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Cardigan Castle, Castell Aberteifi, Ceredigion

Geophysical Survey Report
(Electrical resistance and ground penetrating radar – Archaeology)

Version 1.0

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Cardigan Castle, Castell Aberteifi, Ceredigion

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Non-Technical Summary

A survey was commissioned by Cadwgan Building Preservation Trust to prospect for buried features of potential archaeological interest within Cardigan Castle using GPR (ground penetrating radar) and electrical resistance techniques.

The overall aim was of improving knowledge of the below-ground remains of the castle, with specific objectives of locating the curtain wall and ditch in various locations, investigating the towers, and the state of landscaping and potential structures within the castle.

Little evidence for structures relating to the castle was detected, with the exception of additional parts of known structures. The interior of the castle was clearly landscaped to form the grounds of Castle House, which seems to have included burial of most of the eastern defences and southern areas of the Ward, though elsewhere some truncation of at least central areas is expected and north of the castle, within the garden area, the medieval topography is potentially no longer extant. In general the deepest filled areas are against the eastern medieval defences, including within the mural and southern towers, and to between 80 and 100 cm bgl in approximate terms. That there is intact medieval structure, including probable floors, below this material is beyond doubt.

A wall on the putative line of the curtain was detected crossing the entrance lane and adjacent cottage, with a probable continuation beneath the edge of the courtyard to the east of that. The North Bastion appears to have projected northeast from the line of the medieval curtain wall, assuming this was indeed the function of another fairly thick wall found in the GPR data.

The location of the rear wall of the Mural Tower is now known and also that the whole tower has been filled, after disuse, with rubble. The floor of a room apparent at the present ground level is buried, and below that opens a small chamber from which the arrow slit lower down the tower was accessible. The line of the medieval curtain has been confirmed towards the back of the South Tower and it would appear that the tower projected as much as 6 m from the wall, with the interior appearing instead to be full of soil.

A thick masonry structure found beneath the northern end of the Orchard would be a good candidate for a curtain wall of an outer ward, especially given that this seems to continue the line of another thick wall that now bounds the Kitchen Garden. Within the Kitchen Garden itself nothing of relevance to the castle was detected. The castle ditch around the Great Tower was seen a few metres to the west in a separate test GPR profile west of the tower, and this may confirm the southern end of the Orchard terrace as the edge of the ditch.

There is unexpected evidence for what may be a pre-castle phase of use of the promontory, in the form of a wide and likely rock-cut ditch entering the Ward from the west. Although the geophysical surveys cannot provide evidence for a date, a prehistoric defensive work is possible.

Table of Contents

1 Introduction

A survey was commissioned by Cadwgan Building Preservation Trust to prospect for buried features of potential archaeological interest, with a focus upon the core of Cardigan Castle.

The overall aim was of improving knowledge of the below-ground remains of the castle, with specific objectives of locating the curtain wall and ditch in various locations, investigating the towers, and the state of landscaping and potential structures within the castle.

This report describes the work undertaken using a Mala GPR GX450HDR system, Geoscan Research RM15A with multiplexer, and a separate Leica GNSS receiver used to establish absolute positioning of the GPR profiles on Ordnance Survey grid. It presents the results of the survey with an interpretation informed by the best available information at the time of writing.

The largest part of the survey area is the castle ward, including extensions into the towers, and down the northern drive. Also other small areas were investigated, including the entrance lane and inside the adjacent cottage, the courtyard east of this, the vinehouse, and the orchard to the north of Castle House. Additional individual traverses were also collected in the gardens to the north of Castle House. Whereas GPR was used in all these areas, the electrical resistance survey was limited to the grassed areas in the castle ward and the orchard.

2 Context

2.1 Location

Cardigan Castle is prominently located in the centre of the present town on the north bank of the Teifi estuary opposite the bridge.

Country	Wales
County	Ceredigion
Nearest Settlement	Aberteifi / Cardigan
Central Co-ordinates	217780, 245920

2.2 Environment

The below information is taken from the British Geological Survey (BGS), modern and historic mapping and aerial imagery and provides a basic summary of the survey area.

Soilscapes Classification	Slowly permeable seasonally wet acid loamy and clayey soils [17]
Superficial 1:50,000 BGS	None recorded for the majority of the site Till, Devensian (Irish Sea Ice) – Diamicton [TILDI] in north
Bedrock 1:50,000 BGS	Nantmel Mudstones Formation – Mudstone [NTM]
Topography	Promontory site, slopes down to northeast, east and south
Current Land Use	Recreational, historic site
Historic Land Use	Gardens
Vegetation Cover	Mown grass and hard surfaced areas

2.3 Archaeology

Cardigan Castle is designated as a scheduled monument (Ref. CD123) and has Grade II listed gardens (Ref. PGW72). The medieval castle with the tower incorporated into a later Georgian House are both Grade I listed buildings and there are an additional six Grade II* listed medieval and later structures within its curtilage.

The summary description and the reason for designation of the castle (by CADW) provides a general description of the scheduled monument and states:

"The monument comprises the remains of a Medieval castle built by the Norman lord, Gilbert de Clare around 1110. The castle is located at the southern end of the town of Cardigan, on a rocky spur overlooking the river Teifi. Below the castle, the ground drops precipitously to the east and south.

Lord Rhys captured the castle for the Welsh in 1164 and rebuilt it in stone in 1171, although nothing remains of this earlier phase. By 1240 Walter Marshal, brother of the earl of Pembroke captured and rebuilt the castle, however a major phase of rebuilding took place in about 1244-54 under Robert Waleran, who became constable in 1248. Most of the medieval fabric that remains probably dates to this period. A keep on the north curtain wall was built in 1246-52 (completed in about 1261) and three towers were built in the south-east, east and north of the site. The outer ward is roughly oval in plan enclosing approximately 3 acres. In 1279 Edward III made the castle the administrative centre for the new shire of Cardigan.

Further repairs and building works continued into the fourteenth century, but after this the castle appears to have been neglected. By 1343 the curtain wall was in ruins and by 1610 the Great Tower (north tower), was partially ruined. Excavations in 1984 revealed that there had been a ditch, 7m wide, north of the tower, with a counterscarp bank about 7m wide and 1.5m high. In the Civil War the castle was damaged further during a siege of Cardigan by Parliamentarian forces in December 1644; the curtain wall between the east and south-east towers was partially destroyed.

The monument is of national importance for its potential to enhance our knowledge of Medieval social, domestic and political life and warfare. Notably, the first Eisteddfod was hosted here in 1176."

Castle Green House was built in the early 1800s and a front range was added in 1827. The castle grounds were landscape during this time and the summary description from the Register of Parks and Gardens in Wales (maintained by CADW) states that:

"Registered for the survival of most of the structure, and some planting, of an interesting and unusual Regency period garden, set within the medieval castle ward. The ward was extensively altered and adapted to accommodate and enhance the garden, providing a romantic setting to Castle Green House. The grounds incorporate a pleasure garden and a kitchen garden. The registered garden has group value with Castle Green House (LB: 10459), Cardigan Castle (LB: 10458; scheduled monument: CD123) and the outbuildings at the rear entrance drive to Castle Green House (LB: 10461).

Castle Green House is a substantial, Regency period house in an unusual setting, situated within the ward of Cardigan Castle. The house stands on the north edge of the medieval castle, and its north end incorporates the castle's north tower, which projects beyond the line of the curtain wall. The castle itself is situated at the southern end of the town of Cardigan, on a rocky spur overlooking the river Teifi, to the south.

The first mention of Castle Green House is in 1799, when John Bowen (d. 1815) was leasing it to Thomas Colby. Samuel Meyrick, in The History and Antiquities of the County of Cardigan (1808), indicated that Bowen began the building of the house: '… John Bowen, Esq. who is erecting a house on the site of the keep, the dungeons now serving as his cellars'. Bowen levelled the ward, filled in the ditch around the north tower and generally raised the level of the ward quite considerably. Excavations in 1984 revealed that medieval archaeological deposits are buried under up to 2m of topsoil. The house took on its present form in 1827, when the owner, Arthur Jones, a solicitor and high-sheriff of Cardiganshire, began building a new front range; he also altered and added a storey to the north tower. The architect and master builder was David Evans of Eglwyswrw. Sale particulars of 13 July 1832 described a 'Capital modern mansion' and Samuel Lewis in 1833 called it 'a handsome modern villa'. It is shown in its present form on Wood's map of 1834. The property was bought by David Davies of Carnarchenwen, Fishguard, in 1836. Davies was a wealthy man, founder of the Cardigan Mercantile Company and high-sheriff of the county in 1841. An engraving of the house in Thomas Nicholas's Annals and Antiquities of the Counties and County Families of Wales, vols I and II (1872) shows the house much as it is now.

The gardens of Castle Green House, situated both within and without the walls of the medieval castle of Cardigan, date from the Regency period. The house was built as a prestigious, well-appointed residence, requiring an attractive and appropriate setting of fashionable gardens, grand entrance, drives, coach house and stabling. The castle ward and its immediate surroundings were altered and adapted to provide all of these features. The resultant early nineteenth-century overlay, within the medieval castle, combines elements with two very different purposes: defensive strength and aesthetic pleasure, and so providing an informal romantic setting to the house.

The first phase of landscaping within the castle seems to have been in 1713 in order to create a level terrace, used at least some of the time as a bowling green. This was followed in 1801–15 by a major phase of landscaping under the ownership of John Bowen that created most of the garden layout as it exists today. The entire former ward of the medieval castle was laid out as ornamental gardens. The curtain wall itself was adjusted, punctured, and in places demolished or rebuilt to suit the needs of the garden. The garden was laid out in a mainly informal way, with a central lawn, circuit and side paths and informal planting. An unusual feature is a whale jawbone arch.

To the north, walled garden compartments of various functions were laid out just outside the ward. To the north-east and east are further compartments, including the stables courtyard. The kitchen garden lies to the north of the house. Against the east wall of this area is the Gardener's House (Ty'r Ardd), a small, two-storey stone building built in about 1808 by John Bowen to provide staff accommodation.

The entire complex fell into disrepair and ruin during the twentieth century. In 2003 the castle, including the house, was bought by Ceredigion County Council. Since 2011, a comprehensive programme of repair and restoration has taken place and the site is now open to the public."

2.4 Previous archaeological work

There have been multiple episodes of intrusive ground investigations within the castle between 1984 and 2014. A summary of the work undertaken by the Dyfed Archaeological Trust in 1984 and 2003, and work jointly undertaken by NPS Archaeology and Archaeology Warwickshire in 2012-14, has been viewed by TigerGeo during fieldwork.

The trenches and test pits have confirmed that a range of medieval and post-medieval structures, features and deposits survive below the later landscaping at a depth of approximately 0.5m below the current ground surface. The features include substantial ditches and banks, walls, surfaces and a depth of stratified post-medieval and medieval deposits. The trenches and test pits have also confirmed that in areas of the grounds, garden soil overlies natural sand deposits.

Text documents summarising the history of the castle, including Listing descriptions and known interventions, plus photographs of excavated structures, have been kindly provided by Glen Johnson.

3 Discussion

3.1 Positioning

Geo-location of all survey areas was undertaken using a Leica GNSS with a RTK fix from the UK SmartNet network of correction stations. Each area of resistance survey was formed according to a grid of points established by GNSS, and likewise the panels of individual GPR profiles. Some profiles, e.g. in the Kitchen Garden, were individually surveyed in using GNSS.

A model of the basic landform was formed from a loose scatter of GNSS measurements and is presented as DWG 02. This is not intended as a detailed topographic survey of the site and is merely to capture the broad shape of the ground as context for geophysical measurements.

3.2 Previous excavations

Although reference has been made to summary notes of various trenches excavated over the years, individual correlations with the data have not been sought except in specific cases, due in part to slight ambiguities of their recorded positions and contents. In any case, only a small number are usefully associated with the areas surveyed. Many have been small-scale and hence whether identifications of natural clay soils or bedrock have more general application is in many cases uncertain. For this reason, depths quoted in connection with the GPR data are computed from wave propagation velocities determined for the site to provide a single overall framework; as such, they may differ slightly from depths reported by excavations at any particular point.

3.3 Geology, soils and hydrology

It has not been possible to rationalise some of the summaries of the descriptions of deposits in trenches with the GPR data, e.g. the finding of natural clayey soil where the GPR suggests rock and the lack of buried surfaces where GPR indicates strongly reflective strata typical of these. A significantly more detailed (and time consuming) study that incorporated these trenches into a full 3D interrogation of the data might resolve these ambiguities.

The suggested depths to 'original ground surface' plotted as contours in the literature seem, on the basis of the GPR data, unlikely to be correct, the bedrock surface being irregular and the degree of truncation during 19^{th} century landscaping being unknown. Some of these identifications of 'original' include bedrock, others clays and gravels and the GPR data would suggest a more complex model should apply.

A strong basal reflector seen throughout the Ward is logically rockhead; the small number of small discrete reflections just below this, plus some small areas of fill-like texture, seem likely to be due to weathered material. The surface of this reflector is irregular and sometimes stepped, implying a degree of inclined bedding and jointing. This, and the presence of artificial surfaces sometimes close overlying it, makes identification locally difficult.

3.4 GPR data character

The GPR data is widely variable across the site with areas of only shallow soils and minimal penetration into the underlying rock and areas of deep fills, the base of which was not always detected due to wave attenuation from the varied material within the fills. It has not been possible in plan to distinguish walls from rubble fills and likewise the identification of masonry in the profile data is locally problematic given the number of different fills and textures imparted to the data. Most of the fragments of buried surfaces and bedrock itself have proved significantly more reflective than masonry and similar discrete features.

There is a difference in wave transmission properties between the grass and hard or gravel surfaces, although the effects of this are mostly near the surface. The hard surfaces here tend to be associated with weaker signal strength at depth but greater reverberation near the surface.

Depths are based upon two estimates of wave propagation velocity derived from hyperbola analysis. Towards the western parts of the site a velocity of 0.065 m / ns was measured, increasing to 0.075 below the eastern parts of the Ward. Within the Ward itself, the mean of these (0.070 m/ns) has been used for calculation of timeslice depth and to allow comparison between the different areas of survey near the North Bastion, South Tower, etc. East of the ward, 0.065 m/ns has been used for depth calculation as this seems slightly more appropriate. For comparison, at reflectance time 45.508 ns, the two velocities give depths different by 23 cm.

The timeslices presented in this report are all 6 samples thick which is effectively 1/4 wavelength at 0.07 m/ns velocity. This ensures that differences between slices at successive depths reflect the vertical resolution of the GPR data.

Some linear reflections apparent in time slices move laterally with depth and are due to the intersection of the dip of those reflectors with the angle of the slice which is always parallel to the surface. As examples, the slope past the North Bastion appears in successive slices as such a reflection, creating the impression of more complexity than really exists. Likewise, the fills above a ledge in the bedrock within the ward are associated with a south-eastwards movement as depth increases.

3.5 Electrical resistance data character

There are two areas of this, one covering the grass central part of the Ward and the other the whole of the Orchard. The latter has a slighter greater numerical range (~ 40 Ohm compared to 30 Ohm) but is overall less variable, the difference in range not being significant.

Within the Ward, point to point variation is greater, 10 – 20 Ohm across 5 m, than within the Orchard where < 5 Ohm variation is the norm. This will in part reflect land use and the formation of the ground, the Orchard being upon a garden terrace raised above the castle ditch to the south and the Kitchen Garden to the east and confirmed by the GPR to be mostly a deep fill. Within the Ward, the soil is much thinner and there is a long history of disturbance by landscaping and gardening activities.

North to south there is a trend of increasing resistance, with a 40 Ohm change from in front of the house to southern margin of the lawn. Overlaid upon this trend discrete areas of both raised and reduced resistance likely relate to changes in the soil that will be due partly to the remains of surfaces (apparent in GPR profile data), changes in the distribution of fill materials both ancient and due to 19th century landscaping, and later interventions. Where the soil is most shallow, it is likely there will be greater moisture retention within it, hence the lower resistance but where soils are deeper, the better drainage will increase the resistance of the surface soils.

3.6 Electrical resistance result (DWG 03a & b)

There are no indications of anything structural in the Ward data and most variation can be related to the positions of former flower beds and the depth of deposits above bedrock. The GPR data shows the latter to rise within 50 cm of the surface and hence it can be expected to influence measurements made with a 0.5 m twin probe array with a maximum effective depth of investigation of about 70 cm.

That masonry could be expected to be detected if it existed within the Ward is evident from the Orchard area where a strong anomaly > 10 Ohm is evident over a linear structure beneath the northern end, confirmed by the GPR as likely to be masonry. Elsewhere in this area, a slight increase in resistance along the eastern edge will likely relate to increased drainage, this being the outer edge of the terrace. Along the southern edge the effect of a retaining wall above the line of the castle ditch is apparent, again as elevated resistance.

Within the Ward there is a little direct correlation between changes of electrical resistance and the tree planting (and maybe removal) holes that are clear in the GPR timeslices. As might be expected, where these have been detected electrically they are apparent as small areas of reduced resistance due to locally deeper soil. Elsewhere, areas of reduced resistance close to the northwest edge of the survey seem to relate to past arrangements of planting.

Areas of raised resistance along the southeast edge may relate to slight changes in the position of the path, but maybe also the edge of a region of deeper soil against the internal face of the medieval curtain wall. This deeper soil seems to be the result of landscaping to form the grounds of the present house.

At the southern end of the survey soil depth seems to be greatest although changes of fill materials may also be raising the resistance. It is notable that here the trend of resistance does not directly indicate the depth of the bedrock, there being no indications in this data of a ledge aligned northeast to southwest clearly apparent within the GPR data.

3.7 GPR data - Courtyard

Below the eastern part there is an excavated buried surface that ranges from about 20 - 30 cm bgl, there being a prominent basin-like form immediately outside the outbuilding in the northern part. Below all of the western part of the courtyard there appears to be fill to a significant depth, the base not imaged by the GPR. There may also be fill beneath the excavated surface but whether this is the same fill could not be determined.

ID	DWG	Comments
1	DWG 05	Probable wall footings, up to 0.9 m wide, roughly coincident with possible robber trench at east end of excavated surface
2	DWG 05	Filled slightly sunken area (< 15 cm) above buried surface, maybe site of a structure
3	DWG 05	Area of former excavation, buried surface plus fill of excavation trench
4	DWG 05	Utility, post-dates service building as it curves to pass it
5	DWG 05	Utility – drain?

ID	DWG	Comments
6	DWG 05	Uncertain, maybe another utility at 30 cm bgl or a narrow wall
7	DWG 05	Large utility, likely a drain-sized structure, perhaps connecting with [8], maybe a culvert, up to 0.5 m wide, 0.4 cm bgl
8	DWG 05	Possible soakaway type structure, 1.2 x 1.5 m

The probable wall footings [1] roughly align with those to the south west ([13] and [14]) so appear to continue a curving continuous wall that although only 90 cm thick would appear to at least track, if not actually be, a medieval curtain wall.

The surface excavated within the courtyard is clear in profile data but its extent is less clear within timeslices, no doubt due to the presence of other stony material and the backfill of the trench. The eastern edge appears to be the line of wall [1], maybe visible in photographs as a robber trench; if so, then the surface extended westwards from this and, depending upon its interpretation, could assist interpretation of [1].

3.8 GPR data - Cottage and entrance lane

The western 6 m of the entrance lane looks like fill material from the profile texture, to at least 120 cm bgl (below which there is a loss of signal strength) and this ends to the east at what appears to be a thick wall [13]. East of this penetration is no more than about 50 cm bgl.

Below the floor of the cottage there are variations to about 100 cm bgl but they lack spatial coherence. Without suspecting there was something there most of the reflections would not immediately be recognisable as of relevance to the castle.

ID	DWG	Comments
9	DWG 06	The ground below the slate floor of the cottage is laterally variable whereas outside, beneath the lane, there is a lot of reflection [10] typical of make-up material
10	DWG 06	Probable make-up material of lane
11	DWG 06	Only a little distance below the make-up material (~26 cm bgl) a distinct patch of irregular material appears over [13]
12	DWG 06	Uncertain, possible narrow wall footings, maybe the base of an internal division within the cottage?
13	DWG 06	A broad parallel-sided reflector that seems to be masonry and continues under the cottage floor as [14]. It has an approximate width of 90 cm
14	DWG 06	See [13]; here it is less reflective, no doubt due to different materials above it and different soil moisture conditions below the cottage floor
15	DWG 06	The southern end of a linear reflective region, where it projects beyond the cottage wall, appears to be masonry, no more than 40 cm thick. It could also be some sort of drainage structure
16	DWG 06	A utility passes centrally through the gateway and either turns beneath the building flanking it to the south, or has a spur into it
17 & 18	DWG 06	The predominance of reflective, i.e. inhomogeneous, ground west of [13], in comparison with [18], suggests a fill material and hence a change of former ground level across this feature. It is less evident below the cottage but that may be due to different environmental conditions

It is tempting to suggest that the medieval curtain wall passes unbroken beneath the lane and the cottage as [13] and [14], and formerly bounded the excavated surface in the courtyard as [1]. This would be a slightly different line than suggested by the present layout of the site and is thinner than would be expected for a medieval curtain wall. It is possible that the probable masonry belongs to an associated structure, not the actual curtain, despite appearances. Whether it could be interpreted as part of the 'earlier castle' is not known.

The probable fill west of wall [13] is interesting as it suggests a change of height of former ground level, e.g. a possible ditch west of the wall, which would be expected of the medieval curtain, notwithstanding the lack of thickness to the wall.

There is no sign of any massive masonry structure as might be expected if a gatehouse was here, i.e. the present lane into the castle seems unlikely to have been site of a gate.

3.9 GPR data - North Bastion

All structures here seem superficial, within the top 40 cm of ground, but given the degree of landscaping that must have occurred around the house, considerable truncation of earlier structures and deposits seems likely to have occurred.

There are two superimposed dipping reflections within this survey, one, maybe bedrock, reaching about 160 cm bgl, the other about 140 cm bgl, at the lower end of the survey, behind the retaining wall. Below and outside this wall a section through the upper and inner part of the castle ditch is clearly apparent within the rock face.

ID	DWG	Comments
19	DWG 07a	A probable wall footing ~ 90 cm width, at the top of a north-facing slope buried beneath the present drive
20	DWG 07a	A lateral change of material between probable wall [19] and the logical path of any former continuation northwest of the garden wall
21	DWG 07a	Here the distinction between probable natural ground or garden soils and the fill [22] is clear
22	DWG 07a	Material [20] seems to continue beneath the line of any continuation of the garden wall, seen in profile to be a deep fill above the slope buried beneath
23	DWG 07a	Utility? Drain?
24	DWG 07a	Utility? Drain?
25	DWG 07b	Maybe a footing of a thin (garden?) wall here, e.g. the cause of the lateral change [20], however, it is possible for such reflections to appear in timeslices that cut dipping reflectors. A clearer example of this is apparent to the southwest as [26]
26	DWG 07b	See [25]
27	DWG 07b	A 6 m wide band (within this timeslice) of more reflective ground, maybe natural, e.g. rock, with garden soils and stratified deposits to each side? A band of rubble-rich ground is also possible. Probably related to landscaping activities
28	DWG 07c	Utility? Drain? Below 100 cm bgl
29	DWG 07c	Utility? Drain? Below 100 cm bgl

There appears to be a wall similar to [13] and [14], so narrower than might be expected of a medieval curtain, but occupying the position of such, at the top of a buried slope down to the medieval ditch visible in cross section at the lower level. If this is the medieval curtain then this would mean the northern angle tower must have projected to the northeast beyond it. Whether this related in any way to the proximity of the town wall is uncertain.

The slope down to the ditch is buried, at this height, beneath the garden soils and drive, but is clearly apparent in the GPR profiles, with a rubbly fill above it that may once have supported a continuation of the garden wall.

3.10 GPR data - South Tower

The GPR profiles are all very variable along and across their length, so typically a mixed fill dominates. The modern path, and maybe a slight change of its line, are also apparent in the data.

ID	DWG	Comments
30	DWG 08	Garden wall footings or a path, or maybe a shallow robber trench and material; the data is not clear due to the surface treatment
31	DWG 08	Probable masonry, 1.4 m thick, a close match to the wall found in a trench immediately to the west and interpreted as the medieval curtain, present from about 40 cm bgl and visible within the data as a discrete structure until at least 80 cm bgl. Greater depth is implied by the hard edge of fill [33]
32	DWG 08	Fill of ward (landscaping) behind and northwest of wall [31], apparent as more variable reflection texture in plan and in profile
33	DWG 08	Homogeneous (non-reflective) ground, within the body of the tower and below the 19th century reconstructed parts, so continuing below 100 cm bgl

The curtain wall [31] seems to continue beneath the tower; this may suggest the tower has been added later, however, unless the trench is plotted incorrectly, there appears to be a lateral offset between the wall within it and that mapped by GPR.

The non-reflective fill of the tower outside the line of the curtain wall is in contrast to the Mural Tower which is filled with rubble. Here the fill could just be soil and may be an original feature of the tower, there being no evidence for rooms below the present ground level. It is possible that this was not a tower, but a projection to provide visibility along the wall. This may also explain an apparent lack of access into the tower through the rear wall from the filled area of the ward, although no such access was seen within the Mural Tower either.

The extant medieval masonry of the tower, below the 19th century parapet, does not appear to extent sufficiently far northwest to reach probable curtain wall [31], even allowing for a glacis or battered external face to the wall. What this means is not certain, but given the apparent lateral offset of the rear wall of the tower, maybe this is also evidence for the rear of the tower to have projected slightly into the Ward. If so, then [31] would not be a simple re-use of the curtain wall but a new wall built as part of the tower.

3.11 GPR data - Mural tower

This was surveyed as part of the Ward, but details have been abstracted here for the convenience of discussion of the towers.

ID	DWG	Comments
60	DWG 09d	Probable rear wall of the tower, at ~ 57 cm bgl, clear at ~ 85 cm bgl and up to 140 cm thick. Below ~ 160 cm bgl it is not evident in the data
61	DWG 09d	Probable fill, extends to at least 57 cm bgl across the whole extent of the tower
62	DWG 09e	Probable fill, exists only below about 85 cm bgl in slices but apparent through imaging laterally from the northern garderobe stairs

The tower seems to have been D-shaped though with a rectangular interior and to have had a floor level between 57 and 84 cm below the present ground level. Below this a small room existed below only the outer part of the tower, from which an arrow slit visible externally in the lower part of the tower could be reached. The structure is filled with rubble throughout and therefore the ground and basement floors of the tower may survive buried beneath this. It is not certain how access was gained into the tower, there being no sign of a doorway in the rear wall.

The rear face of the basement room may have been the line of the curtain wall at this depth, the tower having projected inwards into the Ward behind. At the height of ground floor of the tower, this division is about 0.7 m outside the line of the curtain.

The rear wall of the tower is of comparable thickness to that of the South Tower and also the curtain found in a trench adjacent to this.

3.12 GPR data - Ward

Across the Ward reflections change rapidly within the top ~50 cm and are almost everywhere above one or more strong laminar reflections that appear to be bedrock, though not continuously across the area. For much of the area, rock appears to be present within 100 cm of the present surface, rising to within 50 cm in the central part. It appears to shelve away eastwards, descending at a steeper angle than the ground level, most likely due to considerable raising of the ground around the eastern margins.

The topsoil (< 30 cm bgl) is studded with small metal objects, the nature of which is unknown but will likely include material from all periods of use of the castle and subsequent house and gardens.

There have been numerous interventions into the present surface, due to the laying of utilities, construction of flower beds, their subsequent removal, and the same for trees, and more recently, a number of small trenches for archaeological purposes. All of these affect how the GPR couples electromagnetically with the ground, due to the disturbance of the topsoil and independently of whatever may be buried below. These surface coupling variations are apparent within the uppermost slices, within half a wavelength of the surface, and have been overlaid onto DWG 09a. The major changes include [35], [37], [38], [41], all typical of the former locations of garden elements or where paths have been removed. At [34] is a surface change associated with the threshold of the 19th century gates and at [40] there is a change of construction within the make up of the drive.

ID	DWG	Comments
36	DWG 09a	Unknown, possible shallow utility, e.g. a cable laid from the house?
39	DWG 09a	Unknown, very narrow, maybe a small trench from a temporary feature?
42	DWG 09b	Utility trench
43	DWG 09b	Probable tree hole – planting pit or hole left by uprooting
44	DWG 09b	Probable tree hole – planting pit or hole left by uprooting
45	DWG 09b	Probable tree hole – planting pit or hole left by uprooting
46	DWG 09b	Probable tree hole – planting pit or hole left by uprooting
47	DWG 09b	Probable tree hole – planting pit or hole left by uprooting
48	DWG 09b	Probable tree hole – planting pit or hole left by uprooting
49	DWG 09b	Reflective region, overlays [56] which has a more regular form, only about 5 cm below
50	DWG 09b	Probable tree hole – planting pit or hole left by uprooting
51	DWG 09b	Probable tree hole – planting pit or hole left by uprooting
52	DWG 09b	Very narrow linear absorbent feature, maybe a trench, if so with an homogeneous fill. Probable garden feature
53	DWG 09b	Absorbent region with a curved edge of apparent radius of ~4.5 m, probable garden feature
54	DWG 09c	Narrow linear reflection, possible utility, aligned along the contour
55	DWG 09c	Narrow linear reflection, possible utility, aligned along the contour
56	DWG 09c	At this depth (49 cm bgl), only a few cm below the more irregular reflective region [49], there appears an approximately square reflective region of about 4.8 m on a side that could be a buried surface or shallow fill

ID	DWG	Comments
57	DWG 09d	Utility trench
58	DWG 09d	Soakaway? The exact location of this modern feature is uncertain but is believed to be within this area
59	DWG 09d	Fill against a sloping edge or cut in the bedrock, at this depth maybe reaching 5.5 m wide but the outer (shallower) parts are not well defined. Maximum depth 60 cm bgl. A narrow (1 m wide?) trench across this found mainly natural materials and something described as a small gully
63	DWG 09f	See [64]; this appears to be part of the same feature
64	DWG 09f	GPR profiles reveal a sloping and probably rock-cut edge with reflective strata at what seems like its base below 150 cm bgl. Parallel to this is another, slightly less steep, at [65]. This latter seems to continue eastwards at [63], with a combined length of at least 20 m. The western extent is beyond the edge of the survey, perhaps beneath later buildings
65	DWG 09f	The southern edge of the filled feature of which [64] is the northern edge, separated by about 5 - 6 m width
66	DWG 09g	The base of the filled feature defined by [64] and [65] contains reflective, i.e. inhomogeneous materials, although what these are is uncertain. If rock cut then it could be material fallen from the sides

The large filled feature defined by edges [64] and [65] is unexpected and appears to not be natural, instead resembling a wide (~5.7 m) rock-cut ditch extending into the Ward for at least 20 m and maybe longer but not detected by the GPR. Its orientation is not compatible with the castle defences and nor is there any other structure on site with which it could be associated; indeed, there are signs of former surfaces that overlap it from the south. Overall, it appears to be an ancient feature and its location on what is essentially a promontory above the river could imply some defensive work pre-dating the castle.

Garden features are present to at least ~40 cm bgl, i.e. the upper part of the ground and irrespective of 19th century landscaping is highly variable. Medieval deposits may be truncated, but variably so and this could account for some of the variation seen across trenches over the years. Any one trench could be within an island of medieval or post-medieval stratigraphy, or a garden feature.

A large number of almost circular absorbent regions of 2 – 4 m diameter are most like to be planting pits for trees, the ground within them being more uniform than without and typical of just soil, rather than the thin and more reflective strata that typify the Ward overall. In some case these seem to cut through earlier surfaces and some are also apparent in the electrical resistance data.

This evidence for surfaces may provide the only evidence for former structures, maybe preserving their outline, there being no actual evidence for buried masonry or similar structural features with the GPR data, apart from the rear walls of towers.

Although filled area [59] has the appearance of the site of a platform maybe for a building, there is no evidence for masonry and 'Trench 6' which crosses it reported only thin layers of natural sands and gravels, below post-medieval deposits and over rock.

There is widespread evidence for filled areas, maybe post-medieval occupation and 19th century landscaping, however, it is possible that some of this represents re-fortification efforts during the Civil War, and rubble deposition upon subsequent slighting. The thinness and variation of the strata has presented a challenge for interpretation in the absence of structural evidence.

In general the deepest filled areas are against the east medieval defences, including within the mural and southern towers, to at least 80 - 100 cm bgl in approximate terms. That there is intact medieval structure, including probable floors, below this is beyond doubt.

3.13 GPR data - Orchard

This area is beyond the core of the castle, northwest of the Great Tower and backed onto by the closes behind town buildings. It is a garden terrace, maybe of 19th century date, although this is not known for certain, above the sloping Kitchen Garden to the east. The area may be within an outer ward of the castle, the extent of which is not known but may be broadly co-incident with the northern boundary of the Kitchen Garden.

The southern edge of the terrace is raised fairly high above the land against the Great Tower, itself known from excavations and a test GPR profile to be the fill of the medieval defensive ditch.

ID	DWG	Comments
67	DWG10a	Near surface, compaction of path to bench, included for clarity
68	DWG10a	Uncertain origin, reflective region of the surface, maybe a former garden layout, e.g. a buried path. Superficial
69	DWG10a	Possible masonry, at least 90 cm thick, the top just at the base of the topsoil
70	DWG10b	At considerable depth (~ 163 cm bgl) there is a hint of a narrow reflective region up to 50 cm wide. Whether it could be masonry or a drain is unknown

There is no sign of ditch edge below the terrace of the Orchard, so this is either too deeply buried to detect with a 450 MHz GPR or, perhaps more likely, the southern edge of the terrace is itself the edge. An isolated GPR profile (4276) from below the terrace to the wall of the tower found only fill materials, which supports the hypothesis that the terrace ended at the ditch. This correlates with 'Trench 1' which suggested that the ditch is here about 7 m wide, i.e. it reached to the southern edge of the Orchard terrace, but no further.

The same trench revealed evidence for a counterscarp bank north of the ditch but no evidence for this was seen in the GPR data.

At the northern end of the Orchard Wall [69] is thicker than would be expected of a garden wall and has no ground retaining function. Approximately 14 m to the east a similar thick wall bounds the Kitchen Garden before passing beneath later buildings and it is tempting to see this as a continuation of the same structure. Could this be evidence for the curtain wall of an outer ward?

3.14 GPR data - Kitchen Garden

There is nothing known or suspected within this area although a trench ('Trench 1') excavated in this and up to the wall of the Great Tower seemed to reveal a deep deposit of fill, maybe the outer edge of the castle ditch. Evidence for a counterscarp bank was also seen. This area has historically been a garden and hence any shallow deposits contemporary with the castle were likely removed long ago.

Ten GPR profiles were run as five pairs of two aligned along the garden paths, two of which (4330 & 4331) extended from the edge of the orchard down through the east gateway and across the drive below the house, to provide a basic east – west stratigraphic cross section. The depth of investigation within the garden, after processing, was about 70 – 90 cm bgl, increasing to about 120 cm bgl outside the garden to the east. Below all the area seems to be natural and potentially clayey soils.

There is no sign of anything in the GPR data that could relate to the castle. Two long profiles (4324 & 4235) passing across the putative line of the counterscarp bank north of the Great Tower detected no clear evidence for this feature although a change of reflectance texture near the surface is broadly coincident with where the bank is reported to have been truncated by the creation of the garden terraces.

The edge of the ditch was not seen, although the same two profiles passed across this. Whether later landscaping means that this is below the depth of investigation of the GPR is uncertain; however, there is no GPR evidence within the upper 90 cm of ground to corroborate the results of Trench 1.

In contrast, profile 4276 within the reported extent of the ditch revealed fill material throughout the depth of investigation.

3.15 GPR data - Vinehouse

A small number of profiles collected across an accessible part of the Vinehouse revealed a complicated set of possible structures and fills which, from their location, seem most likely to be the substructure of the Vinehouse itself.

4 Conclusions

4.1 Survey results

Overall, little evidence for structures relating to the castle was detected by either method, with the exception of additional parts of known structures, e.g. the rear walls of the towers. The interior of the castle seems mostly to be shallow soils supporting areas of medieval and post-medieval stratified deposits between areas of later interventions. The interior has fairly clearly been landscaped to form the grounds of Castle House, although this fortunately seems to have included burial of most of the eastern defences and southern areas of the Ward. Elsewhere some truncation of at least central areas is expected and north of the castle, within the garden area, the medieval topography is potentially no longer extant.

There is unexpected evidence for what may be a pre-castle phase of use of the promontory, in the form of a wide and likely rock-cut ditch entering the Ward from the west. Although the geophysical surveys cannot provide evidence for a date, a prehistoric defensive work is possible.

North of the castle is the putative site of an outer ward and although no direct evidence for this is likely to be found, a thick masonry structure beneath the northern end of the Orchard would be a good candidate for a curtain wall, especially given that this seems to continue the line of another thick wall that now bounds the Kitchen Garden. Within the Kitchen Garden itself nothing of relevance to the castle was detected, including, unexpectedly, the northern edge of the castle ditch around the Great Tower. This, and a counterscarp bank apparently seen in an excavation, were not apparent in the GPR data. The ditch was seen a few metres to the west in a separate test GPR profile west of the tower, and this may confirm the southern end of the Orchard terrace as the edge of the ditch.

There seems to be a wall beneath both the entrance lane and the cottage that although on the putative line of the medieval curtain, is itself perhaps too thin at about 0.9 m to have been this. What exactly this means is uncertain, but it seems likely that later structures could have been built to reuse medieval masonry upon disuse of the castle. A probable continuation of this wall beneath the edge of the courtyard but at a slightly different alignment, may again reflect re-use of the medieval line. It may be relevant that beneath the entrance lane the same wall seems also to mark a change in the depth of deposits, those to the west and hence likely beyond the medieval curtain being deeper, and maybe the fill of an associated ditch. Insufficient length was available within the GPR data collected within the cottage to be sure of whether this fill continues northwards. However, below the adjacent courtyard fill materials were seen further west, so this could be evidence for the medieval ditch.

Although there has been discussion as to whether structural remains in this area could relate to an earlier castle built by de Clare, it is uncertain whether any of the newly discovered features could belong to this or the rebuilds by the Lord Rhys in the 1170s and again in the 1240s by Marshal or Waleran. The thinness of the masonry counts against this being anything other than a minor structure given the scale of the masonry associated with the 12th and 13th century elements, e.g. the Great Tower and the Mural Tower. This has ramifications for how the castle is interpreted today, and to what extent parts of the structure could represent re-fortification in the 17th century. Indeed, at this time the Great Tower was already described as ruined and there had already been up to three centuries of disuse, hardly the ideal circumstances for a site that was defended during the Civil War. Given these details, it is perhaps too ambitious to identify now the lines of individual medieval defences with any degree of confidence and without modern excavations.

The North Bastion appears to have projected northeast from the line of the medieval curtain wall, assuming this was indeed the function of another fairly thick wall found in the GPR data. This is at the top of a buried slope down to the castle ditch visible in section below. However, much of the structure of the angle tower must be consequently be beneath a steep bank and planting above the present drive to the house and is not accessible for survey.

Further south, the location of the rear wall of the Mural Tower is now known and also that the whole tower has been filled, after disuse, with rubble. The floor of a room apparent at the present ground level is buried, and below that opens a small chamber from which the arrow slit lower down the tower was accessible.

Of the South Tower less was evident in the GPR data, although the line of the medieval curtain has been confirmed towards the back of the tower and it would appear that the tower projected as much as 6 m from the wall, similar to the Mural Tower. The two towers appear to have been of similar appearance, although the Mural Tower seems to have been a more complex structure, with integral garderobes and rooms at ground (Ward) and basement levels. The interior of the southern tower appears instead to be full of soil and there is no evidence for internal division or buried floors. It may have been constructed as a solid platform built against an existing curtain wall, and carried inwards at Ward level to match the Mural Tower (and maybe others, since lost). Unfortunately 19th century rebuilding has meant that nothing medieval survives at Ward level.

For both of these eastern towers, no access into them was detected from the Ward, which might have been expected in the case of the Mural Tower as this is known to have contained rooms. This may imply access was only from a higher level, maybe providing a basic level of security in each case.

The Ward itself is empty of detectable structures, which is not to say that they never existed but have maybe robbed away, the shallow bedrock meaning even fairly trivial landscaping could cause much loss of early fabric. It appears today more level than it probably was in medieval times, with a filled area along the eastern side and maybe truncation of the central and northern parts of the Ward during landscaping. This would imply medieval structures would probably have been against the perimeter walls, where more level, and less exposed, ground might be found. Elsewhere, as implied by the GPR data and as seen at other castles, much of the interior may have been fairly empty, with just lightweight features and areas of paving. Traces of the latter seem to survive in some form in the GPR data although not within an overall coherent form. They also become confused with the bedrock surface often close beneath, or survive in what seem to be pockets of strata below levels affected by landscaping.

In general the deepest filled areas are against the eastern medieval defences, including within the mural and southern towers, and to between 80 and 100 cm bgl in approximate terms. That there is intact medieval structure, including probable floors, below this material is beyond doubt.

4.2 Caveats

Geophysical survey is reliant upon the detection of anomalous values and patterns in physical properties of the ground, e.g. magnetic, electromagnetic, electrical, elastic, density and others. It does not directly detect underground features and structures and therefore the presence or absence of these within a geophysical interpretation is not a direct indicator of presence or absence in the ground. Specific points to consider are:

- some physical properties are time variant or mutually interdependent with others;
- for a buried feature to be detectable it must produce anomalous values of the physical property being measured;
- any anomaly is only as good as its contrast against background textures and noise within the data.

TigerGeo will always attempt to verify the accuracy and integrity of data it uses within a project but at all times its liability is by necessity limited to its own work and does not extend to third party data and information. Where work is undertaken to another party's specification any perceived failure of that specification to attain its objective remains the responsibility of the originator, TigerGeo meanwhile ensuring any possible shortcomings are addressed within the normal constraints upon resources.

5 Technical Considerations - Ground Penetrating Radar (GPR)

5.1 Principles

The strength of a reflection is proportional to the dielectric permittivity contrast between the materials the electromagnetic wave passes through. This property is governed by the electrical and magnetic properties of the material at high frequencies; these are often different from what would be measured by low frequency or passive techniques like electrical resistance or magnetic surveying. The highest contrasts are generally between air and other materials.

Each recorded reflection is the result of an interaction between the wavelength of the wave and the physical dimensions of the object and the strength is a measure of the difference in dielectric permittivity vertically within one quarter of the wavelength. It thus does not respond differently to different materials but to the differences between them, different therefore from electrical methods which respond to the actual materials. A deposit or material that continually varies internally will continue to produce reflections whereas a uniform material will produce reflections only at its edges. Like light, the high radio frequencies used for radar mean that the beam can be multiply reflected and refracted. For these reasons, a profile of radar data is never a direct model of the distribution of materials in the ground.

Ground that is electrically conductive, so clay-rich or wet, will allow the electrical part of the wave induced in the ground to ebb away, preventing regeneration of the wave and hence its penetration into the ground. Dry ground (including dried-out clay) is therefore much more likely to produce useful results.

Radio waves cannot penetrate metal and any metal structure in the ground will cast a shadow over deeper deposits. In addition, a reverberation is likely to occur between the object, the ground surface and any interfaces in between and these echoes then appear as multiples below (i.e. later in time) the original object. Within voids wave propagation velocity increases to near the speed of light, i.e. significantly faster than within the surrounding ground. This can lead to distortion of the GPR profile, with deeper reflectors below the void appearing much closer to the surface than in reality. Voids also tend to create strong internal reflections due to reverberation at the interface between air and the containing structure.

5.2 Instrumentation

TigerGeo normally uses GPR manufactured by Mala Geoscience, e.g. the GX450HDR digital system with a nominal penetration of about 2 mbgl and using bowtie antenna.

Resolution is dependent upon wavelength (inversely proportional to frequency) so the higher the frequency the greater the resolution. However, a 1000 MHz system will penetrate at most 1m and usually less, whereas a 250 MHz system will normally penetrate 3-4m in 'normal' northern European soils and deeper in sand or peat.

Resolution in this context is primarily vertical, although there is also some lateral loss of resolution as the wavelength increases. Critically, the vertical resolution is limited to one quarter of the wavelength and to discriminate both the upper and lower interfaces of a stratum this needs to be at least one half a wavelength thick. If specific targets are sought, the instrumentation and specifically the wavelength used needs to account for the dimensions of these otherwise the survey will fail.

Depths in radar survey are expressed in terms of the length of time taken for a wave to travel to a reflective interface and to return to the antenna. To convert this time to depth, the velocity of the wave needs to be determined and this can vary throughout the ground, although often a median estimate can be formed and used overall.

Frequency	Material / RDP	Vertical resolution (¼ wavelength)	Lateral resolution at 1m depth
500 MHz	Average soil / 9	0.05 m	0.32 m
1000 MHz	Average soil / 9	0.03 m	0.23 m
500 MHz	Dry sand / 5	0.07 m	0.37 m
250 MHz	Dry sand / 5	0.13 m	0.54 m
500 MHz	Dry loamy soil / 6	0.06 m	0.36 m
500 MHz	Wet loamy soil / 15	0.04 m	0.28 m
250 MHz	Wet loamy soil / 15	0.08 m	0.40 m

Source: http://www.gpr-parameters.ch/parameters.php

5.3 Interpretation

Numerous sources are used in the interpretive process, which takes into account shallow geological conditions, past and present land use, drainage, weather before and during survey, topography and any previous knowledge about the site and the surrounding area. Old Ordnance Survey mapping is consulted, also older sources if available. Geological information (for the UK) is sourced only from British Geological Survey resources and aerial imagery from online sources. LiDAR data is usually sourced from the Environment Agency or other national equivalents, SAR from NASA and other topographic data from original survey.

Information from nearby surveys is consulted to inform upon local data character, variations across soils and near-surface geological contexts. Published data from other surveys may also be used if accompanied by adequate metadata.

GPR interpretation is rarely undertaken in a contextual vacuum as the technique it is best deployed to seek specific targets rather than as a pure prospecting technique, not least because the data can easily be especially complex within inhomogeneous ground. This being the case, the interpretation process will often concentrate upon the expected targets and sometimes, depending upon the context of the survey, ignore the rest. For stratigraphic studies, recognition of the strata is more important than processing the detail within each unit, whereas for utilities mapping recognition of individual hyperbolic reflections as instances of of a particular service is the primary objective.

In general, three types of reflection are recognisable:

- hyperbolic point reflectors;
- discrete reflections with width;
- interfaces, e.g. surfaces.

Any combination of these can and usually is present and it is this combination that can render GPR particularly complex in some settings, e.g. historic urban centres where services share space with former foundations, filled areas, surfaces and modified natural deposits. For this reason, there are different strands to processing and interpretation to allow specific aspects of the data to be explored. In some circumstances interpretation may proceed entirely from profile data but in others lateral changes and patterning may be more important and sought using amplitude slicing techniques.

Regardless of approach, there is a need to convert time depth to real depth for this a wave velocity needs to be determined. Practically this is done using hyperbola fitting at several locations within the data, generating a series of relative dielectric permittivity (RDP) estimates and hence velocities. From these a median can be computed and used to convert time to depth across the survey, if this is sufficiently small and the velocities constrained within a sufficiently narrow range. If not, then piece-wise conversions need to be applied.

Practically interpretation uses two main techniques of data visualisation, profile picking and time (amplitude) slice generation. The first relies upon the identification of individual relevant reflections within the profile data, e.g. hyperbolas or interfaces and digitising them into 3D space for construction of a model. The second combines the profiles into a stack (hence the terms 'pre-stack' and 'post-stack' analysis) by computing an amplitude envelope for each and interpolating laterally. These amplitude slices create pseudo-plans of waveform amplitude at a particular depth, i.e. the spatial variation of dielectric permittivity within the thickness of a slice.

Together, these two approaches normally describe the data set sufficiently well for a wide range of interpretive agendas and are often used together as they tend to reveal quiet different aspects. For archaeological projects, time slices are often good at revealing subtle lateral variations within the soil, whereas for utilities and animal burrows the 3D pick is normally better.

If using time slices the hyperbolic reflections associated with point (and edge) reflectors need to be collapsed as they are artefacts of survey and do not represent the plan form of the reflector itself. For this, a migration process is used and this requires accurate knowledge of the wave velocity to function correctly. Sometimes this and conversion to depth are the same function. This not only reduces the lateral complexity of the data but also recovers some of the resolution along each profile which is otherwise lost through the spreading of the reflection with depth.

Time slices can themselves be processed and viewed, within reason, like other forms of planar data, e.g. electrical conductivity.

6 Technical Considerations - Electrical Resistance

6.1 Principles

This section is specifically about planar electrical resistance, i.e. pole-pole or 'twin-probe' survey, not electrical resistivity sounding or tomography.

Electrical resistance is the measured consequence of electrical resistivity, the degree to which a material restricts the flow of electric current. Within soil this is generally due to a combination of factors, including the chemistry due to the mineral and humic components, these to some extent working in opposition, plus the size of pore spaces, their degree of interconnection, to what extent they are water filled and whether the surface of the pore spaces are electro-chemically active. The latter reason is why clay tends to be less resistive than silt while pore dynamics govern the soil's response to hydraulic cycling.

For any given soil, the hydraulic context directly impacts upon the 3D distribution of electrical resistivity variation. Given the temporal character of the former, the latter also varies in time. Electrical resistance data collected in dry conditions after rainfall will be different from that collected in wet conditions after a period of dry weather. Data collected after a short period of rain will be different from that collected after prolonged rain. However, there is one constant: after a period of no rainfall electrical resistivity contrast within soil will always be at a minimum and therefore survey is unlikely to useful. The hydraulic output from a soil is as important as input from rainfall; drainage from a surface soil is influenced by deeper deposits, the degree of saturation of the ground, slope and whether it can physically trap water within its pore spaces, e.g. clays.

Considerable temporal and spatial variation across a variety of scales is therefore normal and the detection and mapping of structures of archaeological interest is dependent upon these. However, certain principles can be applied:

- an open-textured soil will always hydrate and drain faster than a heavier one;
- clay soils will retain moisture longer than sands and silts;
- soils will normally be less resistive than mortared masonry structures, however an un-mortared structure can behave more like an open-textured soil;
- unconsolidated fills tend to be more open-textured than undisturbed ground;
- wet soils are less resistive than dry ones.

With these in mind and given appropriate conditions it is evident that electrical resistance survey can detect things like buried pit and ditch fills, walls and similar structures. Floors may be indirectly detected if they modify drainage of the soil. However, their chances of detection are entirely dependent upon the local soil hydrology and hence the weather conditions prior to and during survey, the soil type and surface treatments (e.g. ploughed, not ploughed, grass or bare soil, etc.). Variation of any of these within a survey will likely change the relationship between measured electrical resistance and the archaeological interpretation.

No physical variation exists in isolation and the patterns of electrical resistance observed at the surface relate not to individual structural variations but to the combination of all variations within the 3D electrical current path. Those variations with the greatest influence upon the current vector will be most manifest within the resistance measurement. As a consequence, closely spaced structures may not be separately resolved, their depth of burial will affect the result and likewise their penetration into the ground. Given adjacent pairs of structures or fills with opposing resistivity characteristics, only one may be resolved. As an extension of this, paradoxes may be evident, e.g. the effect upon drainage (potentially low resistance) of a masonry structure may be more evident than the structure (high resistance) itself. A high resistivity structure close to the surface may force the majority of current to flow over it, producing a low resistance anomaly.

6.2 Instrumentation

The pole-pole, or as commonly called in archaeological applications, the twin-probe array, is one of many that can be used, each with its own benefits and drawbacks across the spectra of resolution, sensitivity, signal to noise ratio and anomaly form. The pole-pole is especially sensitive to lateral variation beneath the array but relatively insensitive to laminar structure. This sensitivity is marked at shallow depths, thus for a

0.5m AM (mobile current and potential) probe separation a depth of investigation of approximately 0.75mbgl applies, though with some variation.

Because the exact geometry of the array is rarely known (due to the constant variation of relative orientation and separation of the two sets of probes) the measurement is expressed as electrical resistance, in Ohm, not the volume specific quantity of resistivity. Measurements are thus not directly comparable across sites and nor is their size indicative of particular materials etc., unlike the resistivity measure available from electrical resistivity tomography or from variations of the Wenner array, both of which shares the same fundamental principles.

Within the pole-pole array configuration, the primary variable is the AM probe spacing. Increasing this from 0.5m increases the sensitivity of the array to deeper variations, however, measurements remain significantly affected by shallower variations due to current paths. Conversely, decreasing the spacing sensitises the measurement to regions closer to the surface.

For discrete buried structural entities (e.g., walls and pit or ditch fills) the volume of ground affected by the resistivity contrast is larger than the physical extent of the structure and thus variations smaller than the survey resolution can be detected not mapped, a behaviour critical to interpretation of the data. As for all planar survey methods the higher the spatial resolution of the survey the better the result will be, although with diminishing returns beyond some resolution dependent upon local resistivity contrast and structure size (and hence weather conditions prior to survey).

6.3 Interpretation

Numerous sources are used in the interpretive process, which takes into account shallow geological conditions, past and present land use, drainage, weather before and during survey, topography and any previous knowledge about the site and the surrounding area. Old Ordnance Survey mapping is consulted, also older sources if available. Geological information (for the UK) is sourced only from British Geological Survey resources and aerial imagery from online sources. LiDAR data is usually sourced from the Environment Agency or other national equivalents, SAR from NASA and other topographic data from original survey.

Information from nearby surveys is consulted to inform upon local data character, variations across soils and near-surface geological contexts. Published data from other surveys may also be used if accompanied by adequate metadata.

The interpretation of electrical resistance anomalies is site and time-specific (hence the designation as 'apparent resistance' and not 'resistivity') and they are not diagnostic of materials. The form of an anomaly is dependent upon the contrast between a body and the surrounding material and thus the same sort of feature can generate different anomalies across a site.

It is fairly common to suppress background trends to improve local anomaly contrast, however, if there are resistance trends across a site, perhaps due to differences of drainage on a slope, then anomaly form will still vary and needs to be taken into account.

Conversion to apparent resistivity is theoretically possible but rarely done as the exact probe geometry at each measurement point is not usually known. In theory this would render the data more diagnostic of materials but in practice this is hindered by the uncertainties of 3D current flow within the depth of investigation. The technique is planar, i.e. 2D, and therefore the result is a projection into 2D of electric current flow within a 3D volume limited in depth by the probe geometry. For the pole – pole array this is the spacing of the mobile potential (M) and current injection (A) probes and the depth of investigation is a maximum of about 0.75m.

The data cannot be interpreted without contextual information, including local hydrological variations and soil types. Even then, it is interpreted from the viewpoint of expecting a particular target, e.g. a buried wall or culvert and therefore an expectation of likely anomaly form.

In general terms, adjacent materials with different porosities and therefore different bulk electrical properties can be distinguished and provided the hydrological context is known, correctly identified. Therefore a wall or culvert buried within a clean soil can normally be detected under a range of conditions but the situation becomes more complex where the target is the fill of a buried pit for example. In this case the survey has to rely upon differences in water retention in the different materials and whether these are laterally distinguishable within the depth of investigation. Such a fill can exhibit either a higher or lower apparent resistance than the surrounding ground and hence variations across a site can result in different anomaly strengths and forms for the same fill.

7 Methodology - Ground Penetrating Radar (GPR)

7.1 Survey

The radar system has a wide ranging set of adjustable parameters, including the time window within which reflections are listened for, the gain (variable across the duration of the window), the time after transmission at which the window starts etc. The correct choice of these is governed by the central frequency of the antenna in use (and hence vertical resolution and penetration), ground conditions and the depth of investigation. Ground conditions tend to vary across a site so once an appropriate set up has been generated this is checked at various locations before survey is started and adjusted if necessary.

All data is recorded and hence can be independently assessed.

Network RTK GNSS was used to establish an accurate survey grid within each area and to survey in adjacent features to help locate the data and inform interpretation. From these accurately located points, grid set out was by tape measures to allow the survey areas to flow around obstacles.

7.2 Data processing

Data processing is minimised and limited to what is essential to extract meaning from the data or necessary to correct or enhance certain characteristics to support interpretation. Reflections are recorded relative to time after pulse transmission and hence the depth measure is actually time, not metres. An approximate conversion to depth is possible by applying an average velocity to the wave; this is best calculated from analysis of the data itself. A more detailed model allows for variations in velocity with depth and across the site.

Processing of GPR data is undertaken within Reflex 3D software and proprietary applications and data is visualised within Manifold GIS for 2D, e.g. time (amplitude) slices.

Normal processing includes adjustment of the zero time (ground surface) and suppression of low frequency noise from the antenna (de-wow). These core processes are followed by others depending upon the character of the data, including bandpass filtering to reject external electromagnetic interference, background removal to suppress ringing effects and re-gaining to optimise signal strength throughout useful regions of the profile.

A mixture of manual and automatic picking procedures are then deployed upon the data to extract relevant reflections as vector data in time and space.

If the data is to be time-sliced, further processes are required, principally the collapse of hyperbola to point sources (migration) if a constant wave velocity can be assumed, application of a down-trace lowpass filter to reduce random noise, especially in the deeper regions, and finally calculation of a unipolar amplitude envelope for each vertical trace. To support time slice and similar 2D visualisations, as well as visualisation of 3D amplitude distribution, the amplitude envelopes are stacked together and then interpolated in 3D to form a prism. The exact process depends upon the software used.

All data from this site was processed according to the following schema.

Pre-stack:

- move start time -8.17292 ns
- Butterworth bandpass 50 – 900 MHz
- background removal
- manual gain (two or three point gain, from 0 to 50 dB depending upon location)

Stack:

- FK migration (Stolt) 0.070 or 0.065 m/ns depending upon location
- envelope function (Hilbert)
- running average, 5 scans

Post-stack:

- slice thickness – average of 6 samples
- contrast stretching depending upon location and sample time

8 Methodology - Electrical Resistance

8.1 Survey

The instrument can be used to collect multiple readings at each array position. The gain and current can be altered to suit ground conditions, e.g. moist or dry surface, and data range.

Network RTK GNSS was used to establish an accurate survey grid within each area and to survey in adjacent features to help locate the data and inform interpretation. From these accurately located points, grid set out was by tape measures to allow the survey areas to flow around obstacles.

Measured variable	Apparent electrical resistance / Ohm
Instrument	Geoscan Research RM15 with multiplexer
Configuration	Pole-pole (twin probe) array, 0.5m AM spacing Current fixed at 10 mA Instrument gain x 1
Sensitivity	0.1 Ohm
Spatial resolution	0.5 m along line x 1.0 m between line

8.2 Data processing

Processing of the areas of survey is minimised to the essential, it being important here to understand what variation could exist at similar scales to the measurement interval, e.g. narrow anomalies from utility trenches, narrow walls or other structures maybe close to the surface.

Process	Software	Parameters
Spike reduction	Proprietary	Ward: Median threshold filter, maximum point deviation 10 Ohm within a 5x5 datum (2.5 x 5.0 m) window Orchard: None
Grid levelling	N/A	Ward: Grids matched to common background level during survey Orchard: None needed (single grid)
Interpolation	Proprietary	Nearest neighbour to 0.5 x 0.5 m
Grid smoothing	Manifold GIS	Ward: 3x3 datum lowpass, weighting of 10 Orchard: 3x3 datum lowpass, weighting of 16

9 Supporting Information

Work generally follows the recommendations of these documents:

- Chartered Institute for Archaeologists (2014, updated 2020) "Standard and Guidance for Archaeological Geophysical Survey";
- English Heritage (2008) "Geophysical Survey in Archaeological Field Evaluation";
- European Archaeological Council (2015) "Guidelines for the Use of Geophysics in Archaeology";

and is undertaken in accordance with the high professional standards and technical competence expected by the Geological Society of London.

For work in Wales, the Welsh Archaeological Trusts' 2022 guidance is also followed.

9.1 Glossary

Acronym / term	Type	Definition
A	Physical quantity	SI unit Amp of electric current
BGS	Organisation	British Geological Survey
CIfA	Organisation	Chartered Institute for Archaeologists
dB	Physical quantity	Decibel, unit of amplification / attenuation
DRM	Process	Depositional Remanent Magnetisation
EAGE	Organisation	European Association of Geoscientists and Engineers
EGNOS	Technology	European Geostationary Navigation Overlay Service
ERT	Technology	Electrical resistivity tomography
ETRS89	Technology	European Terrestrial Reference System (defined 1989)
ETSI	Organisation	European Telecommunications Standards Institute
EuroGPR	Organisation	European Ground Penetrating Radar Association, the trade body for GPR professionals
G-BASE	Data	British Geological Survey Geochemical Atlas
GeolSoc	Organisation	Geological Society of London, the chartered body for the geological profession
GNSS	Technology	Global Navigation Satellite System
GPR	Technology	Ground penetrating radar
GPS	Technology	Global Positioning System (US)
inversion	process	A combination of forward and backward modelling intended to construct a 2D or 3D model of the physical distribution of a variable from data measured on a 1D or 2D surface. It is fundamental to ERT survey
IP	Physical quantity	Induced polarisation (or chargeability) units mV/V or ms
m	Physical quantity	SI unit metres of distance
mbgl	Physical quantity	Metres below ground level
MHz	Physical quantity	SI unit mega-Hertz of frequency
MS	Physical quantity	Magnetic susceptibility, unitless
mS	Physical quantity	SI unit milli-Siemens of electrical conductivity
nT	Physical quantity	SI unit nano-Tesla of magnetic flux density
OFCOM	Organisation	The Office of Communications, the UK radio spectrum regulator
Ohm	Physical quantity	SI unit Ohm of electrical resistance
OS	Organisation	Ordnance Survey of Great Britain
OSGB36	Data	The OS national grid (Great Britain)
OSTN15	Technology	Current coordinate transformation from ETRS89 to OSGB36 co-ordinates
RDP	Physical quantity	Relative Dielectric Permittivity, unitless
RTK	Technology	Real Time Kinematic (correction of GNSS position from a base station)
s	Physical quantity	SI unit seconds of time
TMI	Physical quantity	Total magnetic intensity (measured flux density minus regional flux density)
TRM	Process	Thermo-Remanent Magnetisation

Acronym / term	Type	Definition
V	Physical quantity	SI unit Volt of electric potential
WGS84	Data	World Geodetic System (defined 1984)

9.2 Bibliography

British Geological Survey 1: 50,000 mapping (https://mapapps.bgs.ac.uk/geologyofbritain/home.html)

Google Maps (https://www.google.com/maps/)

National Library of Scotland (NLS) historic mapping (https://maps.nls.uk/geo/explore/side-by-side/)

National Soil Resources Institute (NSRI) Soilscapes mapping (https://mapapps2.bgs.ac.uk/ukso/home.html)

TigerGeo, 2023, "Cardigan Castle, Ceredigion: Specification for Geophysical Survey" unpublished WSI

9.3 Reference

Chartered Institute for Archaeologists, 2014 (Updated 2020), "Standard and guidance for archaeological geophysical survey" Reading

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David, A, *et al*, 2008, "Geophysical Survey in Archaeological Field Evaluation", English Heritage

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National Panel for Archaeological Archives in Wales, 2017, "*The National Standard and Guidance to Best Practice for Collecting and Depositing Archaeological Archives in Wales*", Welsh Museums Federation

Rawlins, B G *et al*, 2012, "The advanced soil geochemical atlas of England and Wales". British Geological Survey, Keyworth

Schmidt, A, 2013, "Geophysical Data in Archaeology: A Guide to Good Practice", ADS

Scollar, I, 1990, "Archaeological Prospecting and Remote Sensing", Topics in Remote Sensing 2, Cambridge University Press

Telford, W M, *et al*, 1990, "Applied Geophysics", 2nd Edition, Cambridge University Press

The Welsh Archaeological Trusts, 2022, "Guidance for the Submission of Data to the Welsh Historic Environment Records (HERs)"

9.4 Archiving

TigerGeo maintains an archive for all its projects, access to which is permitted for research purposes. Copyright and intellectual property rights are retained by TigerGeo on all material it has produced, the client having full licence to use such material as benefits their project. This archive contains all survey and project data, communications, field notes, reports and other related material including copies of third party data (e.g. CAD mapping, etc.) in digital form unless required to delete these, e.g. certain classes of OS digital data upon licence expiry.

The existence of surveys for archaeological purposes will normally be registered on the OASIS system provided there are no conflicting requirements for confidentiality.

9.5 Dissemination

It is assumed that Cadwgan Building Preservation Trust will determine the distribution path for reporting, including to any end client, other contractors, local authority etc., and will determine the timetable for upload of the project report to the OASIS Grey Literature library or supply of report or data to other archiving services including the Historic Environment Record, taking into account confidentiality etc.

TigerGeo reserves the right to display data rendered anonymous on its website and in other marketing or research publications.

9.6 Standards and quality

TigerGeo is developing an Integrated Management System (IMS) towards ISO certification for ISO9001, ISO14001 and OHSAS18001/ISO45001. For work within the archaeological sector TigerGeo has been awarded CIfA (Chartered Institute for Archaeologists) Registered Organisation status.

A high standard of client-centred professionalism is maintained in accordance with the requirements of relevant professional bodies including the Geological Society of London (GeolSoc) and the Chartered Institute for Archaeologists (CIfA). Senior members of TigerGeo are professional members of the GeolSoc (FGS), CIfA (MCIfA & ACIfA grades) and other appropriate bodies, including the European Association of Geoscientists and Engineers (EAGE) Near Surface Division (MEAGE) and the Institute of Professional Soil Scientists (MISoilSci).

In addition TigerGeo is a member of EuroGPR and all ground penetrating and other radar work is in accordance with ETSI EG 202 730.

The management team at TigerGeo have almost 50 years of combined experience of near surface geophysical project design, survey, interpretation and reporting, based across a wide range of shallow geological contexts.

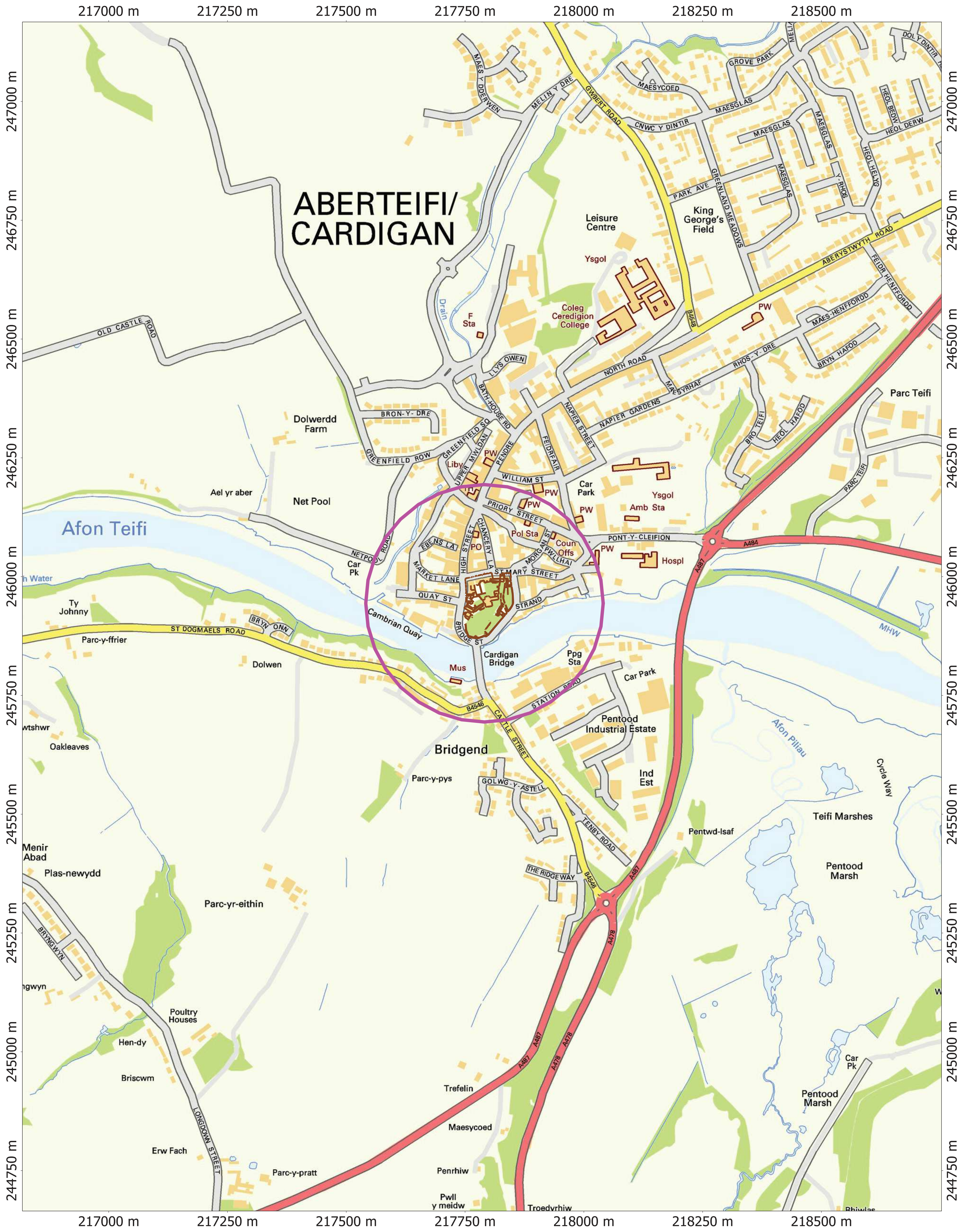
Data processing and interpretation adheres to the scientific principles of objectiveness and logical consistency. A standard set of approved external sources of information, e.g. from the British Geological Survey, the Ordnance Survey and similar sources of data, in addition to previous TigerGeo projects, guide the interpretive process. Due attention is paid to the technical constraints of method, resolution, contrast and other geophysical factors.

There is a strong culture of internal peer-review within TigerGeo, for example, all reports pass through a process of authorship, technical review and finally proof-reading before release to the client. Technical queries resulting from TigerGeo's work are reviewed by the Senior Geophysicist to ensure uniformity of response prior to implementing any edits, etc.

All work is undertaken in accordance with the high professional standards and technical competence expected by the Geological Society of London and the European Association of Geoscientists and Engineers.

9.7 Key personnel

Martin Roseveare, MSc BSc(Hons) MEAGE FGS MCIfA	**Senior Geophysicist, Director**
Martin specialised (MSc) in geophysical prospection for shallow applications and since 1998 has worked in commercial geophysics. Elected a GeolSoc Fellow in 2009 he is now working towards achieving CSci. A member of the European Association of Geoscientists & Engineers, he has served on the EuroGPR and CIfA GeoSIG committees and on the scientific committees of the 10th and 11th Archaeological Prospection conferences. He has reviewed papers for the EAGE Near Surface conference, was a technical reviewer of the Irish NRA geophysical guidance and is a founding member of the ISSGAP soils group. Professional interests include the application of geophysics to agriculture and the environment, e.g. groundwater and geohazards. He is also a software writer and equipment integrator with significant experience of embedded systems.	
Anne Roseveare, BEng(Hons) DIS MISoilSci	**Operations Manager, Environmental Geophysicist, Data Analyst**
On looking beyond engineering, Anne turned her attention to environmental monitoring and geophysics. She is a Member of the British Society of Soil Science / Institute of Professional Soil Scientists (BSSS/IPSS) and has specific areas of interest in soil physics & hydrology, agricultural applications and industrial sites. Working in shallow geophysics since 1998, Anne is a founding member of the ISSGAP soils group, also was the founding Editor of the International Society for Archaeological Prospection (ISAP). Specifications, logistics, health and safety, data handling & analysis are integral parts of her work, though she is happily distracted by the possibilities of discovering lost cities, hillwalking, dance and good food.	
Daniel Lewis, MA BA(Hons) MCIfA	**Consultant Archaeologist**
Daniel studied archaeology at the University of Nottingham and worked in field archaeology for many years, managing urban and rural fieldwork projects in and around Herefordshire. When the desk became more appealing he jumped into the world of consulting, working on small and large multi-discipline projects throughout England and Wales. At the same time, he returned to University, gaining an MA in Historic Environment Conservation. With experience in the heritage sector since 1998, Daniel has a diverse portfolio of skills. Here he ensures that geophysical work within the heritage sector is well grounded in archaeology. His spare time includes much running up mountains.	
Alexandra Gerea, MSc, BSc, PhD Candidate	**Environmental Geophysicist**
Alexandra has a BSc in Geophysics and an MSc in Applied Geo-biology and is in the final stages of a PhD in the UK after living in Portugal for six months working on her master's degree. Since 2008 she has used most mainstream processing applications across electrical, magnetic and radar methods. She combines a love of nature and science and is currently studying plant roots in agricultural environments using geophysical methods. When not doing that she enjoys travelling, hiking, nature, yoga, books, foreign languages and cats. A few years ago she found a passion for electronics and started building different devices including intelligent gardening systems and coding in Python.	



CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 01a Site Location

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TIGERGEO

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 01b Site Location - Detailed

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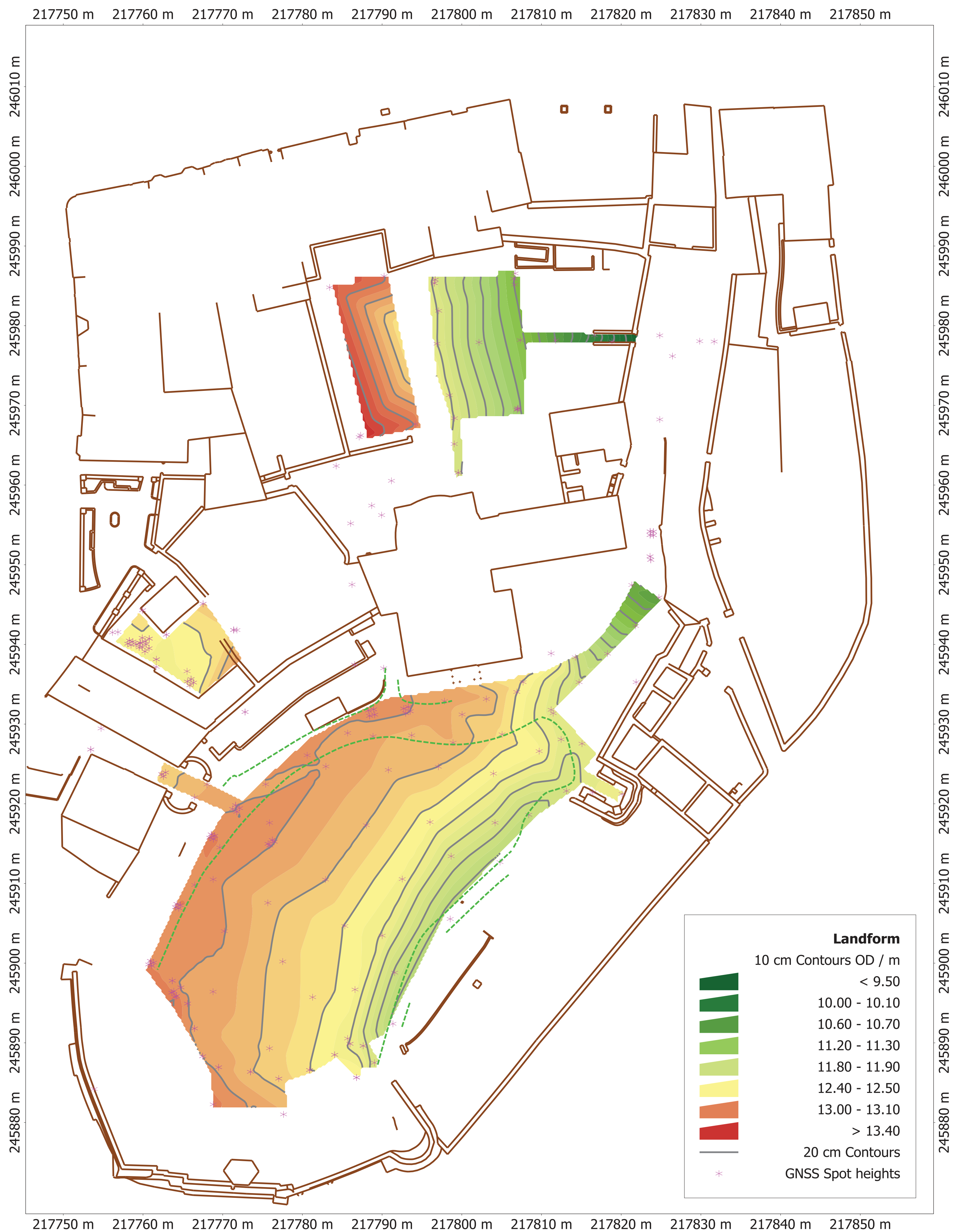

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 02 Basic Landform

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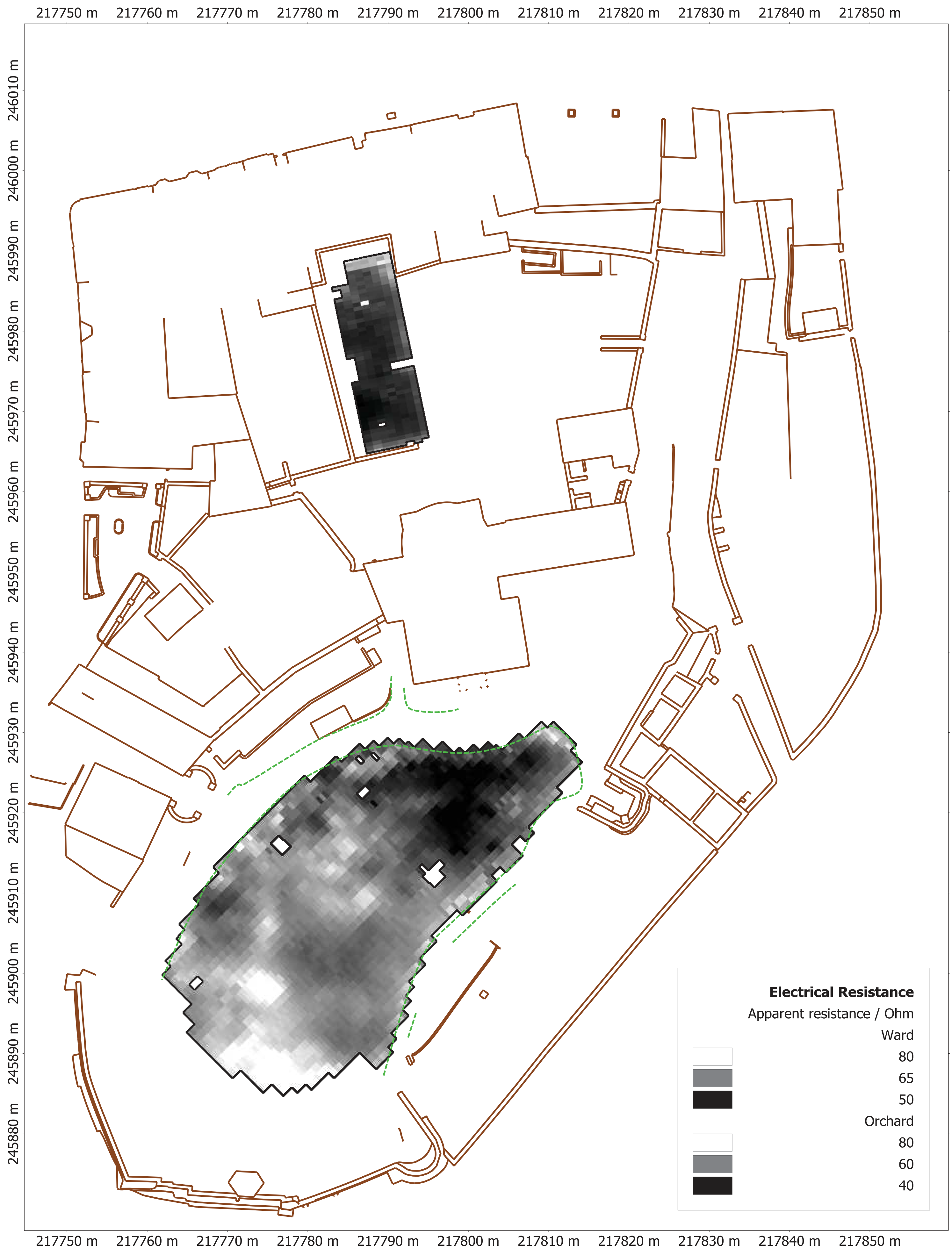

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 03a Electrical Resistance Data - 0.5m AM Spacing

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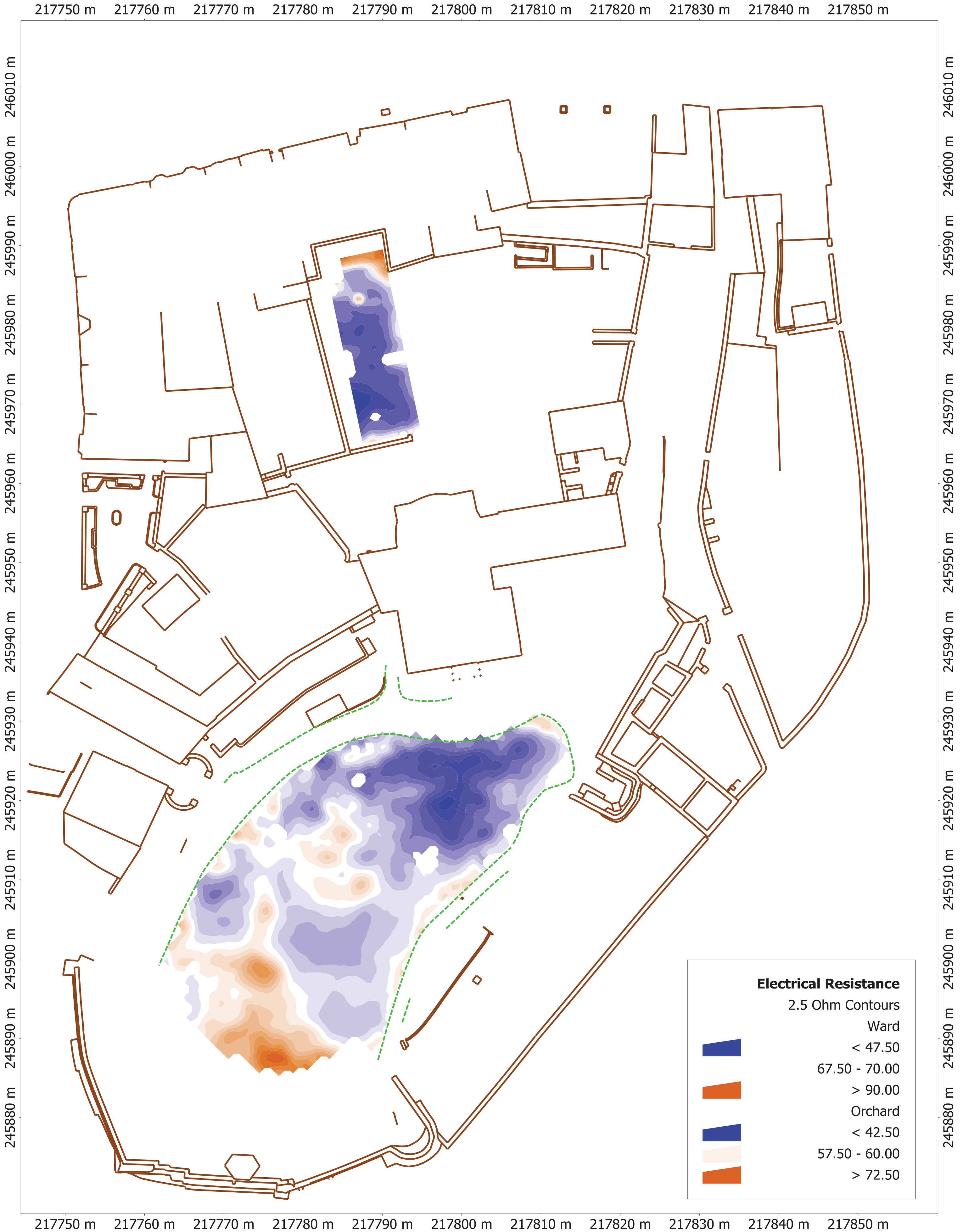

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion

DWG 03b Electrical Resistance Data - 0.5m AM Spacing - Contoured

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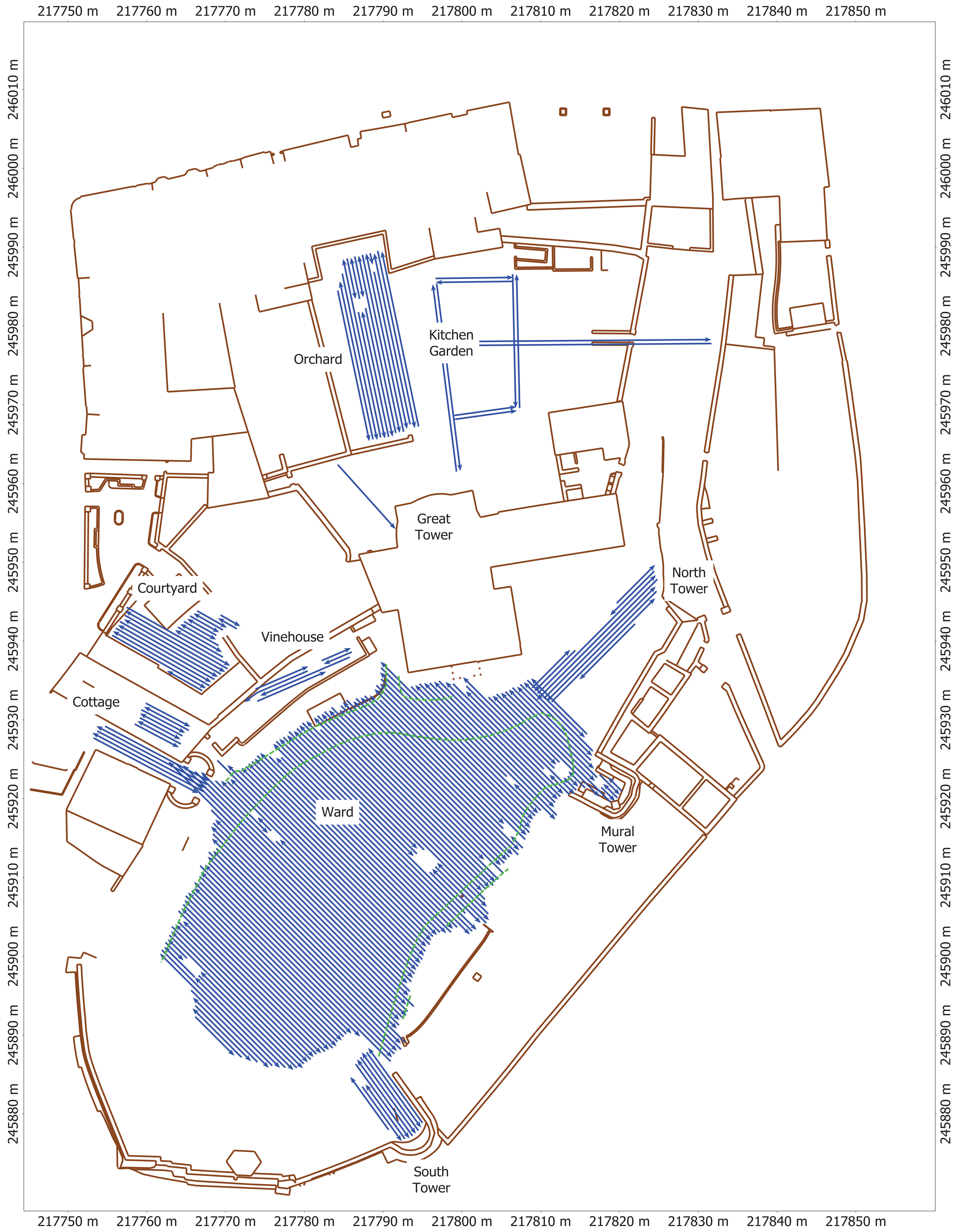

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 04 450 MHz GPR Profile Locations

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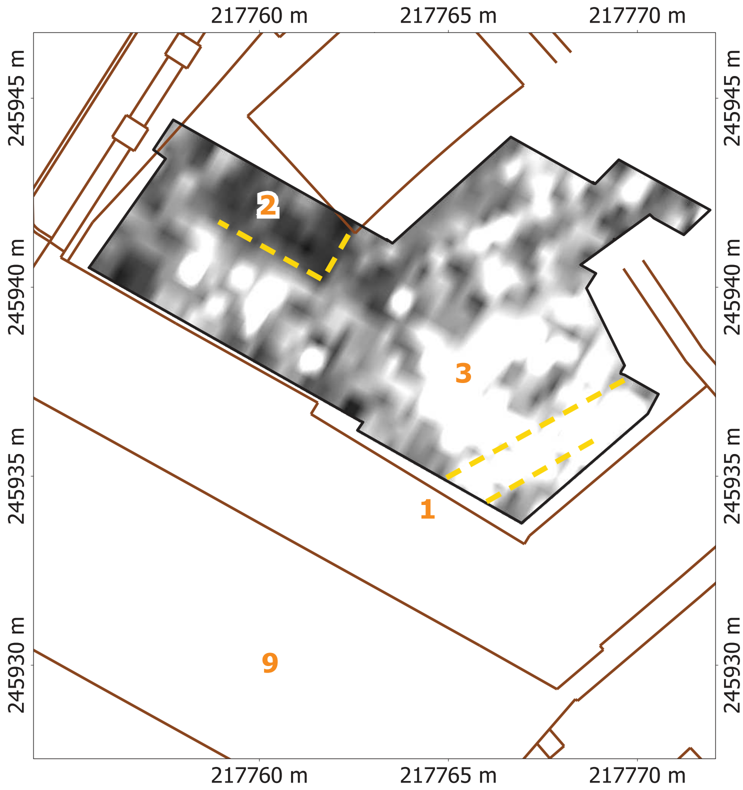

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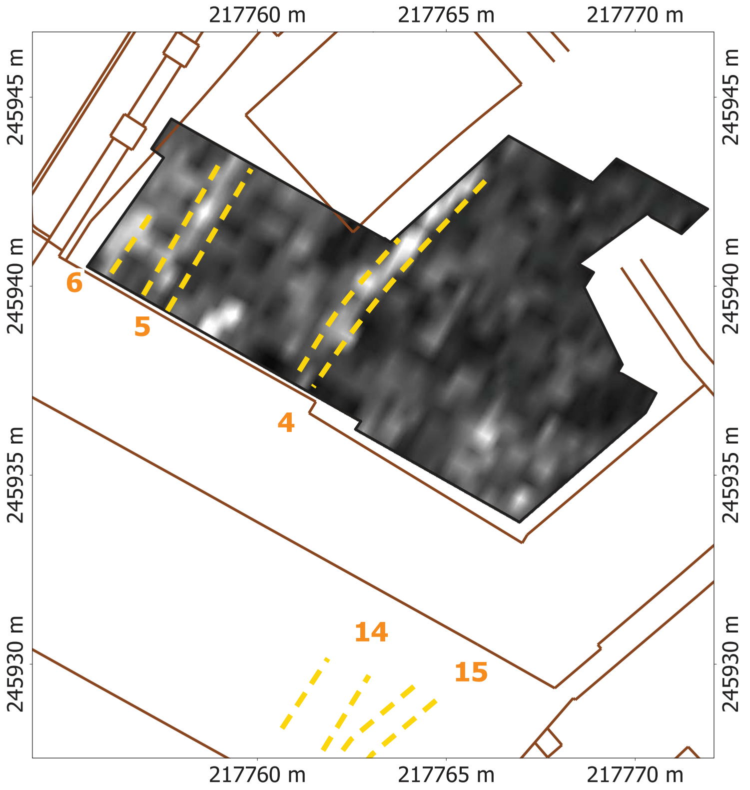

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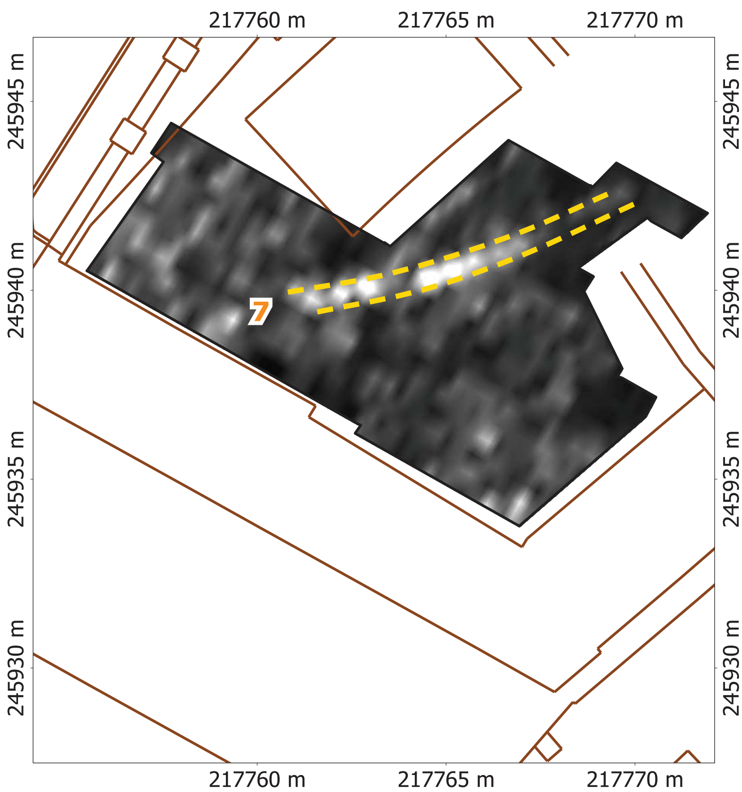

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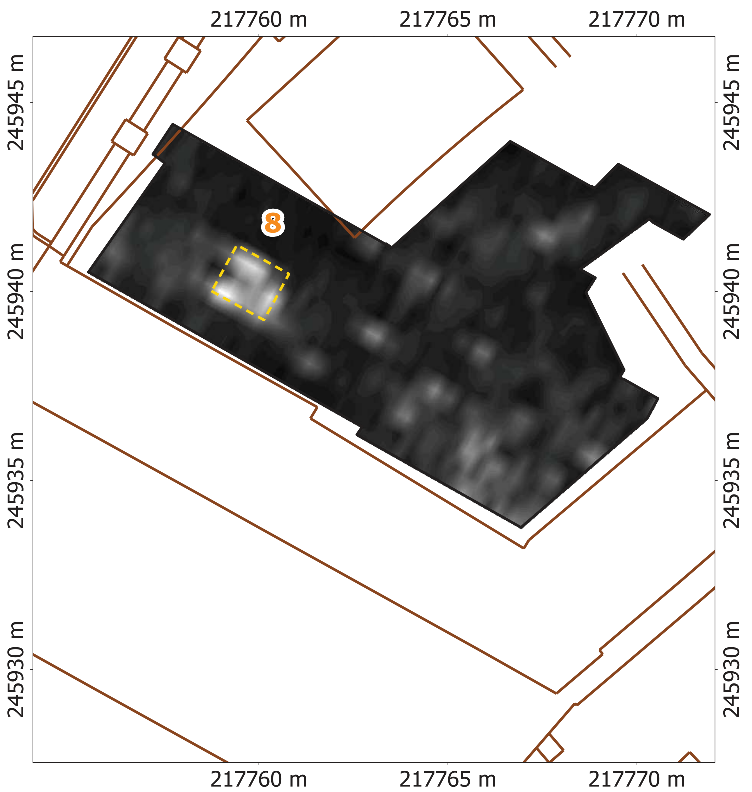

34.96 ns (~ 114 cm bgl)

Time (Amplitude) Slice - Arbitrary Colouration - Lighter Tones Imply Greater Variation of Dielectric Permittivity Within Slice Thickness
All Slices Are 6 Samples Thick, Which Is Approximately 1/4 Wavelength At Velocity 0.07 m/ns

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 05 GPR Timeslices - Courtyard

Orthographic Scale: 1:200 @ A4 Spatial Units: Meter. Do not scale off this drawing

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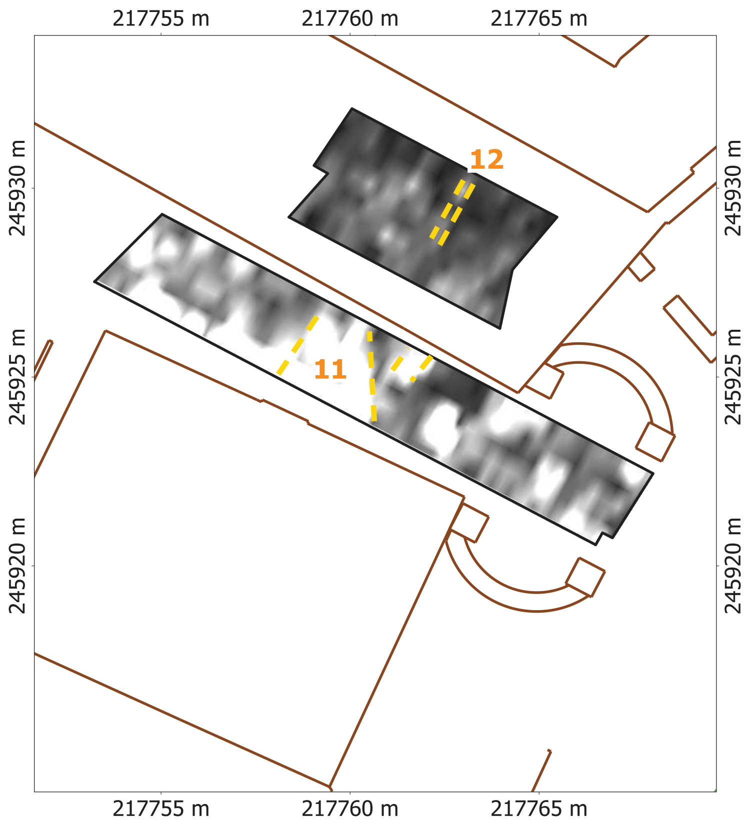
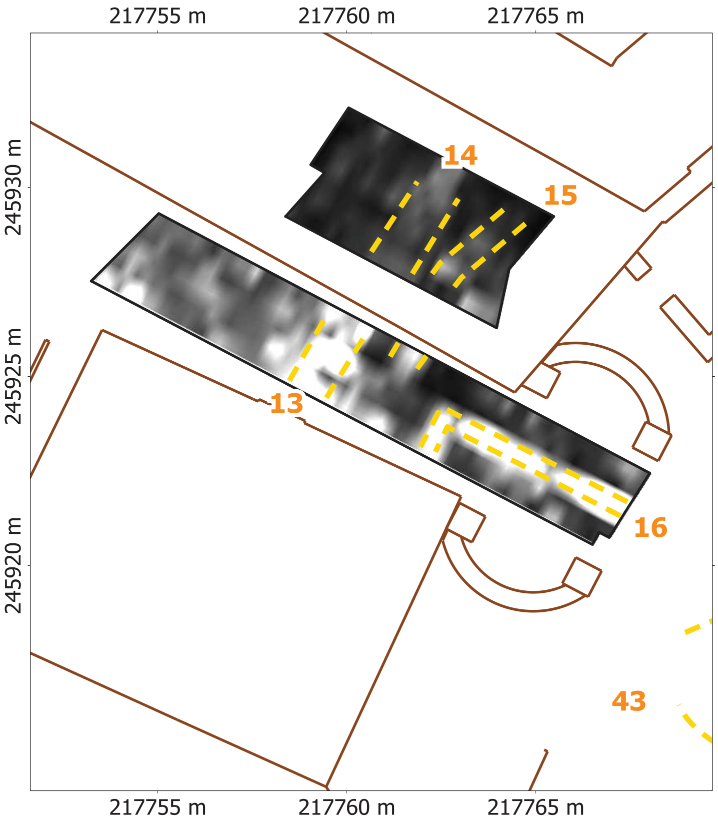
5.64 ns (~ 18 cm bgl)



8.00 ns (~ 26 cm bgl)



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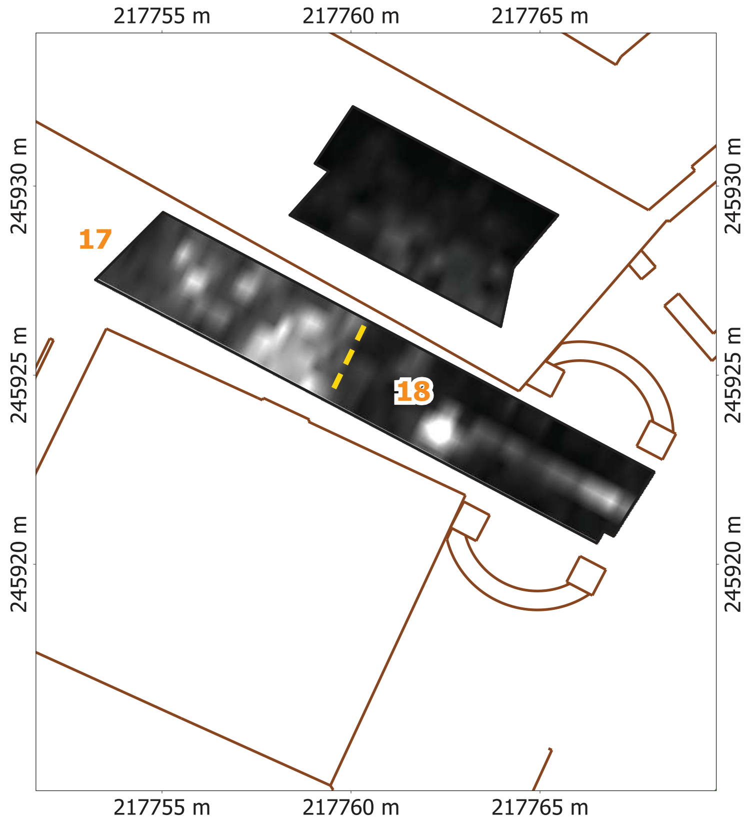

23.24 ns (~ 76 cm bgl)

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All Slices Are 6 Samples Thick, Which Is Approximately 1/4 Wavelength At Velocity 0.07 m/ns

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 06 GPR Timeslices - Cottage

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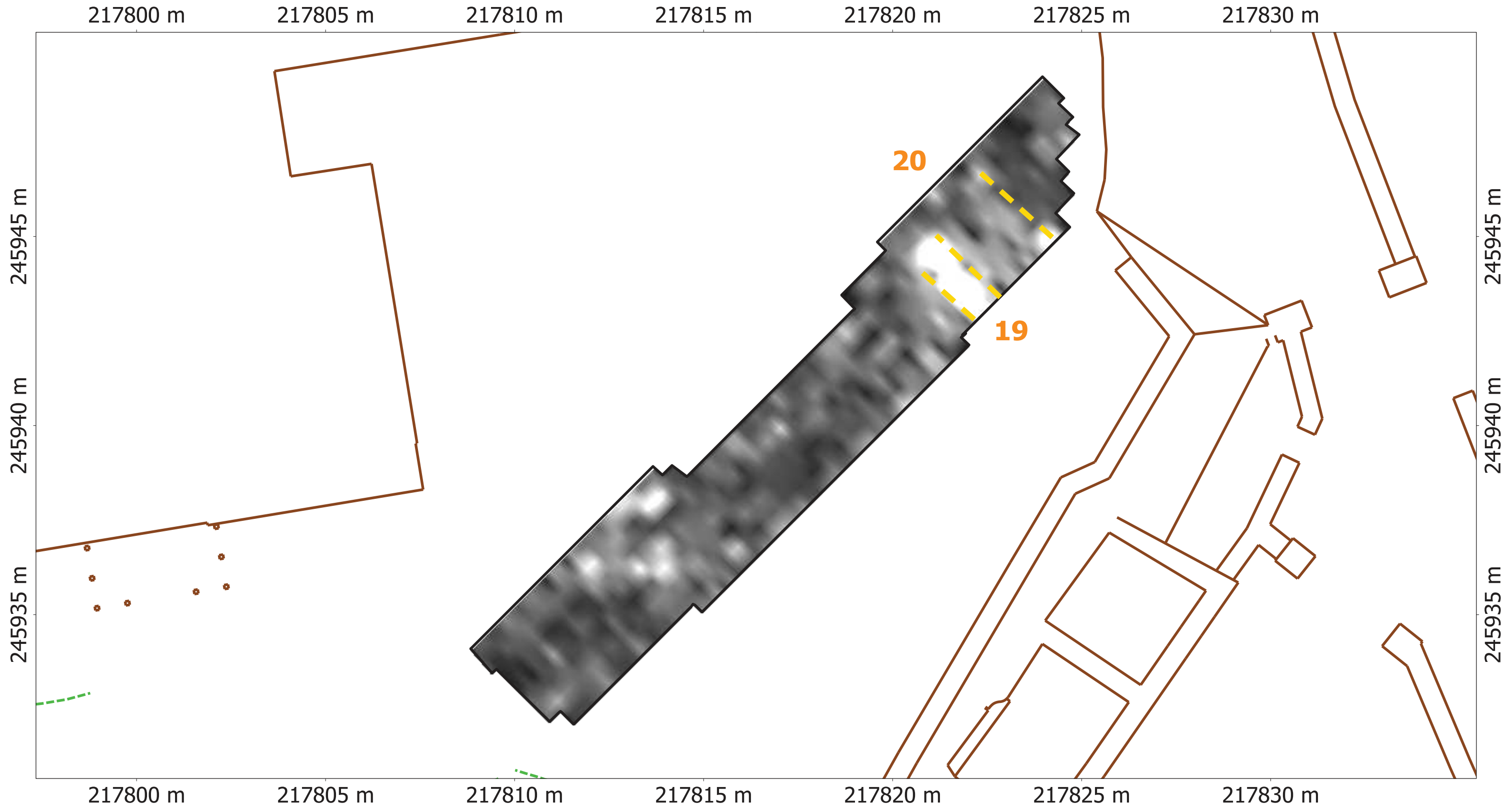
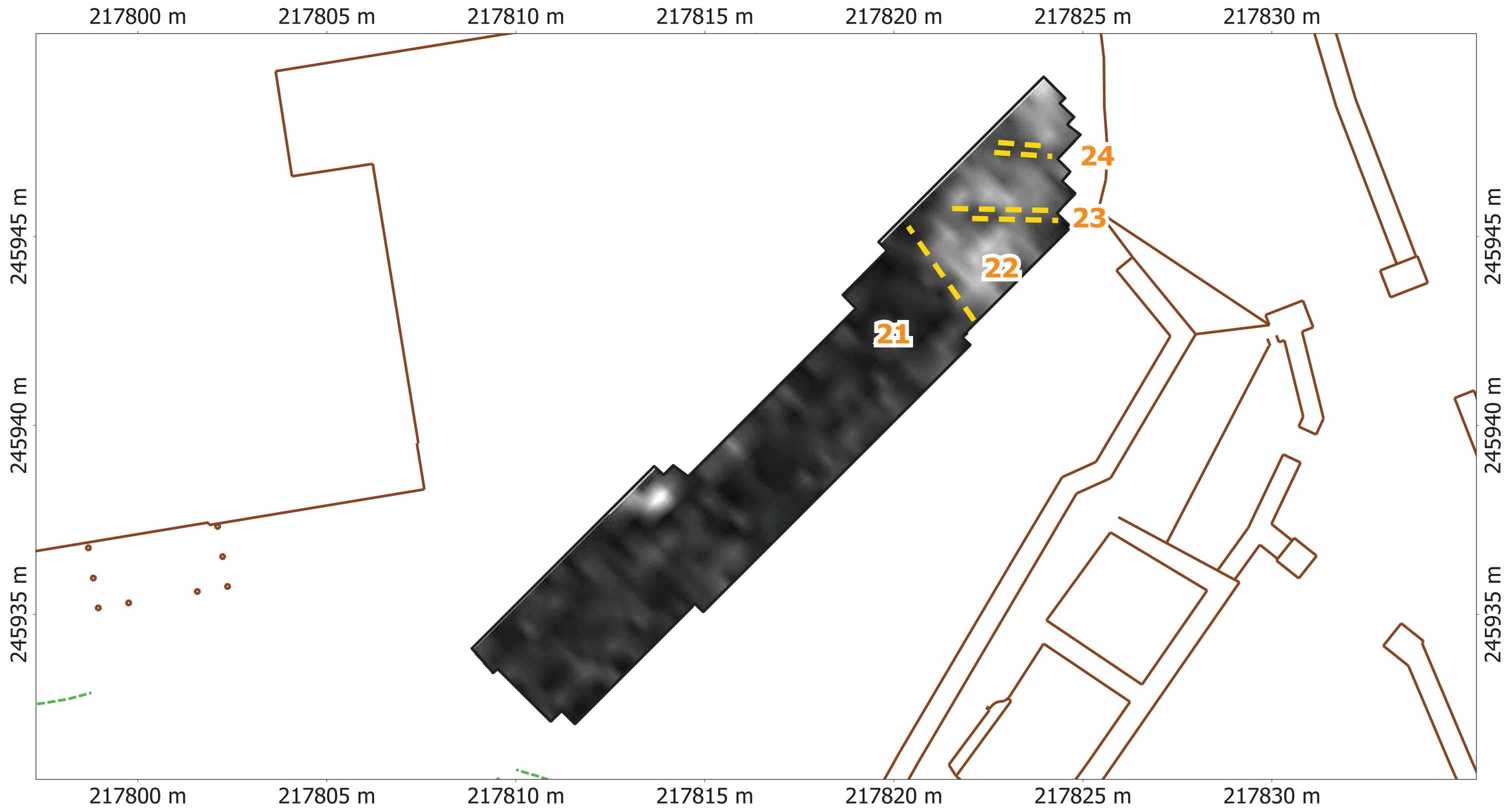


9.17 ns (~ 32 cm bgl)



11.52 ns (~ 40 cm bgl)

Time (Amplitude) Slice - Arbitrary Colouration - Lighter Tones Imply Greater Variation of Dielectric Permittivity Within Slice Thickness
All Slices Are 6 Samples Thick, Which Is Approximately 1/4 Wavelength At Velocity 0.07 m/ns

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 07a GPR Timeslices - North Bastion

Orthographic Scale: 1:200 @ A4 Spatial Units: Meter. Do not scale off this drawing
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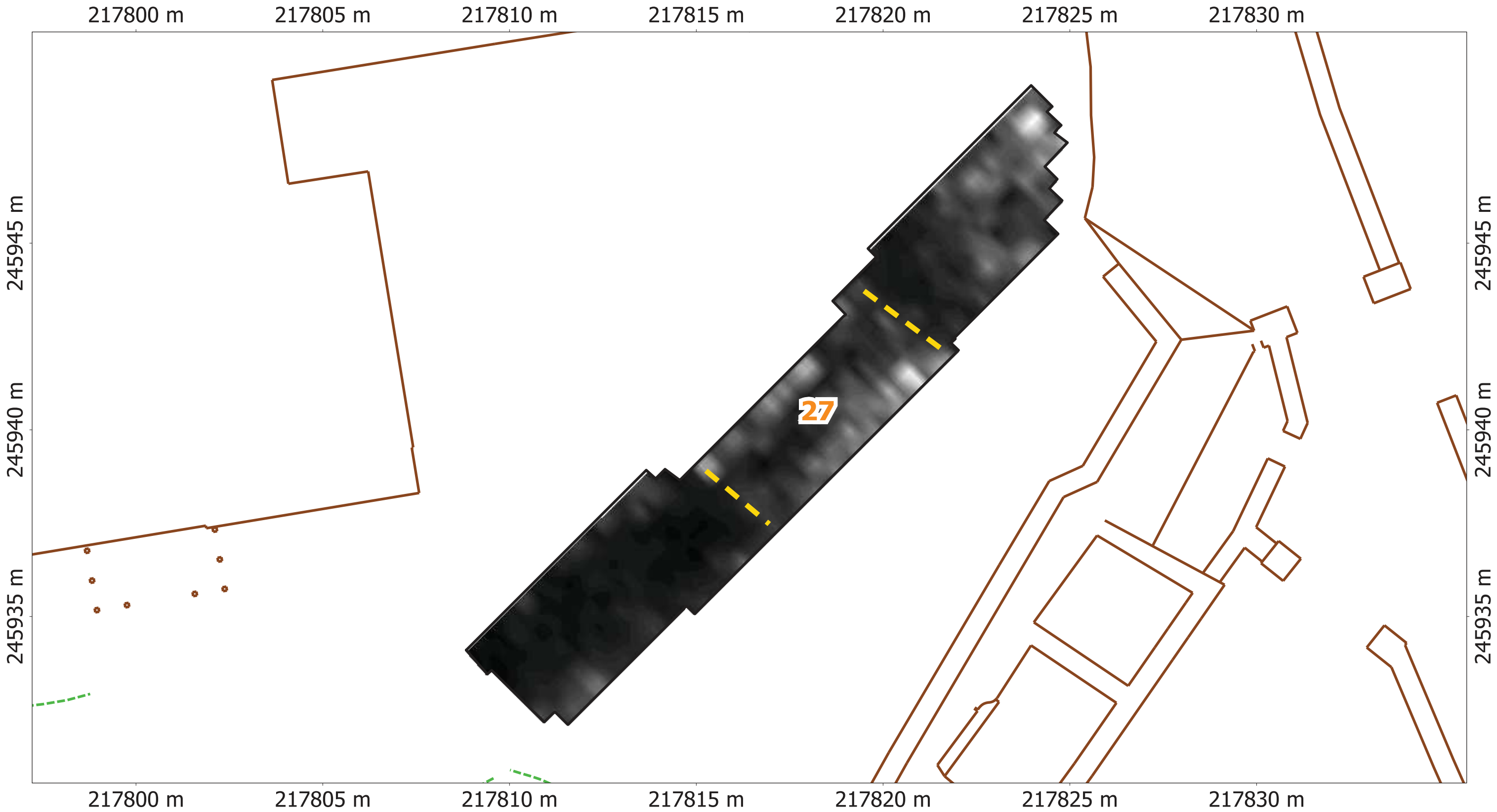
11.55 ns (~ 64 cm bgl)



24.41 ns (~ 85 cm bgl)

Time (Amplitude) Slice - Arbitrary Colouration - Lighter Tones Imply Greater Variation of Dielectric Permittivity Within Slice Thickness
All Slices Are 6 Samples Thick, Which Is Approximately 1/4 Wavelength At Velocity 0.07 m/ns

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 07b GPR Timeslices - North Bastion

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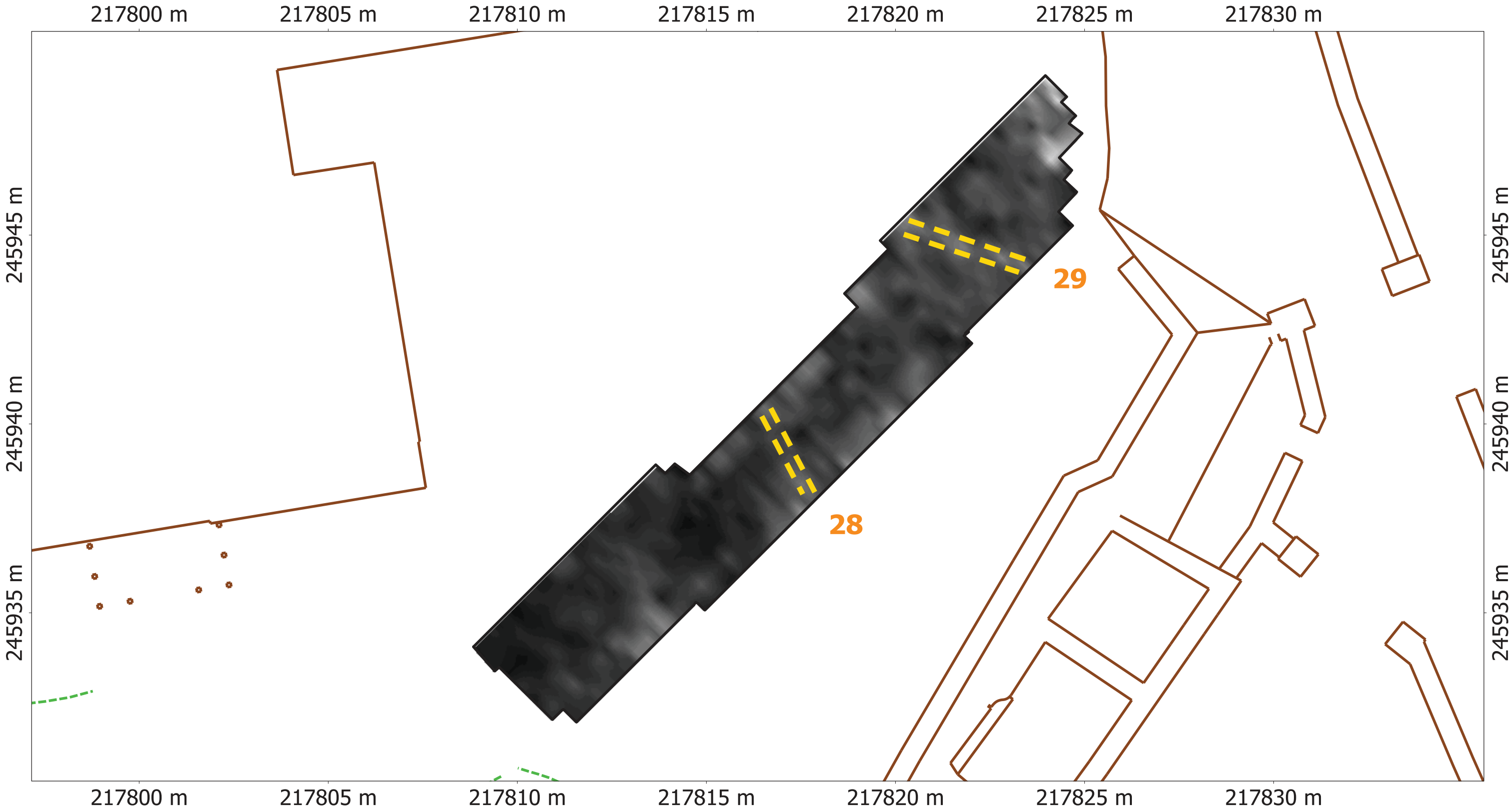

37.31 ns (~ 130 cm bgl)

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All Slices Are 6 Samples Thick, Which Is Approximately 1/4 Wavelength At Velocity 0.07 m/ns

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
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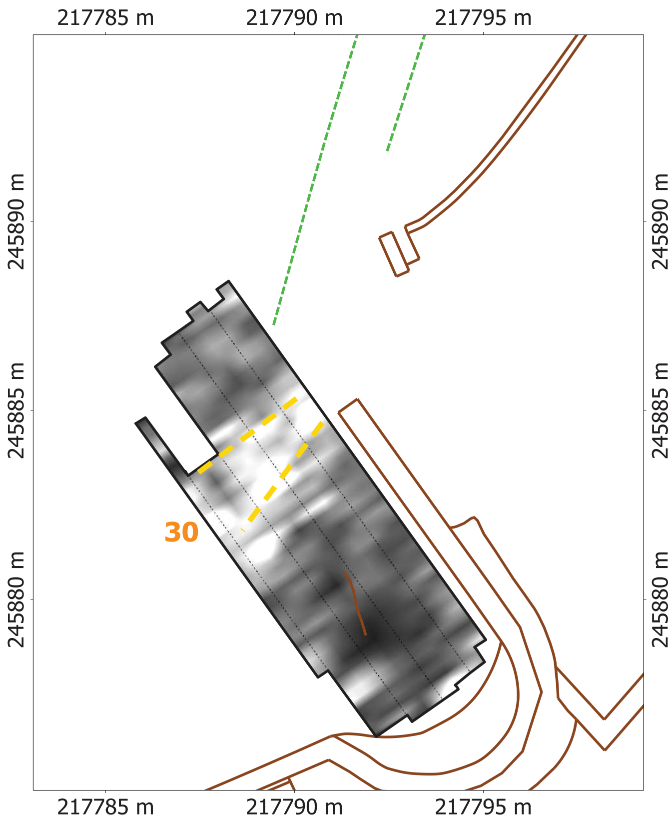

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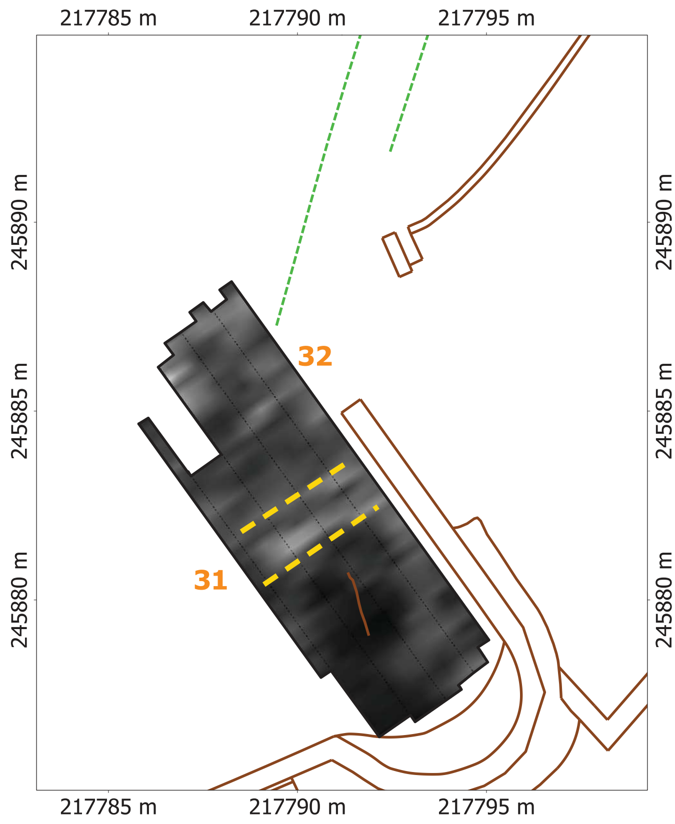
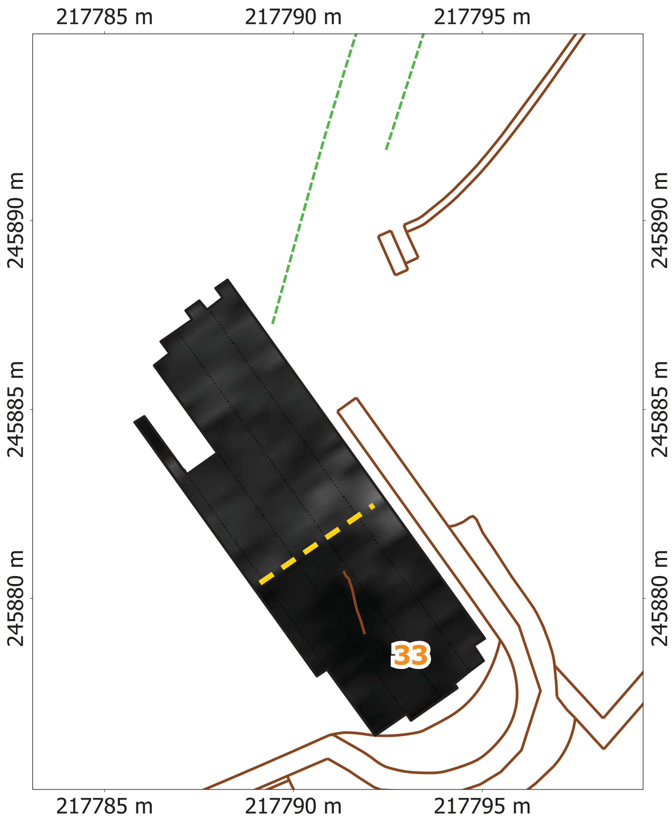


19.73 ns (~ 69 cm bgl)



26.76 ns (~ 94 cm bgl)

Time (Amplitude) Slice - Arbitrary Colouration - Lighter Tones Imply Greater Variation of Dielectric Permittivity Within Slice Thickness
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CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 08 GPR Timeslices - South Tower

Orthographic Scale: 1:200 @ A4 Spatial Units: Meter. Do not scale off this drawing

TIGERGEO

Time (Amplitude) Slice - Arbitrary Colouration - Lighter Tones Imply Greater Variation of Dielectric Permittivity Within Slice Thickness
All Slices Are 6 Samples Thick, Which Is Approximately 1/4 Wavelength At Velocity 0.07 m/ns

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 09a GPR Timeslice - Ward 6.84 ns (~24 cm Below Ground Level)

Orthographic Scale: 1:400 @ A4 Spatial Units: Meter. Do not scale off this drawing
File: CCC231.map

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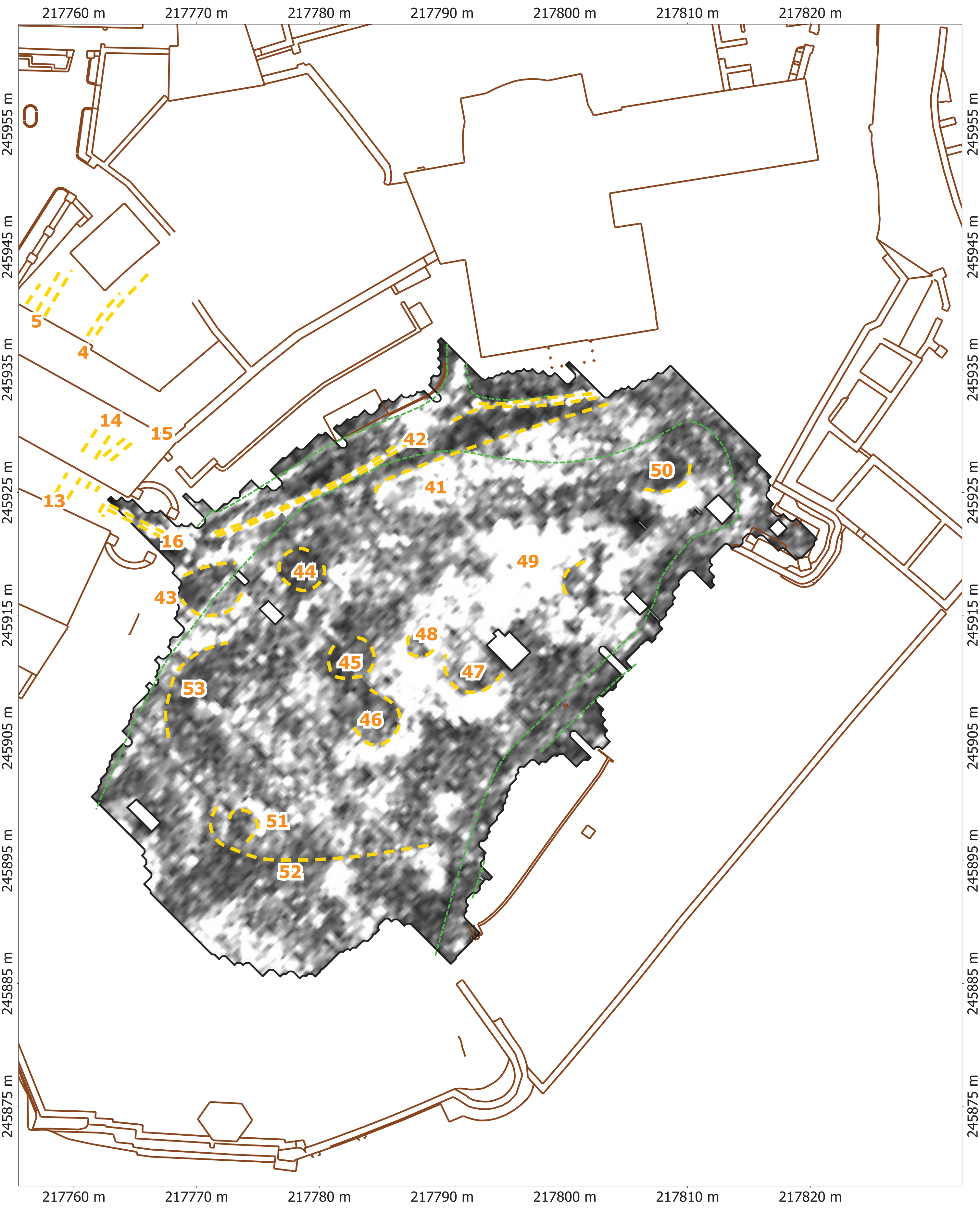

Time (Amplitude) Slice - Arbitrary Colouration - Lighter Tones Imply Greater Variation of Dielectric Permittivity Within Slice Thickness
All Slices Are 6 Samples Thick, Which Is Approximately 1/4 Wavelength At Velocity 0.07 m/ns

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 09b GPR Timeslice - Ward 12.70 ns (~44 cm Below Ground Level)

Orthographic Scale: 1:400 @ A4 Spatial Units: Meter. Do not scale off this drawing
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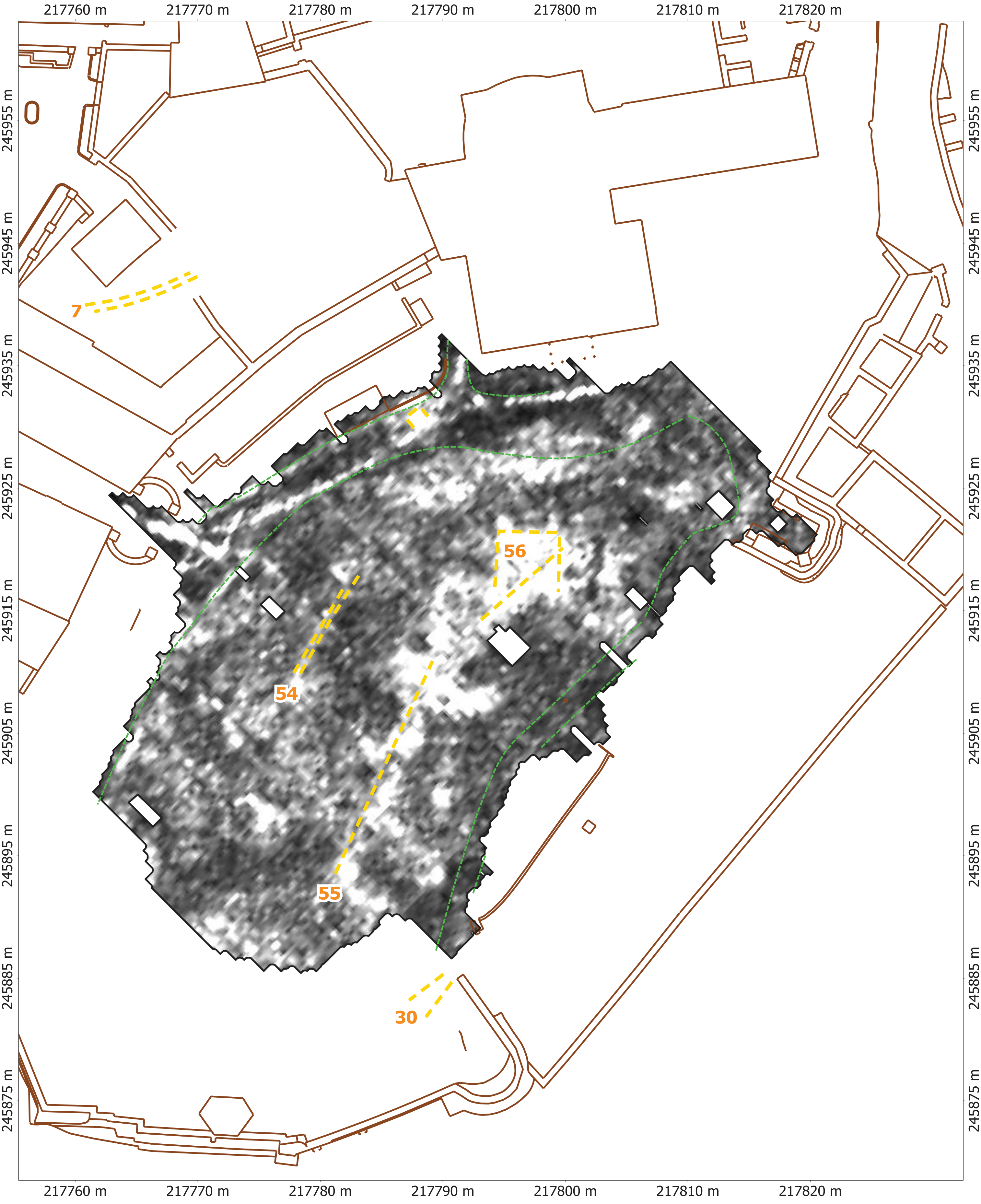
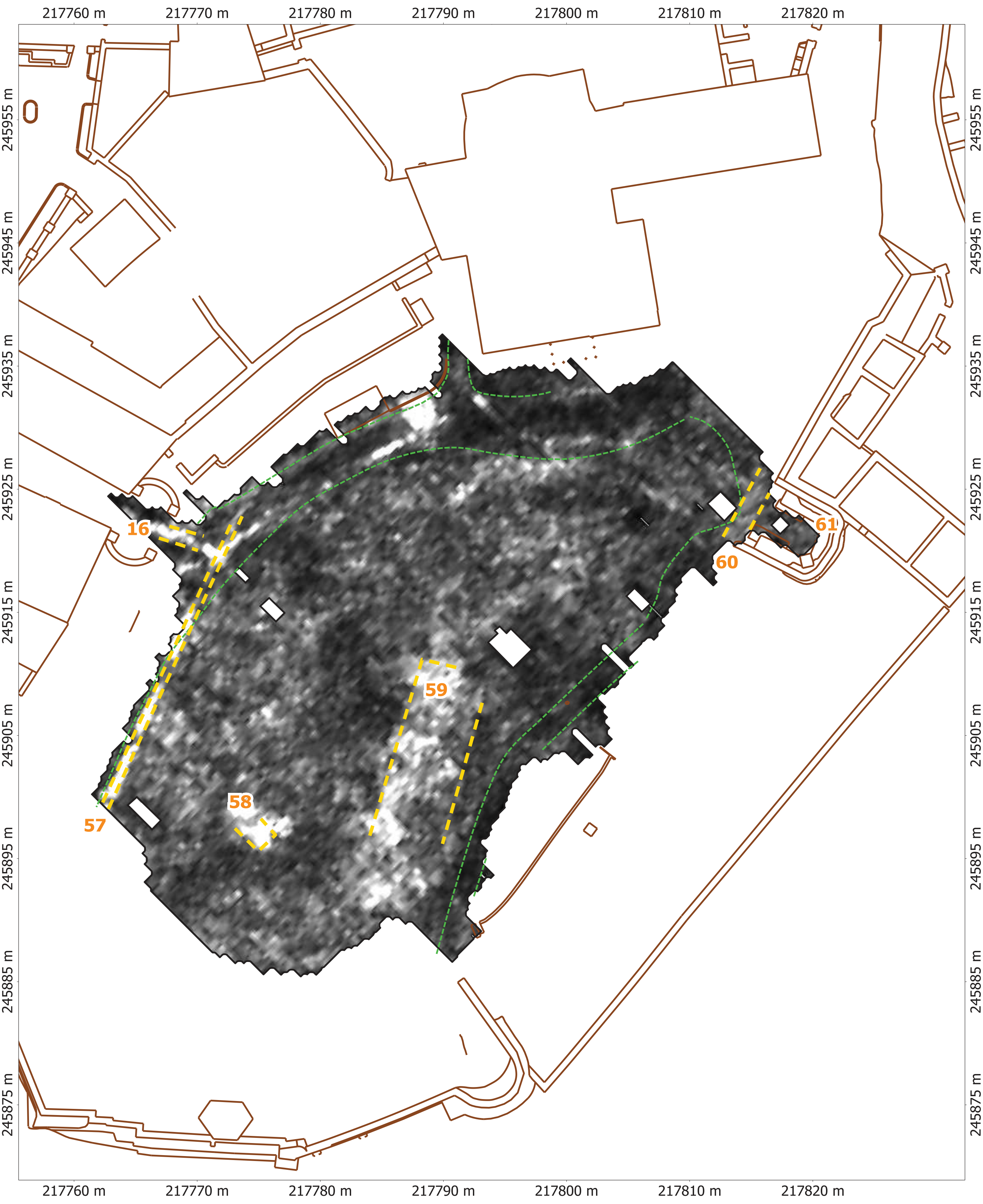


Time (Amplitude) Slice - Arbitrary Colouration - Lighter Tones Imply Greater Variation of Dielectric Permittivity Within Slice Thickness
All Slices Are 6 Samples Thick, Which Is Approximately 1/4 Wavelength At Velocity 0.07 m/ns

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 09c GPR Timeslice - Ward 13.87 ns (~49 cm Below Ground Level)

Orthographic Scale: 1:400 @ A4 Spatial Units: Meter. Do not scale off this drawing
File: CCC231.map

TIGERGEO



Time (Amplitude) Slice - Arbitrary Colouration - Lighter Tones Imply Greater Variation of Dielectric Permittivity Within Slice Thickness
All Slices Are 6 Samples Thick, Which Is Approximately 1/4 Wavelength At Velocity 0.07 m/ns

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 09d GPR Timeslice - Ward 16.21 ns (~57 cm Below Ground Level)

Orthographic Scale: 1:400 @ A4 Spatial Units: Meter. Do not scale off this drawing
File: CCC231.map

TIGERGEO

Time (Amplitude) Slice - Arbitrary Colouration - Lighter Tones Imply Greater Variation of Dielectric Permittivity Within Slice Thickness
All Slices Are 6 Samples Thick, Which Is Approximately 1/4 Wavelength At Velocity 0.07 m/ns

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 09e GPR Timeslice - Ward 24.41 ns (~85 cm Below Ground Level)

Orthographic Scale: 1:400 @ A4 Spatial Units: Meter. Do not scale off this drawing
File: CCC231.map

TIGERGEO

Time (Amplitude) Slice - Arbitrary Colouration - Lighter Tones Imply Greater Variation of Dielectric Permittivity Within Slice Thickness
All Slices Are 6 Samples Thick, Which Is Approximately 1/4 Wavelength At Velocity 0.07 m/ns

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 09f GPR Timeslice - Ward 40.82 ns (~143 cm Below Ground Level)

Orthographic Scale: 1:400 @ A4 Spatial Units: Meter. Do not scale off this drawing
File: CCC231.map

TIGERGEO

Time (Amplitude) Slice - Arbitrary Colouration - Lighter Tones Imply Greater Variation of Dielectric Permittivity Within Slice Thickness
All Slices Are 6 Samples Thick, Which Is Approximately 1/4 Wavelength At Velocity 0.07 m/ns

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 09g GPR Timeslice - Ward 45.51 ns (~159 cm Below Ground Level)

Orthographic Scale: 1:400 @ A4 Spatial Units: Meter. Do not scale off this drawing
File: CCC231.map

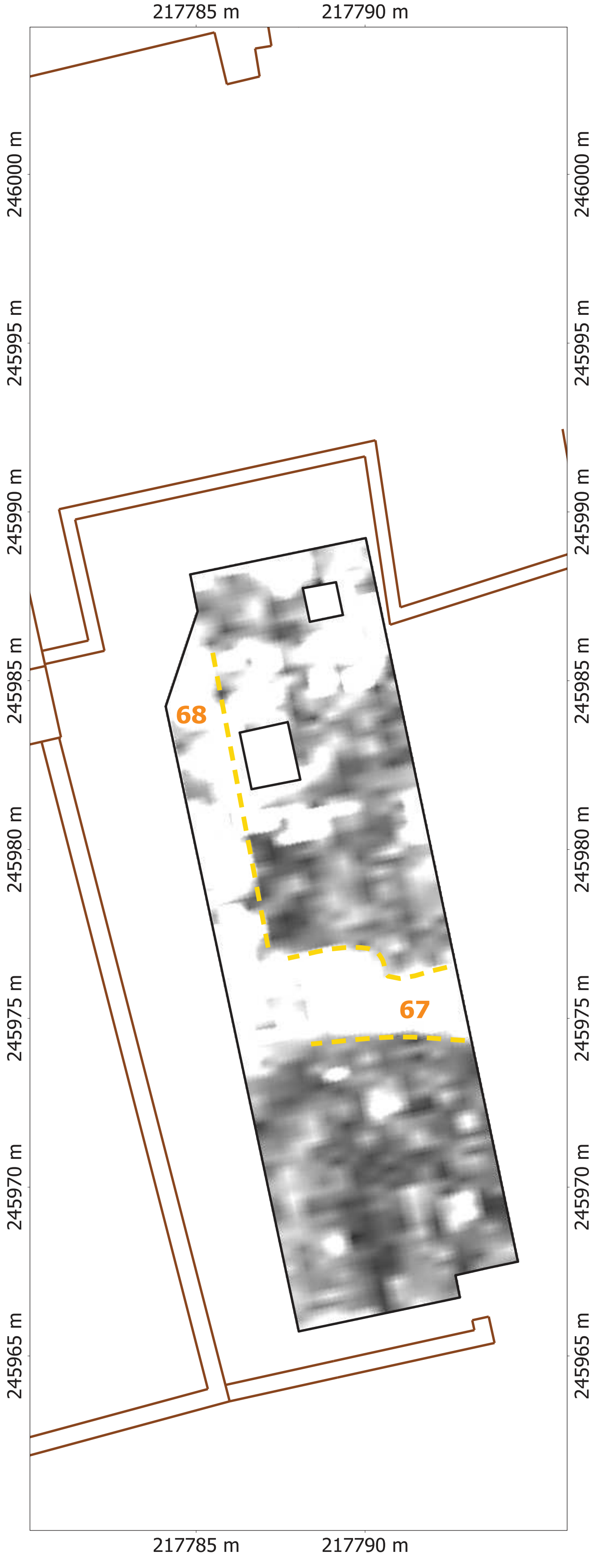
TIGERGEO

Time (Amplitude) Slice - Arbitrary Colouration - Lighter Tones Imply Greater Variation of Dielectric Permittivity Within Slice Thickness
All Slices Are 6 Samples Thick, Which Is Approximately 1/4 Wavelength At Velocity 0.07 m/ns

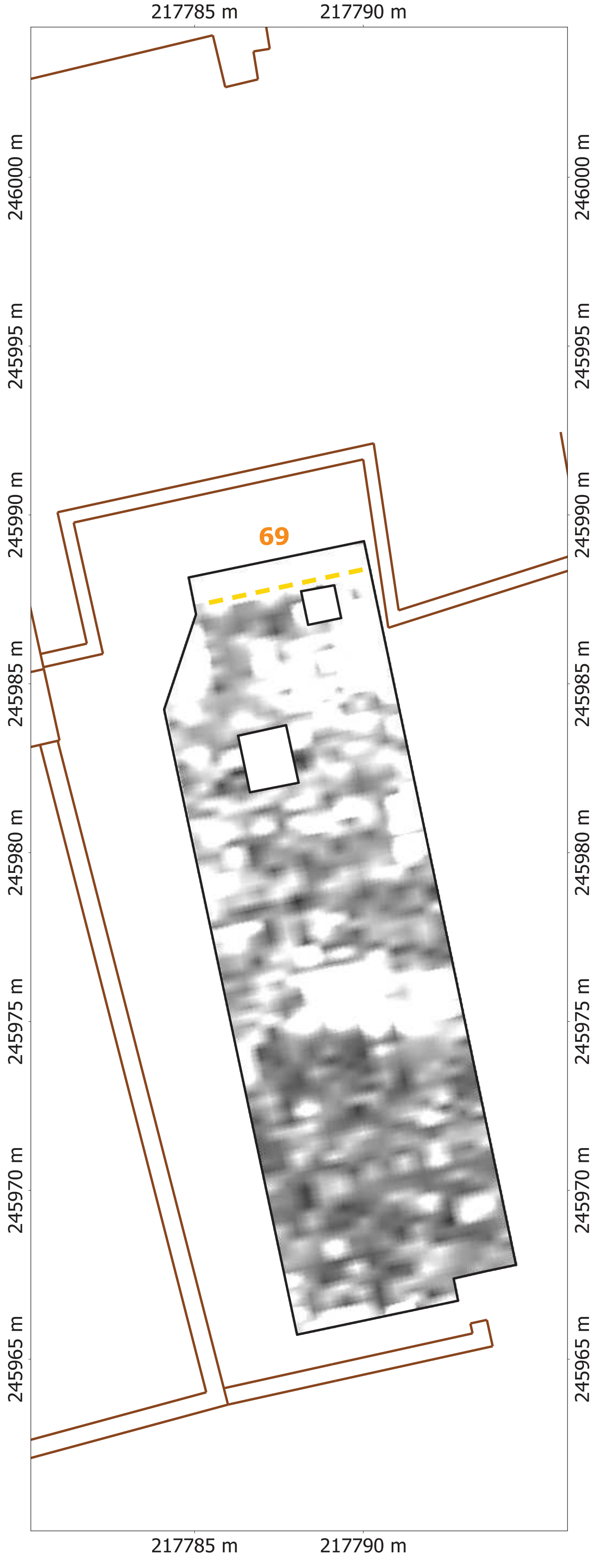
CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 09h GPR Timeslice - Ward 57.23 ns (~200 cm Below Ground Level)

Orthographic Scale: 1:400 @ A4 Spatial Units: Meter. Do not scale off this drawing
File: CCC231.map

TIGERGEO



3.32 ns (~ 12 cm bgl)



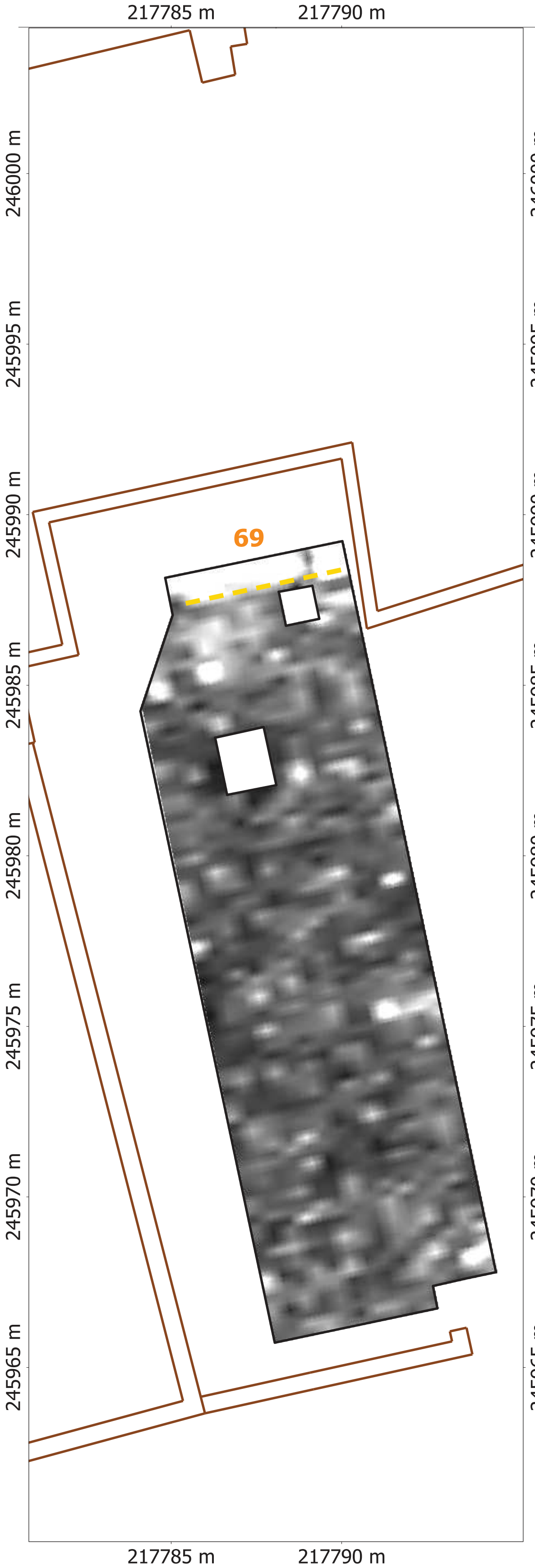
6.84 ns (~ 24 cm bgl)

Time (Amplitude) Slice - Arbitrary Colouration - Lighter Tones Imply Greater Variation of Dielectric Permittivity Within Slice Thickness
All Slices Are 6 Samples Thick, Which Is Approximately 1/4 Wavelength At Velocity 0.07 m/ns

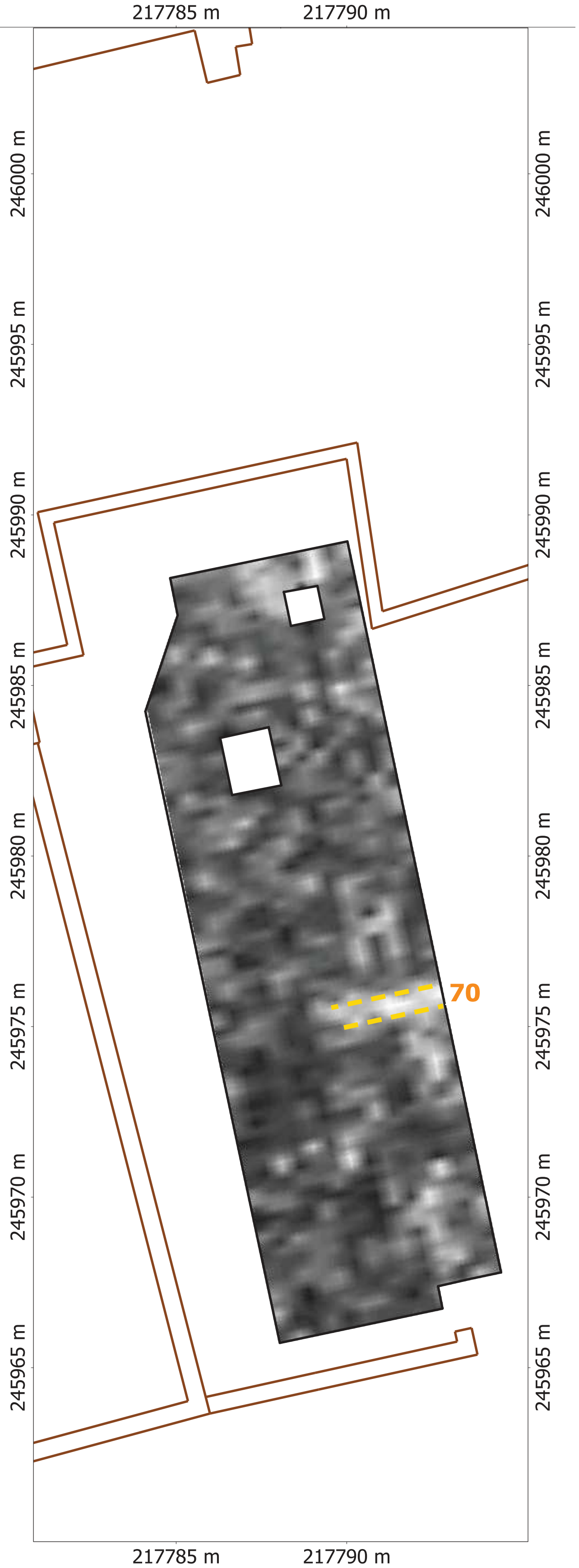
CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 10a GPR Timeslices - Orchard

Orthographic Scale: 1:200 @ A4 Spatial Units: Meter. Do not scale off this drawing
File: CCC231.map

TIGERGEO



12.69 ns (~ 44 cm bgl)



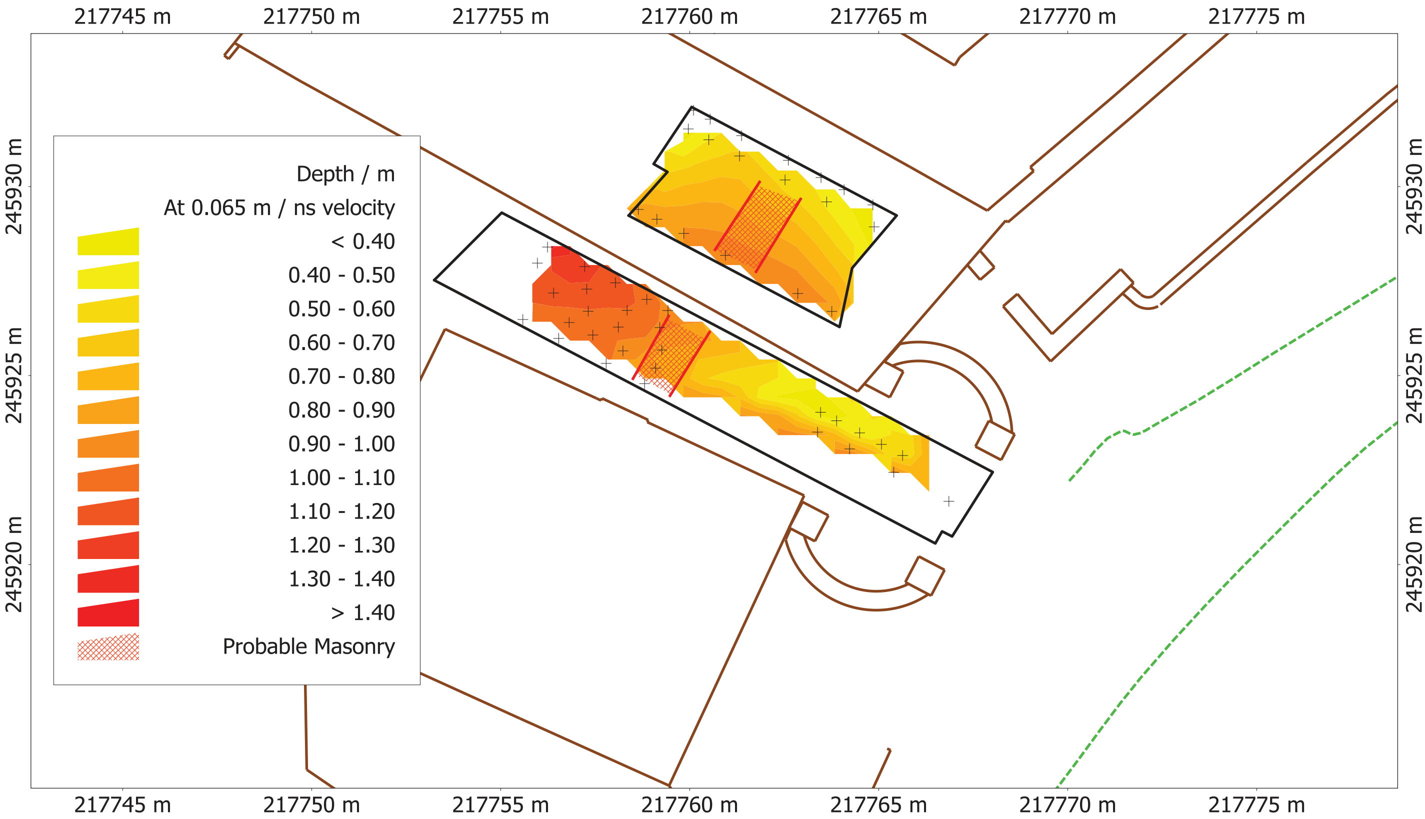
46.68 ns (~ 163 cm bgl)

Time (Amplitude) Slice - Arbitrary Colouration - Lighter Tones Imply Greater Variation of Dielectric Permittivity Within Slice Thickness
All Slices Are 6 Samples Thick, Which Is Approximately 1/4 Wavelength At Velocity 0.07 m/ns

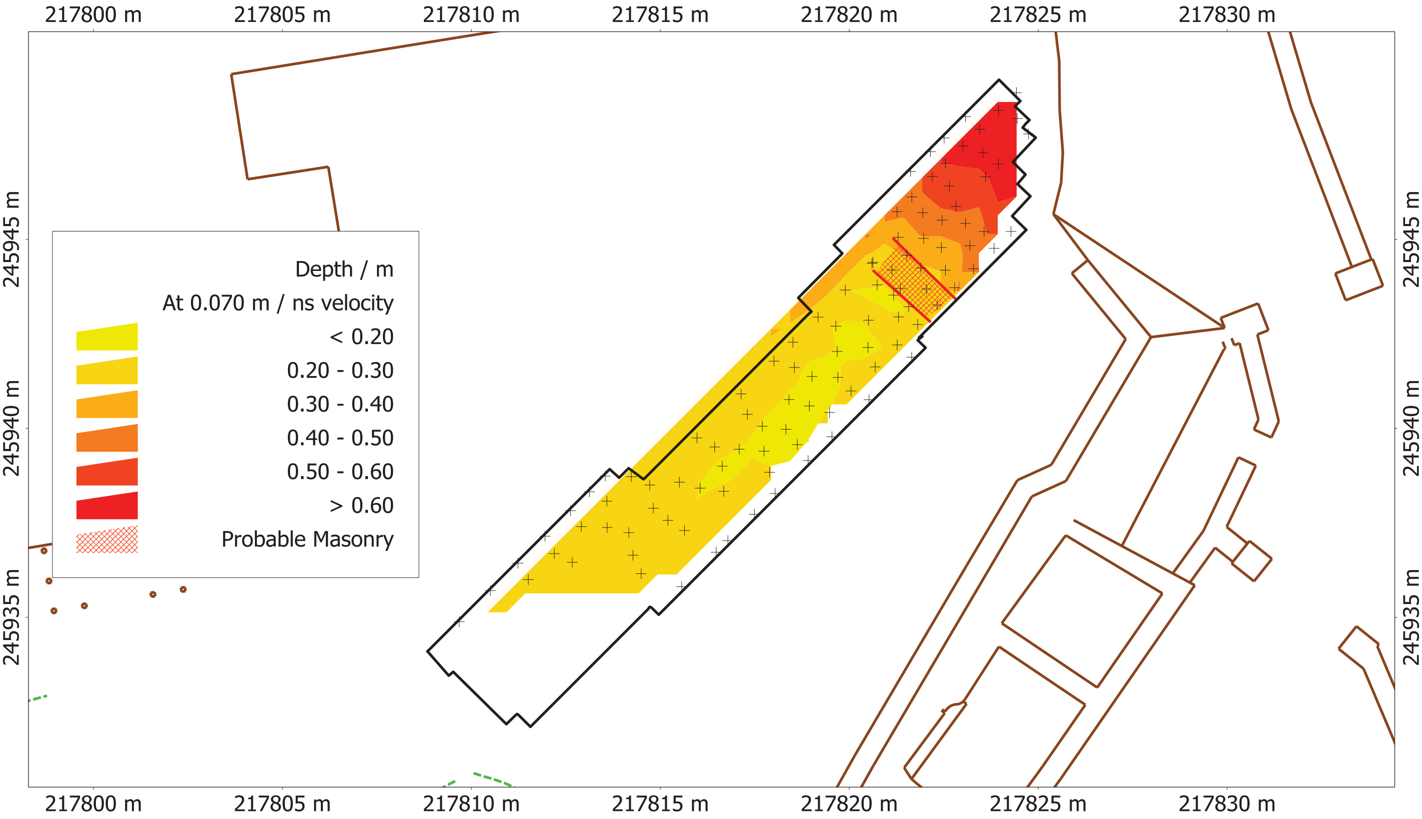
CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 10b GPR Timeslices - Orchard

Orthographic Scale: 1:200 @ A4 Spatial Units: Meter. Do not scale off this drawing

TIGERGEO



Entrance and Cottage

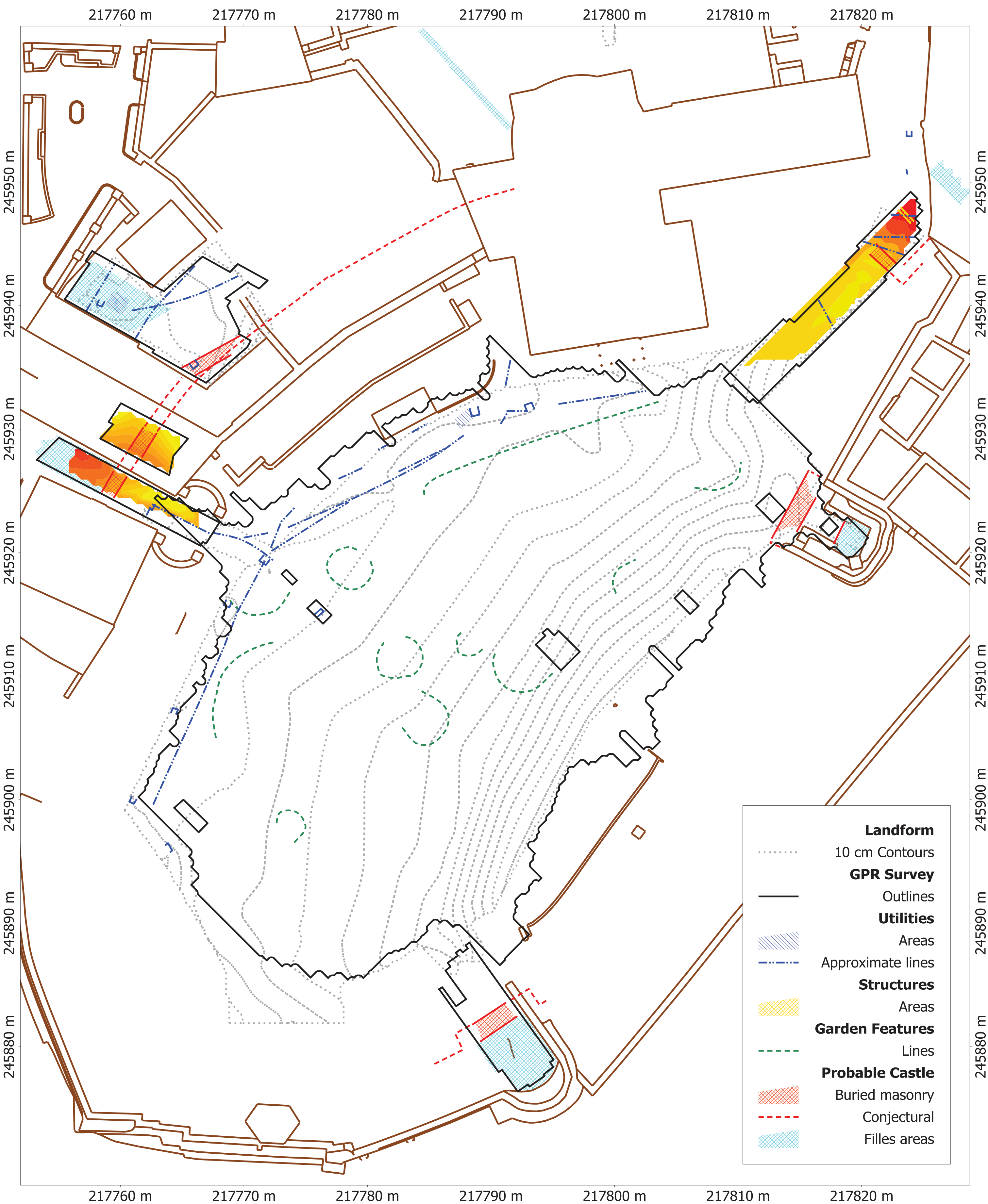


North Bastion

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 11 Modelled Soil Depth

Orthographic Scale: 1:200 @ A4 Spatial Units: Meter. Do not scale off this drawing
File: CCC231.map

TIGERGEO

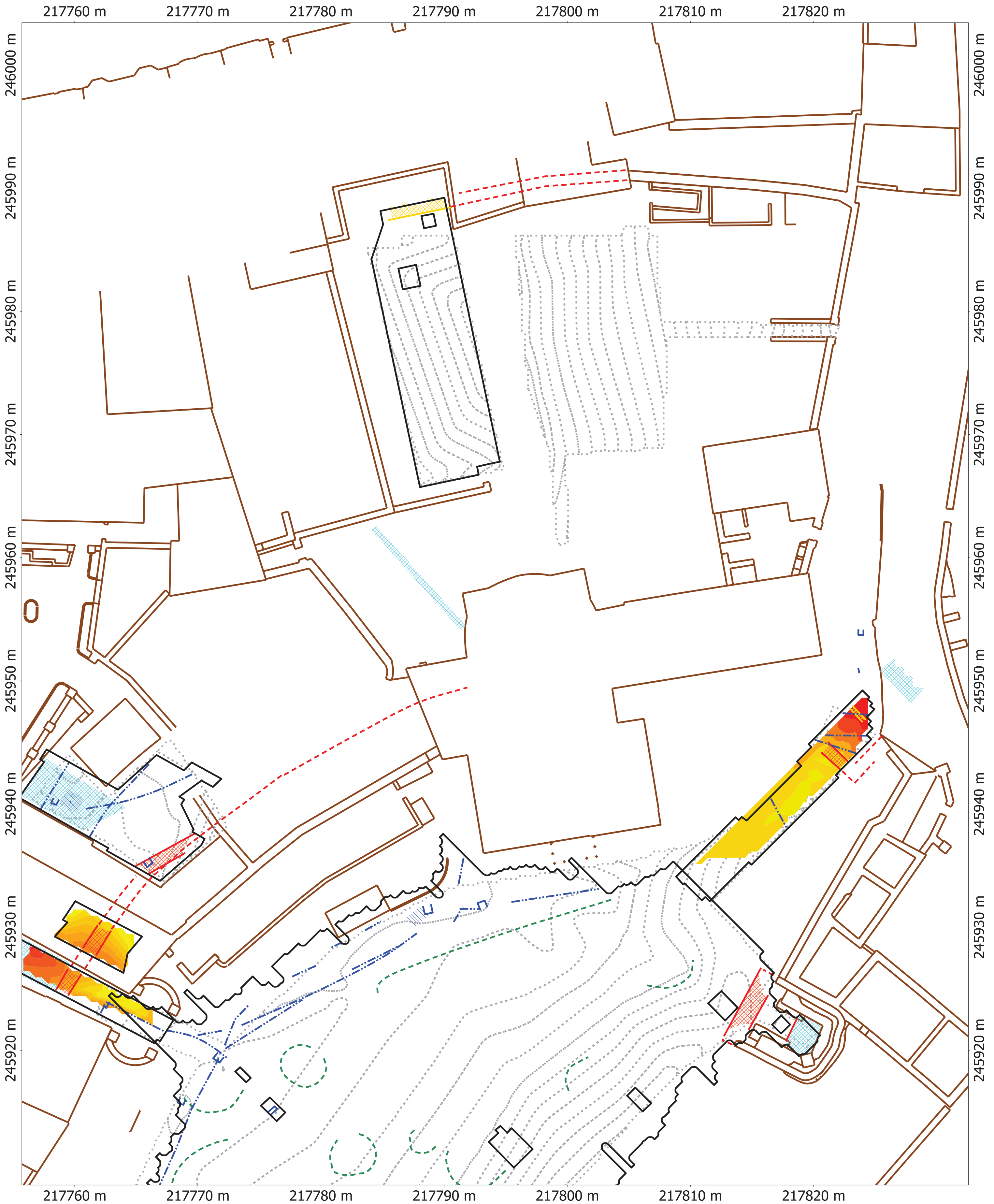


The depiction of any utility on this plan is not definitive and not derived from PAS128-compliant survey

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 12a Summary of Findings - South

Orthographic Scale: 1:400 @ A4 Spatial Units: Meter. Do not scale off this drawing
File: CCC231.map

TIGERGEO

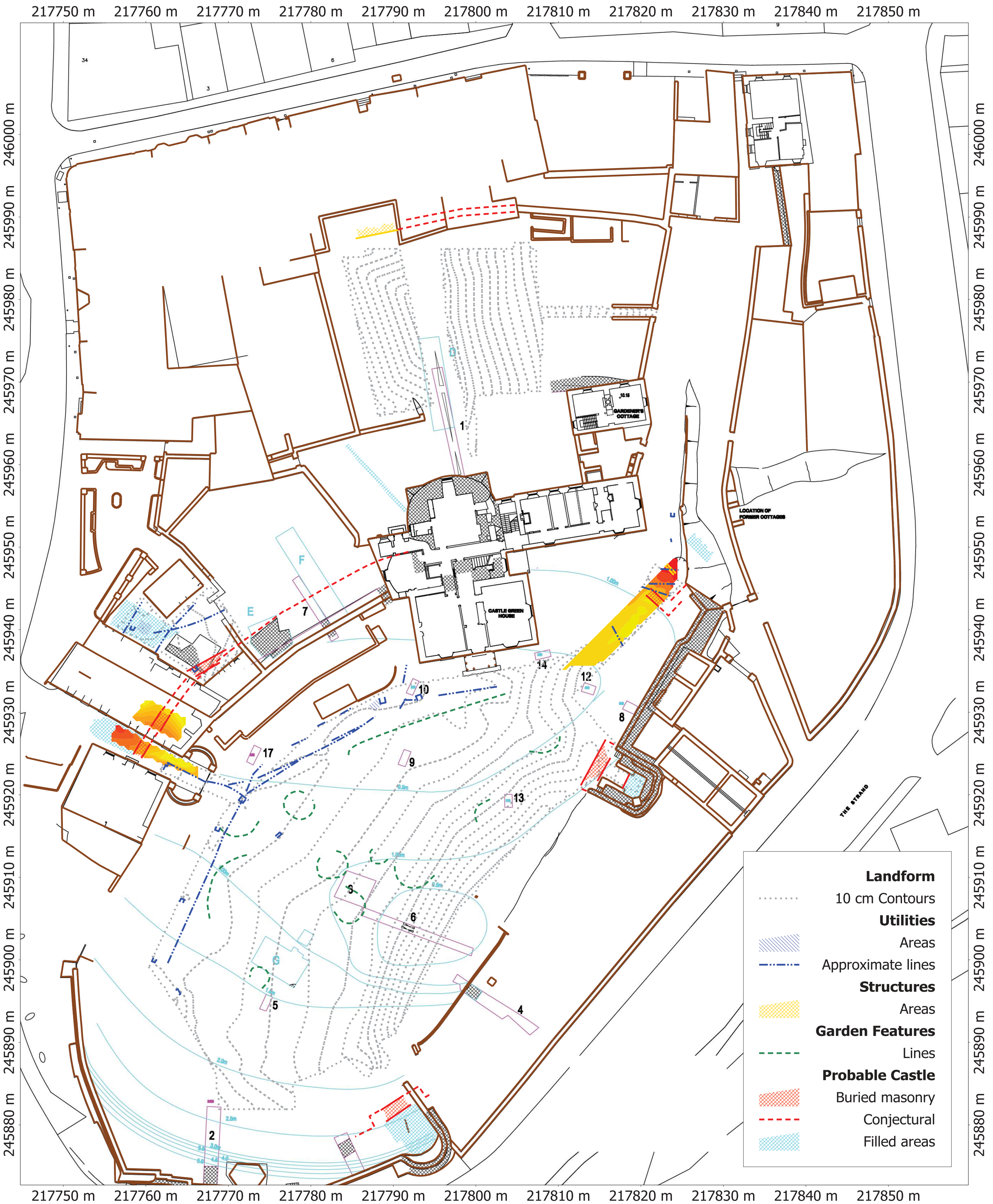


The depiction of any utility on this plan is not definitive and not derived from PAS128-compliant survey

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 12b Summary of Findings - North

Orthographic Scale: 1:400 @ A4 Spatial Units: Meter. Do not scale off this drawing
File: CCC231.map

TIGERGEO



The depiction of any utility on this plan is not definitive and not derived from PAS128-compliant survey

CCC231 Cardigan Castle, Castell Aberteifi, Sir Ceredigion
DWG 13 Newly-Found Elements Overlaid on Known Parts of the Castle

Orthographic Scale: 1:600 @ A4 Spatial Units: Meter. Do not scale off this drawing
File: CCC231.map

TIGERGEO