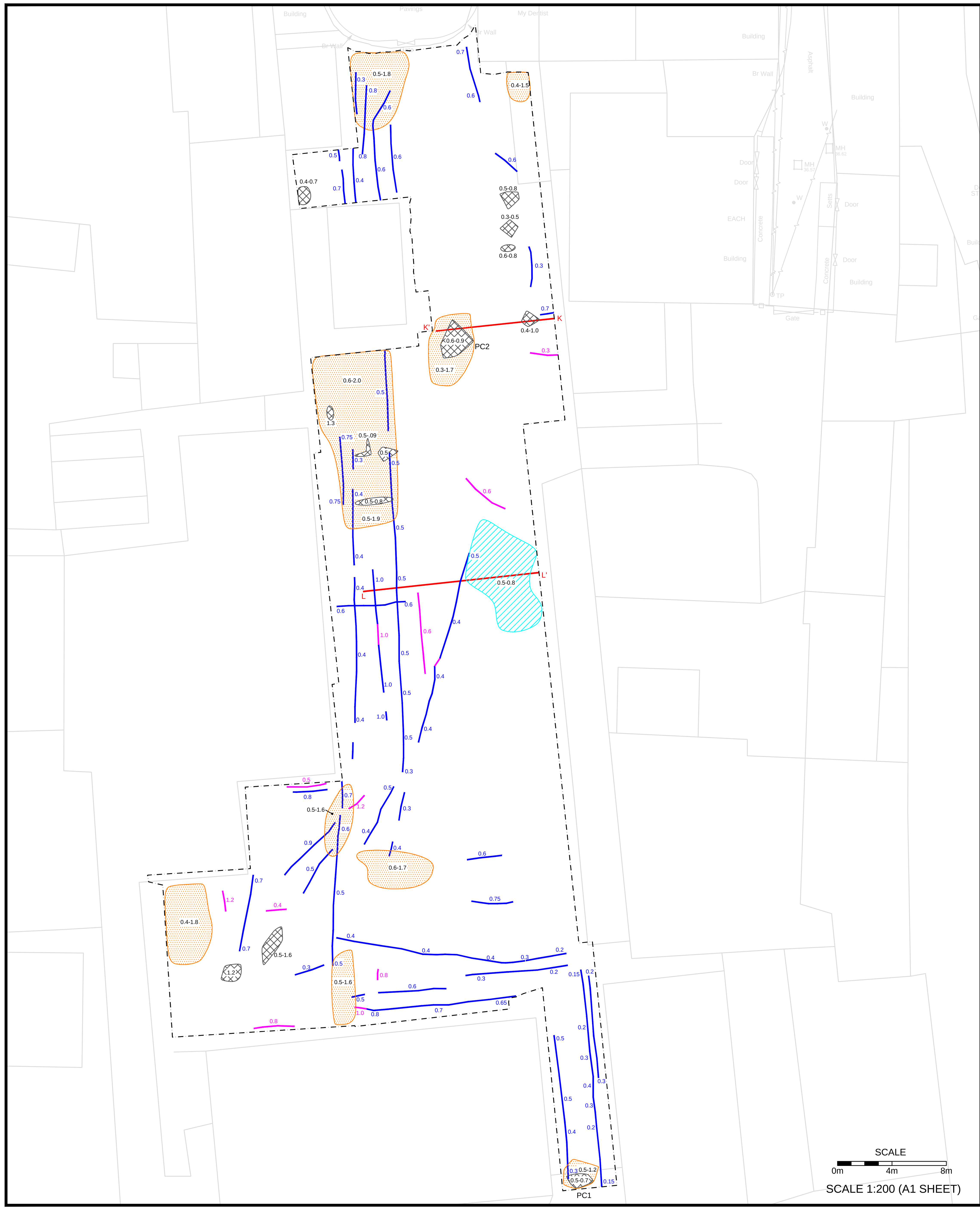
Client: HISTORIC ENGLAND PORTSMOUTH

Site: NORTH WALSHAM HSHAZ NORFOLK

Title: THE MARKET PLACE: INTERPRETATION OF GPR DATA WITH SELECTED RADARGRAMS

Job ref.: ARC_3215_1220

Surveyed	SBC, PW	Drawn	NF
Chk.	MW	Date	17/12/2021

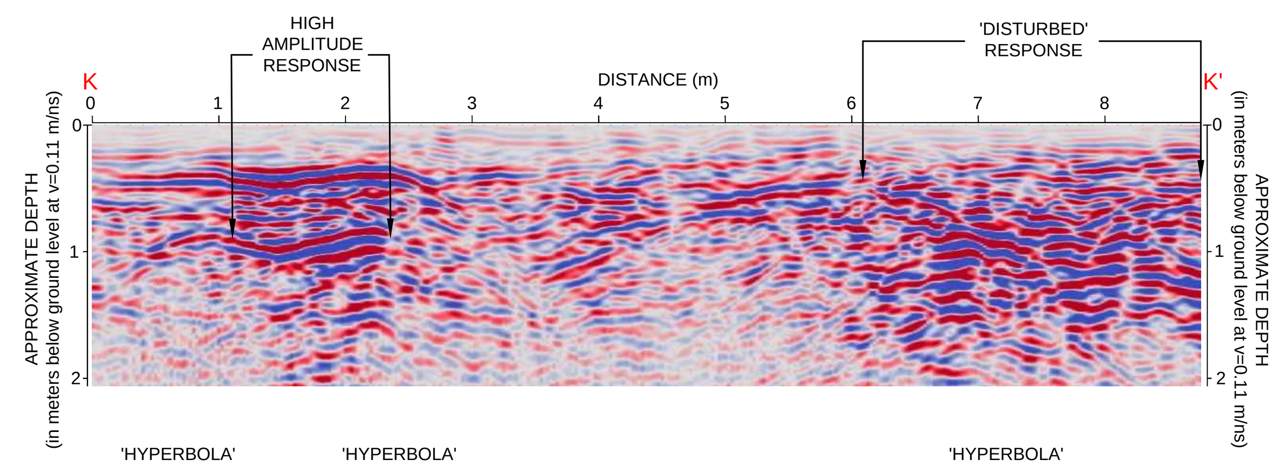


SCALE

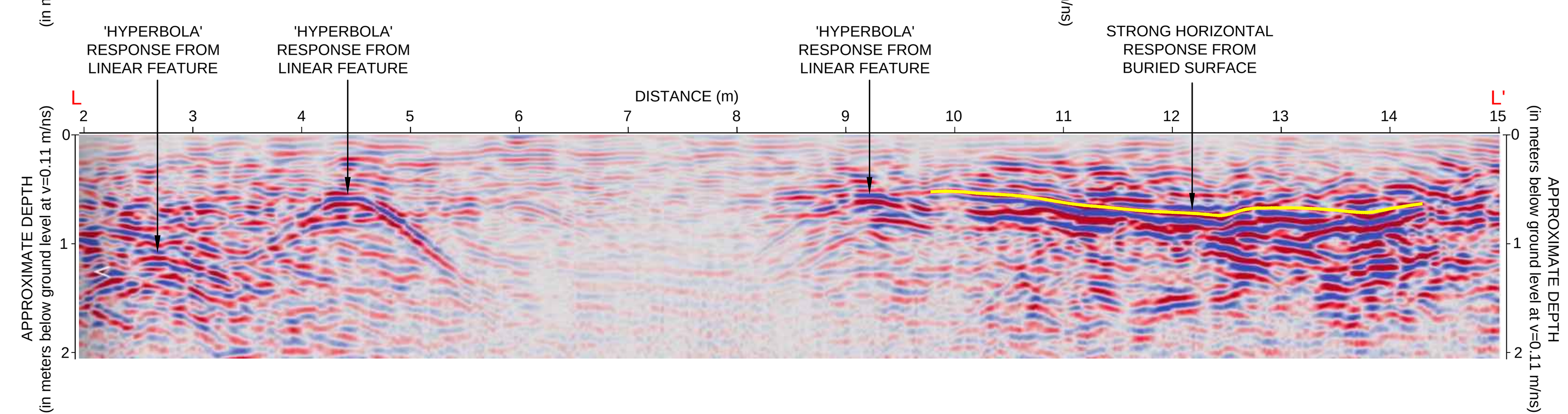
0m 4m 8m

SCALE 1:200 (A1 SHEET)

PROFILE K



PROFILE L



KEY

- - - -	APPROXIMATE EXTENT OF GPR SURVEY AREA
0.1-0.5	AREA OF HIGH AMPLITUDE RESPONSES POSSIBLY CAUSED BY SUB-SURFACE INTERFACE(S) OR FEATURE(S) OF UNKNOWN ORIGIN
0.1-0.5	AREA OF DISTURBED RESPONSES POSSIBLY CAUSED BY SUB-SURFACE FEATURE OR DISTURBED GROUND
0.1-0.5	AREA OF HORIZONTAL REFLECTIONS POSSIBLY CAUSED BY SUB-SURFACE INTERFACE(S) OR FEATURE(S)
0.6	PROJECTED LINE OF PROBABLE LINEAR FEATURE DERIVED FROM HYPERBOLAE RESPONSES. APPROXIMATE DEPTH BELOW GROUND LEVEL IS GIVEN IN METRES
0.6	PROJECTED LINE OF POSSIBLE LINEAR FEATURE DERIVED FROM HYPERBOLAE RESPONSES. APPROXIMATE DEPTH BELOW GROUND LEVEL IS GIVEN IN METRES
A A'	LOCATION OF GPR RADARGRAM
PC1	GROUND PENETRATING ANOMALY DESCRIBED IN THE ACCOMPANYING REPORT ARC_3215_1220_RPT.PDF

WHERE A DEPTH RANGE IS GIVEN THE DEPTHS INDICATED ARE MINIMUM AND MAXIMUM EXTENTS BELOW GROUND LEVEL OF THE ANOMALY. THE ASSOCIATED FEATURE MAY LIE SOMEWHERE WITHIN THIS RANGE.

NOTES

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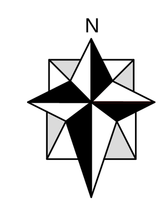
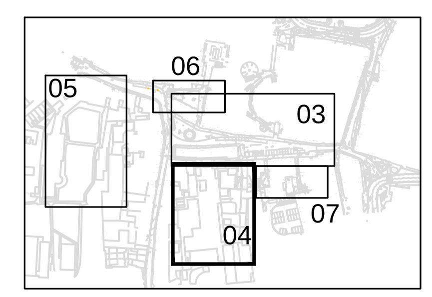


Direction of north taken from drawing 'NorthWalshamTownCentre2022-2D.dwg'

DRAWING LAYOUTS



Rev	Date	Drawn	Chk.	Description
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Scale [A1 Sheet]	Drawing	Status
AS SHOWN	ARC_3215_1220_04	FINAL

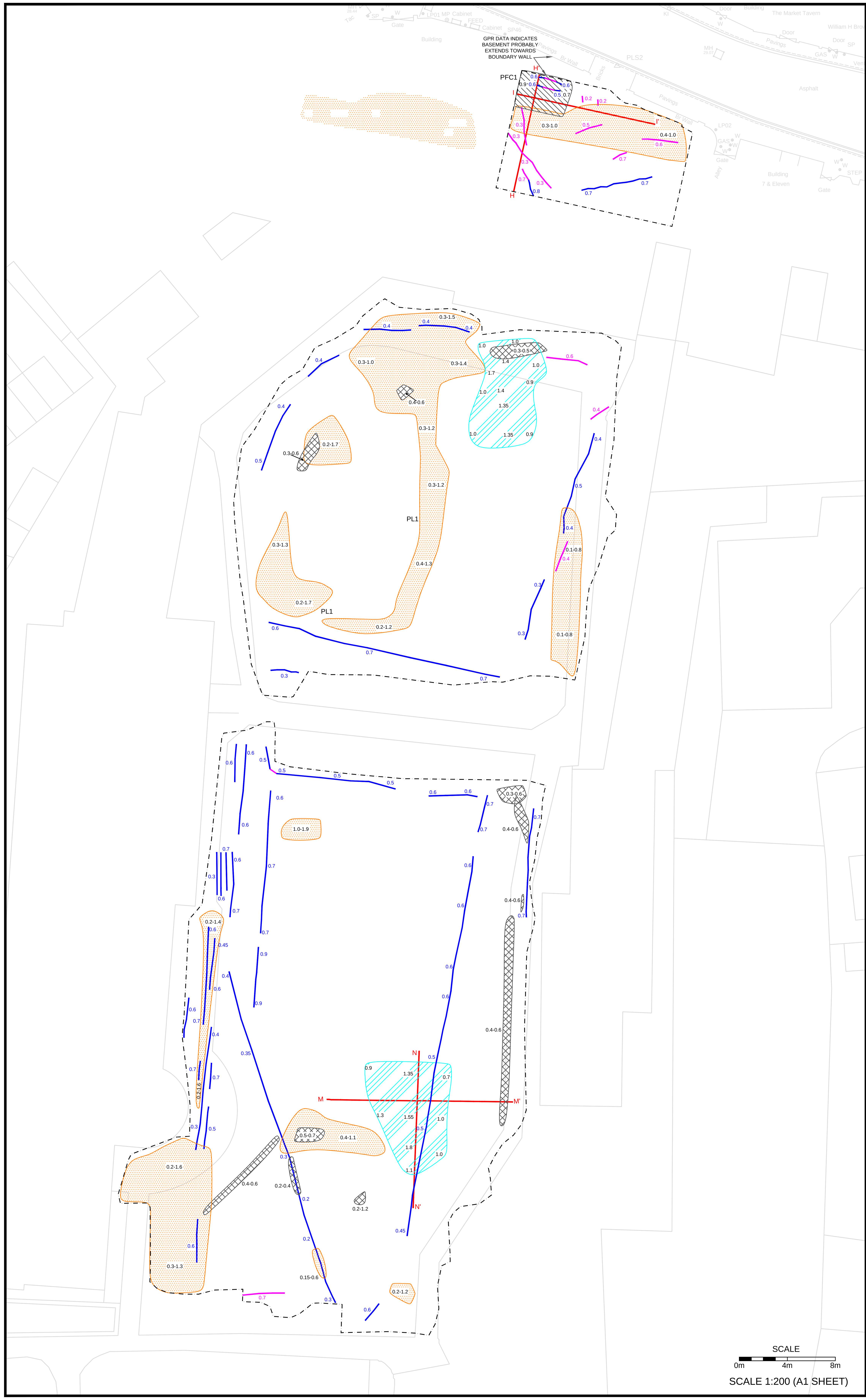
Client: HISTORIC ENGLAND PORTSMOUTH

Site: NORTH WALSHAM HSHAZ NORFOLK

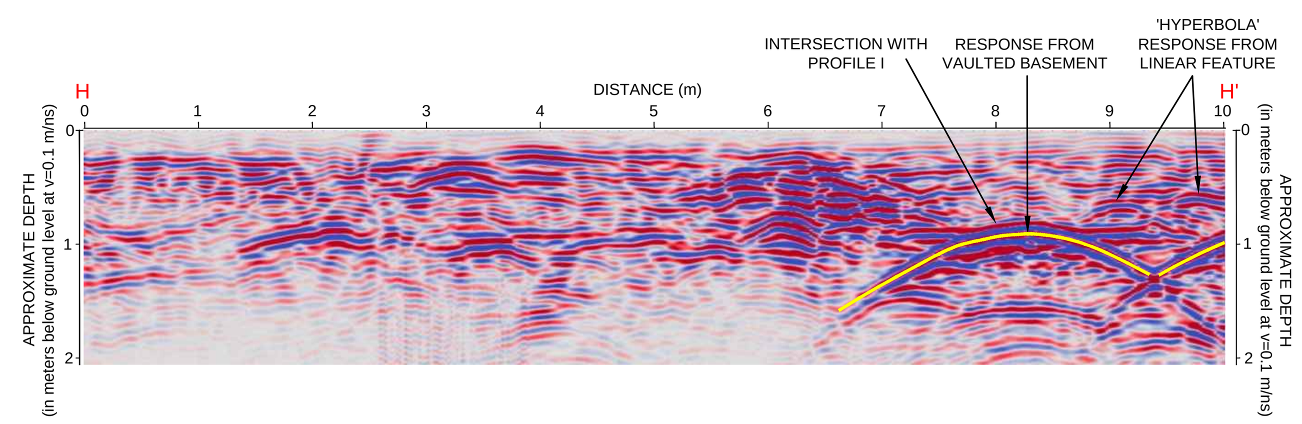
Title: PASTON COLLEGE COURTYARD: INTERPRETATION OF GPR DATA WITH SELECTED RADARGRAMS

Job ref. ARC_3215_1220

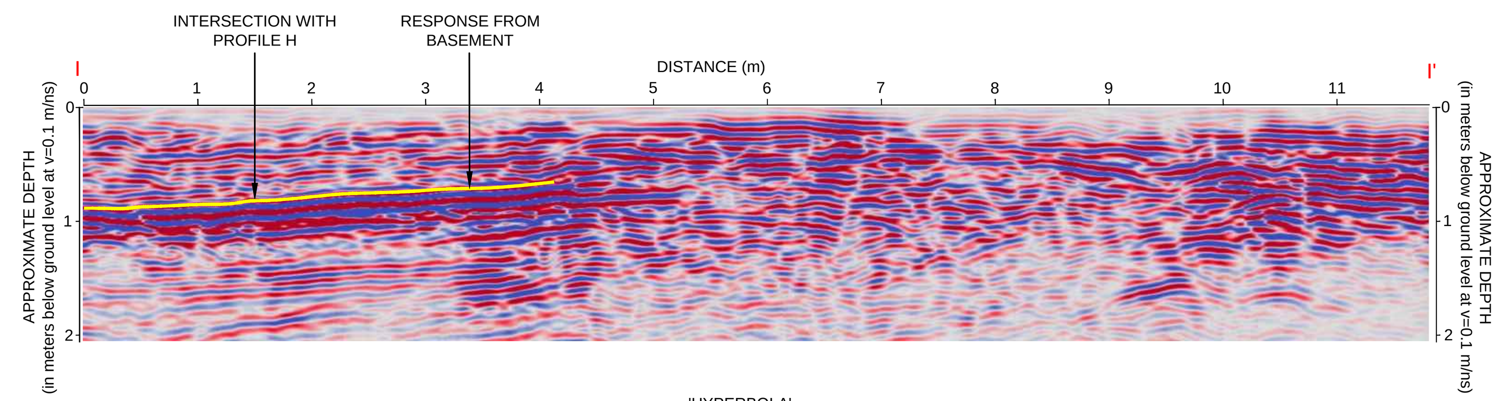
Surveyed	SBC, PW	Drawn	NF
Chk.	MW	Date	17/12/2021



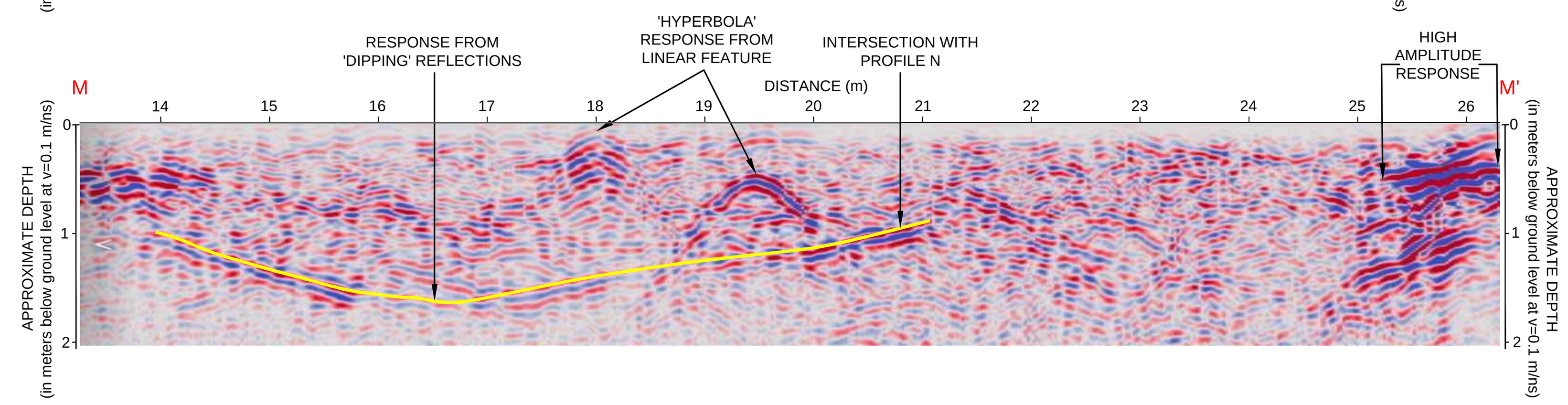
PROFILE H



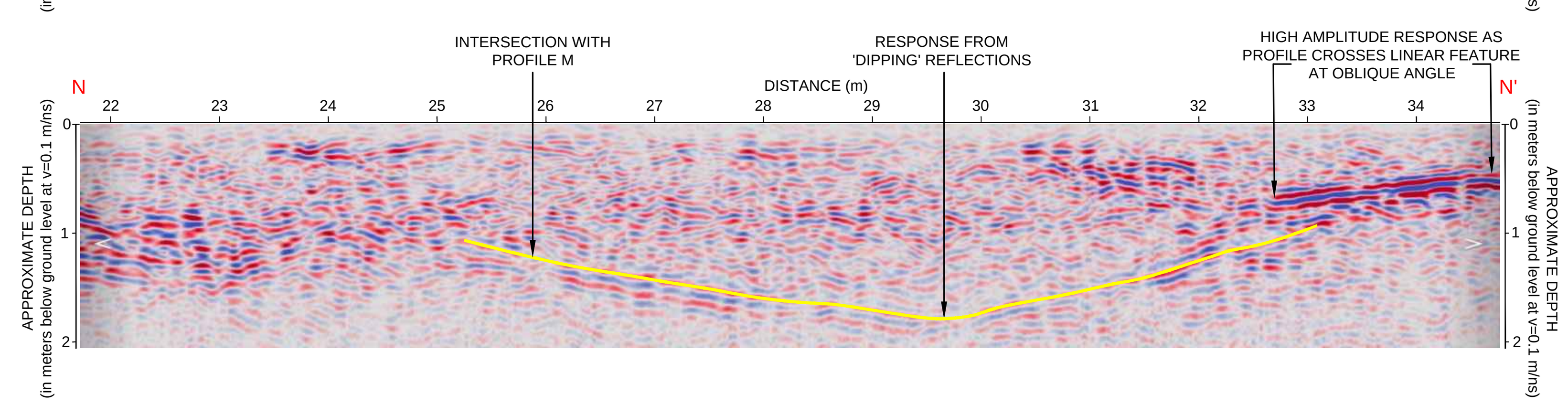
PROFILE I



PROFILE M



PROFILE N



NOTES

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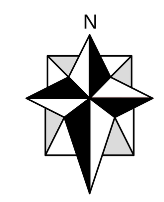
KEY

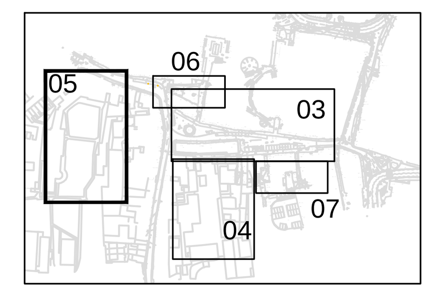
(dashed line)	APPROXIMATE EXTENT OF GPR SURVEY AREA
0.1-0.5	AREA OF HIGH AMPLITUDE RESPONSES PROBABLY CAUSED BY BASEMENT
0.1-0.5	AREA OF HIGH AMPLITUDE RESPONSES POSSIBLY CAUSED BY SUB-SURFACE INTERFACE(S) OR FEATURE(S) OF UNKNOWN ORIGIN
0.1-0.5	AREA OF DISTURBED RESPONSES POSSIBLY CAUSED BY SUB-SURFACE FEATURE OR DISTURBED GROUND
0.1-0.5	AREA OF 'DIPPING' REFLECTIONS - UNCERTAIN CAUSE
0.6	PROJECTED LINE OF PROBABLE LINEAR FEATURE DERIVED FROM HYPERBOLAE RESPONSES. APPROXIMATE DEPTH BELOW GROUND LEVEL IS GIVEN IN METRES
0.6	PROJECTED LINE OF POSSIBLE LINEAR FEATURE DERIVED FROM HYPERBOLAE RESPONSES. APPROXIMATE DEPTH BELOW GROUND LEVEL IS GIVEN IN METRES
A A'	LOCATION OF GPR RADARGRAM
PL1	GROUND PENETRATING ANOMALY DESCRIBED IN THE ACCOMPANYING REPORT ARC_3215_1220_RPT.PDF

WHERE A DEPTH RANGE IS GIVEN THE DEPTHS INDICATED ARE MINIMUM AND MAXIMUM EXTENTS BELOW GROUND LEVEL OF THE ANOMALY. THE ASSOCIATED FEATURE MAY LIE SOMEWHERE WITHIN THIS RANGE.



Direction of north taken from drawing 'NorthWalshamTownCentre2022-2D.dwg'

DRAWING LAYOUTS



Rev	Date	Drawn	Chk.	Description
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W: www.PhaseSI.com

Scale [A1 Sheet]	Drawing	Status
AS SHOWN	ARC_3215_1220_05	FINAL

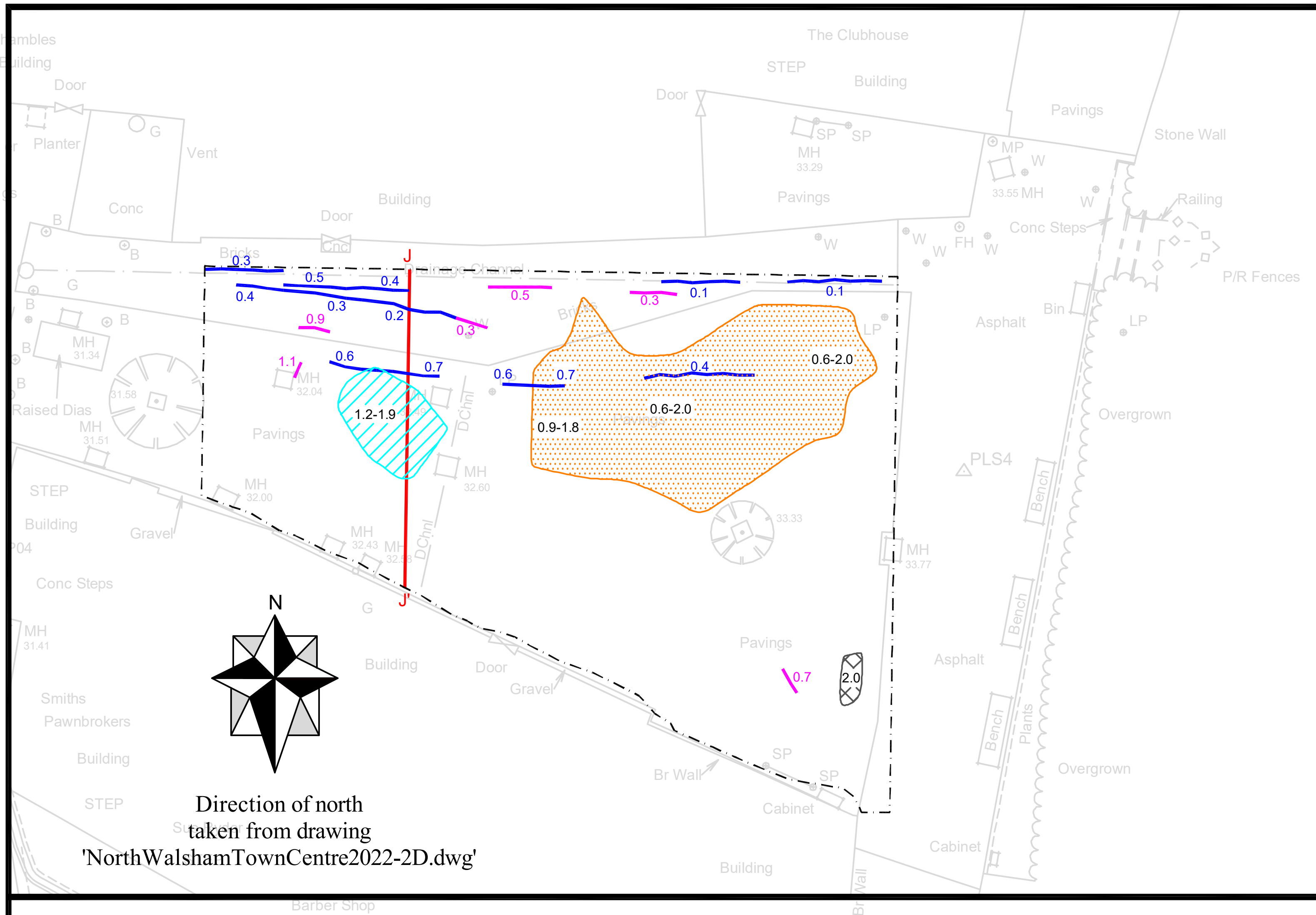
Client: HISTORIC ENGLAND PORTSMOUTH

Site: NORTH WALSHAM HSHAZ NORFOLK

Title: PASTON COLLEGE FRONT COURTYARD AND LAWNED AREA INTERPRETATION OF GPR DATA WITH SELECTED RADARGRAMS

Job ref.: ARC_3215_1220

Surveyed	SBC, PW	Drawn	NF
Chk.	MW	Date	17/12/2021



Direction of north taken from drawing 'NorthWalshamTownCentre2022-2D.dwg'

KEY

APPROXIMATE EXTENT OF GPR SURVEY AREA

0.1-0.5 — AREA OF HIGH AMPLITUDE RESPONSES POSSIBLY CAUSED BY SUB-SURFACE INTERFACE(S) OR FEATURE(S) OF UNKNOWN ORIGIN

0.1-0.5 — AREA OF DISTURBED RESPONSES POSSIBLY CAUSED BY SUB-SURFACE FEATURE OR DISTURBED GROUND

0.1-0.5 — AREA OF HORIZONTAL REFLECTIONS POSSIBLY CAUSED BY SUB-SURFACE INTERFACE(S) OR FEATURE(S)

0.6 — PROJECTED LINE OF PROBABLE LINEAR FEATURE DERIVED FROM HYPERBOLAE RESPONSES. APPROXIMATE DEPTH BELOW GROUND LEVEL IS GIVEN IN METRES

0.6 — PROJECTED LINE OF POSSIBLE LINEAR FEATURE DERIVED FROM HYPERBOLAE RESPONSES. APPROXIMATE DEPTH BELOW GROUND LEVEL IS GIVEN IN METRES

A — A' LOCATION OF GPR RADARGRAM

WHERE A DEPTH RANGE IS GIVEN THE DEPTHS INDICATED ARE MINIMUM AND MAXIMUM EXTENTS BELOW GROUND LEVEL OF THE ANOMALY. THE ASSOCIATED FEATURE MAY LIE SOMEWHERE WITHIN THIS RANGE.

SCALE

0m 4m 8m

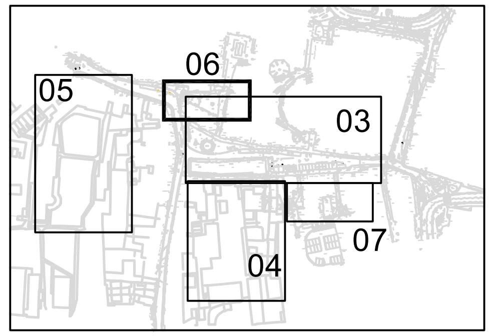
SCALE 1:200 (A3 SHEET)

NOTES

1. THIS DRAWING MUST BE USED IN CONJUNCTION WITH THE ACCOMPANYING REPORT (ARC_3215_1220_RPT.PDF) WHICH PROVIDES DETAILS OF THE TECHNIQUES EMPLOYED, THEIR INHERENT LIMITATIONS AND ANY SITE SPECIFIC ISSUES.
2. PHASE SITE INVESTIGATIONS CANNOT ACCEPT RESPONSIBILITY FOR THE RELIABILITY OR ACCURACY OF ANY INFORMATION PROVIDED BY A THIRD PARTY.

ALWAYS EXERCISE CAUTION WHEN EXCAVATING

DRAWING LAYOUTS



Rev	Date	Drawn	Chk.	Description
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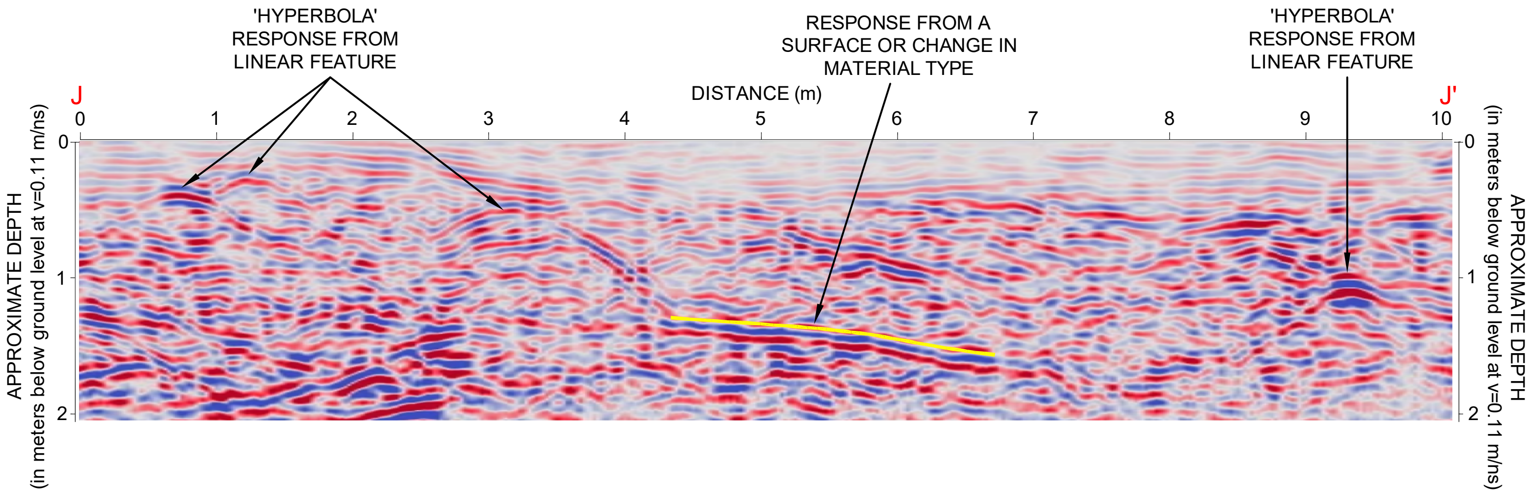
PROFILE J



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Scale [A3 Sheet]	Drawing	Status
AS SHOWN	ARC_3215_1220_06	FINAL

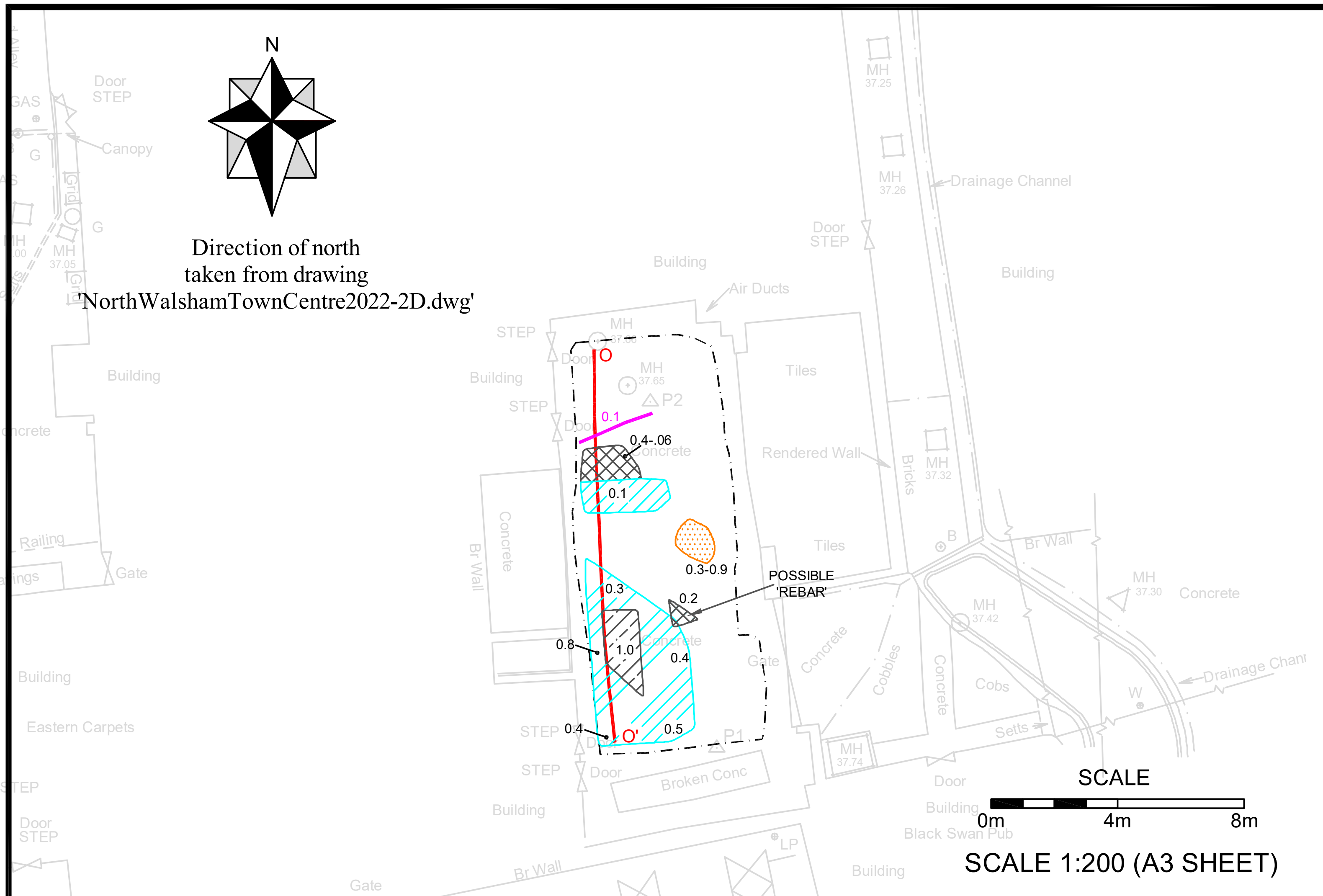
Client: HISTORIC ENGLAND PORTSMOUTH

Site: NORTH WALSHAM HSHAZ NORFOLK

Title: THE SHAMBLES: INTERPRETATION OF GPR DATA WITH SELECTED RADARGRAM

Job No: ARC_3215_1220

Surveyed	SBC, PW	Drawn	NF
Chk.	MW	Date	17/12/2021



KEY

- APPROXIMATE EXTENT OF GPR SURVEY AREA
- 0.1-0.5 — AREA OF HIGH AMPLITUDE RESPONSES POSSIBLY CAUSED BY BASEMENT
- 0.1-0.5 — AREA OF HIGH AMPLITUDE RESPONSES POSSIBLY CAUSED BY SUB-SURFACE INTERFACE(S) OR FEATURE(S) OF UNKNOWN ORIGIN
- A A' 0.1-0.5 — AREA OF DISTURBED RESPONSES POSSIBLY CAUSED BY SUB-SURFACE FEATURE OR DISTURBED GROUND
- 0.1-0.5 — AREA OF HORIZONTAL REFLECTIONS POSSIBLY CAUSED BY SUB-SURFACE INTERFACE(S) OR FEATURE(S)
- 0.1-0.5 — AREA OF 'DIPPING' REFLECTIONS - UNCERTAIN CAUSE
- 0.6 — PROJECTED LINE OF POSSIBLE LINEAR FEATURE DERIVED FROM HYPERBOLAE RESPONSES. APPROXIMATE DEPTH BELOW GROUND LEVEL IS GIVEN IN METRES
- A A' — LOCATION OF GPR RADARGRAM

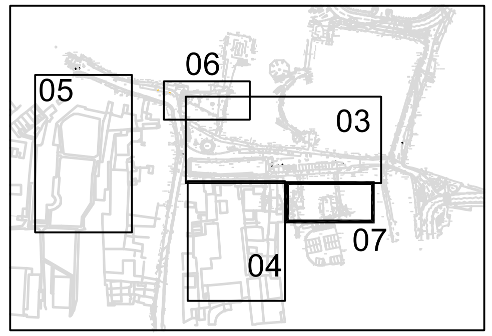
WHERE A DEPTH RANGE IS GIVEN THE DEPTHS INDICATED ARE MINIMUM AND MAXIMUM EXTENTS BELOW GROUND LEVEL OF THE ANOMALY. THE ASSOCIATED FEATURE MAY LIE SOMEWHERE WITHIN THIS RANGE.

NOTES

1. THIS DRAWING MUST BE USED IN CONJUNCTION WITH THE ACCOMPANYING REPORT (ARC_3215_1220_RPT.PDF) WHICH PROVIDES DETAILS OF THE TECHNIQUES EMPLOYED, THEIR INHERENT LIMITATIONS AND ANY SITE SPECIFIC ISSUES.
2. PHASE SITE INVESTIGATIONS CANNOT ACCEPT RESPONSIBILITY FOR THE RELIABILITY OR ACCURACY OF ANY INFORMATION PROVIDED BY A THIRD PARTY.

ALWAYS EXERCISE CAUTION WHEN EXCAVATING

DRAWING LAYOUTS



Rev	Date	Drawn	Chk.	Description
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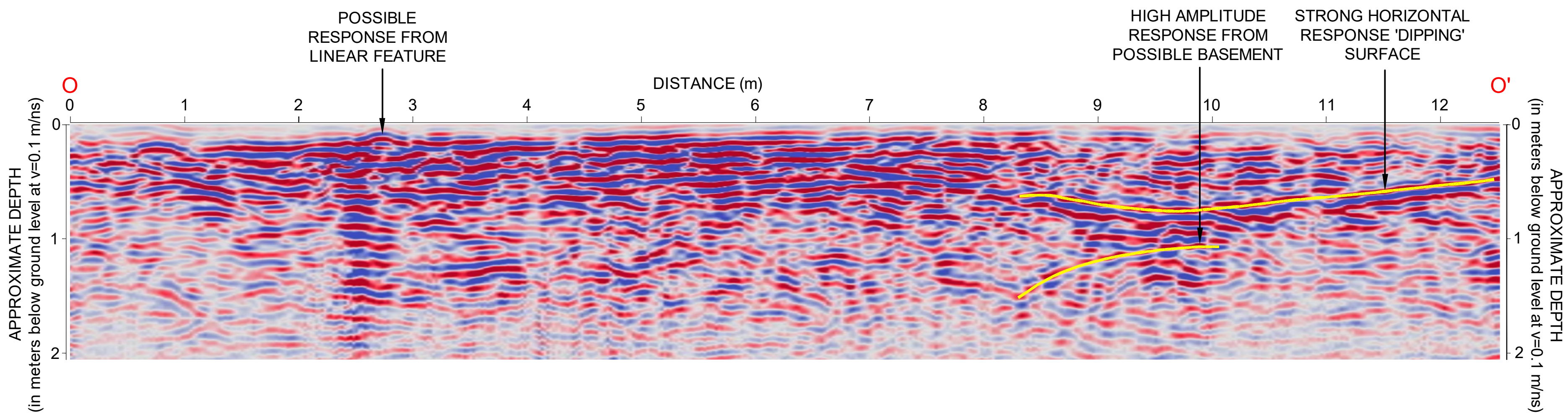
PROFILE O



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Scale [A3 Sheet]	Drawing	Status
AS SHOWN	ARC_3215_1220_07	FINAL

Client: HISTORIC ENGLAND PORTSMOUTH

Site: NORTH WALSHAM HSHAZ NORFOLK

Title: BLACK SWAN LOKE: INTERPRETATION OF GPR DATA WITH SELECTED RADARGRAM

Job No: ARC_3215_1220

Surveyed	SBC, PW	Drawn	NF
Chk.	MW	Date	17/12/2021






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