RESEARCH REPORT SERIES no. 40-2013

PORTLAND CASTLE
PORTLAND BILL, DORSET
REPORT ON GEOPHYSICAL SURVEY, NOVEMBER 2012

Neil Linford

REMOTE
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ENGLISH HERITAGE

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SUMMARY

A Ground Penetrating Radar (GPR) survey was conducted at Portland Castle, Portland Bill, Dorset, to assist with the investigation of ongoing water ingress through the external walls into the Captain's chamber. Access for the survey was provided by a two-tier scaffold platform over the vertical face of the external wall, to assess whether the GPR technique could reveal any useful information regarding the integrity of the structure. The results confirm sufficient penetration of the radar signal to detect reflections from the internal face of the wall and identified known features, such as the timber sockets protruding into the masonry visible from the interior. A potential area of degradation within the core structure of the wall is also indicated within the upper courses of masonry, which contrasts with the response over sound elements of the building.

CONTRIBUTORS

The field work was conducted by Neil Linford and Andy Payne with the assistance of Morgan Cowles.

ACKNOWLEDGEMENTS

The author wishes to express his thanks to the site custodians who were on hand to open the site to allow the survey to take place. Morgan Cowles kindly provided architectural plans that assisted with the interpretation of the data and compilation of the figures.

ARCHIVE LOCATION

Fort Cumberland.

DATE OF FIELDWORK AND REPORT

The fieldwork was conducted on the 11th and 12th November 2012 and the report was completed on 2nd July 2013. The cover photograph shows a view over the gun deck towards the scaffold erected over the North Wall of the Captain's Chamber for the GPR survey.

CONTACT DETAILS

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INTRODUCTION

Portland Castle (Scheduled Ancient Monument no. 22964) is one of a group of artillery forts, built on the orders of Henry VIII in 1540, specifically as one of a pair of forts guarding the anchorage of the Portland Roads. It takes an unusual fan-shaped plan-form, with a two-storey central tower or keep, flanking wings, and a curving wall facing the sea. The castle is externally built in fine Portland ashlar and retains many original features, though some post-Tudor features were removed when the castle came into guardianship in 1955. The castle is a Grade I listed building, the Captain's house and entrance gateway are listed at Grade II* and other parts of the curtain wall are designated at Grade II.

Ongoing incidents of water ingress in the West range of the Castle in the Captain's chamber that have recently occurred are a concern and appear to be related to re-used beam sockets that have reduced parts of the north wall thickness to approximately 300mm (Cowles 2011). Following a period of monitoring it appears that the problem is due to driven rain laterally through voids in the masonry exacerbated by the reduced cover over the beam socket detailing.

The aim of the Ground Penetrating Radar (GPR) survey was to investigate whether this methodology could provide a means of non-invasive analysis at the site, to indicate the structural integrity of north wall and determine whether the presence and extent of any voiding could be established.

METHOD

The survey was conducted against the external face of north wall of the Captain's Chamber from a two-tier, cantilevered scaffold to allow a safe working platform. Individual GPR traces were collected following English Heritage (2008) at 0.02m intervals along parallel profiles separated by 0.075m for the upper courses of masonry and at a 0.15m separation for the lower course (Figure 1). A Sensors and Software Pulse Ekko PE1000 console with a 900MHz centre frequency antenna recording reflections through a 40ns window was used to collect the data with the antenna unit kept in close contact with the outer ashlar face of the wall.

Post acquisition processing involved the adjustment of time-zero to coincide with the true ground surface, background and noise removal, and the application of a suitable gain function to enhance late arrivals. Representative profiles from the GPR survey are shown on Figures 3 and 4. An average velocity of 0.09m/ns was assumed following a detailed constant velocity analysis of the data, and was used for both the migration velocity field and the time to estimated depth conversion (Figure 6).

In addition, owing to antenna coupling between the GPR transmitter and the face of the wall to an approximate depth of $^{\lambda}/_{2}$, very near-surface reflection events should only be detectable below a depth of 0.05m if a centre frequency of 900MHz and a velocity of

0.09m/ns are assumed. However, the broad bandwidth of an impulse GPR signal results in a range of frequencies to either side of the centre frequency which, in practice, will record significant near-surface reflections closer to the wall surface. Such reflections are often emphasised by presenting the data as amplitude time slices. In this case, the time slices were created from the entire data set, after applying a 2D-migration algorithm, by averaging data within successive 2ns (two-way travel time) windows (Linford 2004). Each resulting time slice, illustrated as a greyscale image in Figure 5 represents the variation of reflection strength through successive ~0.1m intervals from the ground surface.

RESULTS

A graphical summary of significant GPR anomalies discussed in the following text is shown superimposed over both the photogrammetric plan of the east facing external elevation of the castle and on selected GPR profiles (Figures 3, 4 and 7).

Significant anomalies

The face of the external wall is partially obscured in the data by the direct GPR wave, although some very near surface hyperbolic responses such as [GPR 1] and [GPR 2] are evident. It is unclear whether these represent undulations or defects in the stone surface or, perhaps more likely, a strong reflective target such as the head of a metal tie bar. Beyond this, few significant near-reflections are seen from between 0 and 5ns (~0 to 0.25m) at which point an intermittent band of reflections (e.g. [GPR 3] on Line 1 and Line 6) are found from between 6 and 12ns (~0.3 to 0.6m). In the upper survey area [GPR 3] demonstrates a less regular response with distinct gaps at [GPR 4, 5 and 6] which correspond with the approximate location of the rafter sockets cut into the inner face of the wall. The response to [GPR 6] is particularly well defined and it is notable that [GPR 3] does not appear to extend W beyond the rafter socket over the door way to the gun deck parapet. The amplitude time slices show [GPR 3] as an area of high amplitude reflection consistent between 6 and 12ns (~0.3 to 0.6m) across the majority of the surveyed area with some suggestion of internal details (e.g. at [GPR 7-10]) together with the low amplitude response [GPR 11] to the W.

A well defined, linear reflector [GPR 12] is found consistently across all the profiles in the lower survey areas at 15ns (~0.75m) and, almost certainly, indicates the internal face of the wall (Figure 4). A similar response is found in upper survey area, although the anomaly is less well defined and, as would be expected, appears at later arrival time as the thickness of the wall increases towards the string corbell. For example, Line 1 shows the onset of [GPR 12] at 30ns (~1.5m) with breaks in the response related to the rafter sockets and a slighter earlier arrival time (27ns) to the W of [GPR 6]. Beyond [GPR 12] any recorded response is unlikely to be related to the structure of the wall and will be caused by internal reflections from within the Captain's Chamber. This is illustrated by the profiles from the lower survey area which show a strong linear reflector [GPR 13] towards the end of the maximum recorded time window (50ns) between 3.5 to 5.5m. Given the increase of the radar wave-front velocity as it exits the wall this would place [GPR 13] at approximately 5m (50 – 15ns x 0.3m/ns) from the inner face, corresponding with a reflection generated by the metal framed display boards in this room.

A similar reflection is found at [GPR 14] in the profiles from the upper survey area, although this is constrained to a location between 7.5 and 9m and appears earlier in the time window (e.g. at ~30ns on Line 3). Again, taking into account the thickness of the wall indicated at this point and the increase in velocity once the wave-front has entered the room, this is likely to be caused by the rear wall of the passage-way immediately above the door-way to the gun deck parapet. Two notable hyperbolic reflections [GPR 15] and [GPR 16] occur at the internal aperture of the rafter sockets into the Captain's Chamber.

DISCUSSION

The surface face of the wall appears sound from the GPR data within the first 0.25m, with the exception of the cover over the rafter sockets that may be reduced to ~0.1m from the response at [GPR 6]. This may indicate the generally sound nature of the facing ashlar, perhaps with some indication of repair work indicated by near-surface hyperbolic reflections (e.g. [GPR 4] and [GPR 5]). An area of more defined reflections then appears from between ~0.25 – 0.65m that is less regular in the upper area of the survey and may represent a layer of more disturbed rubble packing. From 0.65m to the onset of the reflection from the inner face of the wall (varying from ~1.5m at the top of the survey area to 0.8m in the lower area), there are relatively few reflectors suggesting a more sound inner face. However, the upper survey also shows areas of both high [GPR 17] and low [GPR 18] amplitude reflections in the amplitude time slices between 20 and 26ns (~1.0 to 1.3m) consistent with a degradation of the structural fabric in this region.

The area surrounding the door-way to the gun deck parapet [GPR 11] contains few reflection events and, from the slightly earlier onset of the response to the inner face of the wall suggests, perhaps, this represents more sound fabric with a higher velocity. However, due to the presence of relatively few hyperbolic reflectors in this area the interpolated velocity field data suggests a lower average velocity (Figures 6 and 8(C)). The response to the rear face of the wall appears from 28ns (1.4m) over the door way [GPR 19], although it is unclear why this remains persistent throughout the data. The increasing thickness of the wall may also account for the distinct variation in the response seen in the later reflections from 26ns (1.3m) onwards in the upper survey area. Above the line marked by [GPR 20] the response is attenuated but appears to reflect variations in the internal face of the wall, such as low amplitude response associated with the rafter sockets. However, below this line the reflections seem more likely to represent multiples generated from within the Captain's Chamber rather than the structure of the wall itself and the extent of [GPR 19] below [GPR 20] is questionable.

Individual hyperbolic responses identified in the GPR profiles were used to determine the variation of velocity throughout the data set (Figures 6 and 8(A)). The position of each response was recorded and interpolated across a 3D volume representing the full extent of the wall, although some degree of over/under shoot of the interpolation algorithm is evident due to the irregular distribution of the input velocity data. Relatively high, uniform velocities are found in the surface ashlar layer, but a much greater degree of variation from 0.3m onwards suggests the internal structure is less sound. A distinct area of lower velocity immediately beneath the string corbell between approximately 0.7 to 1.0m from the outer face of the wall may well indicate the location of significant water ingress.

Figure 8 also shows the results from a synthetic model calculated to test the fidelity of the interpretation offered for the GPR data. The physical model (Figure 8(B)) is based on a section through the exterior wall containing sections of intact wall, an air-filled beam slot and an area of minor internal voiding. Dimensions have been chosen to match those at the site and a large, linear reflector has also been included to simulate the metal display found in the Captain's chamber. A split-step 2D modelling algorithm following Bitri and Grandjean (1998) was used to calculate a synthetic profile for a 900MHz centre frequency antenna assuming the physical properties described by the model. The synthetic profile (Figure 8(C)) correlates well with the field data, with the intact sections of the wall demonstrating undisturbed, planar reflections from the expected interfaces within the model ([mod1] on Figure 8(C)).

CONCLUSION

The GPR survey has successfully recorded anomalies related to the varying thickness of the outer wall and the location of known defects due to visible beam sockets cut into the inner face. Additional variation in the structural integrity of the wall is suggested by the GPR data and has been verified against a synthetic model, allowing areas of possible voiding to be indentified. Velocity analysis, determined from hyperbolic responses within the survey data, suggests an area of possible water ingress identified through an area of lower velocity immediately below the string corbell. In addition, discrete very near surface hyperbolic responses may be associated with covered ferrous fixings, perhaps associated with historic repair work, as some corroded examples were observed during the survey which had caused visible damage to the surrounding ashlar.

LIST OF ENCLOSED FIGURES

over the photogrammetric plan of the east facing external elevation of the castle. The location of hyperbolic reflections used to create the velocity model are indicated by the + symbols and the full data set is shown in Figure 8(A) (1:50).

Figure 7 Graphical summary of significant GPR anomalies superimposed over the photogrammetric plan of the east facing external elevation of the castle (1:50).

Figure 8 Interpolated velocity field model (A) calculated from hyperbolic responses identified in the data set. Results from a synthetic model (B) to estimate the expected response of the exterior wall at Portland Castle consisting of a 0.25m exterior facing separated into a section with some minor voiding with the core (0 to 4.75m), a central 0.5m wide beam slot (5.0m) and a solid course without simulated defects (5.25 to 10m). A strong reflector is positioned between 3.0 and 8.0m simulates the metal display board within the Captain's chamber. Values of resistivity (ρ), relative dielectric constant (ε) and magnetic permeability (κ) are shown for the target bodies in the model. The results of the synthetic GPR profile calculated from this model are shown in (C) and, despite the relative simplicity of the model and absence of noise, compare favourably with the recorded profiles (*cf* Figures 3 and 4). The time to depth conversion has been compensated for the transmission through air beyond 25ns with revised depths shown in brackets.

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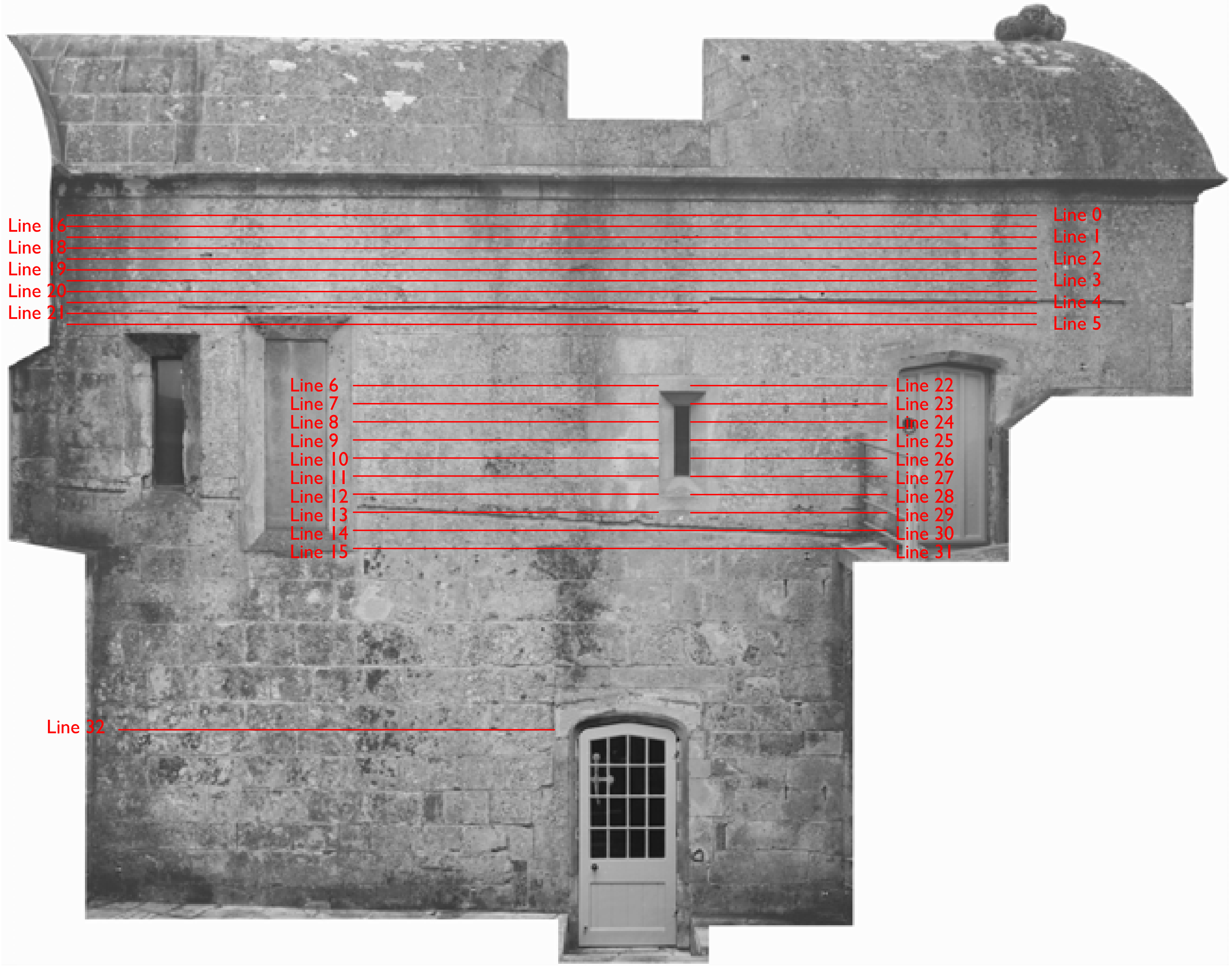
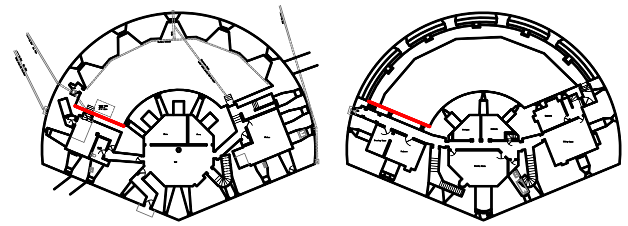
Figure 1

PORTLAND CASTLE
Location of GPR profiles, November 2012



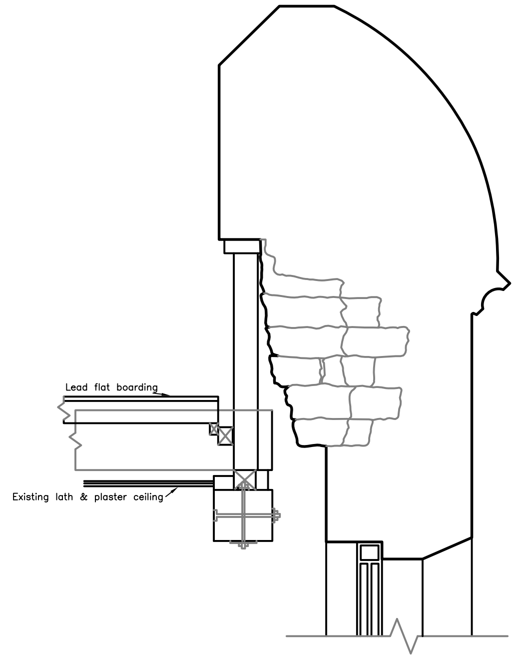
0 3m
1:50

Castle Plan (1:1500)

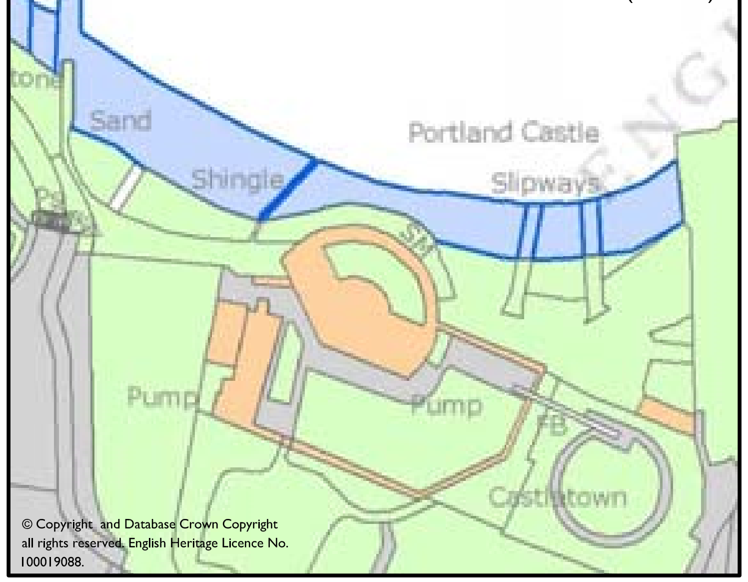


Ground Floor Plan *Upper Floor Plan*

Schematic section through North wall (1:30)



Site location (1:2500)



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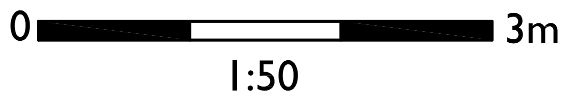
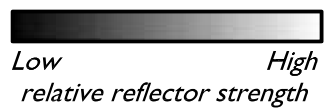
PORTLAND CASTLE

GPR amplitude time slice from between *22.0 - 24.0ns (1.1 - 1.2m)*, November 2012

Figure 2





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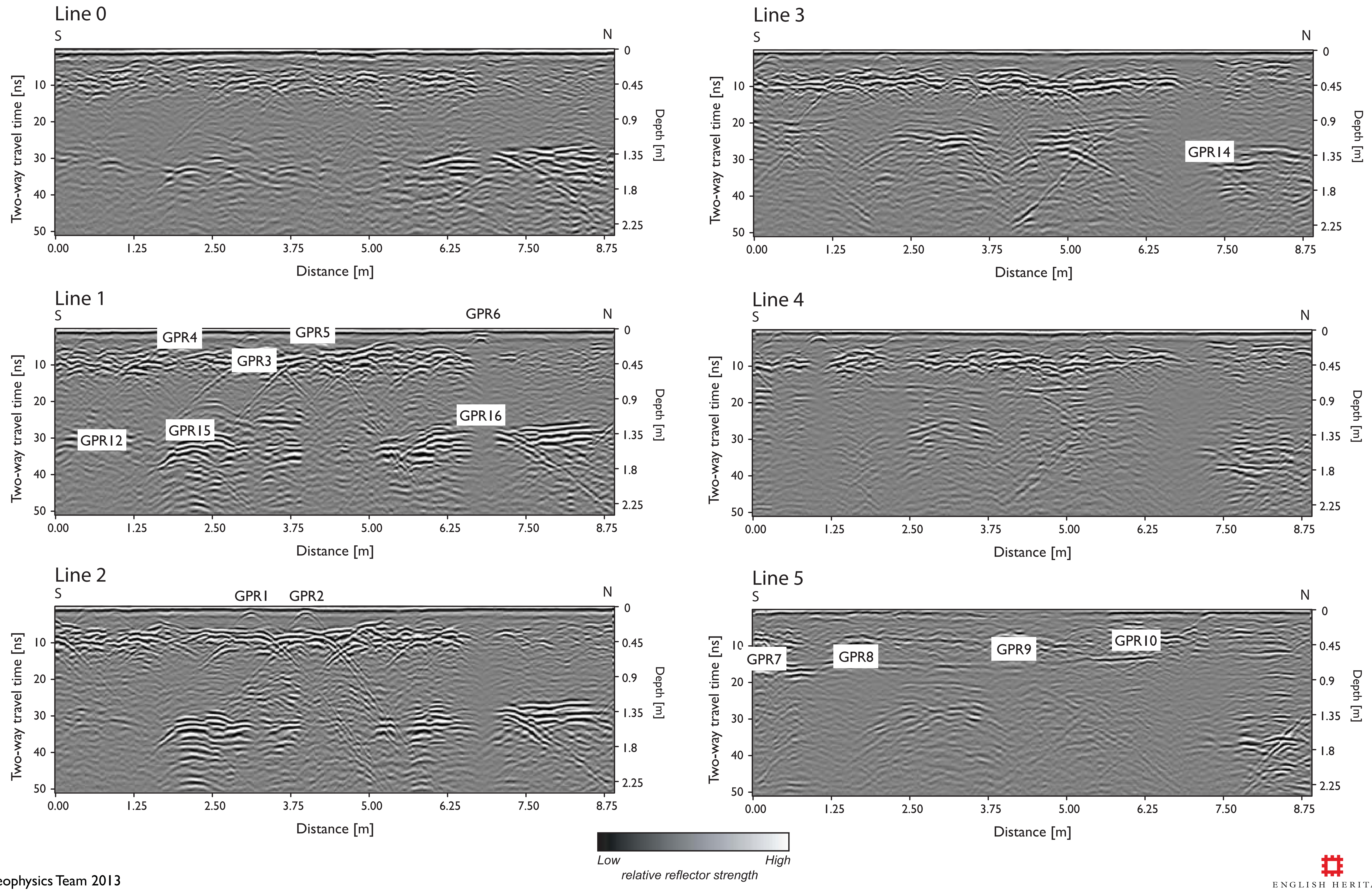
PORTLAND CASTLE
Selected GPR profiles, November 2012

Figure 3



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Selected GPR profiles, November 2012

Figure 4

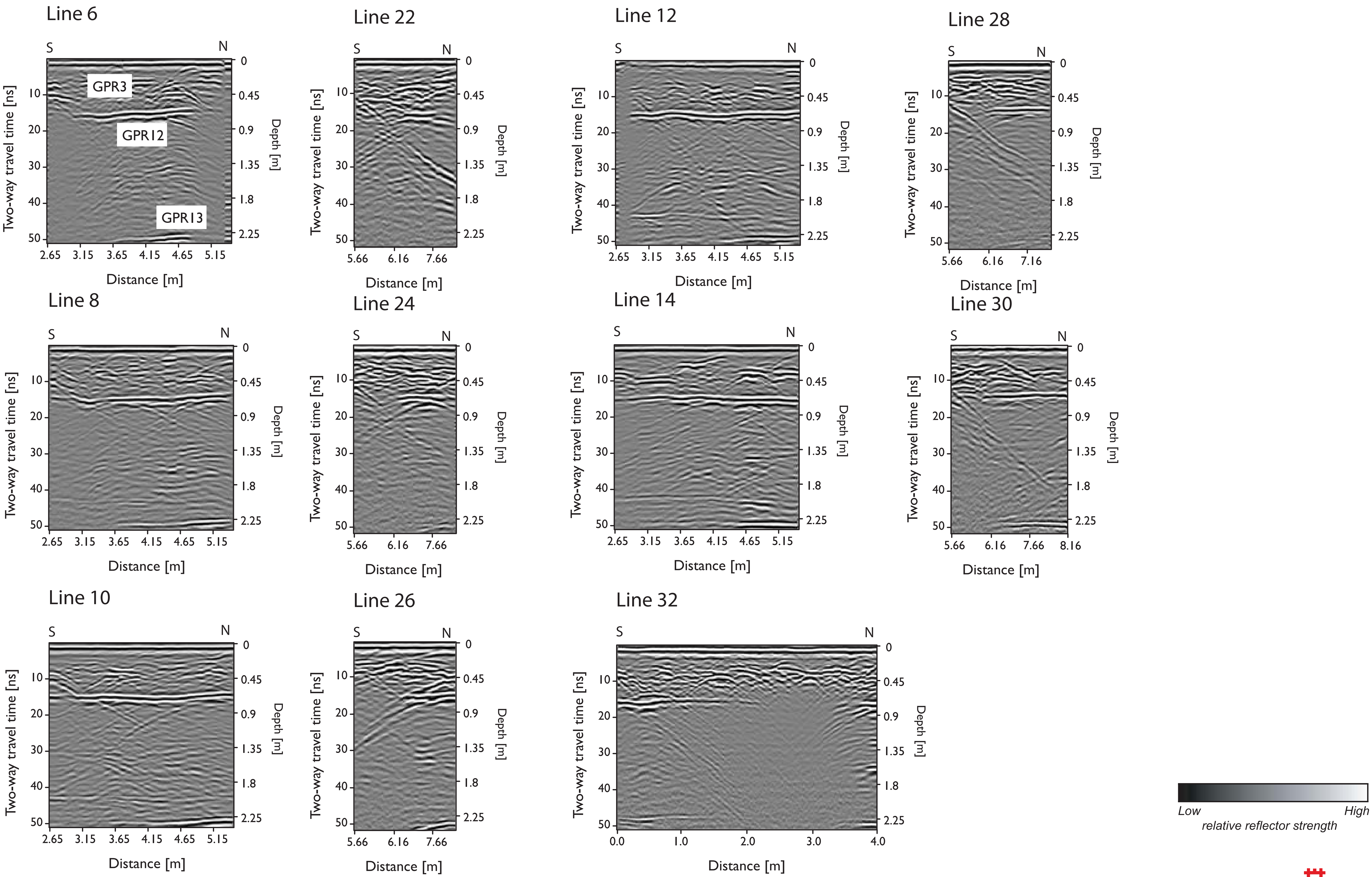

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Figure 5

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GPR amplitude time slices from between 0.0 and 40.0ns (0 - 2.0m), November 2012

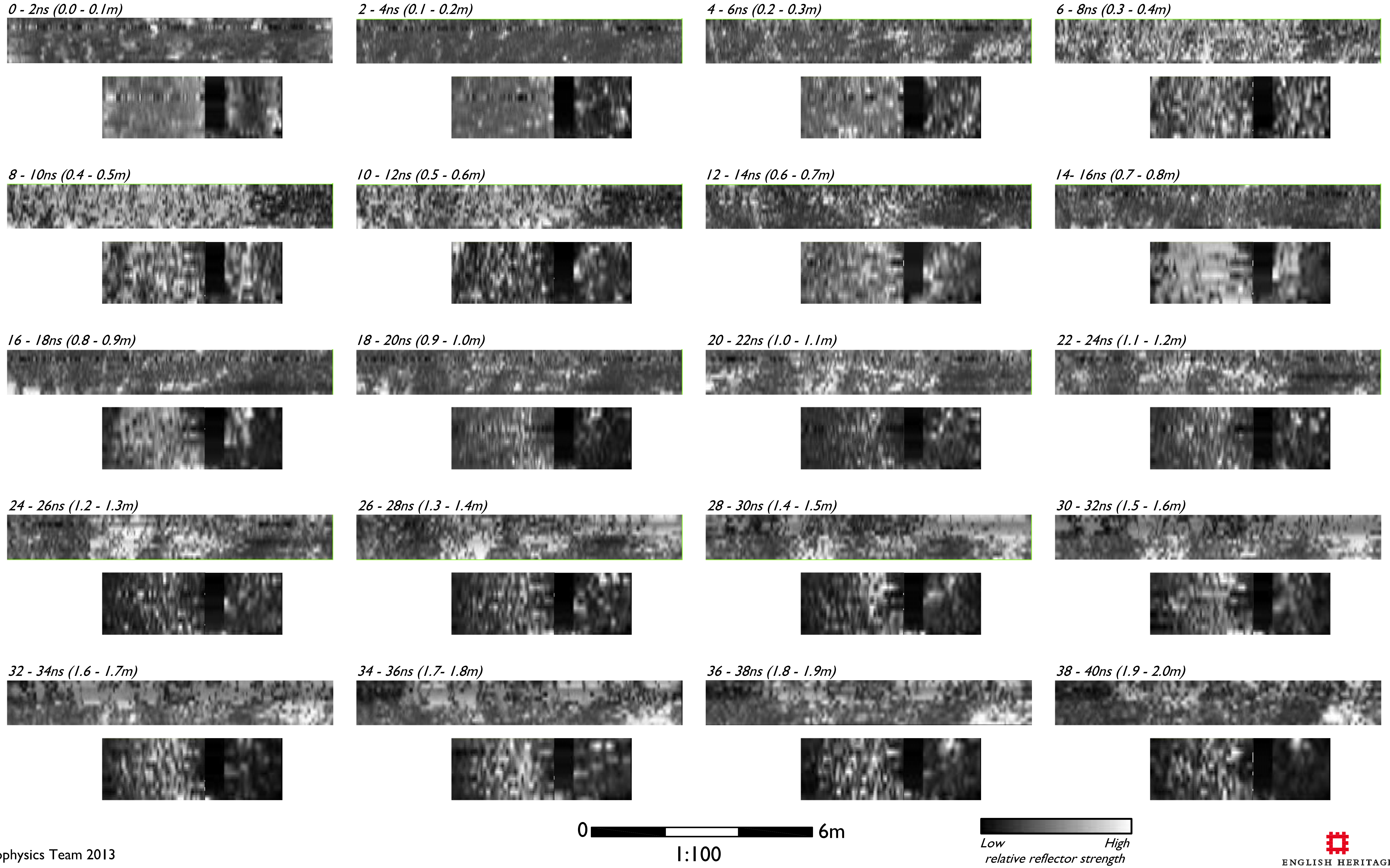
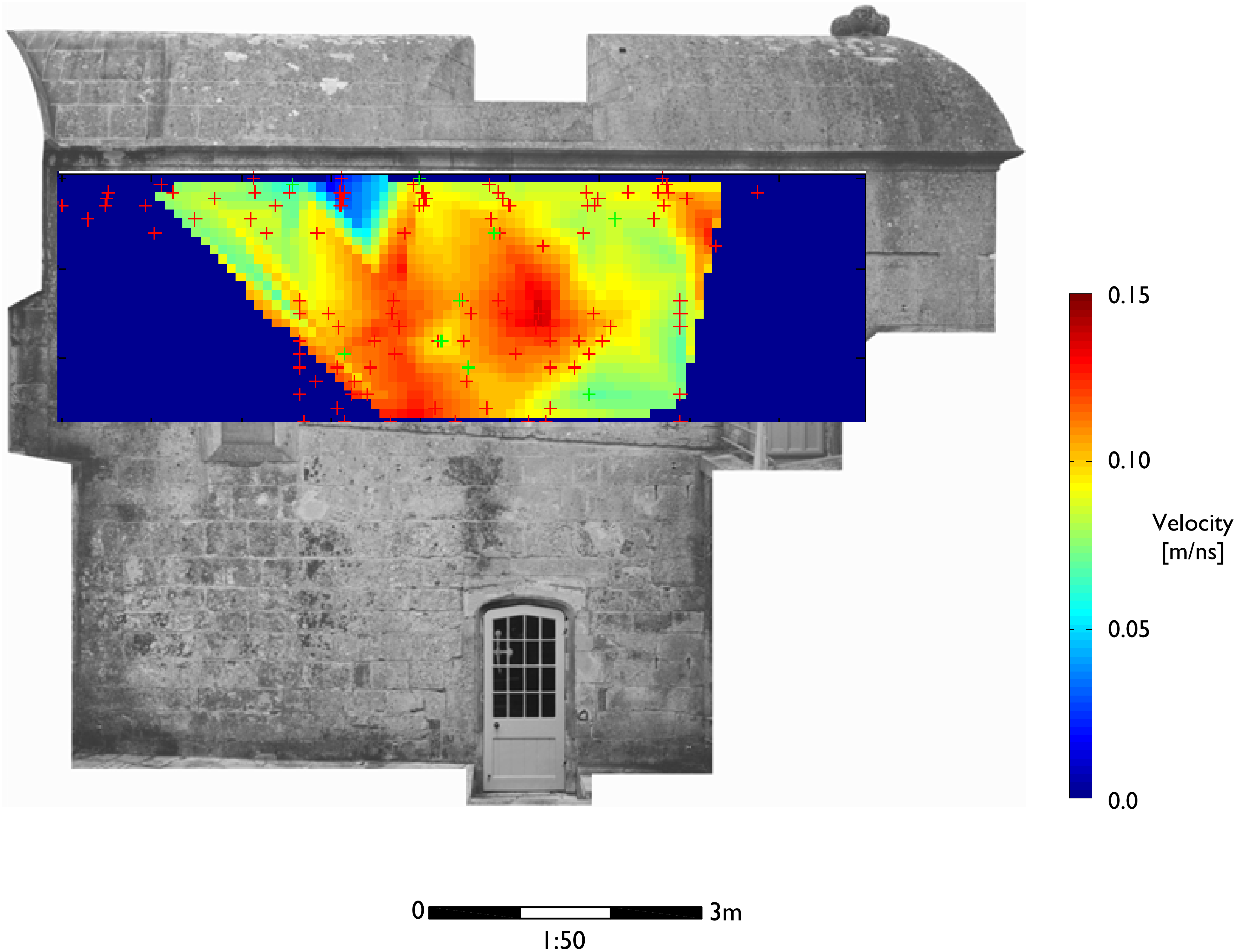


Figure 6

PORTLAND CASTLE

Interpolated GPR velocity analysis between 0.9 and 1.0m



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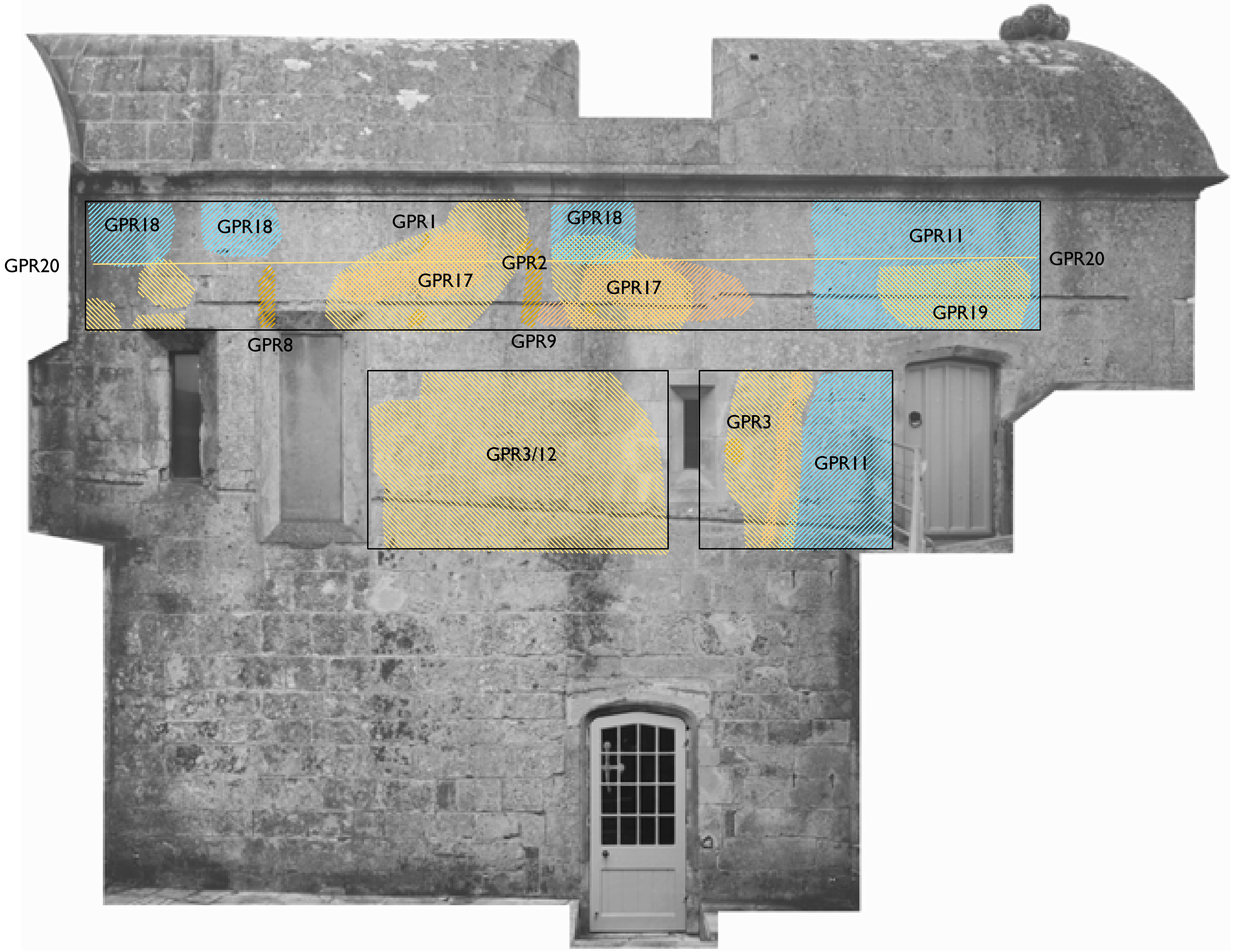
Graphical summary of significant GPR anomalies

Figure 7



0 3m

1:50

low amplitude reflectors

high amplitude reflectors

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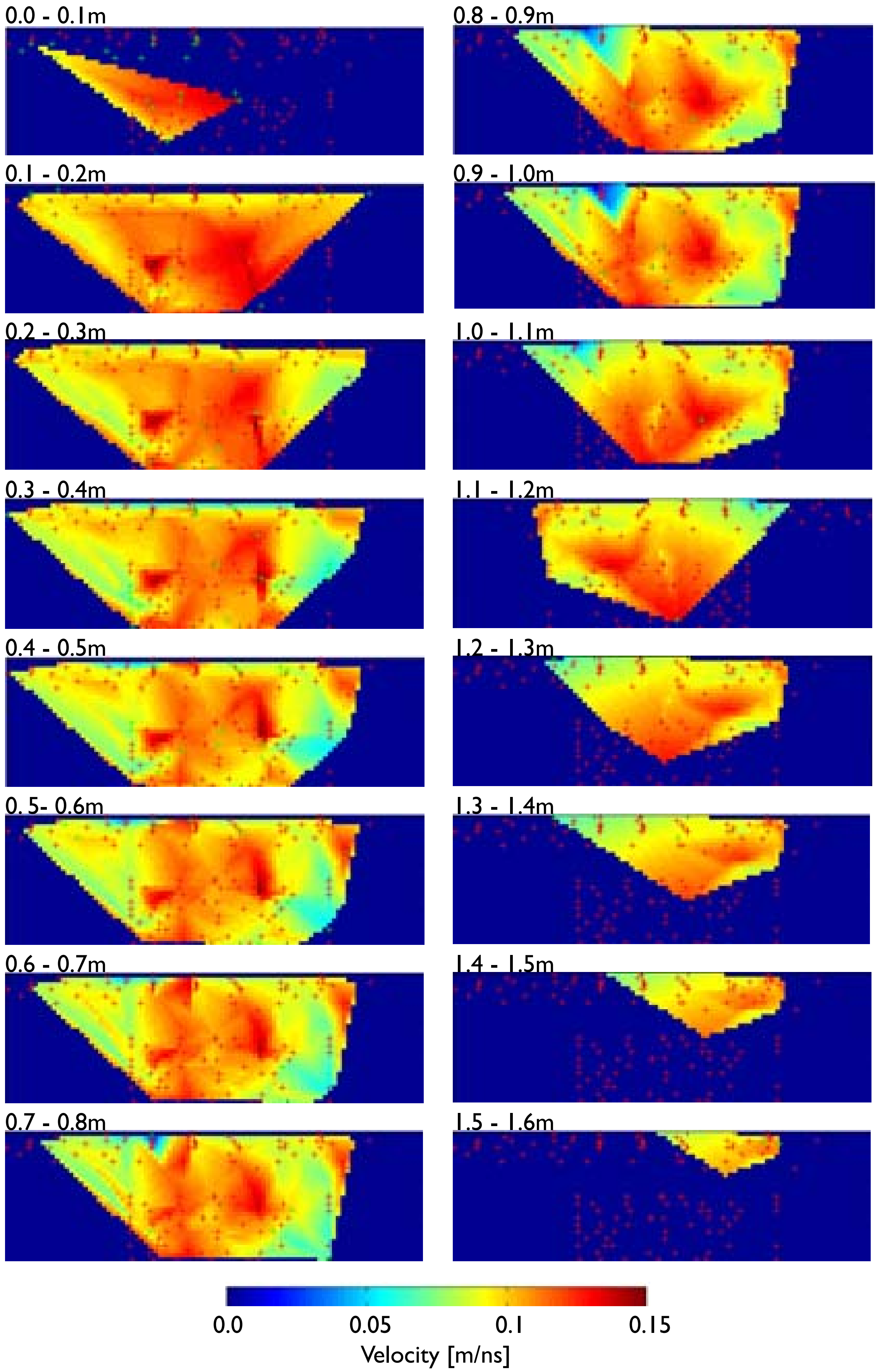
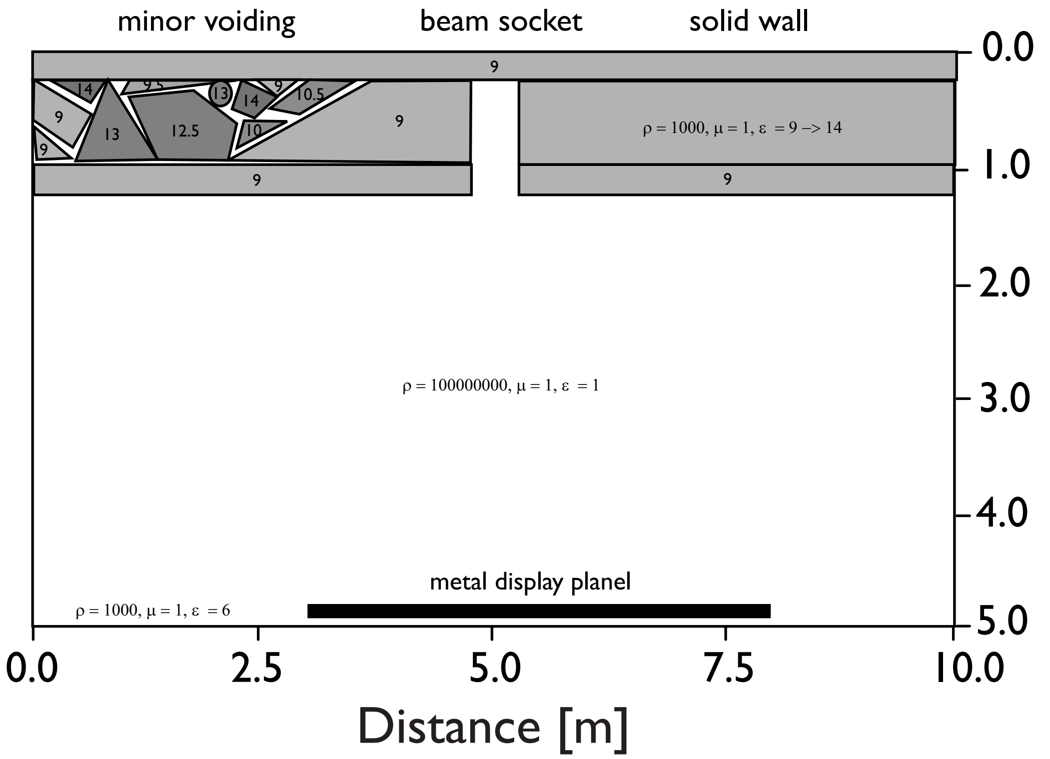
Interpolated velocity field data and Synthetic GPR model results

Figure 8

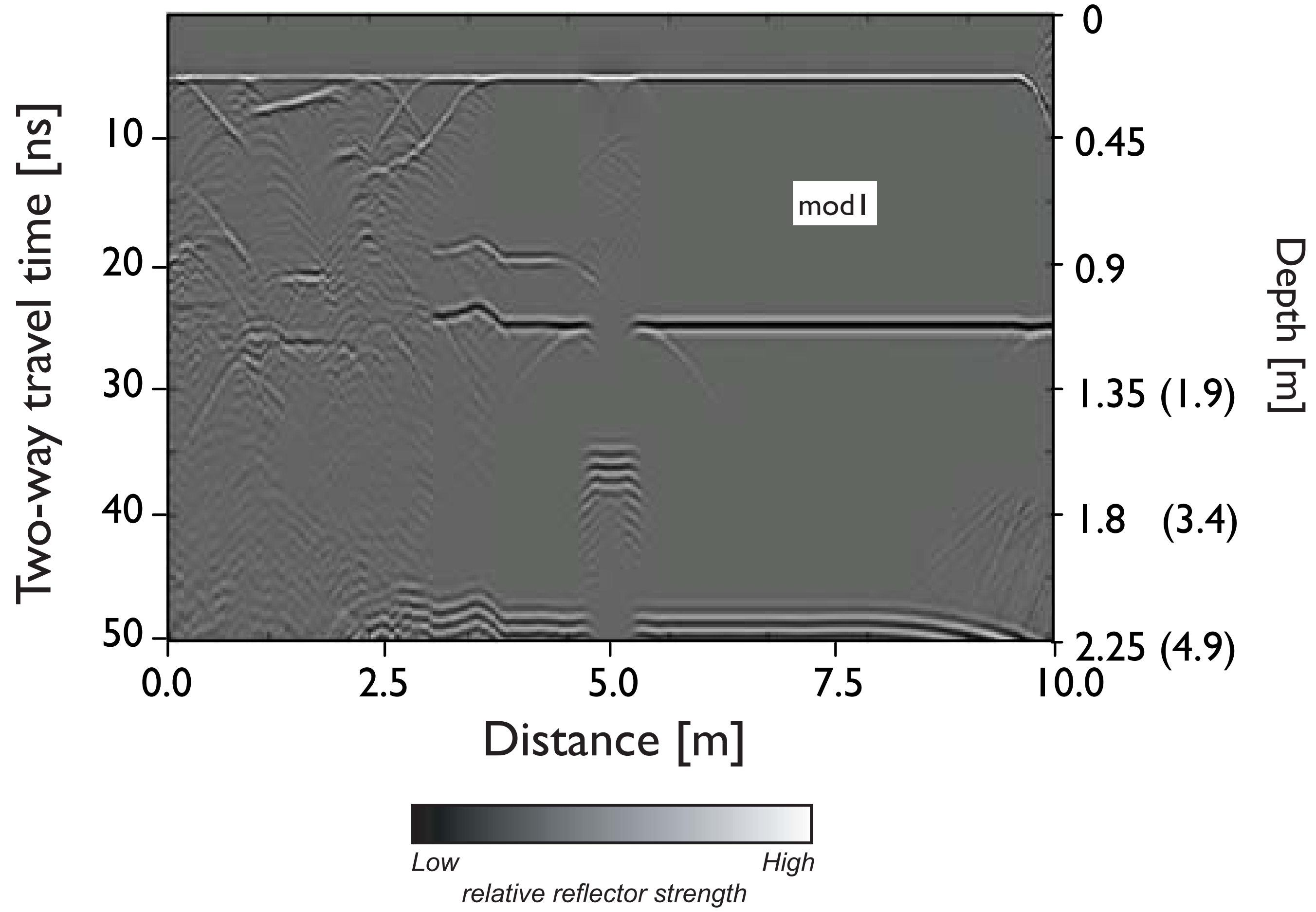
(A) Velocity field data

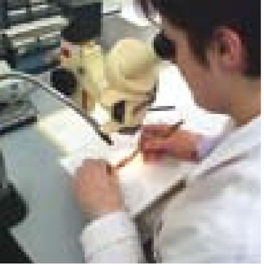
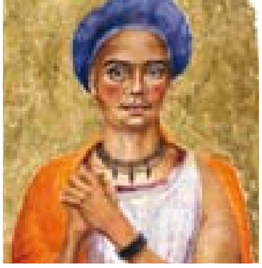


(B) Model wall section



(C) Synthetic GPR profile calculated from (A)





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