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Eltham Palace, Greenwich, Greater London

Report on Geophysical Survey, September 2023

Megan Clements and Neil Linford

Geophysics

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Summary

A Ground Penetrating Radar (GPR) survey was conducted across the North and South Lawns and the South Moat at Eltham Palace, Greenwich, Greater London. The aim of the survey (0.5ha) was to map the location and extent of partially known Tudor tunnels or drains. The results have predominantly identified the remnants of the Tudor palace, which include the royal apartments, kitchen and service buildings, in addition to the nave of the chapel. While anomalies in the vicinity of the known tunnels have been identified, these appear to be tentative and, may not, represent the tunnels themselves.

Contributors

The fieldwork was completed by Megan Clements and Neil Linford.

Acknowledgements

The authors are grateful for the help provided by colleagues from the English Heritage Trust in coordinating access for the survey to take place. The cover image shows the survey of the South Moat in progress (photo taken by Megan Clements).

Archive location

Historic England, Fort Cumberland, Fort Cumberland Road, Eastney, Portsmouth, PO4 9LD

Date of survey/research/investigation

The fieldwork was conducted between the 18th and 20th of September 2023. The report was completed on 27th October 2023.

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Introduction

A Ground Penetrating Radar (GPR) survey was conducted at Eltham Palace, Greenwich, Greater London, at the request of the English Heritage Trust. A network of brick tunnels is known under the South Lawn at Eltham Palace. Historic England Geospatial Team completed an Uncrewed Autonomous Vehicle (UAV) survey in December 2022 and produced measured drawings and rectified photographs showing the nature and partial extent of the tunnels (R Halford pers comm). However, they could not explore the full extent of the tunnels due to the nature of the confined space and difficulty in maintaining a signal with the UAV around sharp corners. A geophysical survey was subsequently requested to further assist with the mapping of the tunnels by conducting a GPR survey over the South Lawn. The South Moat was also surveyed, to determine if the tunnels drained into or beyond the moat, together with accessible areas of the North Lawn. A previous trial GPR survey conducted in 2002 proved inconclusive (N Linford pers comm).

Between the 12th and 17th centuries, Eltham Palace (National Heritage List for England: 1014833) was one of the largest and most frequented royal residences in the country during the medieval and early Tudor periods. Initially the mansion of Anthony Bek, Bishop of Durham, the palace was subsequently gifted to Edward II and it grew into a large medieval and Tudor palace with numerous building works. Eltham Palace fell in importance during the later Tudor years and into the Stuart era, before being sold in 1651 and later demolished. Over the next two centuries, Eltham was used as farmland and eventually returned to the Crown. In the late 19th and early 20th centuries, work began to restore the Great Hall under the direction of the Office of Works. In 1933 Stephen and Virginia Courtauld took out a 99-year lease from the Crown, partially demolishing the standing remains of the palace and building their new home in the ‘Wrenaissance’ style, mimicking late 17th century Renaissance architecture. The Royal Army Educational Corps took over the lease in the 1940s and continued to occupy Eltham Palace until 1992, when they too moved, and Eltham passed into the care of English Heritage.

The site lies over Woolwich Beds sand, silt and clay of the Lambeth Group formed between 59.2 and 47.8 million years ago during the Palaeogene period with no superficial deposits recorded (Geological Survey of Great Britain 1998; British Geological Society 2023). The urban soils have not been surveyed (Soil Survey of England and Wales 1983) but are listed on Soilscapes (2023) as freely draining, slightly acidic and loamy. The brick lined tunnels were observed to be air-filled and large enough to walk through but become blocked with silt.

The ground was mostly flat and comprised of well-kept lawn. Weather conditions were generally dry, before heavy rain during the last half-hour of the survey.

Method

Ground Penetrating Radar

A 3d-Radar (Kontur) MkIV GeoScope Continuous Wave Step Frequency (CWSF) Ground Penetrating Radar (GPR) system was used to conduct the survey collecting data with a hand operated multi-element DXG0908 ground coupled antenna array (Linford et al. 2010; Eide et al. 2018). A roving Trimble R8s Global Navigation Satellite System (GNSS) receiver was mounted on the GPR antenna array, that together with a second R8s base station was used to provide continuous positional control for the survey collected along the instrument swaths shown on Figure 1. The GNSS base station receiver was adjusted to the National Grid Transformation OSTN15 using the Trimble VRS Now Network RTK delivery service. This uses the Ordnance Survey's GNSS correction network (OSNet) and gives a stated accuracy of 0.01-0.015m per point with vertical accuracy being half as precise. Where tree cover compromised the use of a GNSS receiver a Trimble S7 tracking total station and active reflector prism mounted on the GPR array was used to provide continuous positional control.

Data were acquired at a 0.075m x 0.075m sample interval across a continuous wave step frequency range from 40MHz to 2.99GHz in 2MHz increments using a dwell time of 5ms. A single antenna element was monitored continuously to ensure data quality during acquisition together with automated processing software to produce real time amplitude time slice representations of the data as each successive instrument swath was recorded in the field (Linford 2013).

Post-acquisition processing involved conversion of the raw data to time-domain profiles (through a time window of 0 to 75ns), 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 full GPR survey data set are shown on Figure 3. To aid visualisation amplitude time slices were created from the entire data set by averaging data within successive 2.5ns (two-way travel time) windows (e.g. Linford 2004). An average sub-surface velocity of 0.112m/ns was assumed following constant velocity tests on the data and was used as the velocity field for the time to estimated depth conversion. Each of the resulting time slices therefore represents the variation of reflection strength through successive ~0.14m intervals from the ground surface, shown as individual greyscale images in Figures 2, 4 to 7. Further details of both the frequency and time domain algorithms developed for processing this data can be found in Sala and Linford (2012).

Results

Ground Penetrating Radar Survey

A graphical summary of significant GPR anomalies from the full time-window, [**gpr1-18**] discussed in the following text, is shown superimposed on the base OS mapping data in Figure 8.

Modern interference is mostly limited to the current east-west stone paved path [**gpr1**]. Other anomalies include metal service covers, extant garden features and tree roots [**gpr2**]. The interpretation of the data in the vicinity of the trees requires caution as these anomalies may be influenced by the response from the roots. The two grates in the South Lawn that allow access to the tunnels have also been detected [**gpr3**]. Broad diffuse anomalies due to the underlying sand deposits are found on a southwest-northeast orientation from approximately 45.0ns (2.14m) onwards across the South Lawn and Dry South Moat.

South Lawn

The GPR survey has predominantly detected the foundations of the Tudor kitchens and other service buildings [**gpr4**]. More coherent, structural anomalies suggest better preserved walls, while diffuse responses are likely to indicate floor layers or demolition debris. These structural remains are mostly found between 15.0 and 30ns (0.71 to 1.43m). When overlain with a reconstructed plan of Eltham Palace based on an original plan from 1590, a remarkable overlap is seen between the GPR anomalies and the map, particularly over the South Lawn (Figure 9) (MP/ELT0546 - Source: Historic England Archive 1935 - 1960). In addition, a high-amplitude linear reflection [**gpr5**] is likely to be the former south wing of the Great Hall visible in artwork within the house of Eltham Palace, as well as historic photographs (Plate 1).

Linear anomalies [**gpr6**] found between 0.0 and 30.0ns (0.0 to 1.43m) follow a more north-south orientation to the buildings of Tudor origin and seem likely to represent recent services or drains. Very faint reflections [**gpr7**] could either be small drains that feed into the larger tunnels, robbed-out walls, or demolition rubble related to the former service buildings. This may explain the varying response along [**gpr7**] with high-amplitude reflections suggesting in-situ brick or masonry remains compared to more highly attenuating water retentive material from a robbed-out wall or silted drain. However, [**gpr7**] are not substantial enough to be associated with the known network of larger Tudor tunnels.

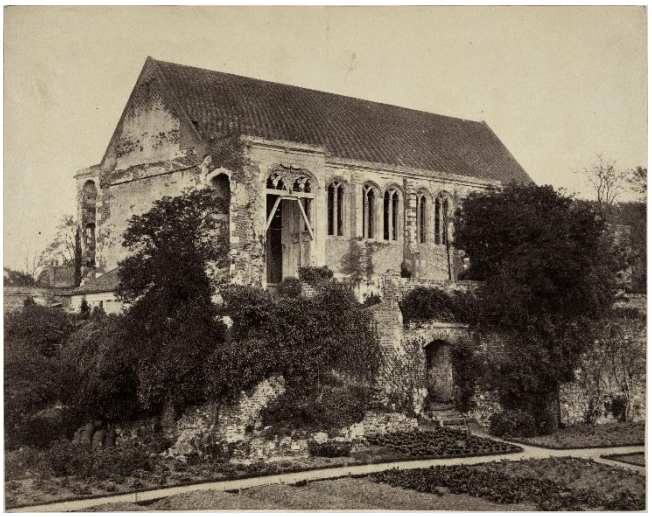

*Plate 1: View of Eltham Palace from the south-west where the south wing of the Great Hall **[gpr5]** and garden path **[gpr17]** are visible (AL2400/062/01 Source: Historic England Archive 1866)*

North Lawn

The walls and possible flooring of the former Royal Apartments have been detected at [**gpr8**], and the large spread of diffuse material is likely to be a result of the back-fill from the extensive excavations that took place in the 1970s (Wood 1982). A large diffuse anomaly [**gpr9**] found in the near-surface between 0.0 and 15.0ns (0.0 to 0.71m), correlates with the location of the chapel nave and towers shown on the 1590s plan. Additional spreads of diffuse anomalies [**gpr10**] further to the north correspond with a linear boundary shown on the modern Ordnance Survey (OS) base map. Historic mapping suggests this was the location of additional buildings (OS Historic County Mapping Series: Kent 1843-1939 Epochs 1, 2 and 3), and [**gpr10**] is likely to represent either the footprint of these structures or back-filled trenches from the 1970s excavations. The OS historic mapping also depicts a small building to the north of the north entrance to the Great Hall in the vicinity of a diffuse high-amplitude anomaly [**gpr11**]. This building has also been recorded in a photograph from 1913 (FL01211/10/006 - Source:Historic England Archive 1913).

A linear anomaly [**gpr12**] appears to originate from an inspection cover and correlates with a rain water drain recorded on a plan of the drainage of Eltham Palace ‘by Smeaton & Sons Ltd’ (MP/ELT0482 - Source: Historic England Archive 1936). The anomaly [**gpr12**] is quite diffuse, likely responding to the cut trench rather than the drain itself. While [**gpr13**] shares a similar northeast-southwest orientation to [**gpr12**], it does not appear to align with any drains on the Smeaton & Sons Ltd design plan and no inspection covers were observed. However, the continuous high-amplitude response from [**gpr13**] suggests a modern buried utility.

Dry South Moat

High-amplitude reflections [**gpr14**] have been detected around the present bridge piers, possibly remnants of a former bridge in the same location as the current structure. Two parallel linear anomalies [**gpr15**] are found immediately to the west of the bridge possibly associated with a more discrete, near-surface response [**gpr16**] that continues to between 45.0 and 60.0ns (2.14 to 2.85m). The deeper reflections associated with [**gpr16**] could be due to the reverberation or “ringing” from a compacted near-surface layer, but it does suggest [**gpr16**] has quite substantial dimensions and may be connected with a feature shown on aerial photography found in this location (Aerial Photo - RAF_106G_UK_1356_V_5442 - Source: Historic England Archive 1946). It could, therefore, be suggested that [**gpr15**] and [**gpr16**] are the foundations of another former bridge, possibly the privy bridge that connected the royal apartments to the gardens.

Further to the west a high-amplitude linear anomaly [**gpr17**], is present throughout the data set. The reflection aligns with a former garden path observed in a photograph taken of the Dry South Moat and Great Hall in 1866 (Plate 1). The response of [**gpr17**] appears in the very near-surface data and has also been recorded through parch marks developed during very dry summers (Aerial Photo - 27170_007 - Source: Historic England Archive 2010).

Synthetic GPR model

Figure 3 (inset) shows the results of a synthetic model based on the approximate dimensions and likely depth of burial of the Tudor tunnels. Appropriate dielectric parameter values were chosen for the background soil, brick work with models created to simulate air, silt and soil-filled void spaces. The most distinctive synthetic anomaly is generated by the air-filled void and is similar to the response of [**gpr7**] in the proximity of the access grate, and the individual, discrete anomaly [**gpr18**]. However, there are few, if any, similar anomalies beyond the location of the known tunnels.

Conclusions

The ground penetrating radar survey has successfully detected remains of the Tudor palace associated with the royal apartments, kitchen and other service buildings. The nave of the chapel has also been identified and the possible location of the privy bridge suggested. While linear anomalies in the vicinity of the known tunnels have been identified, these are extremely tentative and do not appear to represent a response from the tunnels themselves.

List of Enclosed Figures

Historic England Archive Information Consulted

Reference	*Title*	*Year*	*URL*
AL2400/062/01	View of King John's Palace at Eltham, from the south-west	1866	https://historicengland.org.uk/images-books/photos/item/AL2400/062/01
MP/ELT0482	Copy of the final drainage plan at Eltham Hall by Smeaton & Sons Ltd	1936	https://historicengland.org.uk/images-books/photos/item/MP/ELT0482
MP/ELT0545	Copy of a plan of Eltham Palace by John Thorpe	1590	https://historicengland.org.uk/images-books/photos/item/MP/ELT0545
MP/ELT05046	Plan of Eltham Palace based on the drawing by John Thorpe	1935 - 1960	https://historicengland.org.uk/images-books/photos/item/MP/ELT0546
MP/ELT1153	Annotated copy of a plan of Eltham Palace showing areas for excavation and the tunnels	Early 20th century	https://historicengland.org.uk/images-books/photos/item/MP/ELT1153
FL01211/06/001	Exterior view of the south bay of the Great Hall from the south during repairs	1911 - 1914	https://historicengland.org.uk/images-books/photos/item/FL01211/06/001
FL01211/10/006	Exterior view of the north elevation of the Great Hall from the north showing the completed renovations	1913	https://historicengland.org.uk/images-books/photos/item/FL01211/10/006
Aerial Photo - RAF_106G_UK_1356_V_5442		1946	https://historicengland.org.uk/images-books/archive/collections/aerial-photos/record/RAF_106G_UK_1356_V_5442
Aerial Photo - 27170_007		2010	https://historicengland.org.uk/images-books/archive/collections/aerial-

			photos/record/27170_007

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Historic England Archive 1866 AL2400/062/01 View of King John's Palace at Eltham, from the south-west.

Historic England Archive 1913 FL01211/10/006 Exterior view of the north elevation of the Great Hall from the north showing the completed renovations.

Historic England Archive 1935 - 1960 MP/ELT05046 Plan of Eltham Palace based on the drawing by John Thorpe

Historic England Archive 1936 MP/ELT0482 Copy of the final drainage plan at Eltham Hall by Smeaton & Sons Ltd.

Historic England Archive 1946 Aerial Photo - RAF_106G_UK_1356_V_5442, April 2, 1946.

Historic England Archive 2010 Aerial Photo - 27170_007, Flight 2829, 28 July 2010.

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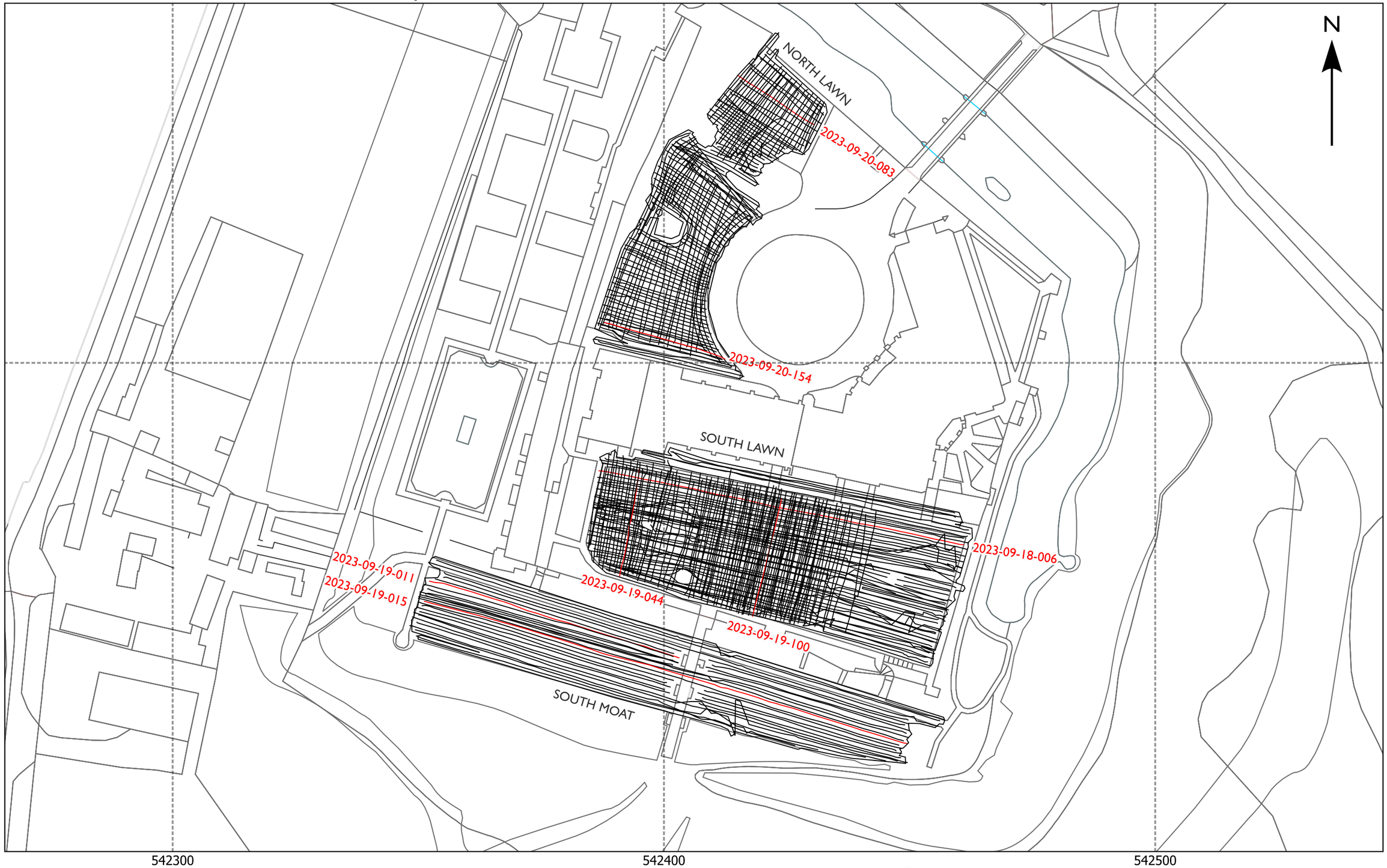
ELTHAM PALACE, GREENWICH, GREATER LONDON

Figure 1

Location of GPR instrument swaths, September 2023



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1:750

GPR Survey Swaths

Location of selected GPR profiles shown on Figure 3

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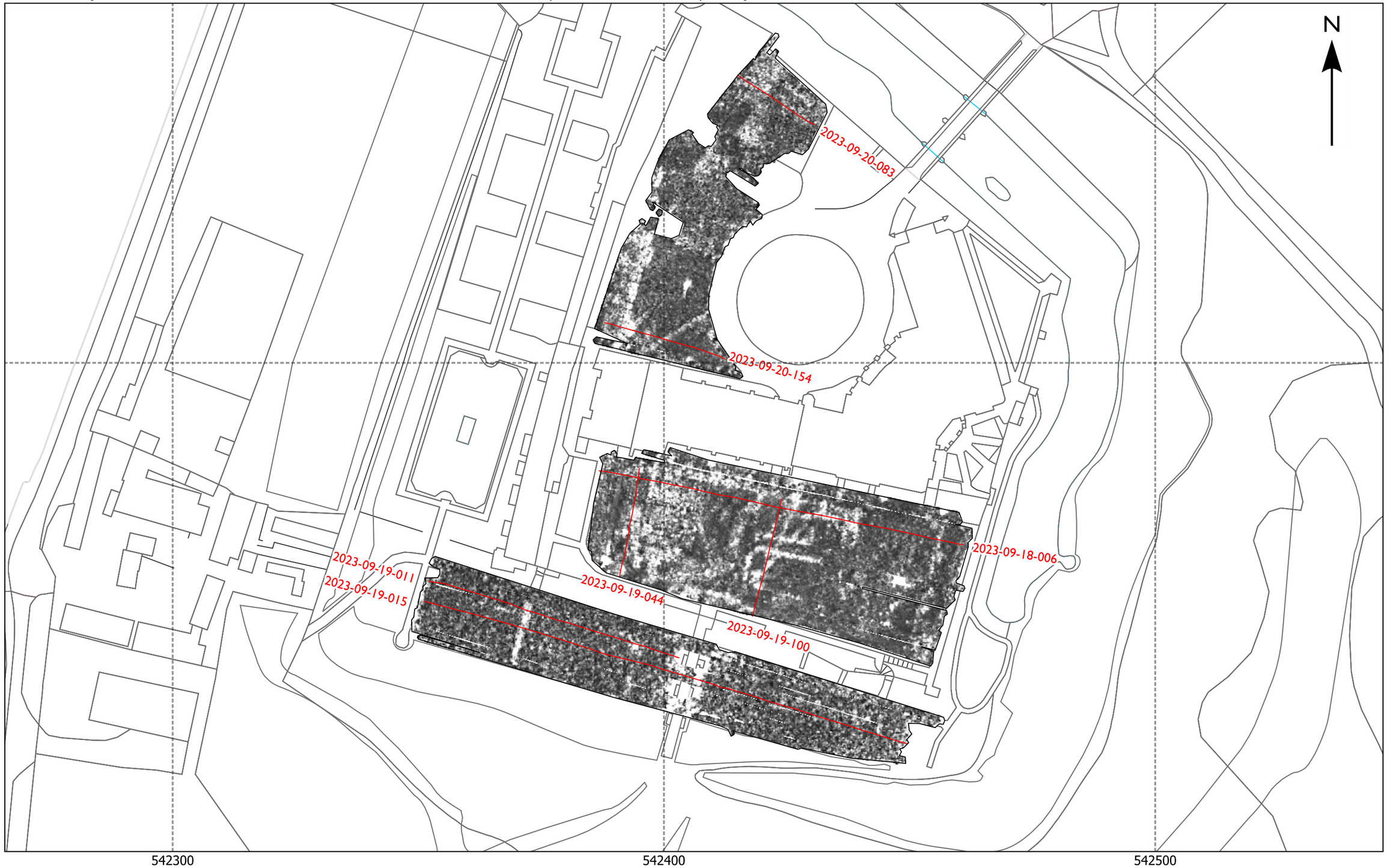
Figure 2

GPR amplitude time slice between 15.0 and 17.5ns (0.71 to 0.83m), September 2023



0 25 50 75 m

1:750

Low High
relative reflector strength

Location of selected GPR profiles shown on Figure 3

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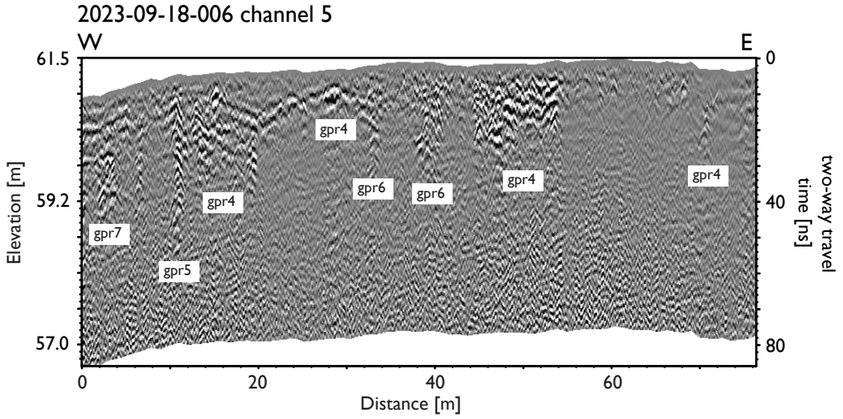
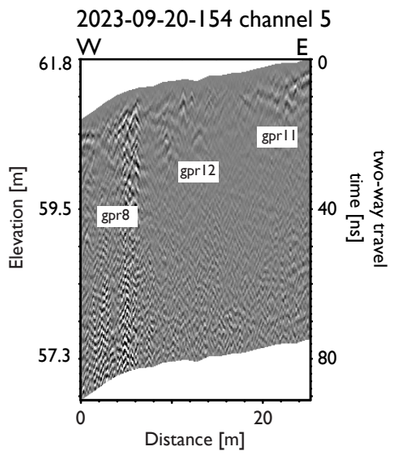
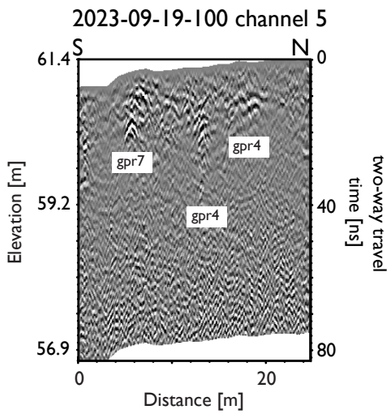
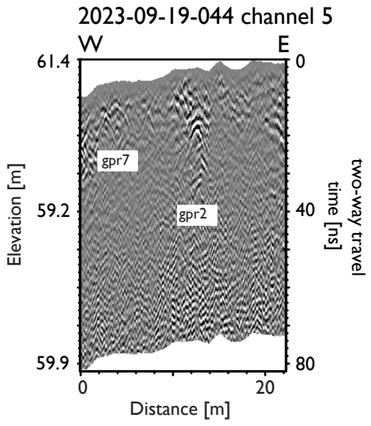
Representative topographically corrected GPR profiles, September 2023

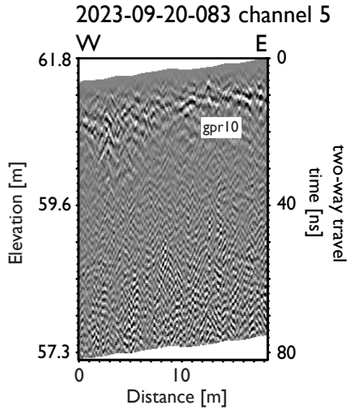
Figure 3

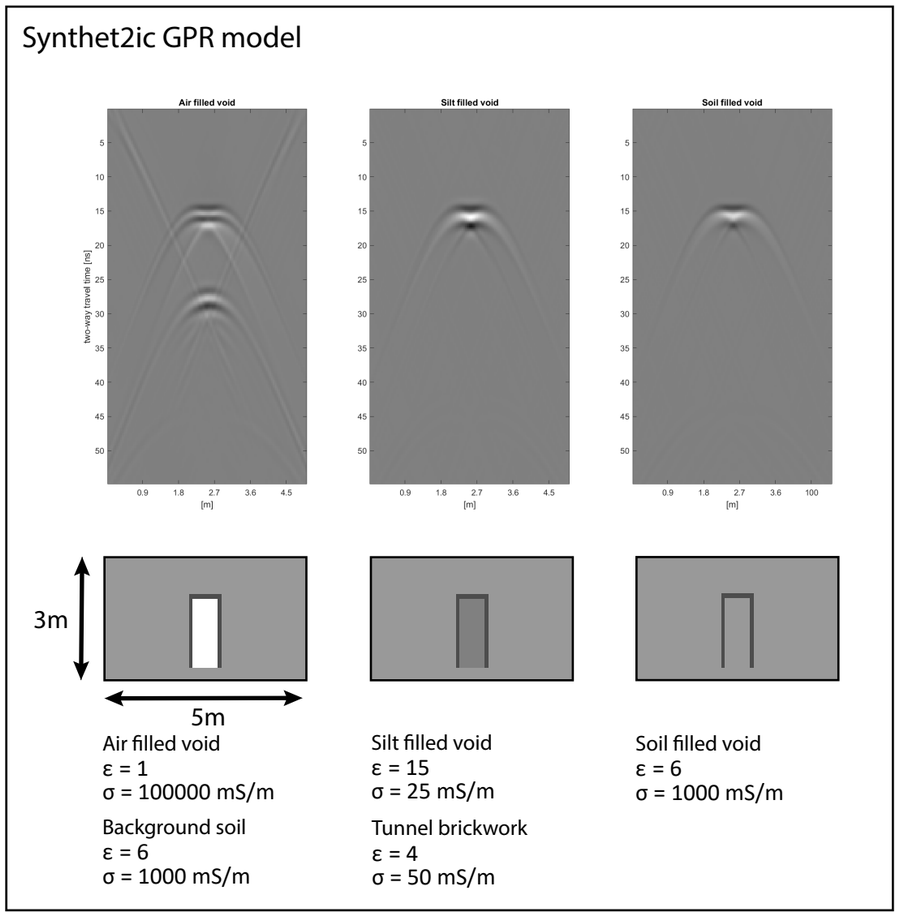


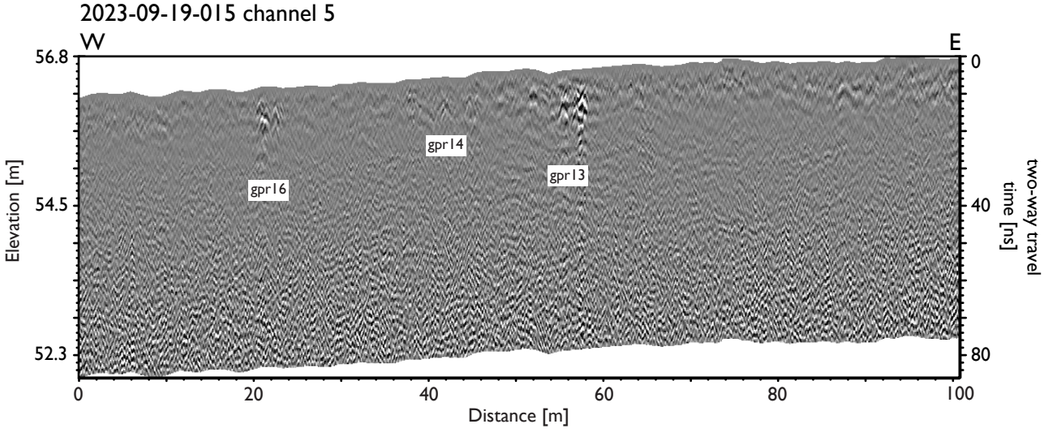












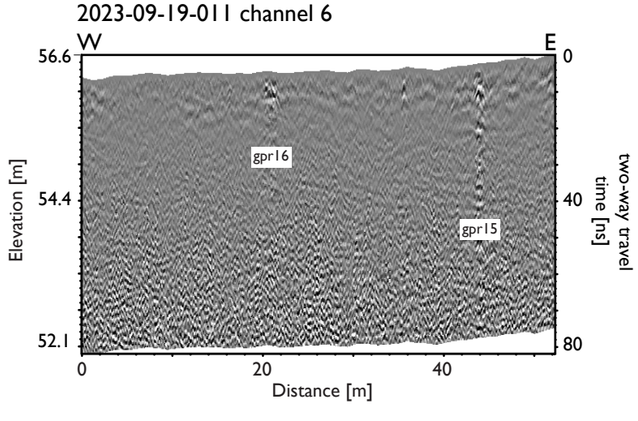


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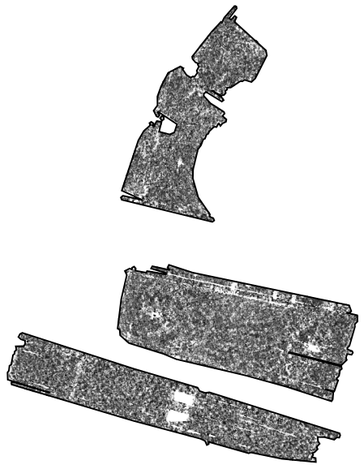
Figure 4

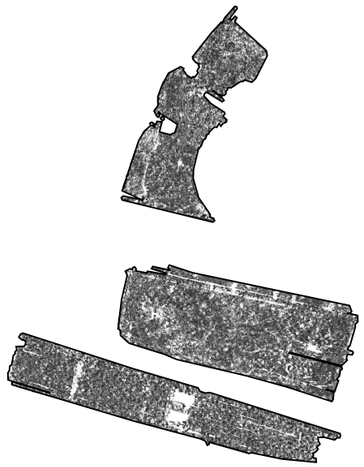
GPR amplitude time slices between 0.0 and 15.0ns (0.0 to 0.71m), September 2023

N

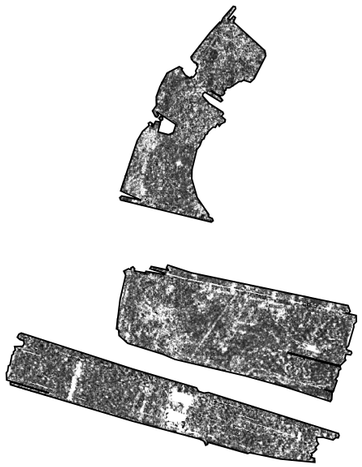
0.0 - 2.5ns (0.0 - 0.12m)



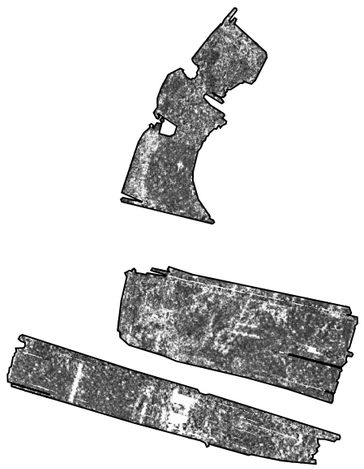
2.5 - 5.0ns (0.12 - 0.24m)



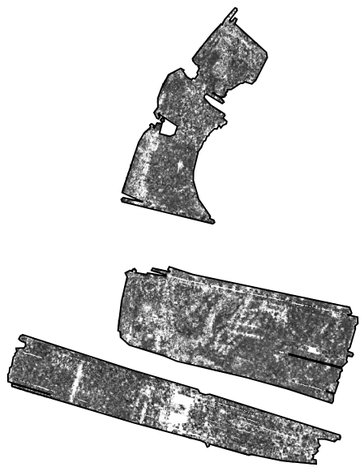
5.0 - 7.5ns (0.24 - 0.36m)



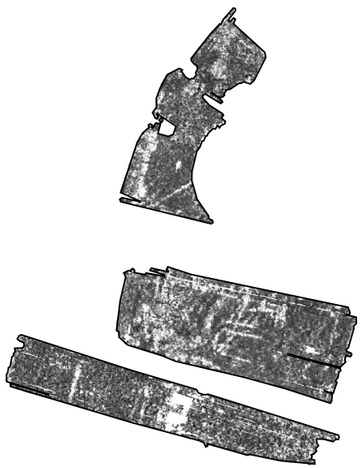
7.5 - 10.0ns (0.36 - 0.47m)



10.0 - 12.5ns (0.47 - 0.59m)



12.5 - 15.0ns (0.59 - 0.71m)



0 25 50 75 m

1:2,000

Low High

relative reflector strength

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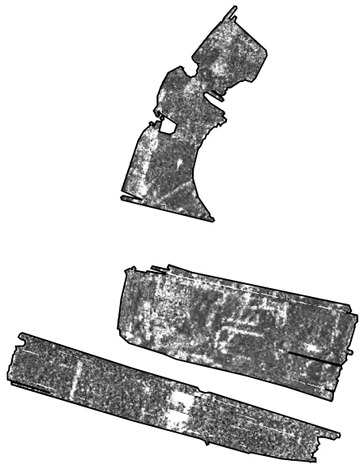
Figure 5

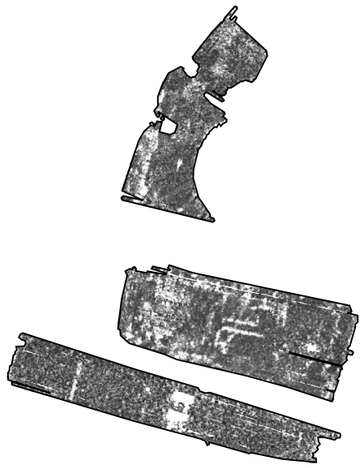
GPR amplitude time slices between 15.0 and 30.0ns (0.71 to 1.43m), September 2023

N

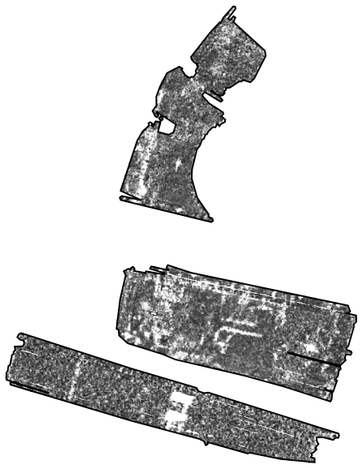
15.0 - 17.5ns (0.71 - 0.83m)



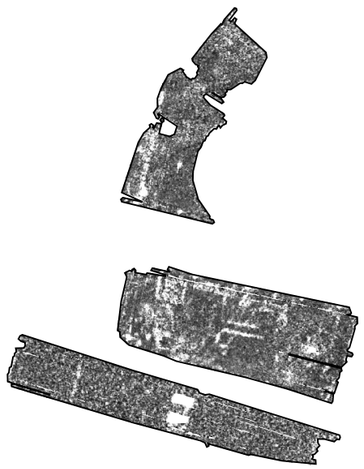
17.5 - 20.0ns (0.83 - 0.95m)



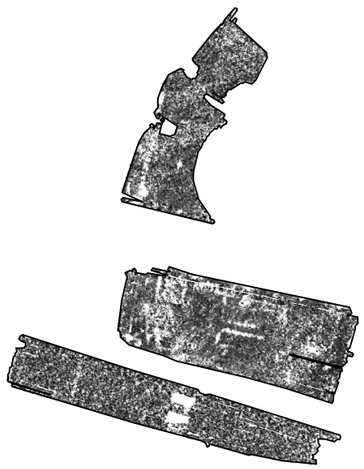
20.0 - 22.5ns (0.95 - 1.07m)



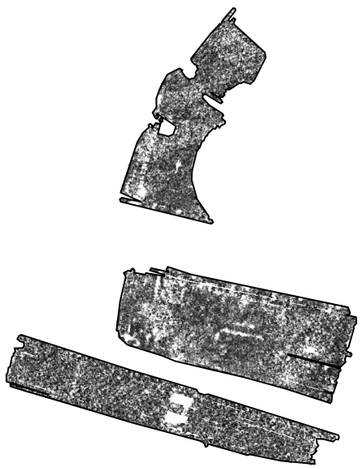
22.5 - 25.0ns (1.07 - 1.19m)



25.0 - 27.5ns (1.19 - 1.31m)



27.5 - 30.0ns (1.31 - 1.43m)



0 25 50 75 m

1:2,000

Low High

relative reflector strength

Geophysics Team 2023

Historic England

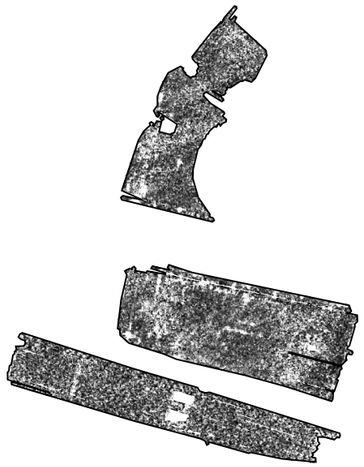
ELTHAM PALACE, GREENWICH, GREATER LONDON

Figure 6

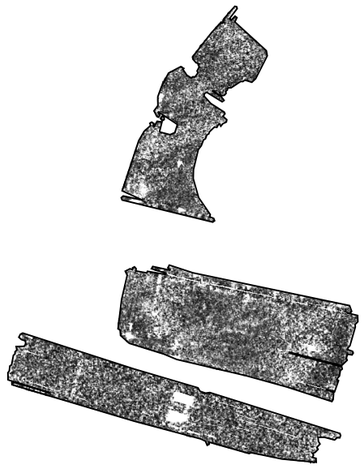
GPR amplitude time slices between 30.0 and 45.0ns (1.43 to 2.14m), September 2023

N

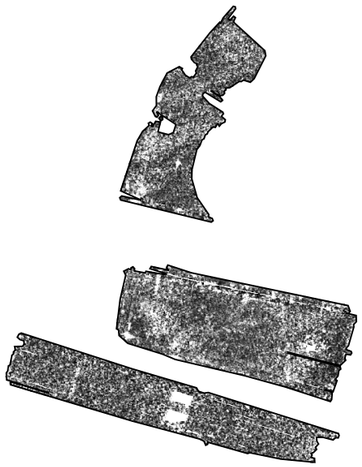
30.0 - 32.5ns (1.43 - 1.54m)



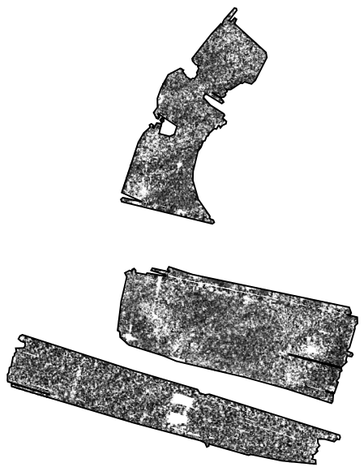
32.5 - 35.0ns (1.54 - 1.66m)



35.0 - 37.5ns (1.66 - 178m)

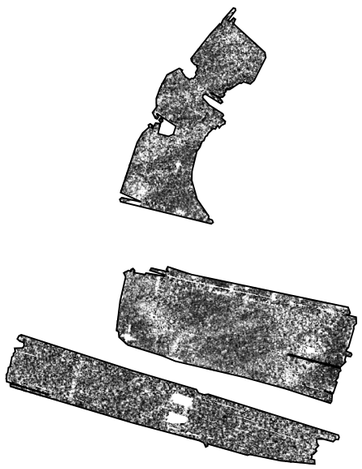


37.5 - 40.0ns (1.78 - 1.90m)



40.0 - 42.5ns (1.90 - 2.02m)

42.5 - 45.0ns (2.02 - 2.14m)



0 25 50 75 m

1:2,000

Low High

relative reflector strength

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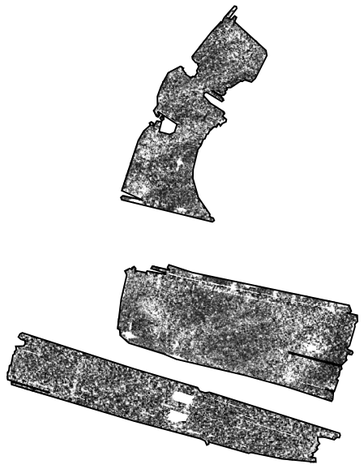
Figure 7

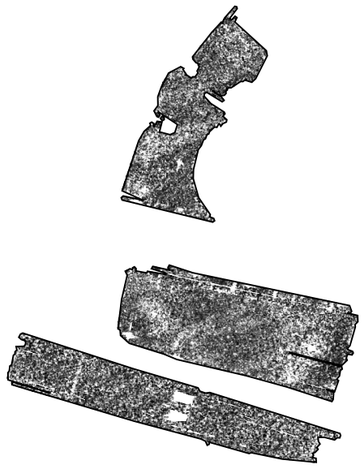
GPR amplitude time slices between 45.0 and 60.0ns (2.14 to 2.85m), September 2023

N

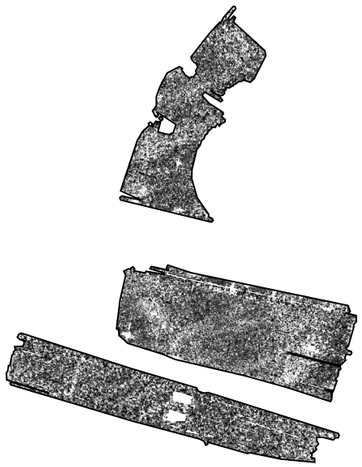
45.0 - 47.5ns (2.14 - 2.26m)



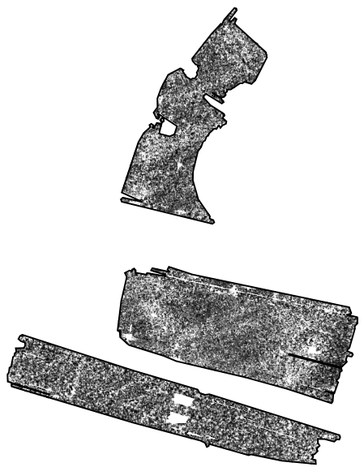
47.5 - 50.0ns (2.26 - 2.38m)



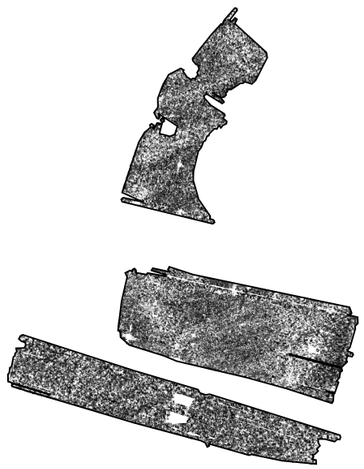
50.0 - 52.5ns (2.38 - 2.49m)



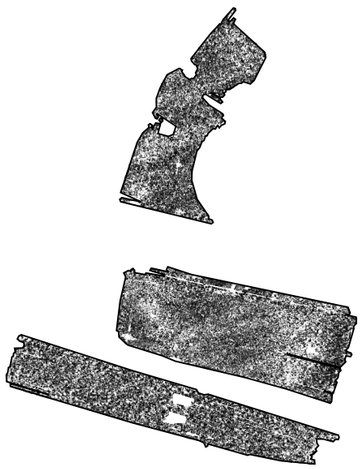
52.5 - 55.0ns (2.49 - 2.61m)



55.0 - 57.5ns (2.61 - 2.73)



57.5 - 60.0ns (2.73 - 2.85m)



0 25 50 75 m

1:2,000

Low High

relative reflector strength

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Figure 8

Graphical summary of significant GPR anomalies between 0.0 and 60.0ns (0.0 to 2.85m), September 2023

0 25 50 75 m

1:750

High Amplitude Reflectors 0.0 - 60.0ns

High Amplitude Reflectors (diffuse) 0.0 - 60.0ns

Low Amplitude Reflectors 0.0 - 60.0ns

Anomalies of Known or Recent Origin 0.0 - 60.0ns

Location of selected GPR profiles shown on Figure 3

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Figure 9

Graphical summary of significant GPR anomalies between 0.0 and 60.0ns (0.0 to 2.85m) overlain on 1590s plan, September 2023

0 25 50 75 m

1:750

High Amplitude Reflectors 0.0 - 60.0ns

High Amplitude Reflectors (diffuse) 0.0 - 60.0ns

Low Amplitude Reflectors 0.0 - 60.0ns

Anomalies of Known or Recent Origin 0.0 - 60.0ns

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