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**Ground Penetrating Radar Survey**

**of**

**the Central Area between the Vestry and the Altar**

**and**

**2 External Areas overlying the former Lady Chapel**

**of**

**Dunfermline Abbey**

**For**

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## **SURVEY OBJECTIVE**

The royal Abbey of Dunfermline served as the primary burial place of Scotland's monarchs from the early 12<sup>th</sup> century until the demolition of the East end of the building began in 1560 as part of the religious reformation. In 1821 a new church was erected to the East of the remaining Abbey Nave in place of the demolished building. As part of the construction process, the site of the East end of the Abbey was levelled and pitch poured into the former building remains. The Abbey is now in the joint care of the Dunfermline Abbey Church, Historic Environment Scotland, and Fife Council.

Although historical records indicate that six Scottish kings, their spouses and close relations were buried beneath the floor of the Abbey, the location of most of these graves is currently unknown. The exception to this is the large grave uncovered in the choir of the current church, currently situated below the pulpit. This grave is currently designated as that of Robert I.

While it would not be reasonable to suggest that the historical role played by the Abbey has been neglected, it is true that the extant buildings which include several phases of church buildings, the remains of a royal palace and the shrine dedicated to St Margaret, do not currently demonstrate their full cultural and historical importance to the interested visitor. It is intended that this should be remedied by a programme of research including the use of non-destructive surveys in order to confirm the relationship of the current church to that of at least its predecessor and to locate, if possible, the site of as many large tombs as possible.

A first Ground Penetrating Radar survey of part of the North Transept and the Vestry was completed in 2016. Although this did provide grave locations, there was no clear evidence, on the basis of size and relative location, for royal tombs. This survey also confirmed that it was useful to deploy antennas of 400MHz and 250MHz as part of the strategy. The 400MHz has the better image definition capability, useful for resolving closely spaced targets but the 250MHz antenna has the advantage of greater depth penetration and better detection capability where moisture is present.

This second stage survey covers three areas, namely the central area of the church from the door of the Vestry to the Altar (Area 1) and two external areas thought to lie above the Lady Chapel of the former Abbey Church (Areas 2 and 3). The area lying between the Vestry and the Altar was chosen because it links the two surveys carried out in 2016. The external areas were chosen in order to cover the remaining areas of the Lady Chapel not surveyed in 2016. The Lady Chapel is known to have contained royal graves.

## **SURVEY STRATEGY**

### **Use of Ground Penetrating Radar**

GPR operates on the same principles as conventional radar except that it uses a wider frequency range, a shorter pulse, and a much shorter range of detection. The radar generates a short pulse which is transmitted into the ground via an antenna. The return signal is received by another antenna. The amplitude of the returning signal



provides information about changing ground characteristics with depth. The use of the radar does not affect underlying deposits: it is non-destructive.

GPR cannot identify the nature of the material through which the electromagnetic pulses pass. The signals returned to the radar are the result of changes in the electromagnetic properties between two or more adjacent materials. The amplitude (strength) of the returned signals is a measure of the magnitude of the difference between these materials rather than being a characteristic of any one material.

Identification of graves is normally made on the basis of patterning in the horizontal data. It may be possible to detect potential graves on the basis of 2-dimensional, vertical data but it can be difficult to determine the full extent of the feature unless an area survey is completed. Identifying the extent of a potential grave is often the easiest way to distinguish between a grave and any other subsurface feature.

The type of patterning depends upon the style of burial, the surviving contents of the grave and the frequency of radar antenna used for the survey. Human remains, of themselves, are not usually identifiable except in the early stages of decomposition where associated liquids and gases may be detectable. Bones buried in soil interact with their environment and rapidly become electromagnetically indistinguishable from it. Large tombs which incorporate air gaps are easily detected by GPR. Typically, the interface between stone and air (or soil and air) results in a strong signal response since the two materials have very different electromagnetic properties. Where either metallic grave goods have been interred with the deceased or a metallic coffin or coffin lining has been used for burial, detection by GPR is a good prospect. The electromagnetic response of metal is typically very strong because of its conductive properties. It is also not possible for radar to penetrate metal so, providing that the artefacts under examination are large enough for the conical radar beam not to penetrate past them, the only signals below metal objects should be echo effects, known as ringing.

It is important to appreciate that the radar can only detect the final state of any extant remains and not the process which has brought about this result. The separate identification of two or more objects requires these to be sited a distance of one wavelength apart from each other. If this separation is not present they may be detected as a single object. For these reasons, where a site has been used and re-used over centuries it can be difficult to understand the structures represented in the data. Inter-cutting of graves is a good example of where this may be a difficulty. It is to be expected that royal graves will not intercut with one another although the possibility exists of ground clearance prior to a royal burial.

As far as built structures such as the footings of walls are concerned, identification may be possible in the vertical plane if sufficient vertical extent exists. It is usually easier to identify wall foundations from their patterning in the horizontal plane by recognising the remains of a linear, rectangular, or other non-randomly shaped feature.

It is a feature of GPR that the same signal patterning may be produced by different combinations of features &/or materials. It is also not possible to date remains except relatively where one set of remains overlies another.

Christian graves in the UK are invariably oriented East/West (Rodwell, 2012) and all three surveys were therefore carried out along a North/South axis in order to optimise detection of any extant identifiable graves. Optimal detection by GPR occurs when the radar crosses the target at right angles. Although other subsurface material may be differently orientated, a primary aim of this survey is the detection of graves.

Probing depth was a major concern for this survey due to the demolition of the mediaeval Abbey and the construction above of the present building. Although it was not possible to determine the full depth extent of any former Abbey Church foundations, historical records researched by Dr Michael Penman of Stirling University suggested that a gap of 2m to 3m between the floor of the current Abbey church and the remains of the previous church was to be expected. Part of this gap is air. With this in mind, low frequency antennas were selected for the initial trial so as to maximise depth penetration. Unfortunately, this also means that the degree of target definition is limited since both probing depth and target definition are the direct product of the wavelength(s) emitted by the radar. Longer wavelengths increase probing depth at the expense of a reduced degree of target definition. In dry soil the wavelength of a 400MHz antenna is approximately 25cm making objects of less than 2.5cm undetectable. Under the same conditions the wavelength of a 250MHz antenna is approximately 40cm making objects of less than 4cm undetectable. In practice, the target definition may be considerably less than these calculations suggest. In order to distinguish one target from another, the separation required, as noted above, is 1 wavelength and therefore 25cm in the case of the 400MHz antenna, 40cm for the 250MHz antenna.

## **Equipment**

The equipment used for these surveys was a GroundVue 3\_1 with two different frequencies of antenna, 400MHz and 250MHz. GroundVue3\_1 is a single channel radar and the two antenna frequencies were therefore used sequentially rather than simultaneously. Within the church, the space available for survey is restricted due to the position of church furniture and therefore it would not have been practical to have surveyed using a multi-channel radar.

In order to ensure that the maximum data were obtained from relatively small survey areas, the antennas were deployed on manually towed skids rather than using a more traditional trolley for which there would have been an offset between the front of the trolley and boundary walls, pews etc. All antennas used contain arrays for narrowed signal beam and are heavily screened in order to avoid interference from objects above ground. It is not possible however to fully eliminate transmissions such as those emanating from the Abbey's fire alarm system since these are also reflected from the subsurface. The transmission frequency differs sufficiently from that of the radar that, although this makes the data relatively unsightly, it has not prevented target detection.

## **Site Conditions**

Most but not all of the floor in the area between the Vestry door and the Altar is carpeted, the remainder being wooden. The variation in surface level was consistent

with the expected variation found in the floor levels of most historic churches and did not prevent the survey from being carried out in a regular and accurate manner.

There was more variation in the surfaces outside the current church where there are both manmade surfaces (tarmac, gravel) and grass around graves and lights. This also did not prevent the survey from being carried out in a systematic and accurate manner.

### **Site Coverage**

In order to maximise the information obtained by the GPR, survey lines for all six surveys were completed at a transect spacing of 0.25m. This is half the spacing required by the widely accepted guidelines published by Historic England (English Heritage, 2008). These were originally set as a compromise between the investment required to optimise the imaging capability of the radar and an acceptable level of information with a lesser use of resources. For this investigation, it is more appropriate to achieve the optimum level of data for imaging purposes because of the limited area access and the potential difficulty of interpretation given the history of the site. Also, the areas being limited in extent means that there is a negligible incremental impact on resources. The 0.25m spacing complies with current European guidance (Schmidt et al, 2015).

### **Survey Parameters**

A sampling interval of 31.6mm along the line of travel of the radar was set in all six surveys. The 400MHz data were collected to a probing depth of 80ns (approximately equivalent to 4m in dry conditions). The 250MHz data were collected to a probing depth of 100ns (approximately equivalent to 5m in dry conditions). As will be seen from the data, the actual depth of penetration of each antenna is less than theoretical. The actual probing depth is determined by the electromagnetic properties of the subsurface.

### **Calibration**

GPR depths are measured in nanoseconds time because electromagnetic waves do not travel at a constant velocity. To translate this into depths measured in metres, it is necessary either to know the speed of transmission through the ground or to calibrate using either borehole information or curve fitting to hyperbolas (targets) in the data.

In the previous survey of parts of the North Transept and the Vestry it was not possible to determine a single transmission velocity in the subsurface as the values within each area varied significantly, presumably due to the presence of moisture. For this survey, area 1 appears to be uniformly dry and curve fitting provided a transmission velocity of 0.1m/ns. Unsurprisingly since it is located outside the church, area 2 proved to be damp and curve fitting produced the slightly lower speed of 0.08m/ns. Area 3, also outside the church, proved to be similarly damp. Within area 3 it was not possible to use the 250MHz data set for curve fitting because of a lack of suitably clearly defined hyperbolas but it was possible to calibrate within the 400MHz data set, recorded on the same day and under the same conditions.. This gave an average reading of 0.08m/ns.

The calibrated velocities have been applied to each survey area i.e. 0.1m/ns in Area 1 and 0.08m/ns in Areas 2 and 3.

## Fieldwork

Area 1, the central area lying between the Vestry and the Altar, was surveyed on Monday 12<sup>th</sup> June 2017. Area 2, the eastern area covering the former Lady Chapel, was surveyed on Tuesday 13<sup>th</sup> June and Area 3, its counterpart to the West of the main Church door, was surveyed on Wednesday 14<sup>th</sup> June 2017. The weather conditions for days 2 and 3 were similar i.e. overcast with occasional light showers. See Appendix A for the position of the 3 survey areas.

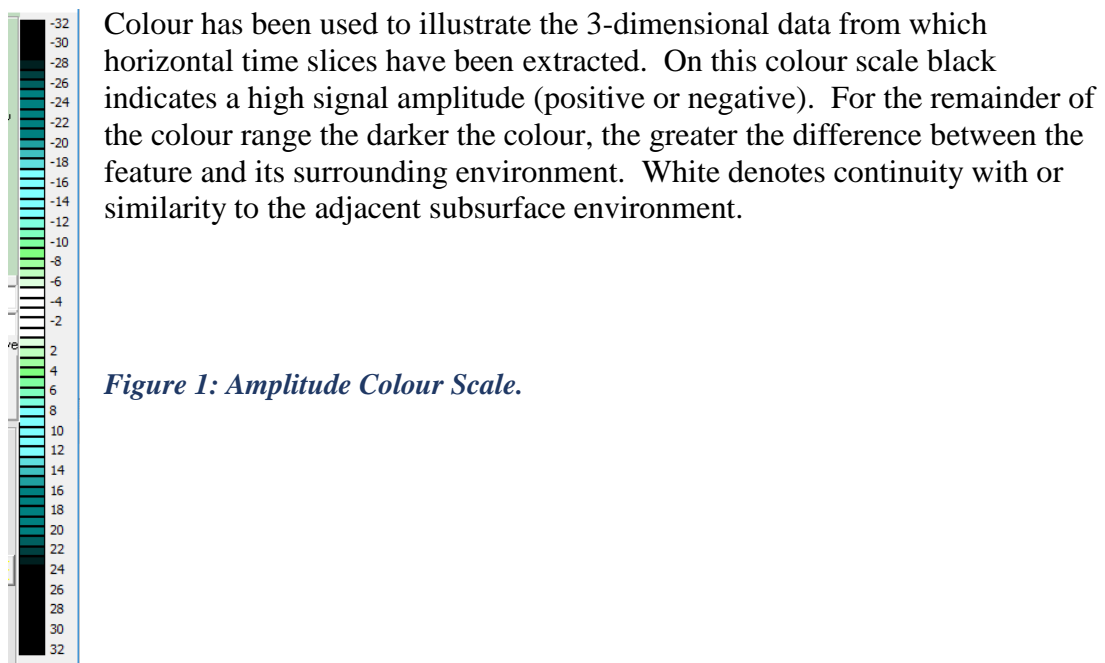
## SURVEY RESULTS

### Data Display

All 2-dimensional data is presented from North (on the left) to South (on the right). All horizontal time slices extracted from 3-dimensional data are presented with East at the top of the page and North to the left-hand side.

### The Use of Colour in GPR Data

It is important to realise that GPR uses electromagnetic pulses (radio waves) and is not an optical technique. The signal amplitude indicates a change of materials but it is a relative and not an absolute measure. As such, it does not and cannot usually be used as an indicator of the actual materials present. The stronger the signal, the more contrast is visible in the data. Similar colours (signal amplitudes) can originate from different combinations of materials. It is only legitimate to postulate continuity of a feature if that continuity is evident directly from the data and not solely on the basis of similarity of signal amplitude. For that reason, greyscale images have been used for analysis of the 2-dimensional data. The 2-dimensional data is displayed in greyscale of black (strong positive) to white (strong negative). On this colour scheme, grey represents continuity rather than an absence of material. Black and white indicate anomalous material.



## Area 1 - The Central Area between the Vestry and the Altar

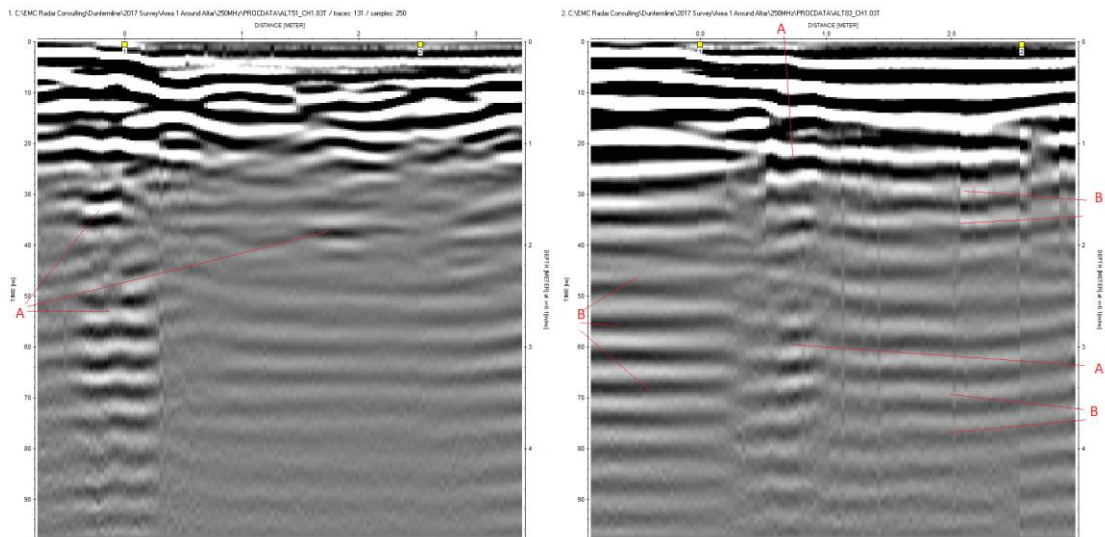
Two parallel survey reference lines were laid out in along an East/West orientation. Line 1, to the North, was placed along the interface between the carpet and the wooden flooring at a distance of 2.15m from the North wall of the church. Line 2, to the South, was placed leading from the South side of the Vestry door, past the royal tomb and the altar. The distance between the two lines was 2.5m. Markers 1 and 2 on the 2-dimensional data indicate the positions at which the radar crossed the survey reference lines.

### 2-Dimensional Data: 250MHz

The 2-dimensional data has been processed by:

- Correction for Tzero;
- Constant background removal;
- Addition of gain to compensate for diminishing signal strength with depth;
- Application of Bandpass Butterworth to remove any spurious signals.

The data in this area are characterised by a band of complicated signals within the first 20ns (c. 1m) of depth. This depth equates to the modern building rather than the archaeology and includes the known air gap. Below this there are relatively few signals although such as there are suggest large features (see Figure 2).



*Figure 2: Survey Lines 51 and 83 (250MHz, Area 1)*

There is also a great deal of ringing (echo effects) from the near surface and it is not always clear the extent to which some of the apparently subsurface features constitute echo effects rather than real buried features. This is particularly true where the feature is located at the edge of the survey area. In Figure 2, signals marked 'A' are returns from real subsurface features. The areas of horizontal striping marked 'B' are echo effects. The type of broad echo effect seen in Figure 2 is typical of lossy soils such as damp clay. The signals transmitted by the radar pass into the ground as a weak electric current and little or nothing is returned to the receiver antenna. However, the few hyperbolas which allow transmission velocity to be calculated

indicate a velocity of 0.1m/ns which suggests dry conditions which suggests that the subsurface material is not wet clay. Since there are real signals present, it appears that there are real features, albeit relatively few below this floor but that the remaining material in the subsurface is not entirely suited to GPR survey. It is not clear what this material might be since it appears to be more lossy than that of either the Vestry or the North Transept.

There is another potential issue affecting the radar's ability to detect in that the low frequency/long wavelength of this antenna, 40cm in dry conditions, is not suited to detecting any features below 4cm in dimension and any features within one wavelength or 40cm of another will be combined with the neighbouring feature since it cannot be separately detected within that range. Nevertheless, there is no indication from the 2-dimensional data collected within survey area 1 of the presence of a substantial tomb, consistent with a royal burial. It is, of course, possible that any such structure might have been removed before from this area before or during the construction of the current church.

It proved possible to survey across the known royal tomb in the area, at least in part due to the judicious use of a protective cover. This grave features a large brass plaque, the echo effects from which are visible in the data. It is not possible to detect within the tomb since radio waves do not penetrate metal.

### **3-Dimensional Data: 250MHz**

The 2-dimensional survey lines have been incorporated into a 3-dimensional data block on the basis of their relative positions along survey line 1. Time slices, horizontal plans, have been extracted from this data block on the basis of changing patterns visible in the data. East is at the top of the page for all of the time slices. Where air gaps exist, or moisture is present the view will be quasi-horizontal i.e. apparently horizontal but not physically so due to the differing transmission velocities in different parts of the survey area. Survey line 1 is located along  $x = 0$ .

As there is a known air gap between the current church floor and the historic land surface (measured to 55cm in the previous survey), it is extremely likely that transmission velocity does vary across the site. The calibrated velocity in this area of 0.1m/ns has been used to translate into metres and centimetres. Where air gaps exist, the actual depth is greater because the radio waves travel three times faster in air. A gap of 55cm will appear as c.18cm within the immediate subsurface.

The thin white line running along  $y = 3.75\text{m}$  in the time slices has no significance and should be ignored. Data from this line failed to record. The outline of the known tomb is not fully discernible as it proved possible to cross this feature. The small blank in the data towards the West indicate part of the position of this grave. The altar is located in the lowest central white strip.

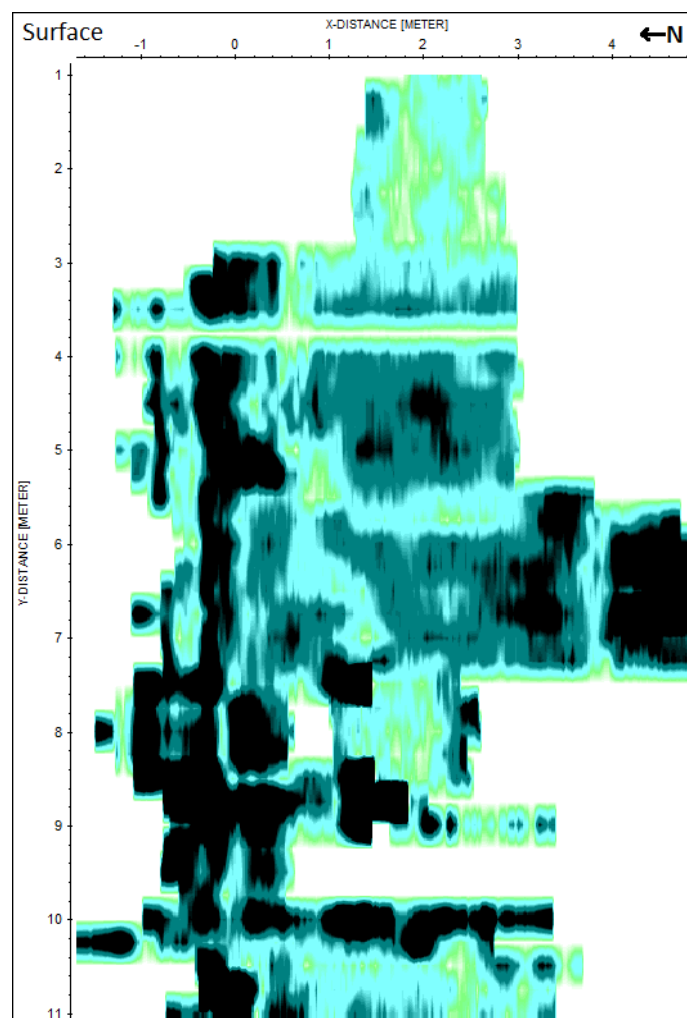
The 2-d data selected for illustration can be located as follows.

| <b>Survey Line</b> | <b>Y position on Time Slices</b> |
|--------------------|----------------------------------|
| 51                 | 1.5m                             |
| 83                 | 7.75m                            |

## Surface Time Slice

There are some very strong signals at the level of the surface. As these may be the source of some of the echo effects, this time slice has been illustrated for comparative purposes (Figure 3). There is a very clear division along  $x = 0$ , the position of survey reference line 1. This marks the line between the carpet (to the South or rhs) and the floorboards (to the North or lhs). For orientation purposes, the top (East end) of the time slice begins outside the Vestry door. The central small white gap forms part of the tomb and the longer gap below marks the position of the altar.

It is possible that the dark area to the North is related to the proximity of air gaps beneath this floor given that the linear feature leads towards the Abbey organ.



*Figure 3: Time Slice at the Surface (250MHz, Area 1).*

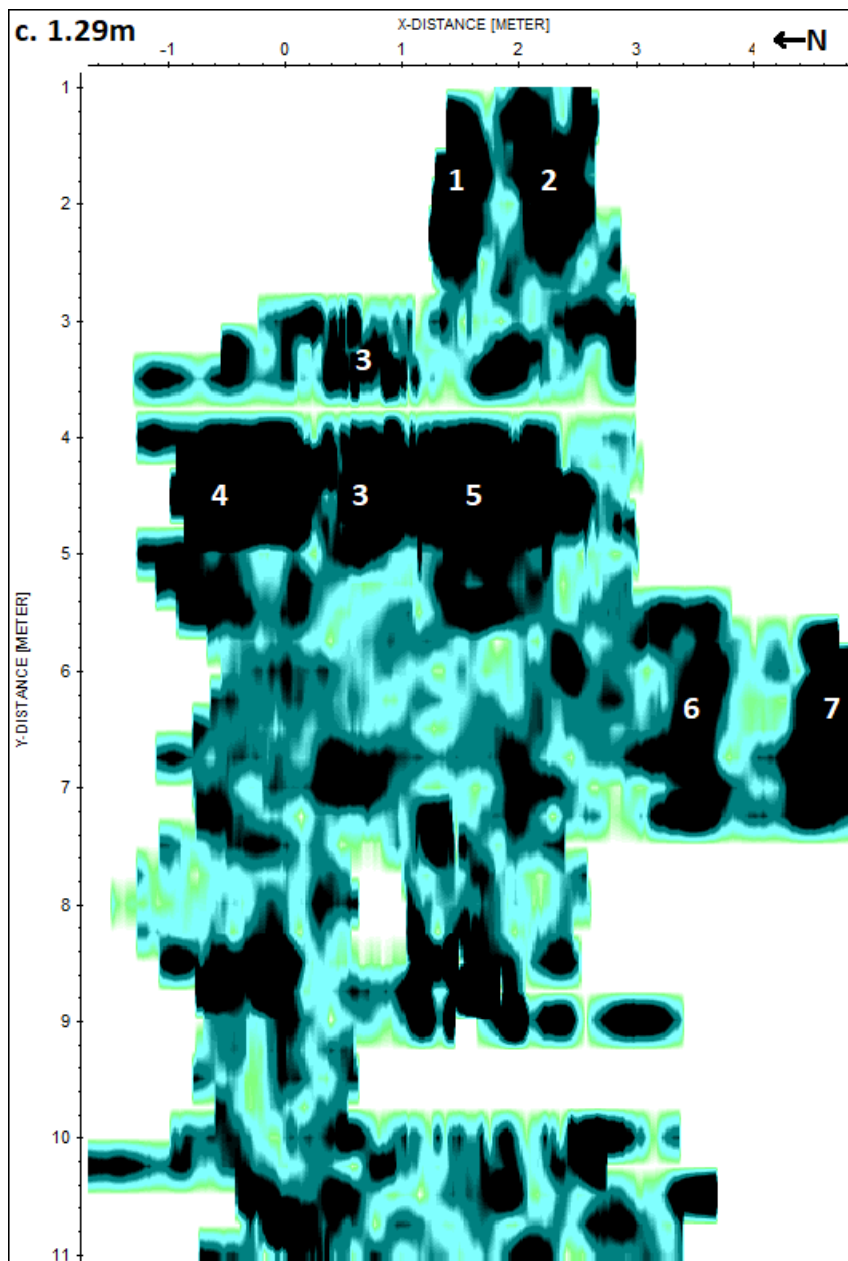
Within the first 5cm below the surface the majority (but not all) of the area shows a near uniform very high amplitude signal return. This will be a reflection of the air gap below the floor.

## Time Slice at 1.29m Depth (c. 26ns)

Around 1.29m in depth a series of nearly rectangular shapes appear (Figure 4). In

spite of the lack of evidence of graves in the 2-dimensional data, this does raise the possibility of a series of graves in these locations. The irregularity of the shapes would imply that the radar might be detecting air gaps which, in turn, suggests partial fill of these features.

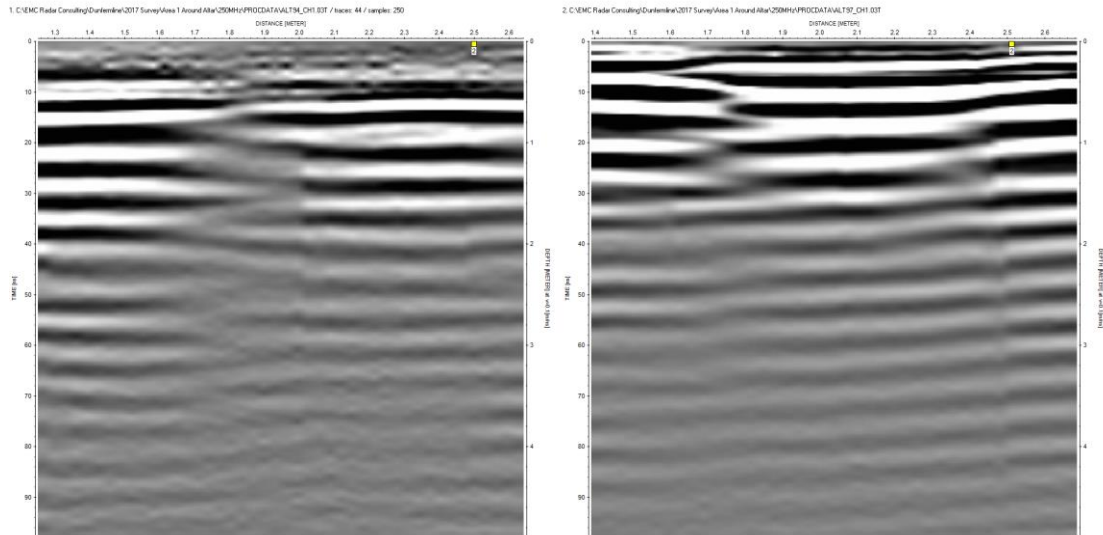
Viewed in the vertical dimension, features 1 and 2 could potentially be air gaps (Figure 5). However, at this depth it is their lower extent which is being detected. It is difficult to separate out the black and white banding which marks these features from the smaller areas of strong signal lying directly above (Figure 5). As illustrated in the time slice, these do appear to be two individual features rather than one larger one although survey line 97 suggests that there could also be a third similar feature to the South.



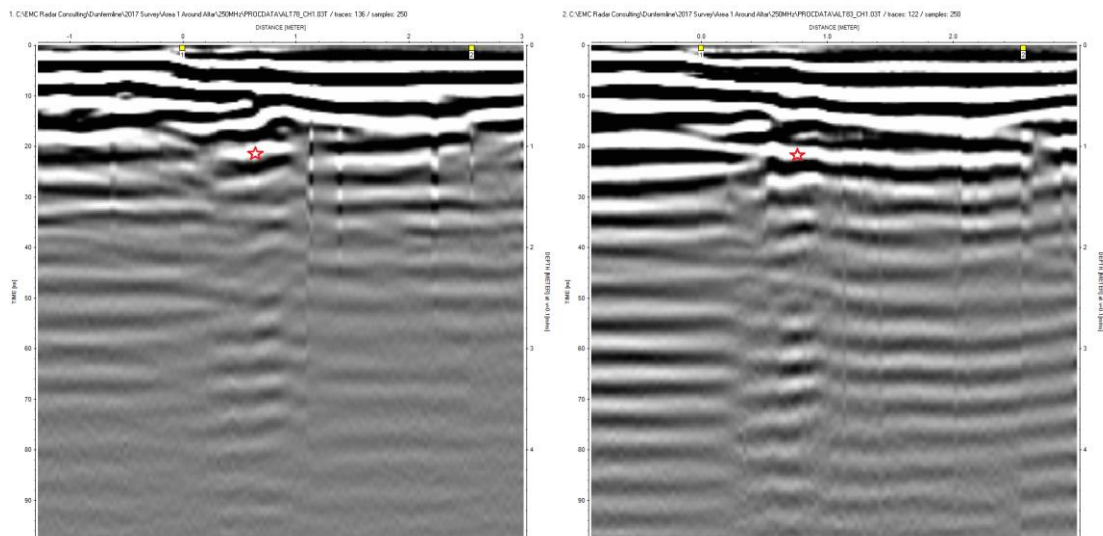
*Figure 4: Time Slice at c. 1.29m (250MHz, Area 1).*



Below these two features there are no further real signals. The banding which can be seen consists entirely of echo effects (ringing) from the strong signals above. Although ringing is often associated with air gaps, it can also be associated with the presence of metal although, typically, ringing from metal covers the full depth below the feature. The two features measure an approximate length of 1.7m and approximate width of 50 to 60cms and the ground beneath these potential air gaps is completely unsuited to GPR survey. If air is present, either within the possible graves or the features directly above them then it is likely that their actual depth is greater than this time slice suggests because radio waves travel three times faster through air than through dry soil.



*Figure 5: Survey lines 94 and 97 showing the vertical profile of Features 1 and 2 in Figure 4 (250MHz, Area 1).*

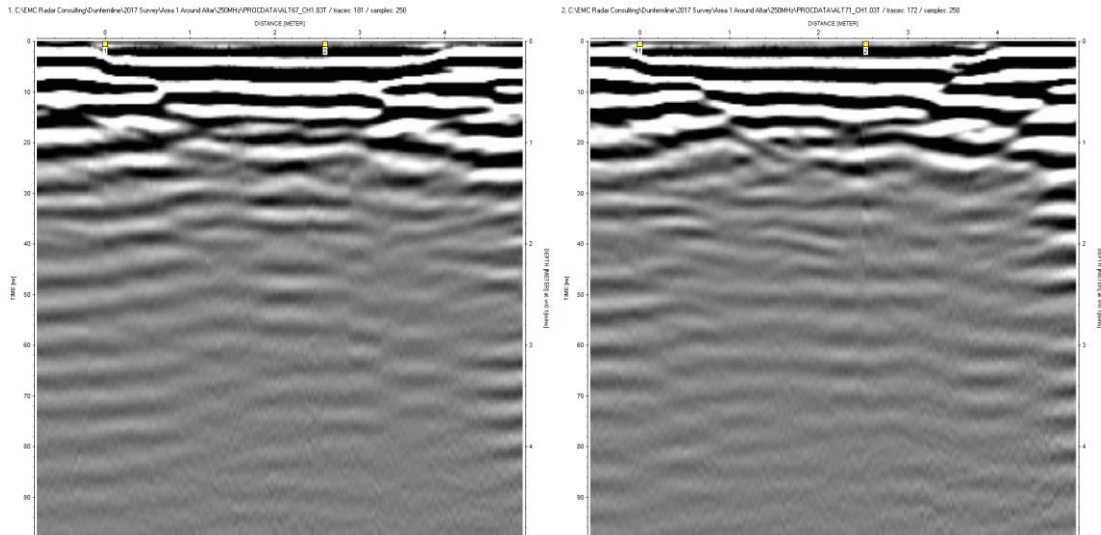


*Figure 6: Survey lines 78 and 83 showing the vertical profile of Features 4, 3 and 5 in Figure 4 (250MHz, Area 1).*

The evidence in features 3, 4 and 5 is similar. Feature 3, in particular, does appear to cross the artificial line at  $y = 3.75\text{m}$  in Figure 4. Of these 3 features, only Feature 3 is

separately discernible. It is indicated by a red star in Figure 6. As for features 1 and 2, the ground below shows clear evidence of ringing from this level and no obvious other signals. It seems likely that these features are therefore similar in nature. If these are burials, features 4 and 5 appear to be short relatively to features 1 to 3. This may simply represent the discernible air gaps as opposed to the full extent of the possible graves, but it could also indicate the burial of immature persons.

Features 6 and 7 also appear very similar in nature. There does not appear to be as much ringing below feature 6 but there is considerably more below feature 7 towards the southern edge of the survey area (cf rhs of Figure 7).



*Figure 7: Survey Lines 67 and 71 showing the vertical profile of Features 6 and 7 in Figure 4 (250MHz, Area 1).*

This suggests that the targets detected in features 6 and 7 are not identical in nature. This may be because metal is present in feature 7 but not in feature 6 (x = 3 to 3.7m in Figure 4). Feature 6 shows only generalised ringing as opposed to the more specific echo effects visible at the South end of the radargram, the position of feature 7.

The main problem with any of these features being interpreted as graves is their proximity to the current floor of the church, even allowing for the depth of the air gap. Also feature 7 appears at floor level in the surface time slice (Figure 3).

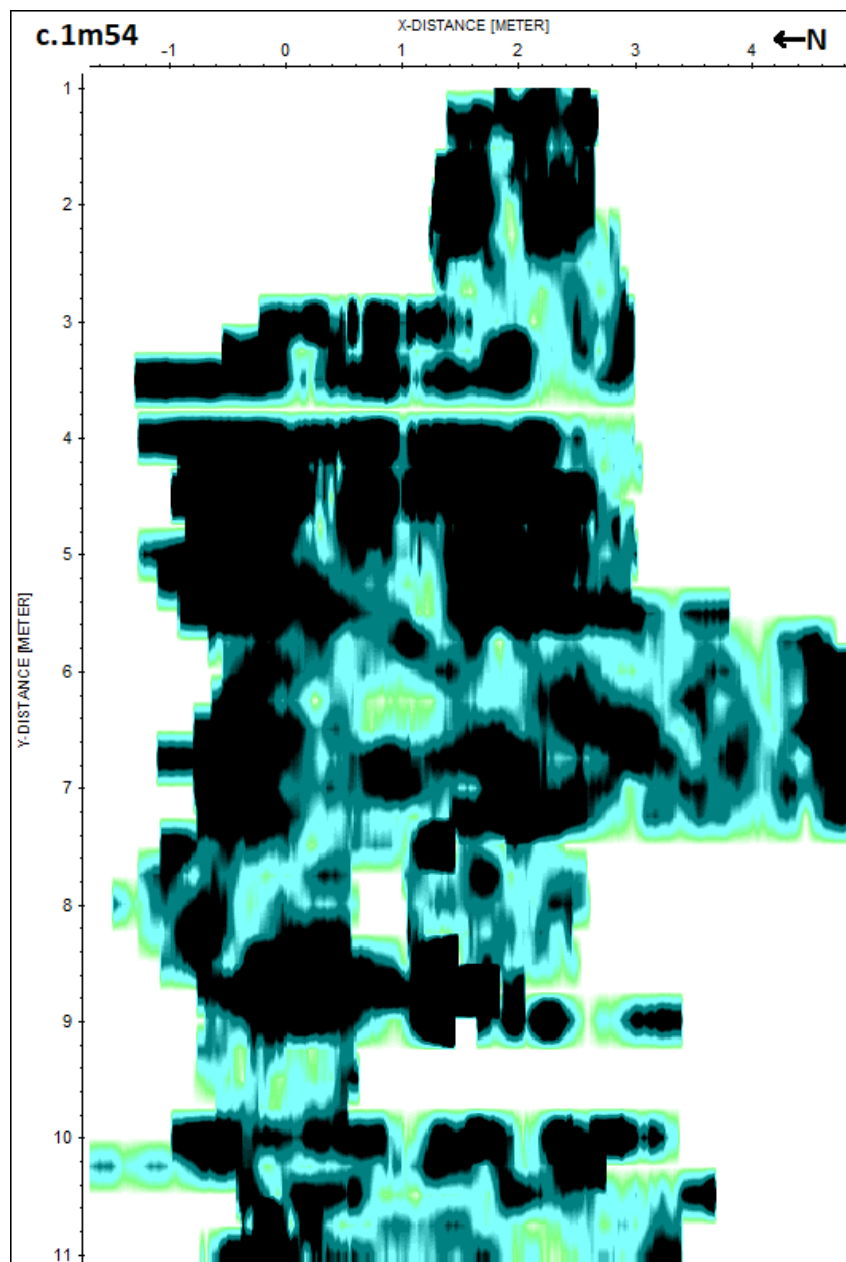
### **Time Slice at 1.54m Depth (c. 30.9ns)**

By this depth the same areas which appeared to hold potential graves are not only still visible but appear to be more extensive (cf Figures 4 and 8). The exception to this is possible grave 6 for which the evidence has largely disappeared (cf also Figure 7). As can be seen in Figures 5, 6 and 7, this level of the subsurface seems to be the final one before real signals give way to echo effects and it therefore seems likely that these features are real, whatever their actual nature. In Figure 7, the ringing from feature 7 is typical of metal and the ringing generated from this means that its vertical extent can therefore not be measured as only its surface is detectable.

It is interesting to note that features 4 and 5 have both lengthened and broadened

significantly suggesting that, at least at this depth, these features are more substantial both in length and in width.

The other areas of strong signal visible in the time slice are much more irregular. They may represent the remnants of other graves, but there is no supporting evidence and it is difficult to be sure. In general, these appear as bands of signal which simply indicates the presence of a different material.



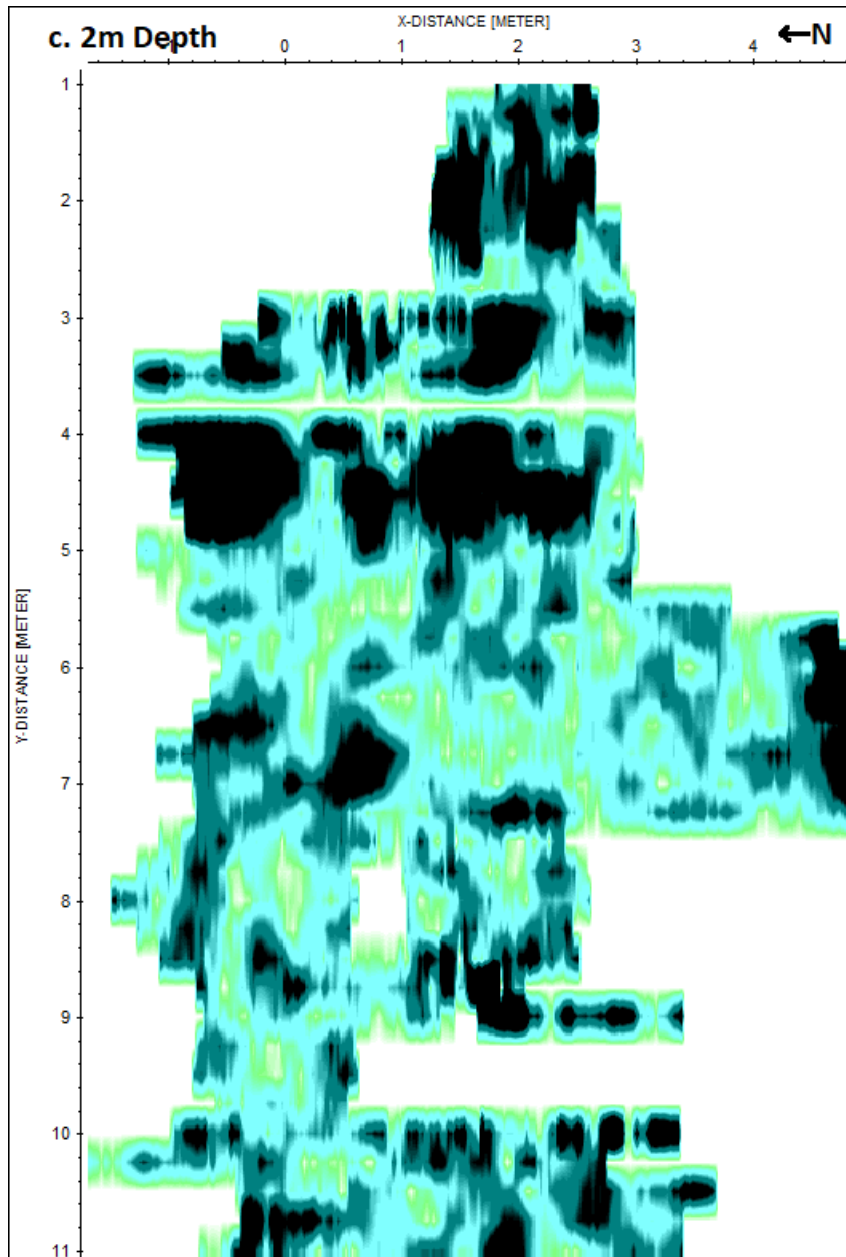
*Figure 8: Time Slice at c. 1.54m Depth (250MHz, Area 1).*

### **Beneath c. 1.54m Depth**

There is an air gap directly below the floor of c. 55cm (report dated 12th September 2016). Assuming that the strong signals described above originate as seems possible from graves then the depths as given in metres, including this one, are understated

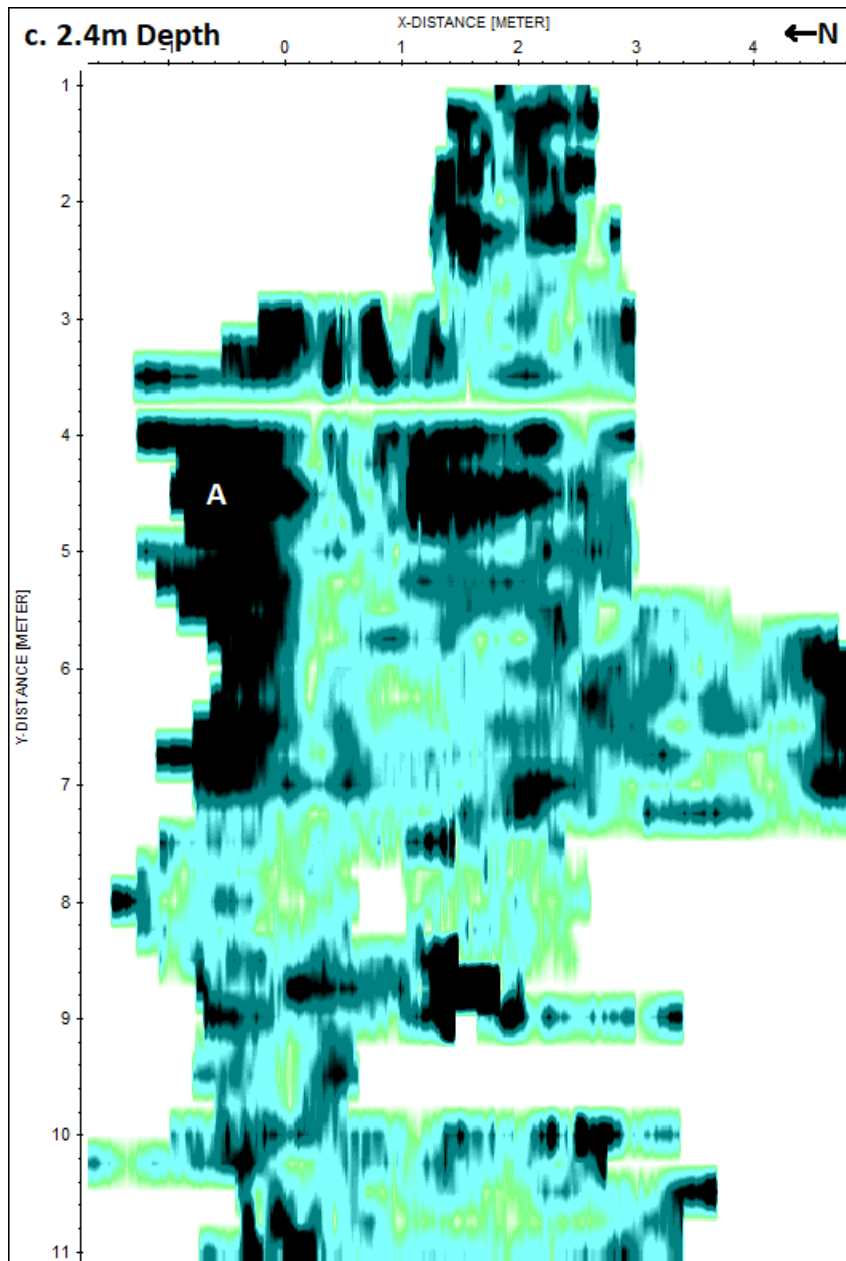
although the depths given in nanoseconds time are accurate. Taking the air gap into account increases the depth of 1.54m to c. 1.9m, for example.

Beneath the level of the previous time slice there is no evidence of any new features. The only visible signals are echo effects from features 1 to 5 inclusive and feature 7 (cf Figures 9 and 10). An additional area, that marked “A” in Figure 10 becomes visible below the 2m depth. This appears in 2-dimensional data to be



*Figure 9: Time Slice at c. 2m Depth (250MHz, Area 1).*

ringing from the shallow subsurface rather than a new feature and may indicate a more modern air gap (Figure 10). It also correlates, to some extent with the surface time slice (Figure 3). No new features appear below 48ns (c. 2.4m).



*Figure 10: Time Slice at c. 2.4m Depth (250MHz, Area 1).*

### **2-Dimensional Data: 400MHz**

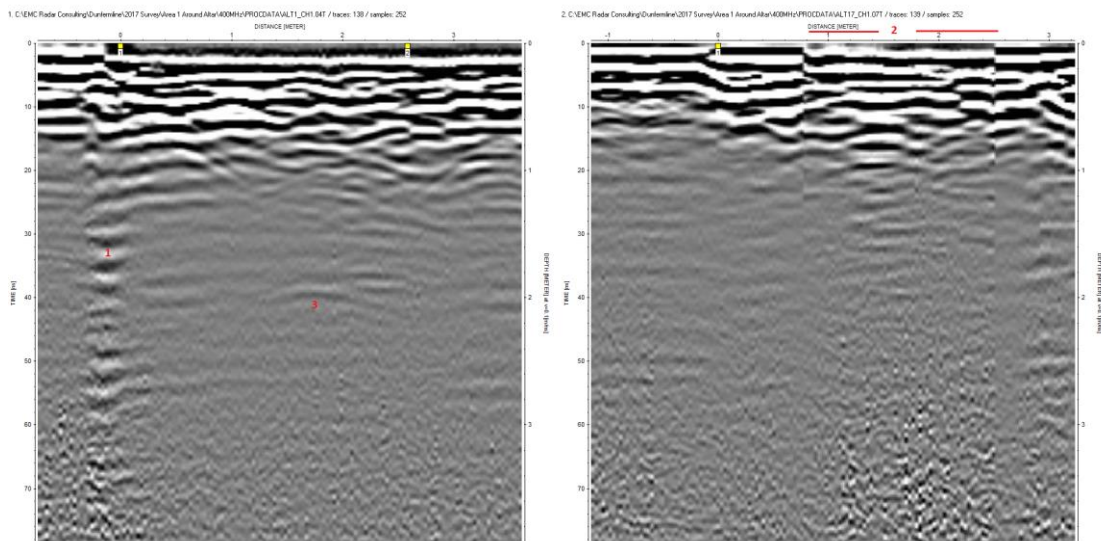
The same survey reference lines were used for the 400MHz survey of the North Transept as for the 250MHz investigation. The 2-dimensional data has been processed by:

- Shallow depth correction for the separation of the transmit and receive antennas;
- Correction for Tzero;
- Constant background removal;
- Addition of gain to compensate for diminishing signal strength with depth; and
- Application of Bandpass Butterworth to remove any spurious signals.

The 2-dimensional data from the 400MHz survey are unsurprisingly similar to those from the 250MHz survey with the primary difference of better target definition, consistent with the use of shorter wavelengths. Although depth penetration should in theory be correspondingly less, there is very little difference. The maximum depth of real signals varies from 20 to 40ns with evidence of ringing (echo effects) below this level. Although this depth is consistent with the evidence from the 250MHz survey, it contrasts with the previous 400MHz survey of the area of the Lady Chapel within the current church and also of the Vestry. There is very much less evidence of deeper archaeological material.

It needs to be noted that the lack of information below this depth could potentially be due to the nature of the soil rather than homogeneity of the subsurface. If it is practical to obtain a sample from an area known to respond in a similar manner, it may be possible to analyse the soil's electromagnetic response and determine whether this is the reason or not.

Survey lines 1 and 17 are reasonably representative of the area (Figure 11). The feature marked "1" in line 1 (left hand side of image) is ringing from a metal object at or near the surface, most probably the metal edge holding the carpet in place. The feature marked "2" in line 17 (right hand side of image) shows a discontinuity in the current church floor, covering an unknown feature. The only evidence of any deeper structure is seen in the relatively faint hyperbola at "3" in line 1 at a depth of 38ns (c. 1.9m in dry soil). In this context, potential grave information appears to be minimal, confirming the findings of the 250MHz survey. The feature numbers used in Figure 11 do not relate to those used in Figure 4 of the 250MHz survey.



*Figure 11: Survey lines 1 and 17 (400MHz, Area 1).*

### 3-Dimensional Data: 400MHz

The 400MHz data were combined into a 3-dimensional data block on the basis of their relative positions along survey line 1. Time slices, horizontal plans, have been extracted from this data block on the basis of changing patterns visible in the data. East is at the top of the page for all of the time slices and  $x = 0$  marks the position of survey reference line 1. Where air gaps exist, or moisture is present the view will be

quasi-horizontal i.e. apparently horizontal but not physically so due to the differing transmission velocities in different parts of the survey area.

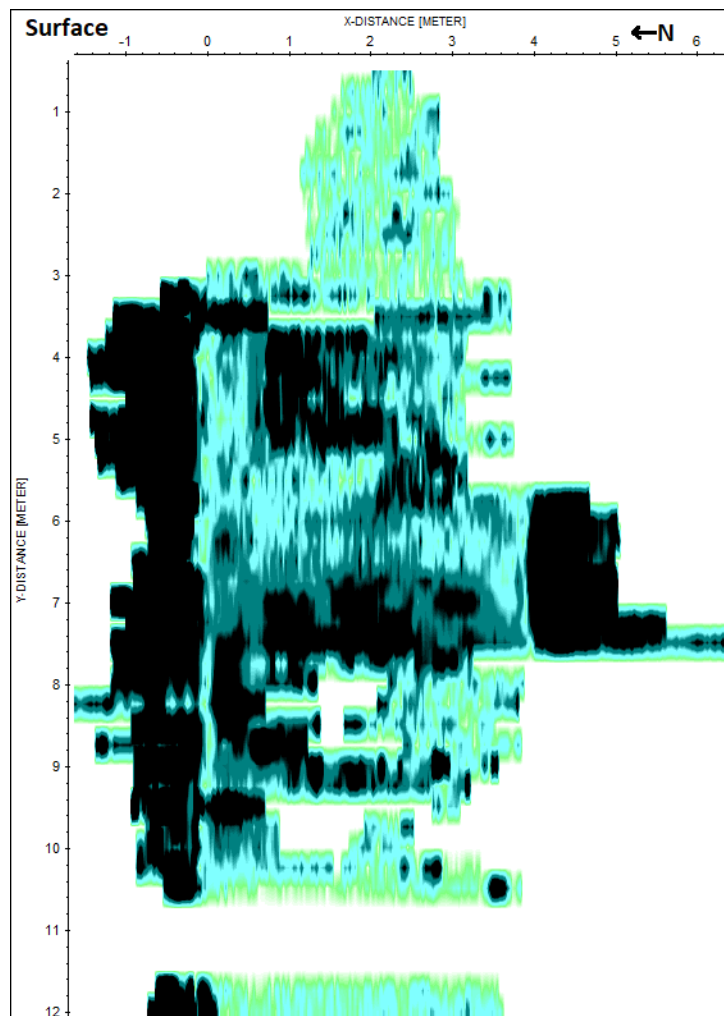
The outline of the known tomb is not fully discernible as it proved possible to cross this feature after laying down a protective covering. The blanks in the data towards the West indicate parts of the position of this grave. The band of white towards the western end of the area indicates the position of the altar.

The 2-d data selected for illustration can be located as follows.

| Survey Line | Y position on Time Slices |
|-------------|---------------------------|
| 1           | 0.5m                      |
| 17          | 5m                        |

### Surface Time Slice

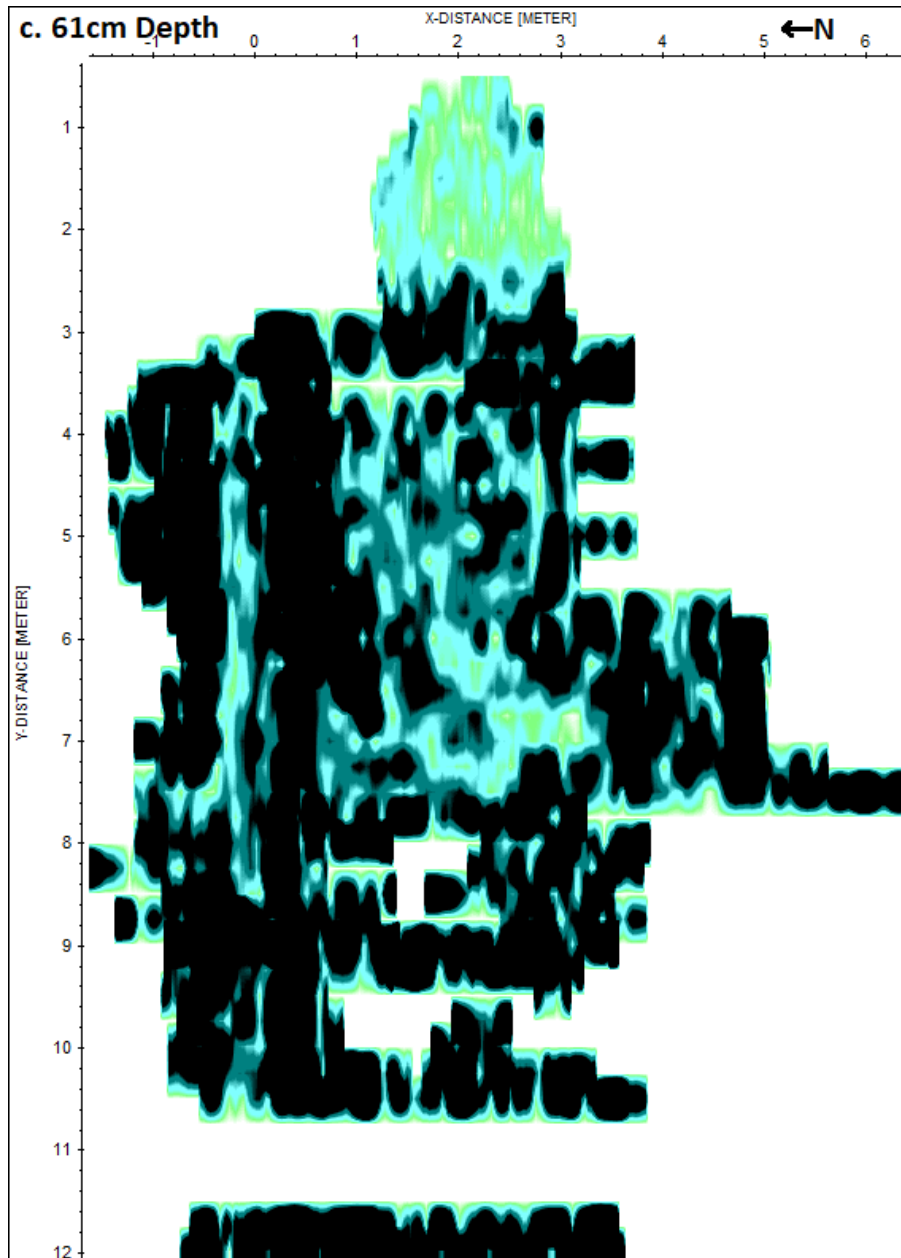
The surface time slice has been included in order to assist in identifying echo effects from this level potentially providing false data in the subsurface (Figure 12). As expected, it is similar to that from the 250MHz survey of the same area (Figure 3).



*Figure 12: Time Slice extracted at the current floor surface for comparative purposes (400MHz, Area 1).*

### Time Slice at c. 61cm Depth (c. 12ns)

As explained above, this depth measurement is understated assuming that the 55cm air gap is present uniformly across the area. Assuming this is the case, this depth could equate to 1.4m (55cm of air and 85cm of dry soil-type material).



*Figure 13: Time Slice at c. 61cm Depth (400MHz, Area 1).*

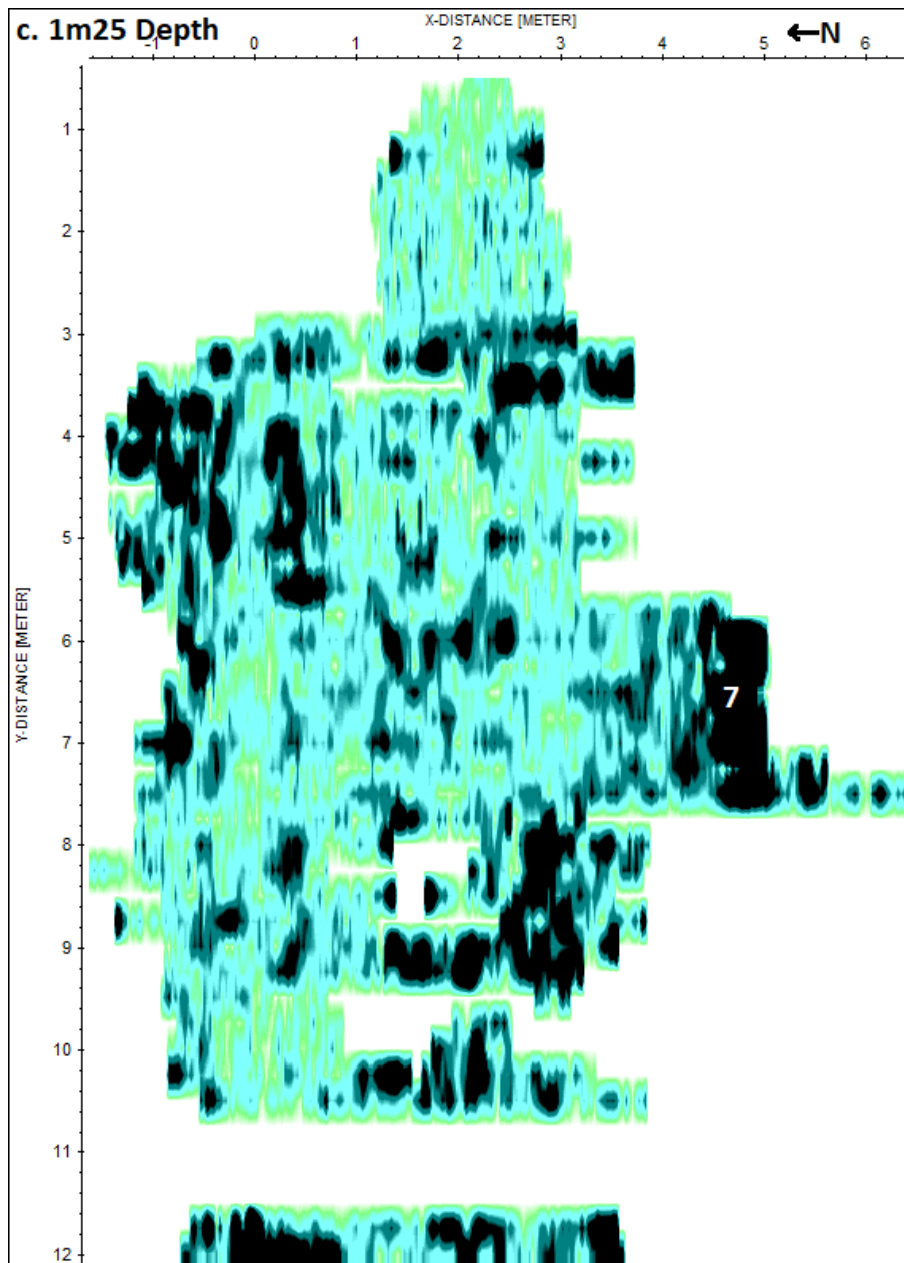
The series of lines in this time slice appears to show the lower structure of the current church. This image remains substantially the same for at least another 14cm in depth.

### Time Slice at 1.25m Depth (25ns)

This time slice is notable for the re-appearance of a single very strong outline of a potential grave to the SE of the known royal tomb and adjacent to a block of pews.



This feature corresponds to feature 7 in the 250MHz data (see Figure 4). As noted previously, feature 7 is also visible covering a larger area at surface level (cf Figures 3 and 12) and also in the previous time slice (Figure 13).



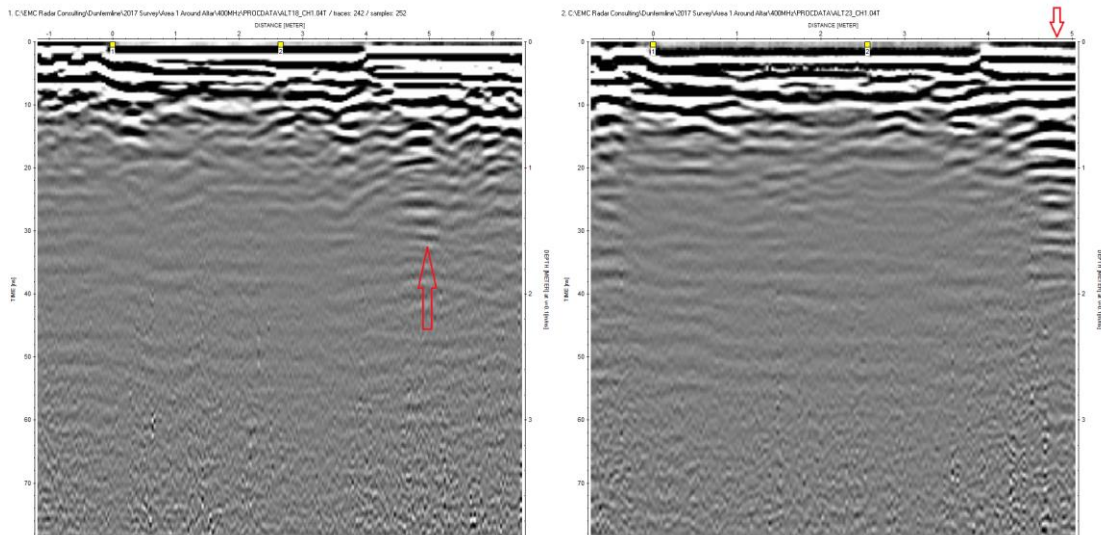
*Figure 14: Time Slice extracted at c. 1.25m Depth (400MHz, Area 1).*

However, this is not an echo effect, but a real subsurface construction as can be seen when the 2-dimensional data from this area is viewed (Figure 15). Red arrows indicate the upper and lower levels of the series of signals delineating this feature. The northern edge of the feature is also visible at the extreme right-hand side of survey line 17 (Figure 11). This evidence does suggest that feature 7 is likely to be a grave, albeit one which is closer to the current floor than might be expected. Figures 14 and 16 (with increased gain) also suggest that there is a possible outer boundary around feature 7.

It seems likely that the discontinuity visible in Figure 11, lying immediately to the

North, corresponds to feature 6 in the 250MHz data. This makes feature 6 appear more substantial in the 400MHz data than it does in the 250MHz data and potentially also a grave. Both feature 6 and feature 7 appear to lie directly below other features at floor level which makes it difficult to gauge their likely date.

Figure 15 shows the clear delineation of another discontinuity, similar to feature 7, at current floor level at the start of survey line 23. Lying beneath the discontinuity a series of signals can be seen, the lower ones being echo effects of those above. This indicates the presence of another possible grave. Although the outline of the feature only measures 1.6m in length in Figure 14, it may continue westwards into the area which could not be surveyed due to church furniture.



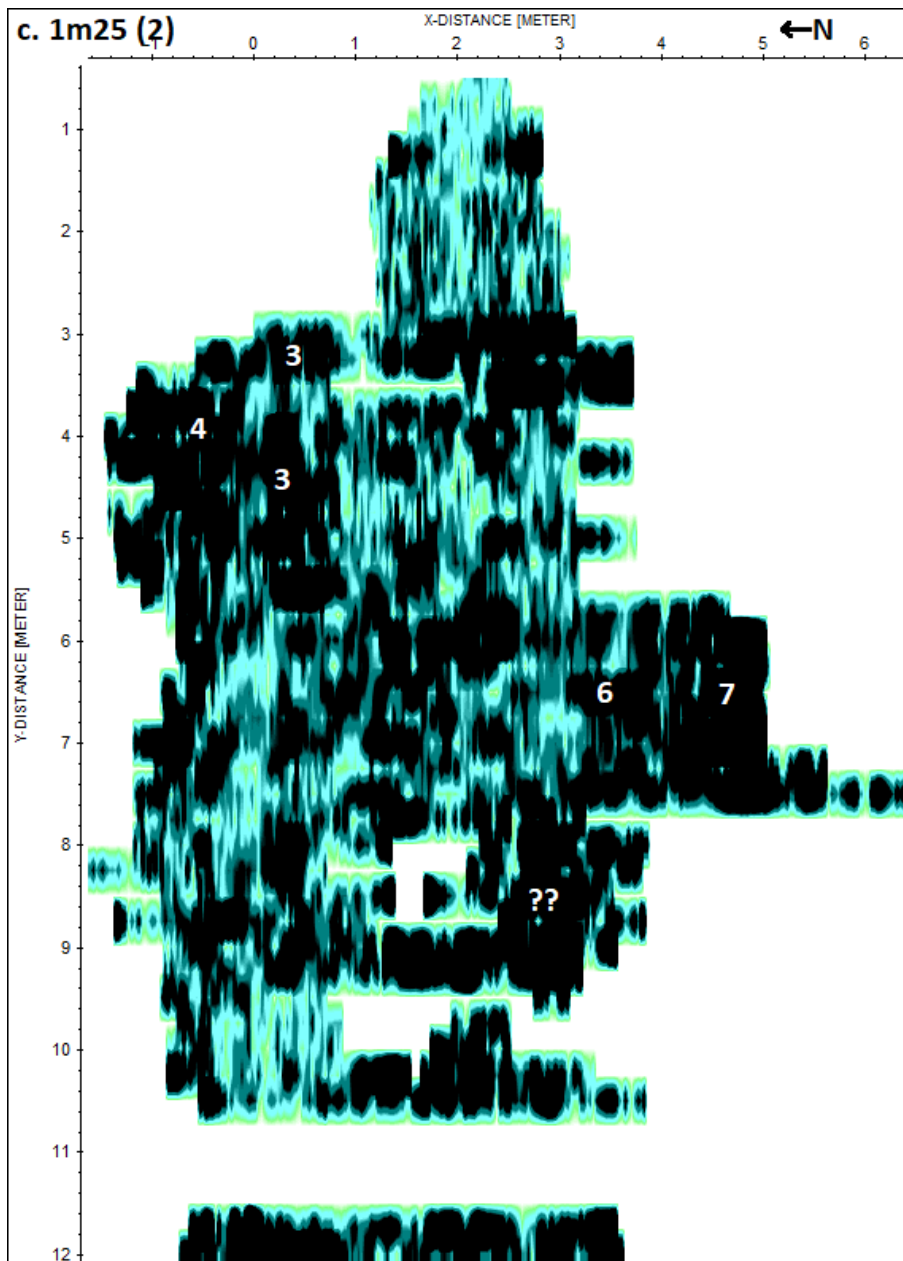
*Figure 15: Survey lines 18 and 23 showing the cross section of Feature 7.*

Comparison of Figure 14 with Figure 4 begs the question of why potential graves 1 to 5 are not also visible and why potential grave 6 is visible only in section (cf Figure 11).

The question of grave 6 is relatively easy to deal with. Figure 11 indicates that, like feature 7, this has a substantial feature overhead connecting to the current church floor, marked “2” in this image. The 250MHz data suggested that the visibility of this feature was less than that of its neighbour cf Figures 4 and 8. If more gain is applied to Figure 14 then it is possible to see a partial delineation of features 3, 4 and 6 as well as 7 and there is also a suggestion that there could be a similar feature directly to the South of the known royal grave (Figure 16).

The weaker signal strength in the 400MHz data set is easily explained by either a much smaller air gap within the possible grave or the absence of any metallic content, for example. Soil properties can also play a part since attenuation (loss) increases with frequency so that the 400MHz system’s ability to detect will be more adversely affected than that of the 250MHz radar. A smaller air gap, although possible, is less likely in that a smaller air gap ought in principle to be more easily detected by an antenna emitting shorter wavelengths. As far as the effect of the subsoil is concerned, the amount of ringing in the subsurface suggests that the soils beneath Area 1 are not wholly suited to GPR. That being the case, the 400MHz will be disadvantaged

relative to the 250MHz. The amount of gain which has had to be applied to the respective data sets confirms that this is the case. Taking these factors into account, it appears likely that feature 6 is also a potential grave, as suggested by the 250MHz data.

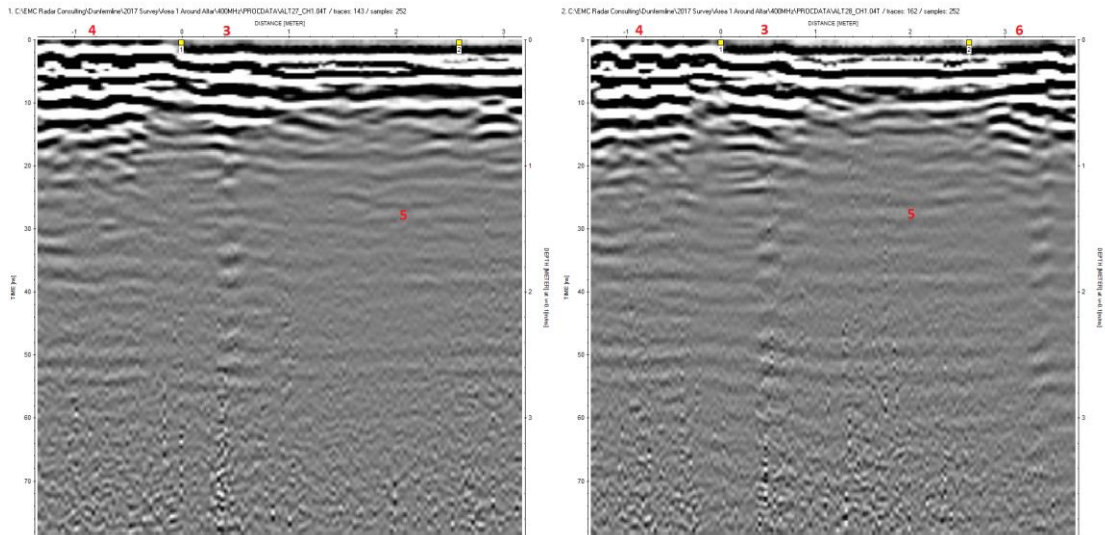


*Figure 16: Time Slice from Figure 14 (c. 1.25m Depth) with added gain (400MHz, Area 1).*

From Figure 16, it seems likely that features 3 and 4 are similarly affected. Since potential grave 3 is very clear also in vertical section (cf Figures 6 & 17) this is likely to be a grave also. Features 4 and 5 are much more diffuse than 3. In Figure 16, although the probability of 4 being a grave is reduced, it retains this potential. Feature 5, on the other hand, could potentially be an echo effect from the surface or near subsurface of the surface time slice (Figure 12).

Figure 17 is the 400MHz equivalent to Figure 6 in the 250MHz data set. It shows probable grave 3, including some associated ringing, very clearly. Feature 4 contains

a number of layer-type signals with material concealed beneath them. This could indicate graves but could also be a different type of structure. Figure 5 is very much more ephemeral although its lower extent is visible and does not appear to be an echo effect. (Echo signals usually follow the same shape as the original signals which they repeat.) On the right-hand side of survey line 28, there appears to be another potential grave, marked “6” (Figure 17). This survey line lies along  $y = 4.75\text{m}$  in the time slice. In this location it cannot be feature 6 although it does align with it. Most of the feature lies beneath the pews.



*Figure 17: Survey lines 27 and 28 from the 400MHz data set showing cross sections of features 3 to 5 inclusive.*

This leaves features 1 and 2 in the East of the survey area apparently missing. The equivalent survey lines to those used in Figure 5 are lines 39 and 43. The data shows some ringing at both ends of the data but only a few small and faint indications of anomalous material around  $x = 1.8\text{m}$  to  $2\text{m}$ . This potentially corresponds with grave 2. It is not possible to draw any definitive conclusion from these data, but it seriously lessens the probability of any feature in this vicinity being a grave.

### **Time Slice at 1.75m Depth (c. 35ns)**

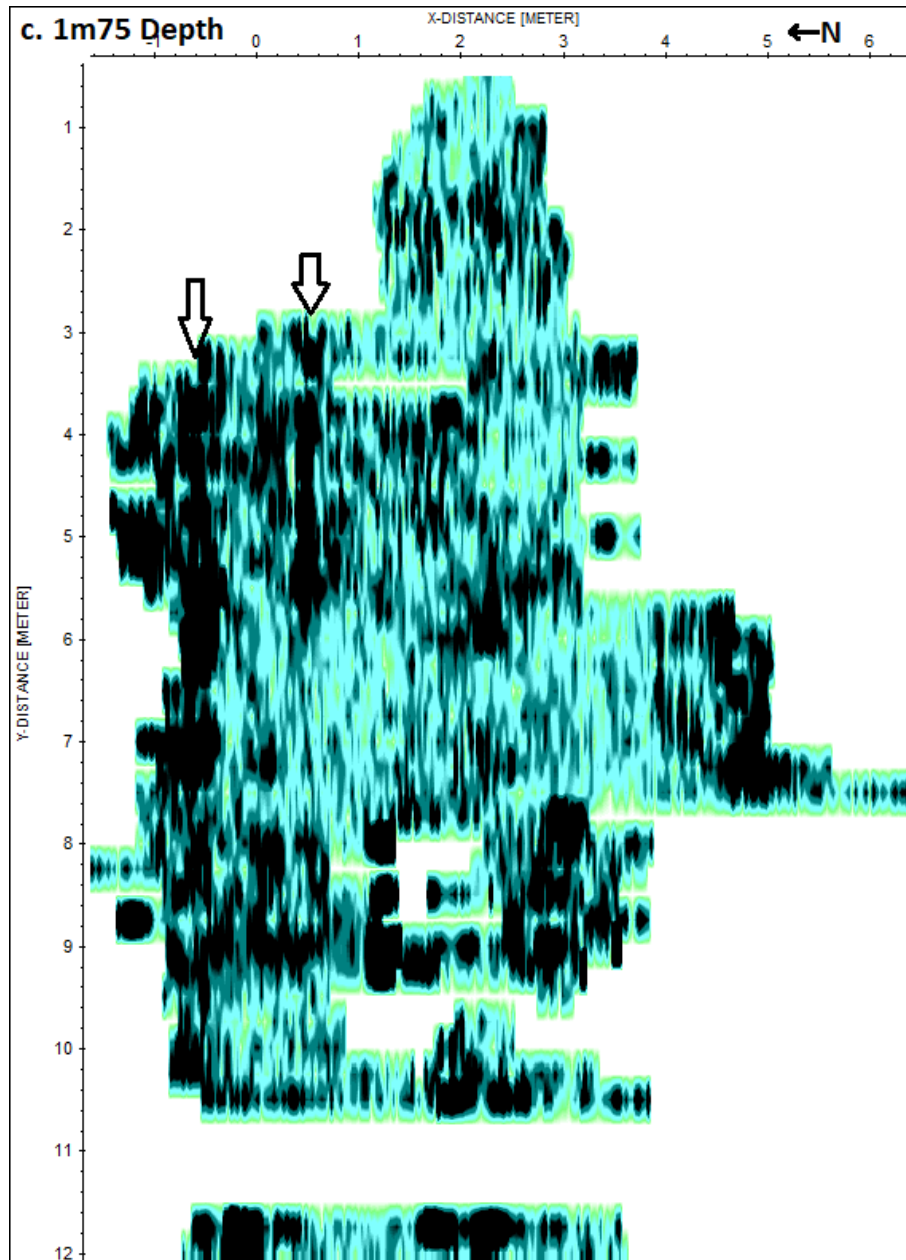
This time slice is notable for the appearance of two parallel straight lines in the northern half of the survey area. The more northerly of the two lines appears to be linked to another area of high amplitude signals although its precise extent cannot be determined. Further South there is a small rectangular corner at approximately  $(x = 2, y = 6)$  the East/West arm of which also runs parallel to the first two lines.

It is very doubtful that these are reflections of real subsurface features. The line centred on  $x = c. 0.5\text{m}$  corresponds to the ringing directly below and potentially associated with feature 3 as seen in Figure 17. The northern line, centred on  $x = -0.5\text{m}$  has less of an appearance of ringing at this depth but it is difficult to be sure given the density of layering above which essentially masks the signal shapes. The corner feature corresponds to a very faint line within the data.

However, the outlines represented by these lines correspond to the outer edges of the

features visible in Figure 8, the time slice at 1.54m from the 250MHz data. The image therefore may represent either earlier structural remains or potentially the outlines of extant graves. If so, these are potentially substantial in size, as indicated by Figure 8.

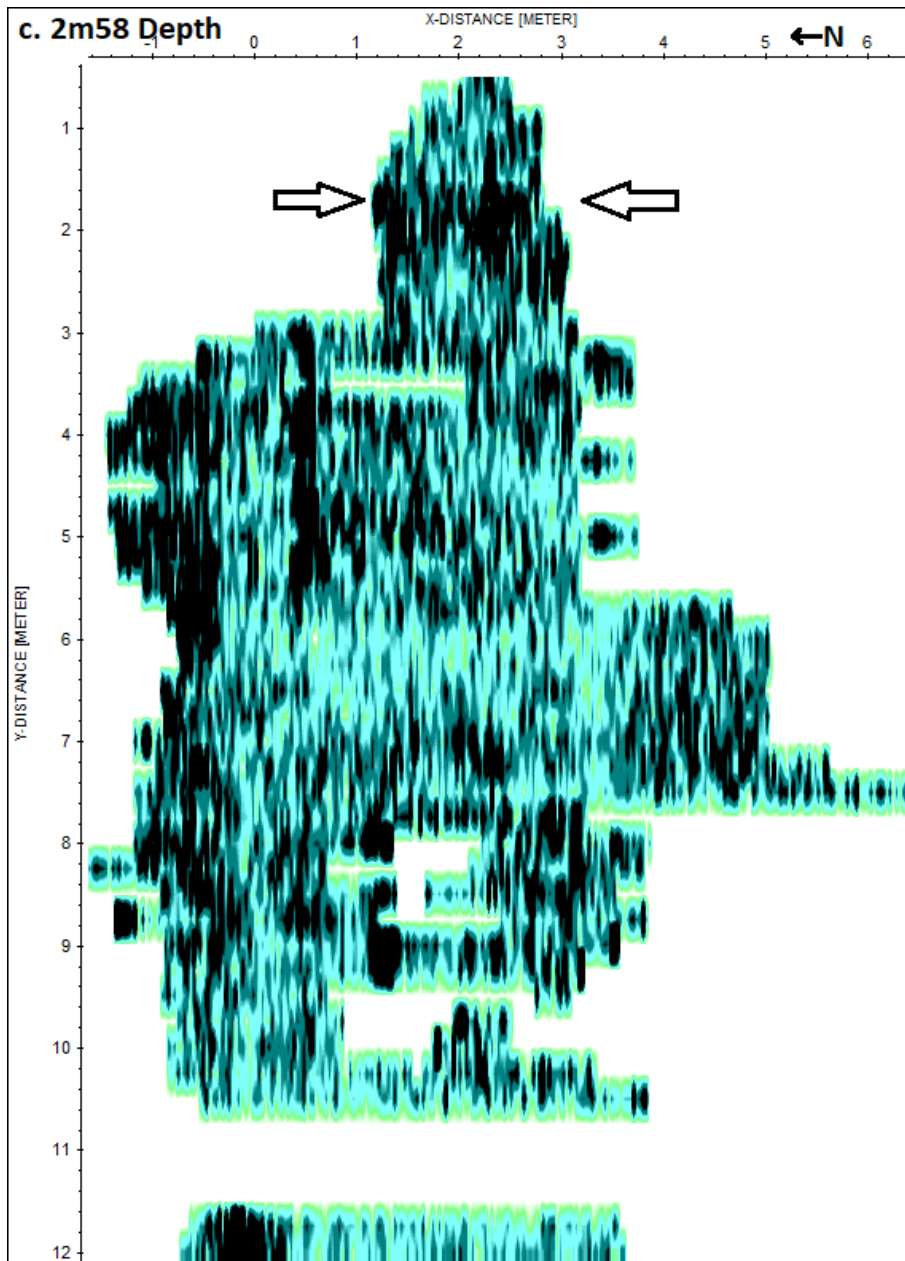
This presents again the problem of attenuation (or loss) of the 400MHz signals, confirming the relatively unsuitable soil in the subsurface within survey area 1.



*Figure 18: Time Slice at 1.75m Depth (400MHz, Area 1).*

**Time Slice at c. 2.58m Depth (c.52ns)**

This time slice is similar to the previous one (which may be due to echo effects rather than continuity of structures). There is one additional North/South line at the eastern end of the survey area, marked with arrows in Figure 19. It is unfortunately not possible to check this line in vertical section due to the superimposition of wi-fi

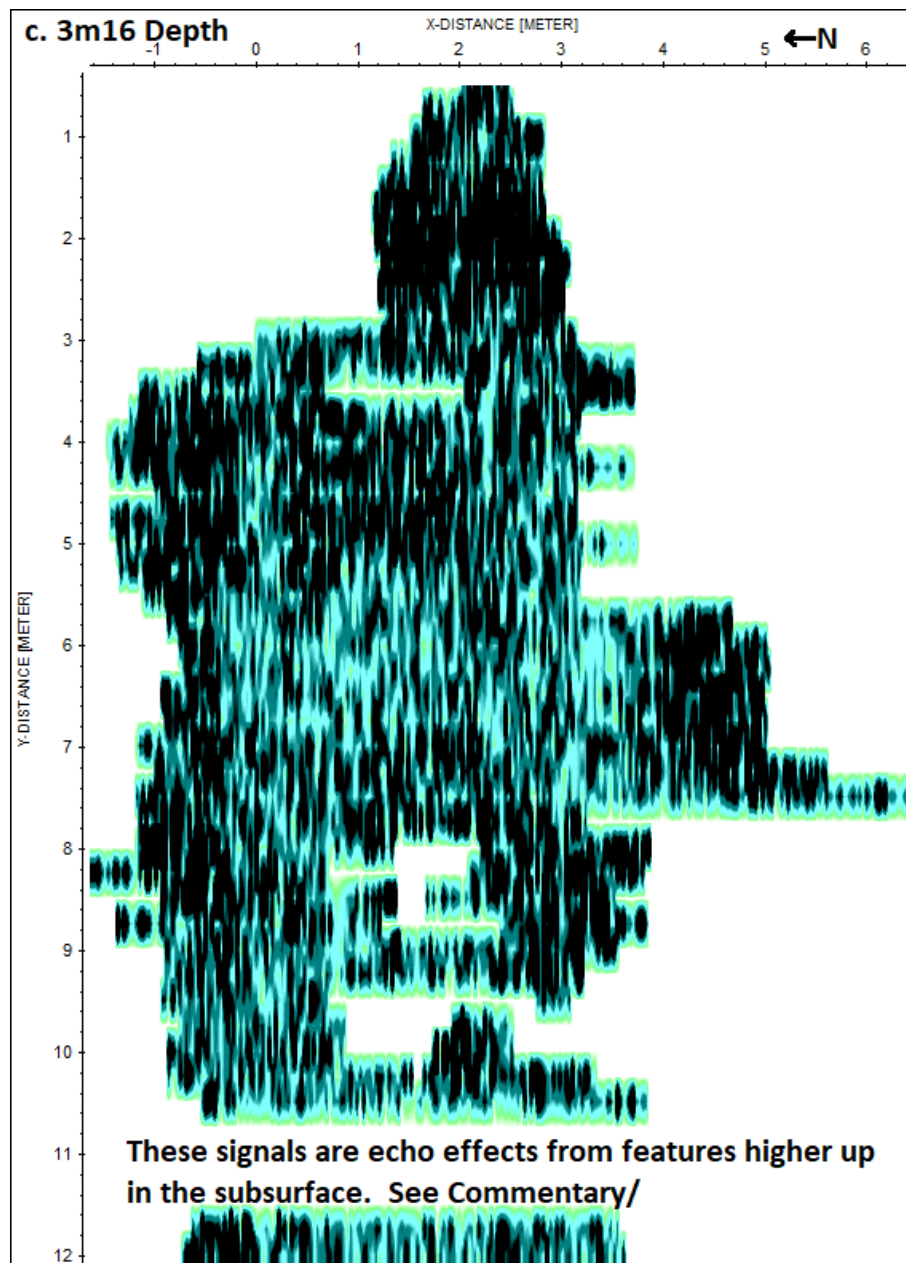


*Figure 19: Time Slice extracted at 2.58m Depth (400MHz, Area 1).*

signals (from the Abbey fire alarm circuit) over the radar data. There are faint traces which might indicate either remains in line with the path of the radar or a stratigraphic layer change, but it is not possible to say whether or not these are echo effects rather than real signals. The speckled effect across Figure 19 is also due to these wi-fi signals.

#### **Time Slice at 3.16m Depth (c. 3.7ns)**

Below the level of the previous time slice almost all signals appear to be echo effects, coupled with the wi-fi signals from the Abbey's alarm signals. At a number of levels, notably c. 60ns (not illustrated) and c. 63ns (Figure 20), these echo effects reflect the features described above but also indicate the presence of features 1 and 2 in a manner consistent with the data from the 250MHz data set. There is clearly some sort of feature here, but it is not possible to determine what these represent non-intrusively.



*Figure 20: Time Slice showing combined echo effects (400MHz, Area 1).*

## **Area 2 - The East End of the Lady Chapel outside the current Abbey Church**

This survey area lies outside the current Abbey Church, to the NE of the main entrance. Two parallel survey reference lines were laid out along an East/West orientation, aligned with the North side of the Abbey. Line 2 was placed at 0.85m from the NE wall of the church with line 1 at a distance of 8.93m from line 2. Markers 1 and 2 on the data indicate the position of these lines.

Area 2 is adjacent to the Vestry and the proximity of the signals from the Abbey's fire alarm system has resulted in these transmissions being recorded on the GPR data. They are visible as thin columns of signal, indicating a different frequency from those deployed by the radar. This does not obscure larger targets in the GPR data but does result in a speckling effect in both the 2-dimensional data and the extracted time

slices. An example of the effect on raw data is shown in Appendix B. Unfortunately processing the data cannot eliminate this interference.

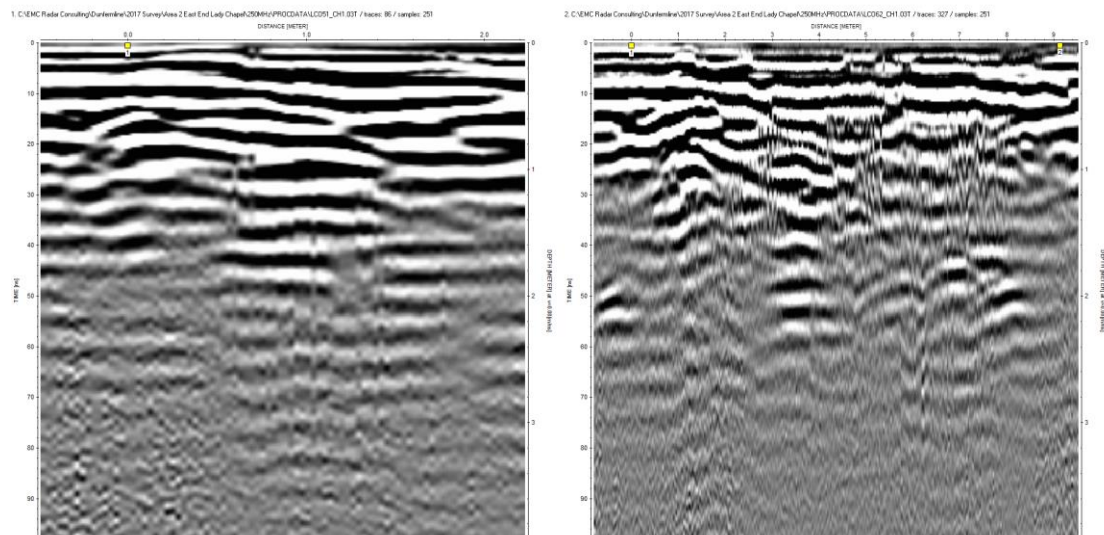
## 2-Dimensional Data: 250MHz

The 2-dimensional data has been processed by:

- Correction for Tzero;
- Constant background removal;
- Addition of gain to compensate for diminishing signal strength with depth;
- Application of Bandpass Butterworth to remove any spurious signals.

All 2-dimensional data is presented from North to South (left to right). The 2-dimensional data from Area 2 is different from that of Area 1. Although there is evidence that the soil is lossy i.e. not entirely suited to GPR, the depth penetrated by the radar is generally greater. For most of the data there are real signals around the 50ns level (equivalent to 2m at the calibrated velocity) and, particularly in the immediate vicinity of the church, these may go as deep as 70ns (equivalent to 2.8m at the calibrated velocity of 0.08m/ns).

Many of the survey lines show large targets within these depths. Consecutive lines show clearly the continuity of features from one to the next indicating the probable presence of at least one former wall. Survey lines 51, 62, 66 and 72 are good examples (Figures 21 and 22).



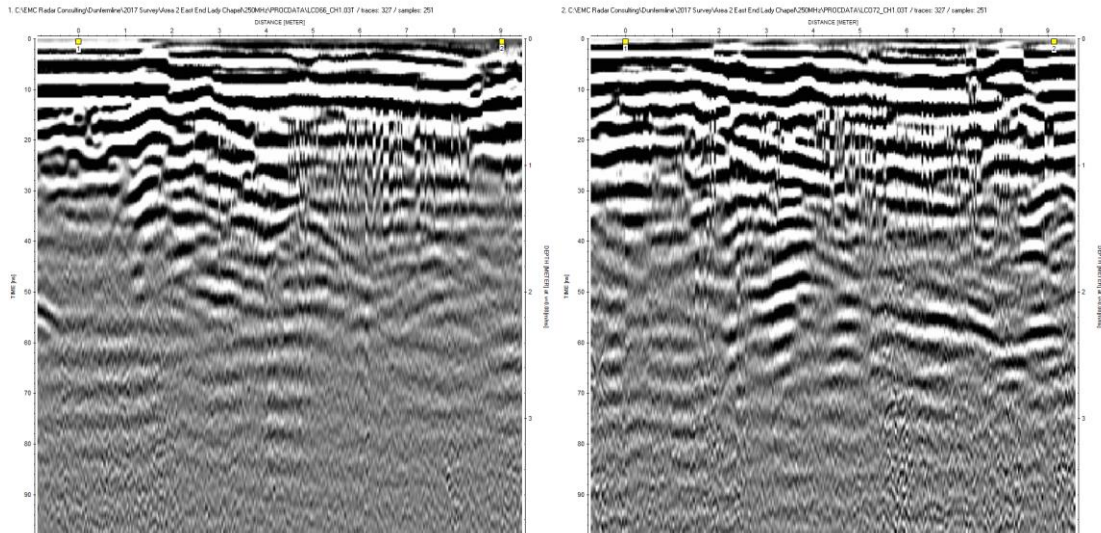
*Figure 21: Survey Lines 51 and 62 showing large features in the subsurface at different depths (250MHz, Area 2).*

Survey line 51 is the second line to be recorded in this area, a short line ending at the side of the church directly to the East of the main door (Figure 21). There is a large block of signal in the centre of the radargram indicating the presence of a substantial feature, the top of which lies just within 1m of the ground surface. Survey line 62, located 1.75m to the East of line 51, within the angle of the NE wall of the church and the outer wall of the North Transept, shows a variety of features, some at greater depth. Both survey lines show evidence of echo effects towards the bottom of the



radargrams in the form of repeated signals mimicking those above. Line 62, being closer to the Vestry wall, also shows the thin striping effects from the Abbey’s fire alarm system.

The complexity of the extant remains increases in the data lying to the East of these



*Figure 22: Survey lines 66 and 72 showing a variety of archaeological features (250MHz, Area 2).*

two survey lines. Survey line 66, 1m to the East of line 62 has a very large feature within it and also some evidence of a line leading towards the NE wall of the current church (Figure 22). Line 72, 1.5m to the East of line 66, has a completely different array of features including what could be the stump of a wall foundation and a layer change leading from its base towards the NE wall of the current church.

Beyond the eastern limit of the current church, the data shows fewer shallower features in the subsurface and the deeper depths are primarily characterised by ringing (echo effects).

### 3-Dimensional Data: 250MHz

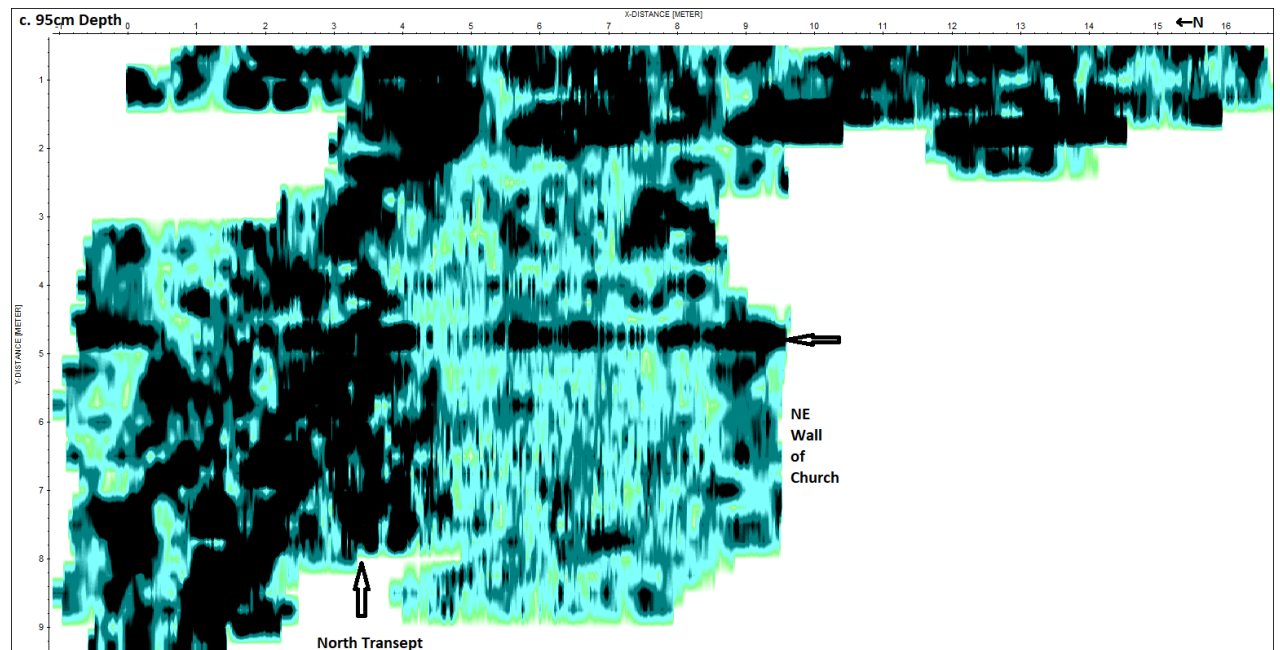
The full set of survey lines has been incorporated into a 3-dimensional data set on the basis of their respective positions along survey reference line 1. Time slices, horizontal plans, have been extracted from the data set on the basis of changes in patterning. East is at the top of the page for all of the time slices and x = 0 marks the position of survey reference line 1. Where air gaps exist, or moisture is present the view will be quasi-horizontal i.e. apparently horizontal but not physically so due to the differing transmission velocities in different parts of the survey area.

The 2-d data selected for illustration can be located as follows.

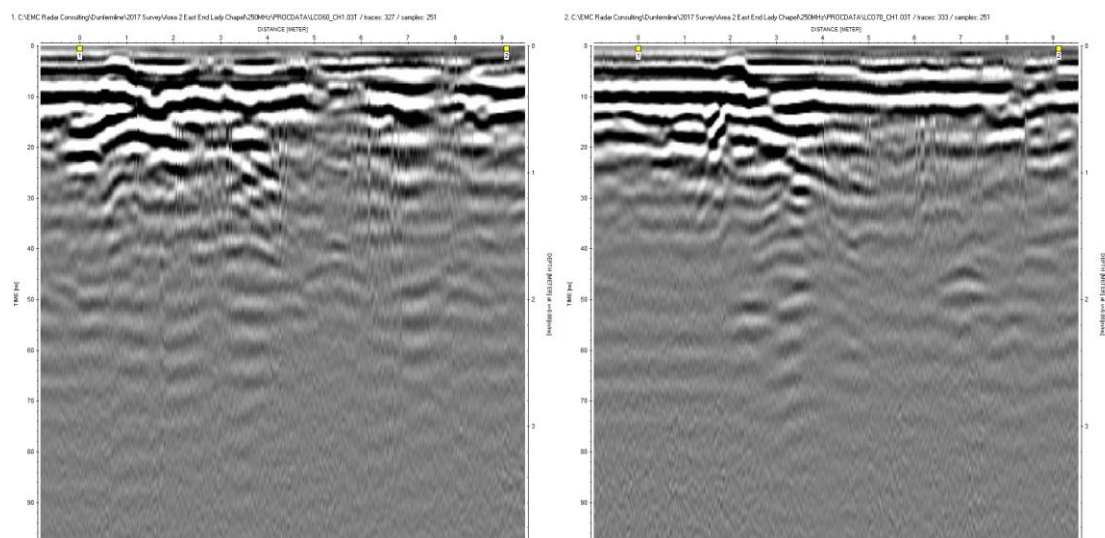
| Survey Line | Y position on Time Slices |
|-------------|---------------------------|
| 51          | 9                         |
| 62          | 7.25                      |
| 66          | 6.25                      |
| 72          | 4.75                      |

**Time Slice at 95cm Depth (c. 23.8ns)**

The first patterning that moves beyond distinguishing the path and areas of damp ground shows a thin rectangular feature in the angle between the East wall of the North Transept and the NE wall of the church. This is marked by arrows in Figure 23. The North/South line leading towards the NE wall of the church can be seen in survey line 72, Figure 22. It forms the bottom layer of the near subsurface and is credible as being the remains of a former construction directly underlying the present ground surface. The anomalies forming the more substantial East/West line of the feature appear in vertical section to be consistent with the remains of a wall of Figure 24 at  $x = 3.5\text{m}$ .



*Figure 23: Time Slice extracted at c. 95cm Depth (250MHz, Area 2)*

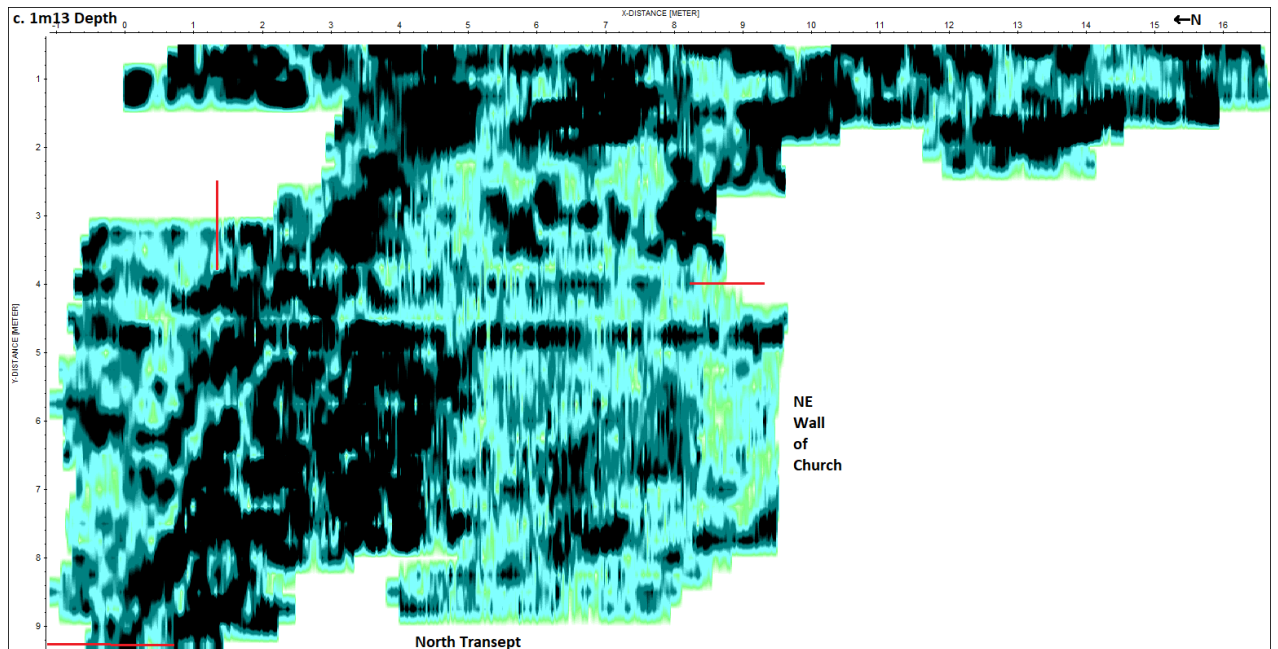


*Figure 24: Survey lines 60 and 70 showing evidence of a damaged former wall (250MHz, Area 2).*

### Time Slice at 1.13m Depth (c.28ns)

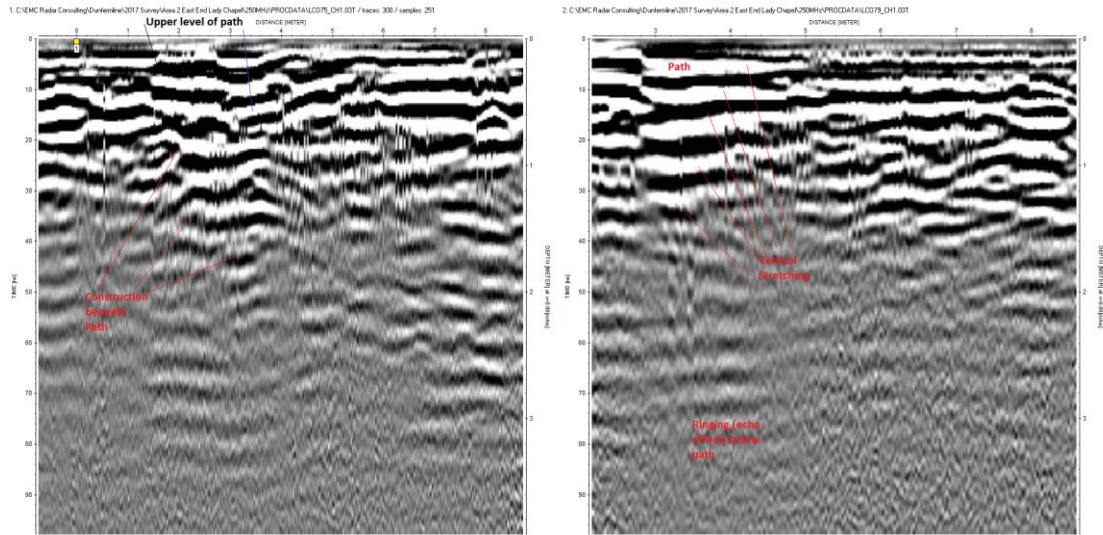
The same rectangular outline is visible at this depth (Figure 25). The definition of the East/West wall segment is improved, and it is clear that this is (and was) a substantial wall. The North/South element, by contrast, has only partial remains. However, these include a faint parallel line approximately 1m to the East not previously visible, indicated by a red line in Figure 25. Examination of the relevant survey line, line 75, confirms that there is a line of material at this depth underlying the modern subsurface (Figure 26 lhs). There is a problem in being sure that, even with the double line, these signals represent a former wall. Each line is only 1 survey line's width and, since it lies in the direction of travel of the radar, is impossible to check in vertical section. There is another candidate for the North/South wall approximately 1m to the East of the eastern line. If this is a wall, it is heavily degraded and does not extend far enough to meet the northern boundary wall. It has, however, a more realistic outline.

Figure 25 also demonstrates that there is another large block of former construction adjacent to the original rectangular feature on its North side. The East and West corners of this feature are marked by red lines in Figure 25. It is not clear what the relationship is between these two features, a situation which is complicated by the fact that this second linear feature underlies the modern path. Several survey lines, including 60 and 75 (Figures 24 and 26), do not show any gap between them although only the original line continues below 40ns (c.1.6m) in the subsurface.



*Figure 25: Time Slice extracted at c. 1.13m Depth (250MHz, Area 2).*

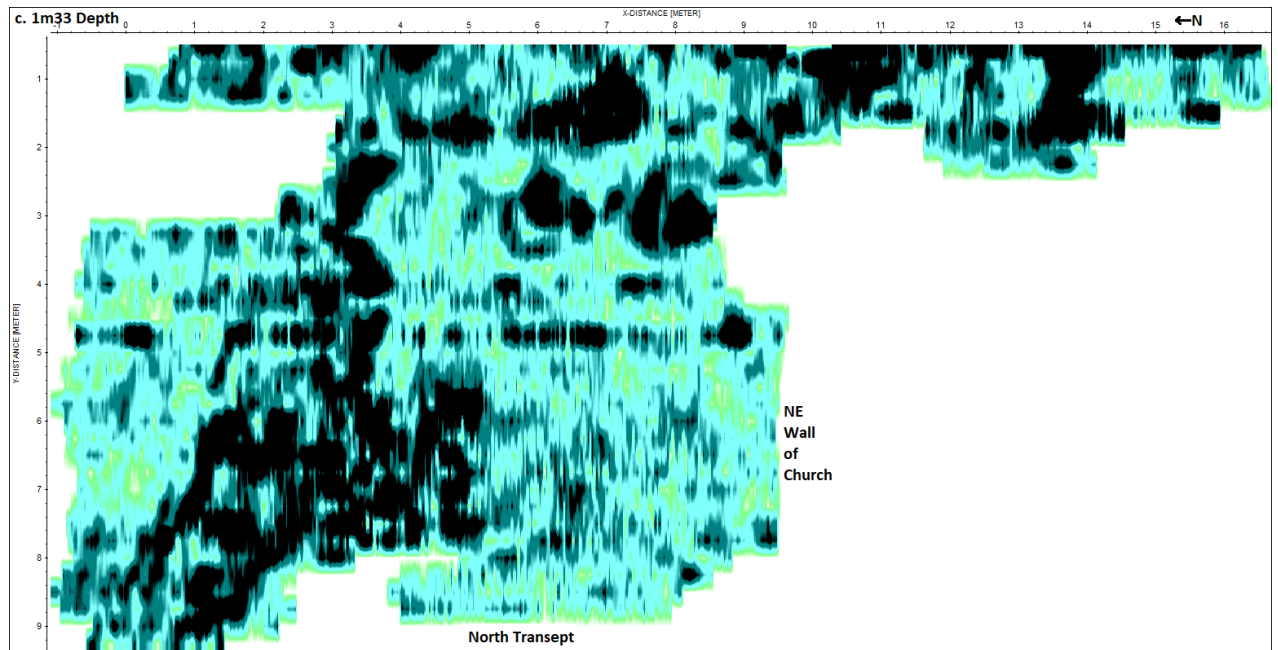
Beyond the North/South boundary the dark areas in the time slice appear to be relatively modern infill and are probably showing as anomalous from additional moisture content. When black and white lines in the data stretch in the vertical direction this can mean that the signals are slowing down which is one indicator of the presence of moisture. The prevalence of ringing lower down suggests an increase in attenuation (loss of signal) in the soil below which is another potential effect of added moisture. Both of these phenomena are visible in survey line 79 (Figure 26 rhs)



*Figure 26: Survey lines 75 and 79 showing former construction (lhs) and relatively modern features (rhs) [250MHz, Area 2].*

**Time Slice at c. 1.33m Depth (c.33ns)**

The same features are visible at this depth as were visible in the previous two time slices (Figure 27). The image is clearer due to the disappearance of many of the shallower, more randomly spaced anomalies.



*Figure 27: Time Slice extracted at c. 1.33m Depth (250MHz, Area 2).*

From the irregular shaping, the majority of other anomalous areas are likely to represent pockets of additional moisture. There is nothing indicating an irregular void within a square or rectangular outline such as might be expected for a grave.

However, the possibility of the area of the Lady Chapel being defined by the badly degraded wall to the East of the 2 parallel lines originally observed seems now to be very likely (cf Figure 25). The larger rectangular area, thus formed by the two

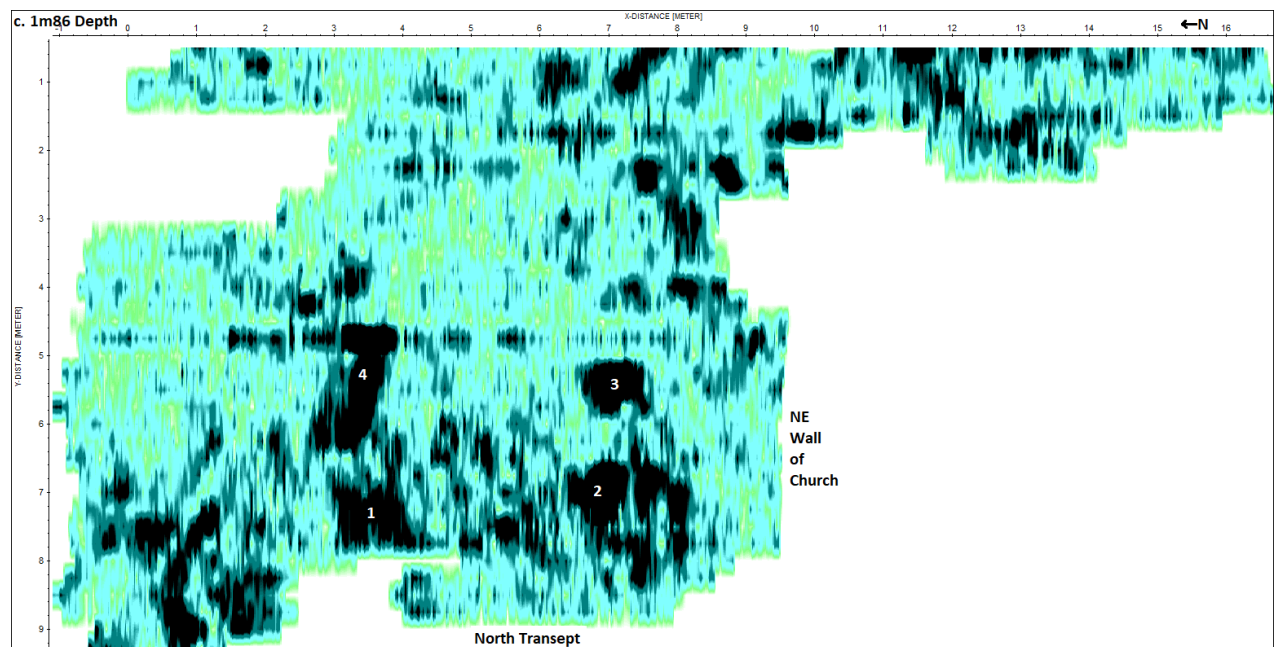
boundary walls is defined by:

- the two East/West lines previously observed;
- a continuation towards the East formed by irregularly shaped outlines; and
- another partial North/South line along  $y = 3\text{m}$ .

The North/South line along  $y = 1.5\text{m}$  relates to more modern construction and, in particular, the path. Seen in vertical section, the evidence indicates that this is the subsurface of the path leading eastwards and the one leading South to the eastern end of the church and in the general direction of St Margaret's Shrine. There is evidence of increased moisture content (vertical stretching of the signal) and multiple layers which could indicate systematic infill. This does not appear to represent earlier structural features with the proviso that such material has not been entirely removed in advance of the more modern construction.

### Time Slice at c.1.86m Depth (c. 46.5ns)

Below 40ns the larger features disappear (Figure 28). Four main features remain within the area of the rectangular feature previously described. The first of these lies beneath the possible wall described earlier. It appears to be the upper layer of a feature whose base lies on a possible floor (evidenced by a layer change). Line 60 in Figure 24 illustrates this in vertical section. The lower column of signal is likely to represent a column of construction material. It is clearly different (narrower) than what lies above and is separated from it by a possible curved cap. It is not clear what this represents although drainage is a possibility.



*Figure 28: Time Slice extracted at c. 1.86m Depth (250MHz, Area 2).*

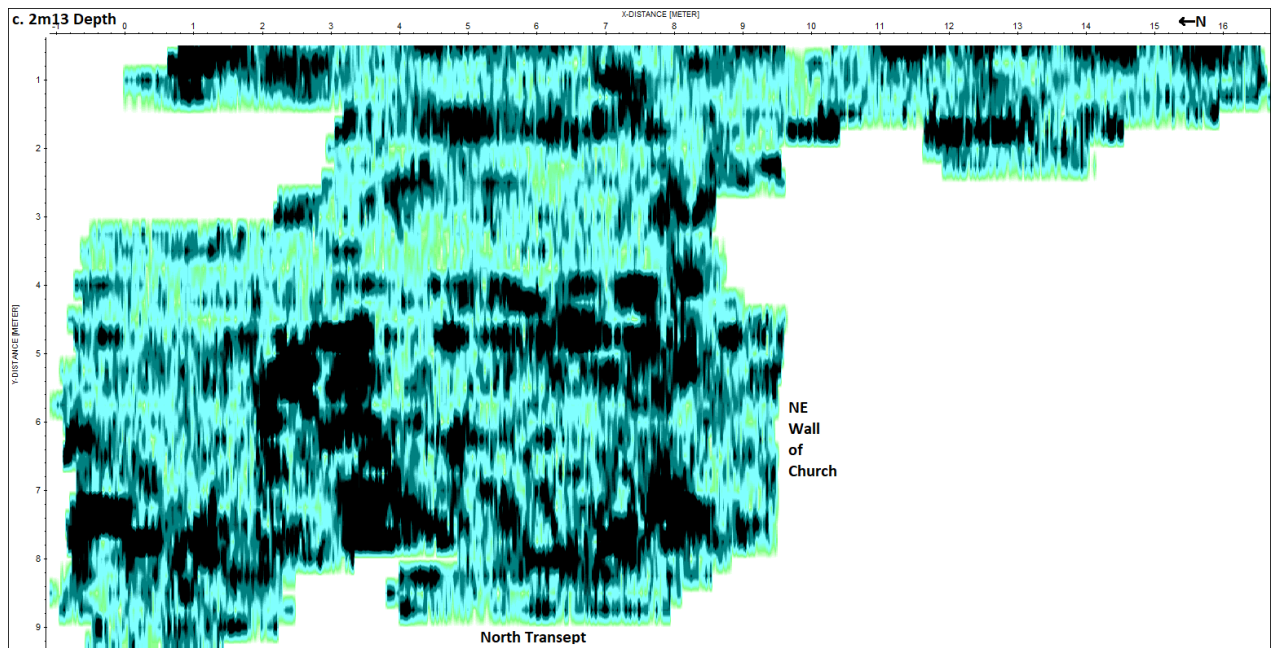
Feature 2 is composed of an interesting group of hyperbolas, suggesting undamaged material in close proximity but at least 32cms (1 wavelength) apart. Any part of the feature which is closer to another than this would be included in the same hyperbola. Any single hyperbola does not necessarily represent a single item, nor does it necessarily follow its shape. Feature 2 aligns with feature 3 although there is a clear break between them. It is of very similar composition. This could either be a group of

different separate materials or potentially something larger which has been sculpted. It is not possible to be definitive on this. There is also a possibility that feature 2 may extend to the West but the position of the North Transept wall makes it impossible to know.

Feature 4 is similar in nature to the first feature. Two cross sections can be seen in lines 66 and 72 (Figure 22). The signals resemble constructional material and they underlie the previously observed probable wall and are situated above a lower column of signal which may also represent constructional material. They do not appear to be undamaged. It is more likely that they represent the ruined remains of an earlier structure. The broad V shaped feature in the NW corner is very similar in nature. A vertical section from this area can be seen in survey line 60 (Figure 24).

### Time Slice at c. 2.13m Depth (c.53ns)

The lower columns of signal resolve quite clearly at this depth into a simpler rectangular feature which follows the lines of the probable walls initially detected higher up.

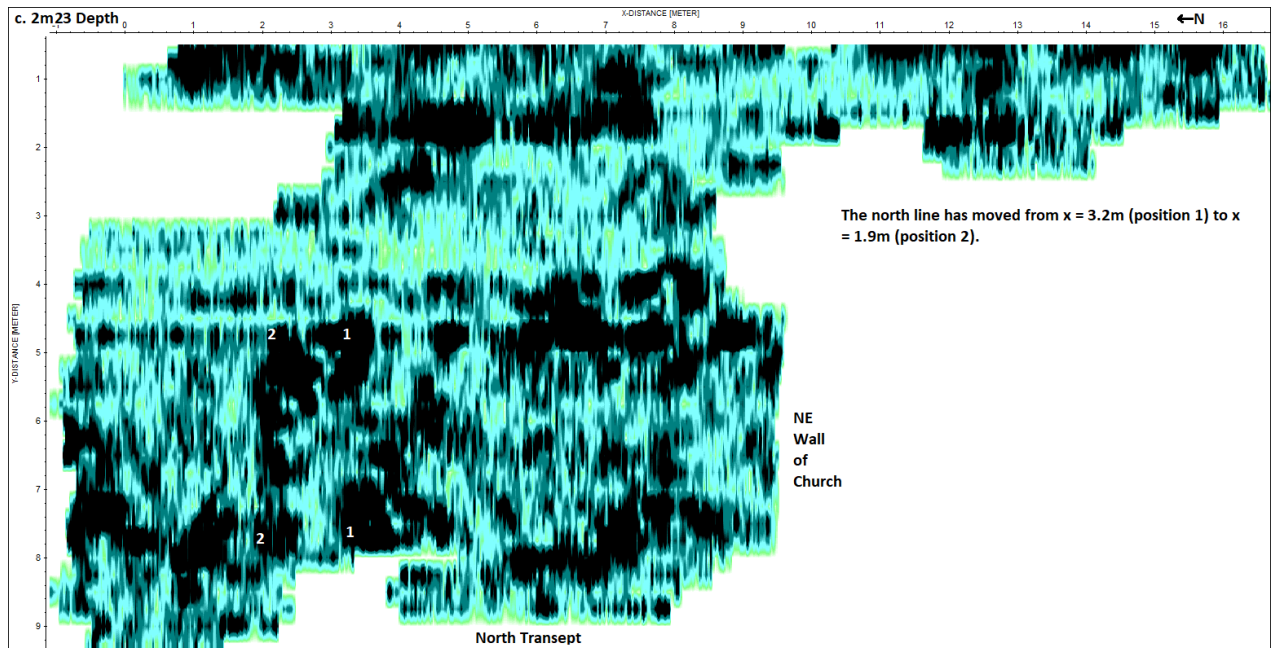


*Figure 29: Time Slice extracted at 2.13m Depth (250MHz, Area 2).*

Material visible in the SW corner of this feature suggests that this is a complete rectangle rather than two outer lines of the former Lady Chapel walls. Although this is possible, it is more likely from the difference in vertical patterning that this represents extant material within the Lady Chapel of lines 60 and 62 (Figures 24 and 21). Some of it forms part of the lower section of feature 2 in the previous time slice (grouped hyperbolic returns).

### Time Slice at c. 2.23m Depth (c. 56ns)

The same group of features is visible at this depth, but the size of the rectangle formed by/around them has increased (Figure 30). The North/South boundary wall, visible



*Figure 30: Time Slice extracted at 2.23m Depth (250MHz, Area 2).*

along  $y = 4.75\text{m}$  and  $4\text{m}$  is unchanged from its initial position in Figure 23. The intermittent signals which might continue these lines northwards are not substantiated by the 2-dimensional data and are mostly echo effects from moisture above. However, the East/West line marking the northern boundary has moved from  $x = 3.2\text{m}$  northwards to  $x = 1.9\text{m}$  (2 in Figure 30). The vertical view of the data confirms the likely presence of structural material.

Of the former presumed wall, only two irregular shapes remain at the NE and NW corners: 1 in Figure 30. This, too, could potentially be structural material although the odd shaping in this and the two previous time slices might be indicative of air gaps. As with the newly appeared wall, the outlines of the anomalous material are incomplete. It is not easy to determine whether the original wall is not a wall at all but a large monument in the NE corner of the Lady Chapel which case the dark areas represent air gaps rather than masonry. The underlying problem is that the signals could represent either air or masonry. If this were a tomb or related monument, it would explain why the strong signals cover less of the area at c.  $2.23\text{m}$  depth than they apparently do at a depth of c.  $1.13\text{m}$ .

In the SW corner of Figure 30 there is an apparent right angle of extant remains. Part of this structure is related to features 2 and 3 in Figure 28 from its position. It is not possible to tell definitively but it is possible that this may also mark a large grave (rather than a substitute for the current North Transept wall) if it can be safely assumed that the strong anomalous signals are air gaps rather than structural material.

The apparent line of signals along  $y = 1.75\text{m}$  can be ignored. This is ringing, echo effects from shallow pockets of moisture in the near subsurface.

The V shaped pattern of signals to the North of line 2 in Figure 30, the presumed remains of the North wall of the Lady Chapel, is similar in nature to the patterning of signals along line 1 even though it lies outside the area of the Lady Chapel. There is no overall shape which would indicate the presence of another possible grave in this

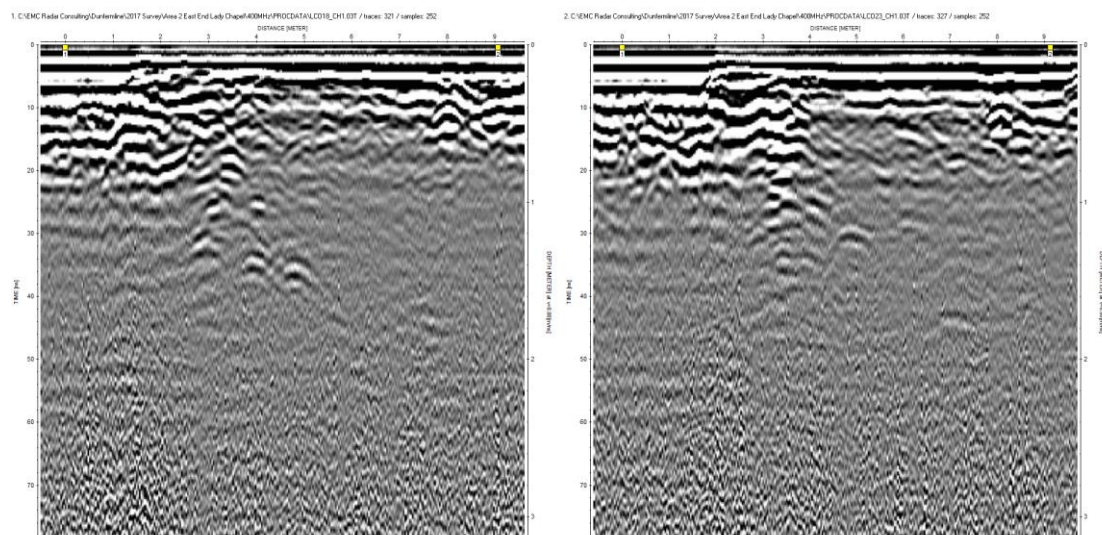
location. It is therefore more likely that this represents structural material, potentially in situ but, if so, damaged. It would be useful to compare the results of the last two time slices with historical plans of the Lady Chapel in order to resolve the anomalous East/West lines. It is not possible to determine, on the basis of the GPR evidence alone, whether these represent an addition to the original Lady Chapel, an adjacent monument or the spread of damaged material.

## 2-Dimensional Data: 400MHz

The 2-dimensional data has been processed by:

- Sender/Receiver correction;
- Correction for Tzero;
- Constant background removal;
- Addition of gain to compensate for diminishing signal strength with depth;
- Application of Bandpass Butterworth to remove any spurious signals.

The 400MHz data is characterised by a band of crowded signals in the shallow subsurface, a range of discrete hyperbolas below 15ns (c.60cm) depth and fewer deeper hyperbolas below 40ns (c.1.6m). There is also much more evidence of the effect of the transmissions from the fire security system, particularly below 40ns than is found in the lower frequency data set. As expected target definition is less diffuse and probing depth is also less than that achieved by the 250MHz antenna. Lines 18 and 23 are reasonably representative (Figure 31).



*Figure 31: Survey Lines 18 and 23 (400MHz, Area 2).*

## 3-Dimensional Data: 400MHz

As was done for the 250MHz data, the full set of survey lines has been incorporated into a 3-dimensional data set on the basis of their respective positions along survey reference line 1. Time slices, essentially horizontal plans, have been extracted from the data set on the basis of changes in patterning. All time slices are presented so that East is at the top of the page and survey reference line 1 lies along  $x = 0$ . There is a



small amount of striping across this and subsequent time slices, especially as the depth increases. This is the effect of interference from the fire alarm monitoring transmissions and should be ignored.

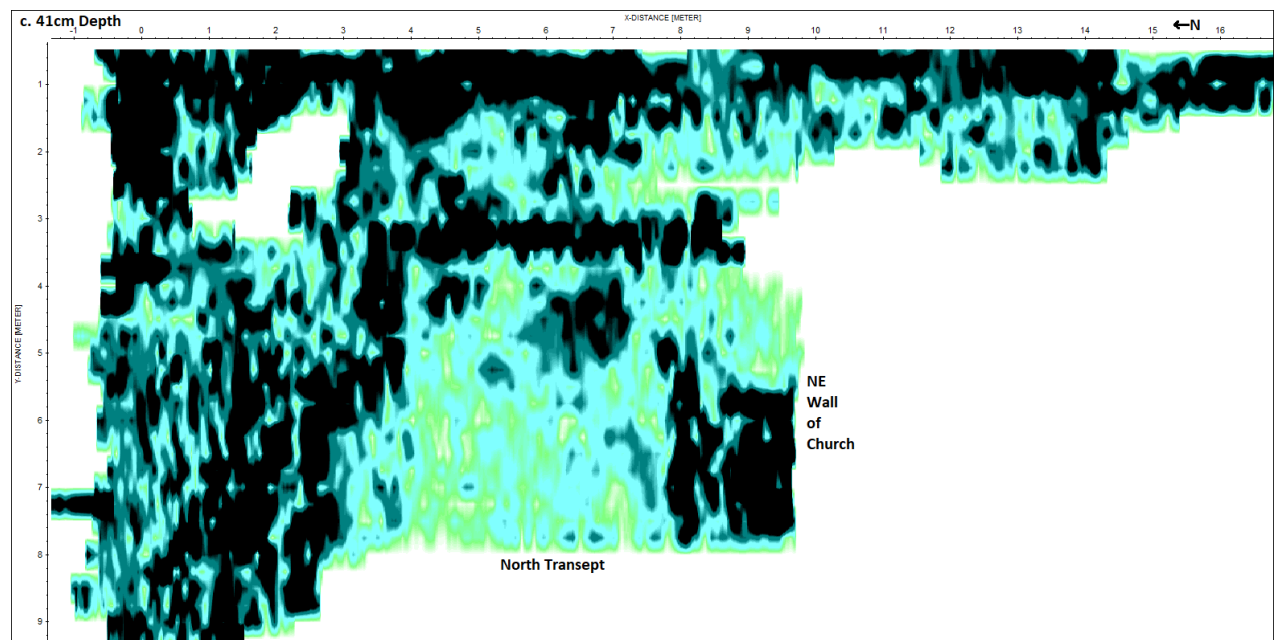
The 2-d data selected for illustration can be located as follows.

| Survey Line | Y position on Time Slices |
|-------------|---------------------------|
| 18          | 6.75m                     |
| 23          | 5.5m                      |

### Time Slice at c. 41cm Depth (c. 10.3ns)

The first coherent pattern appears very close to the surface with the outline of a rectilinear feature and, close to the angle between the NE wall of the current Abbey church and the eastern wall of the North Transept, a rectangular feature with dimensions of c. 2.1m in length by c. 1m wide, consistent with the presence of a grave (Figure 32). The closeness of the latter to the NE wall of the church mean that it is impossible to determine whether or not the grave continues beneath the wall.

To the North of this possible grave there is a linear feature which may be associated. Examination of the vertical section reveals a short column of signal, apparently undamaged, consistent with a small wall of c. 0.5m in height. It is not possible to provide dating evidence for this. The fact that this feature does not appear in the 250MHz data suggests that either its size is too small or its proximity to the grave too small.



*Figure 32: Time Slice extracted at c. 41cm Depth (400MHz, Area 2).*

There is an obvious difference between this two data set and the 250MHz one visible in the surrounding rectilinear feature which appears to be a good candidate for the walls of the former Lady Chapel. If this feature pre-dates the church, then it looks very much as though the current church was constructed so as to match the position of the buttresses to that of the former walls. Unfortunately, this does not match the

patterning of the 250MHz data. Not only are none of the features visible at this depth perceptible at a similar depth in the 250MHz data, the eastern boundary reaches the church at a place further to the West and there is no evidence of a dog-leg in the northern boundary. It is, in fact, possible to trace the same outline to a depth of 53cm within the 250MHz data set but without the dog-leg, although the definition of the eastern wall is very far from complete, unlike in the 400MHz data. The difference in depth is almost certainly due to the differences in wavelength and hence in ability to image. This means that the double line which appeared to form the eastern boundary is not a robbed out wall as originally suggested. The eastern boundary within the 250MHz data set is formed by the irregularly shaped anomalies adjacent to the same area of wall as defined in Figure 32 and visible in Figures 23, 25, 27 and 28. Although the linearity can be seen by comparison with the 400MHz data set, it is not as visible within the 250MHz data set alone. This is also a function of the target definition of the two antennas used.

There are two further implications of this:

1. The remains of the mediaeval church appear to lie much closer to the current ground surface than expected; and
2. The grave in the corner probably pre-dates the church even though its upper surface is so shallow. There is, however, no dating evidence and it is quite likely, on the basis of its proximity to the surface, to date to the period between the destruction of the East end of the abbey and the building of the present church.

The northern boundary visible in Figure 32 begins along the line  $x = 3\text{m}$  and moves northward to  $x = 1.4\text{m}$  to  $3.1\text{m}$  at  $y = 5\text{m}$ . No such dog-leg is visible in the 250MHz data. There is a single straight line centred on  $x = 3.4\text{m}$ . This may imply that the boundary visible at this depth is not entirely related to that visible lower down. By c. 1m depth both data sets agree on a broader feature whose northern edge runs along  $x = c. 3\text{m}$ .

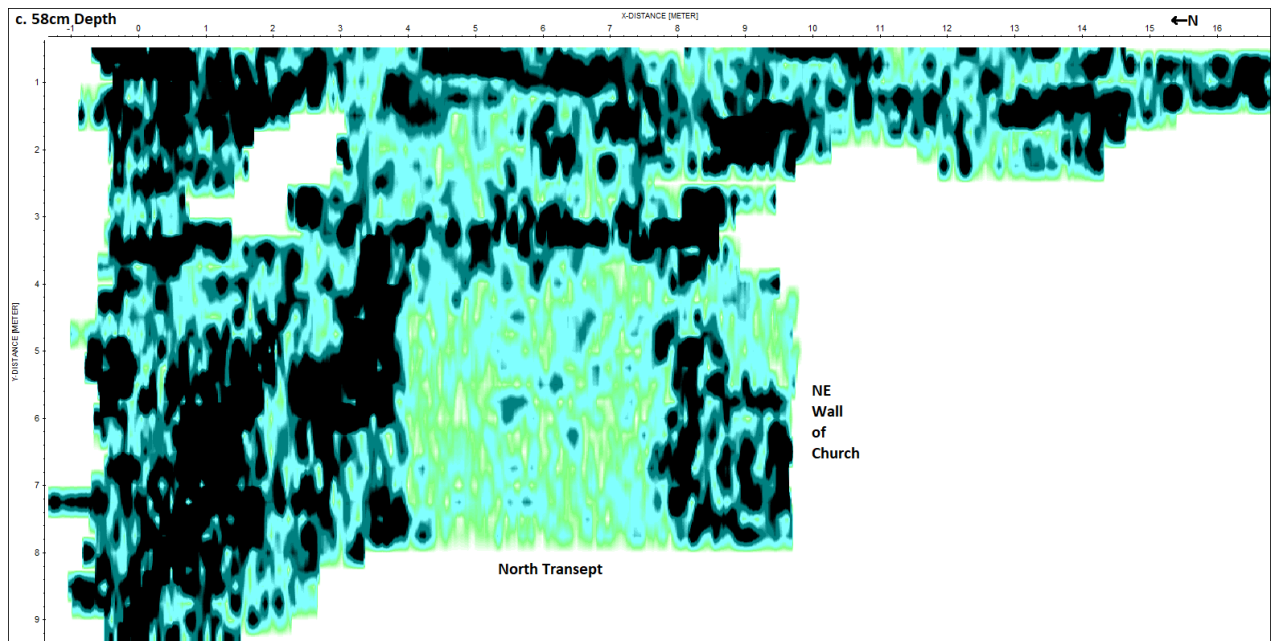
### **Time Slice at c. 58cm Depth (c. 14.4ns)**

Both the corner grave and the wall next to it remain visible at this depth. The anomalous material within the grave is reduced which suggests that the signals of strong amplitude are probably reflections of air gaps rather than construction.

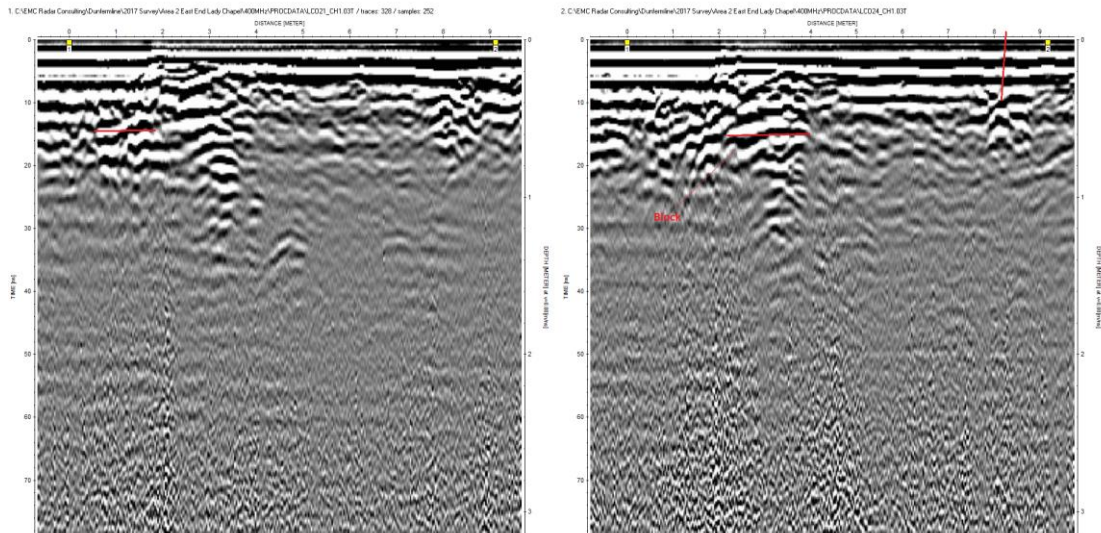
The eastern boundary to the area is equally visible and appears more complete than in the 250MHz data. This implies that the material being detected is smaller in size and hence more easily detected by the higher frequency antenna.

The dog-leg in the northern boundary now shows as a single rectangular block oriented North/South. The 2-dimensional data shows this to be composed of large regular blocks of signal (cf the feature indicated in Line 24, Figure 34). This could be structural material but it is also possible to obtain this patterning within the burial lairs of a modern cemetery, for example, so that it might represent a burial of one or more children although its apparent orientation makes this unlikely.

There is a large irregular area of anomalous material to the North of this area. Viewed in vertical section this appears to be made up from double signal columns



*Figure 33: Time Slice extracted at c. 58cm Depth (400MHz, Area 2).*

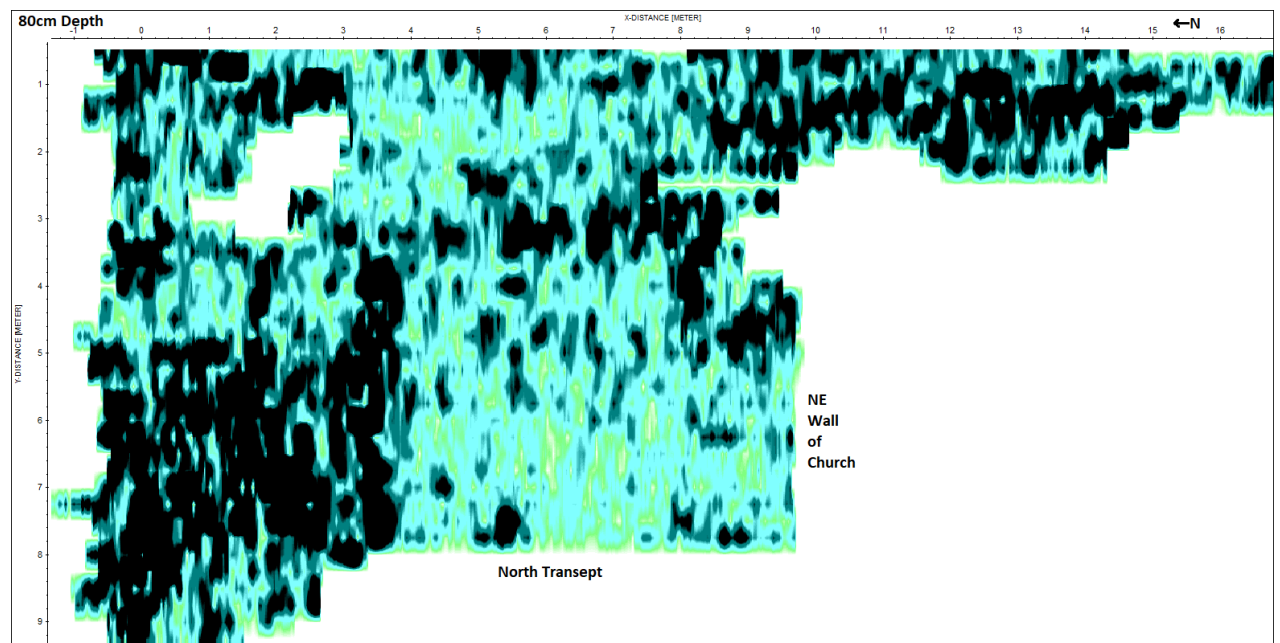


*Figure 34: Survey lines 21 (left) and 24 (right)[400MHz, Area 2]*

which may indicate structural material, lying beneath the current path. The red line within survey line 21 indicates the relevant position (Figure 34, lhs).

The line to the North of the grave in the SW corner appears longer at this depth and seems to meet and cross the eastern boundary line. The 2-dimensional data indicate that this does appear to be the same feature. The short, undamaged column of hyperbolic signals is indicated by a red vertical line in survey line 24 (Figure 34, rhs). The rectangular area delineated by the two external boundary lines and this third line is remarkable for not being disturbed in any way.

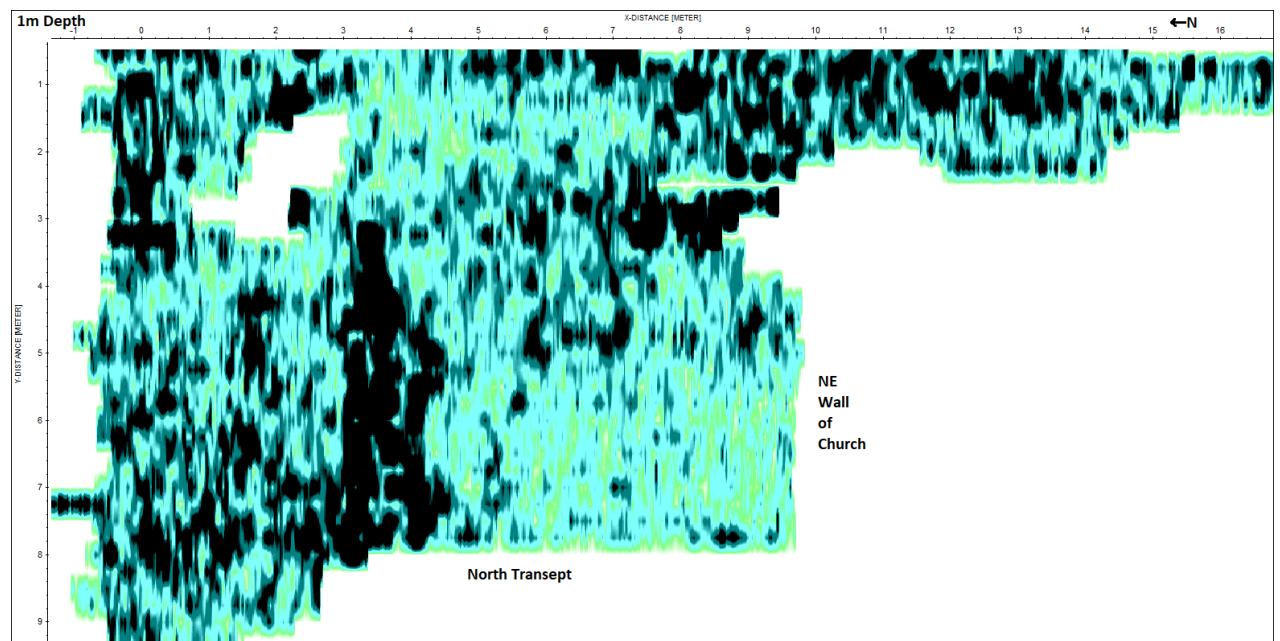
### Time Slice at 80cm Depth (20ns)



*Figure 35: Time Slice extracted at 80cm Depth (400MHz, Area 2).*

By 80cm depth the grave in the corner and most of the shallow wall have disappeared to be replaced by a new perimeter. The overall appearance of the northern and eastern boundaries is closer in appearance to the 250MHz data. The area to the North of the main features is full of strong signals but there is no discernible interpretable pattern.

### Time Slice at 1m Depth (25ns)



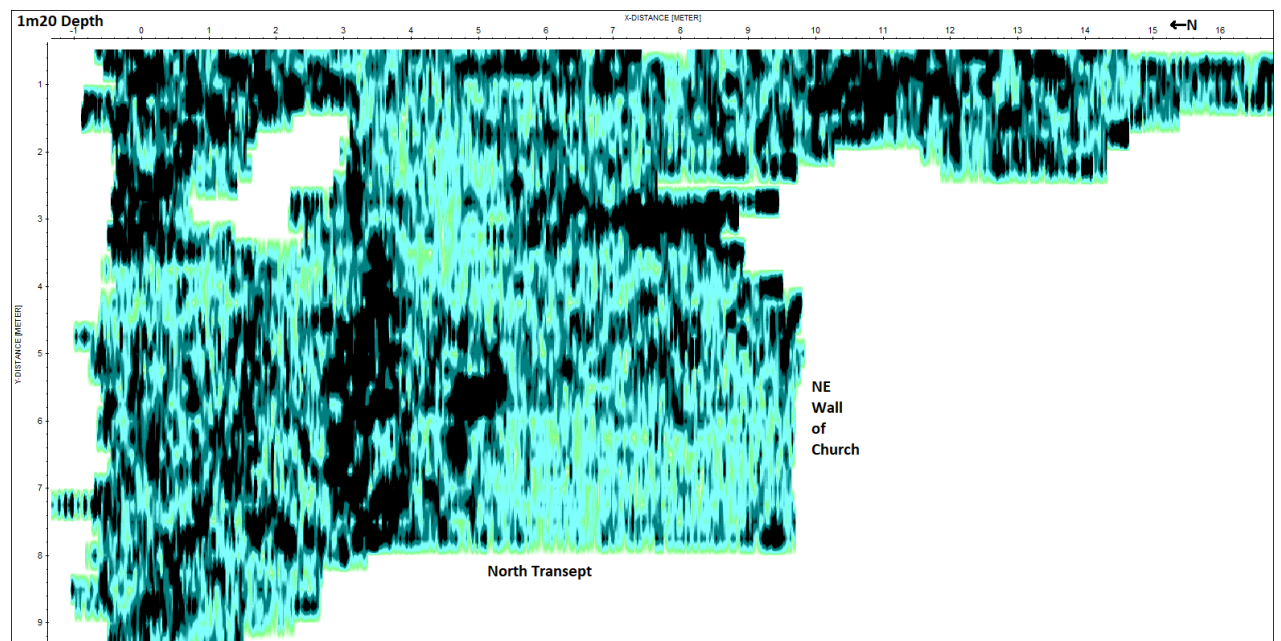
*Figure 36: Time Slice extracted at 1m Depth (400MHz, Area 2).*

By 1m depth, the evidence is similar to that of the 250MHz survey of the 95cm time slice (Figures 23 and 36). The eastern boundary is as partial but more coherent. The

northern boundary is easier to discern because of the lack of adjacent strong reflectors.

At the eastern end of the principal area of interest and approximately in the middle of the eastern boundary there is a faint trapezium shaped outline. The size is approximately 2m length by 1.1m width which could potentially represent the perimeter of an adult grave. It is not possible to confirm or reject this proposition from the vertical section. All of the reflectors are small and only one found to be hyperbolic in shape (implying a smooth, undamaged surface).

### Time Slice at 1.2m Depth (30ns)



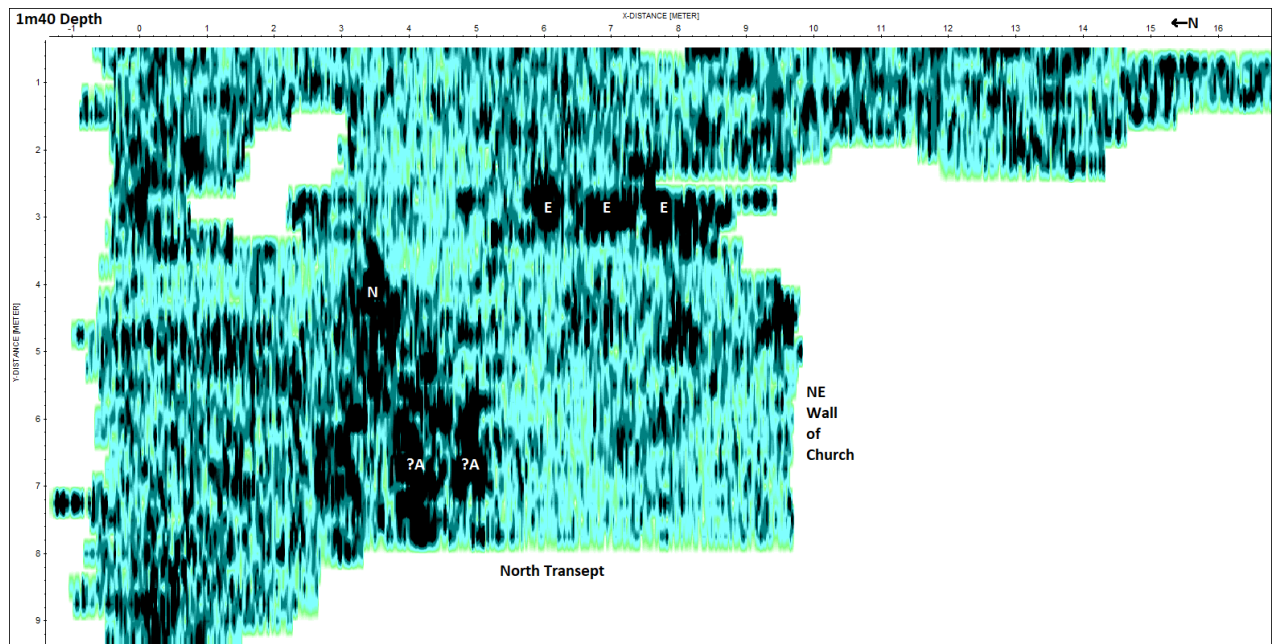
*Figure 37: Time Slice extracted at 1.2m Depth (400MHz, Area 2).*

The speckled effect of this time slice is due to external interference and is therefore not of significance for the purpose of this analysis. The northern boundary is consistent with the previous time slice and also with the 250MHz data (cf Figures 37 and 25). The eastern boundary is slightly more extensive which is also consistent with the 250MHz data. Directly to the South of the northern boundary there is a patch of strong signals of indeterminate shape. These are real signals at depth. The eastern end which is roughly rectangular relates to a large hyperbolic return. The lower, tail-like part relates to a distinctive series of 3 smaller hyperbolas, similar to the grouping of signals in survey line 18, Figure 31. It is not possible to tell what these represent beyond saying that they are likely to be archaeological remains in situ. Full hyperbolas normally represent undamaged material.

### Time Slice at 1.4m Depth (35ns)

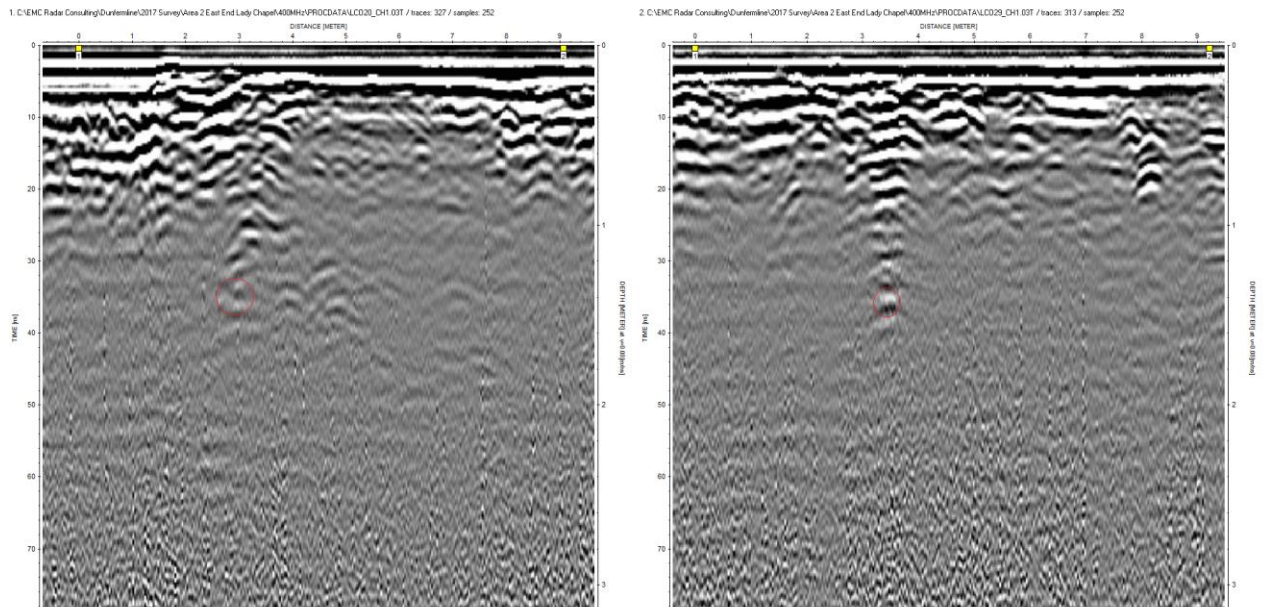
The speckling on this time slice can safely be ignored as it is interference and not reflections from the subsurface (Figure 38). The line of anomalies marked E is the formerly observed eastern boundary, presumably to the former Lady Chapel. The identification of these strong signals with masonry is probable because the feature becomes more extensive with depth as would be expected for the partial remains of a

structure.



*Figure 38: Time Slice extracted at 1.4m Depth (400MHz, Area 2).*

The feature marked N lies along the line of the northern boundary as can be seen in survey line 29 (Figure 39, rhs). From the 2-d data, this may not be the wall itself although it is associated with it. The feature has been degraded at some point in the past from the truncated nature of the signals.



*Figure 39: Survey lines 20 (lhs) and 29 (rhs) [400MHz, Area 2]*

By contrast, the areas marked “?A” are relatively undamaged. The 2-dimensional data shows mostly clear hyperbolas in groups. Although it is not certain what these are it is possible that they relate to either the interior or exterior of one or more graves. In this respect the time slice is very similar to the data from the 250MHz survey (cf

Figure 27. The groups of hyperbolas can be observed in survey lines 18 (Figure 31) and 21 (Figure 34).

The dark area directly to the North of the possible grave evidence is difficult to interpret. In the vertical dimension, it is related to other construction materials but the signals are typically so small and so truncated that it is not possible to interpret them (e.g. survey line 20, Figure 39).

### **Below 1.4m Depth**

From the 2-dimensional data, there are real signals potentially as low as 50ns although these are few and very faint. It is impossible to examine these in time slice a) because of the interference (cf Figure 39) and b) because the soil is not entirely suited to GPR survey and there is a lot of ringing lower down in the data. These two effects combine to obscure the real features below 1.4m. It should be noted that, although the soil is not entirely suited to GPR survey, this is insufficient to prevent the survey being useful and there is a stark contrast, for example, between the quality of the results in Area 2 in comparison with Area 1. This is likely to be due to the way in which the floor of the current church has been constructed.

### **Area 3 - The West End of the Lady Chapel outside the current Abbey Church**

This survey area lies outside the current Abbey Church, to the NW of the main entrance. Two parallel survey reference lines were laid out along an East/West orientation, aligned with the North side of the Abbey. Line 2 was placed so as to pass directly in front of the buttresses, at 0.83m from the North wall of the church, with line 1 at a distance of 7.2m from line 2. Markers 1 and 2 on the data indicate the positions of the survey reference lines.

Although Area 3 is not as close to the Vestry as Area 2, the signals from the Abbey's fire alarm system have impacted on the GPR data. They are visible as thin columns of signal, indicating a different frequency from those deployed by the radar. This does not obscure larger targets in the GPR data but does result in a speckling effect in both the 2-dimensional data and the extracted time slices. The resulting interference has had an unequal effect on different survey lines.

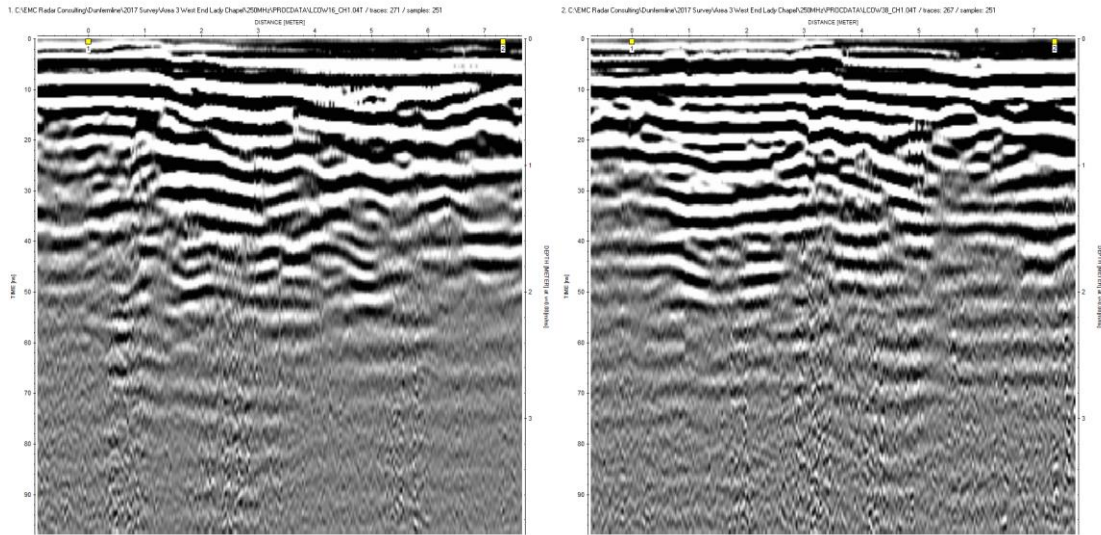
### **2-Dimensional Data: 250MHz**

The 2-dimensional data has been processed by:

- Correction for Tzero;
- Constant background removal;
- Addition of gain to compensate for diminishing signal strength with depth;
- Application of Bandpass Butterworth to remove any spurious signals.

All 2-dimensional data is presented from North to South (left to right). The 2-dimensional data from Area 3 is different from that of Areas 1 and 2. Although there is evidence that the soil is lossy i.e. not entirely suited to GPR, the depth penetrated by the radar is generally greater than in Area 1 but not so great as Area 2.

The subsurface, especially the near subsurface is considerably more crowded than that of the other two areas. This is probably an indication of its use as a burial ground during the period between the destruction of the East end of the mediaeval church and the construction of the current church. The near surface is dominated by black and white banding which may also be a reflection of the creation or repair of the current ground surface closest to the church. Lines 16 and 38 (Figure 40) are reasonably typical.



*Figure 40: Survey lines 16(lhs) and 38 (rhs) [250MHz, Area 3].*

### 3-Dimensional Data: 250MHz

The full set of survey lines has been incorporated into a 3-dimensional data set on the basis of their respective positions along survey reference line 1. Time slices have been extracted from the data set on the basis of changes in patterning.

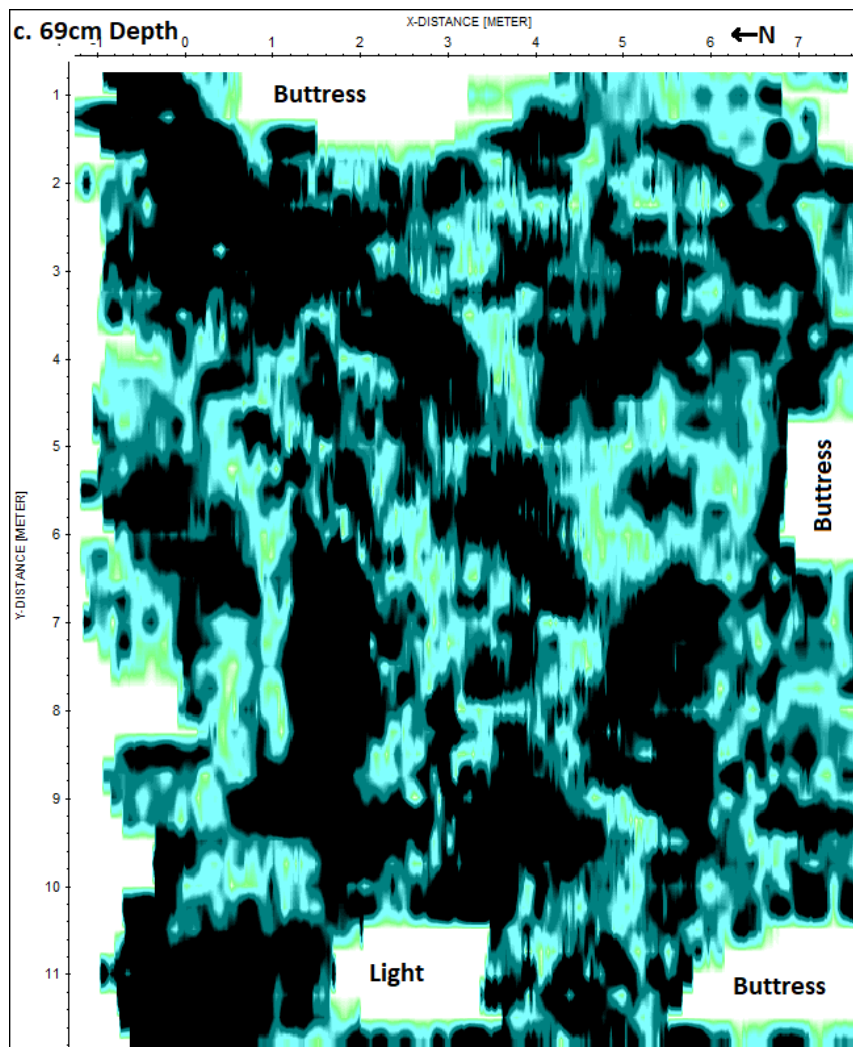
The 2-d data selected for illustration can be located as follows.

| Survey Line | Y position on Time Slices |
|-------------|---------------------------|
| 16          | 4m                        |
| 38          | 9.25m                     |

### Time Slice at 69cm Depth (c. 17ns)

This time slice essentially illustrates the near random pattern of the shallow subsurface while also suggesting that there may be graves present since there are 2, possibly 3 quasi-rectangular outlines visible at this depth (Figure 41). There are two parallel to each other in the lower (western) half of the image and the beginnings of a squared off feature in the NW corner. The patterning is typical of a grave which is retaining either an air pocket, or more likely in this instance, excess moisture. The orientation, size and shape are all typical. From the depth, these will not be mediaeval burials. They illustrate that this area has been used for burial since that time.

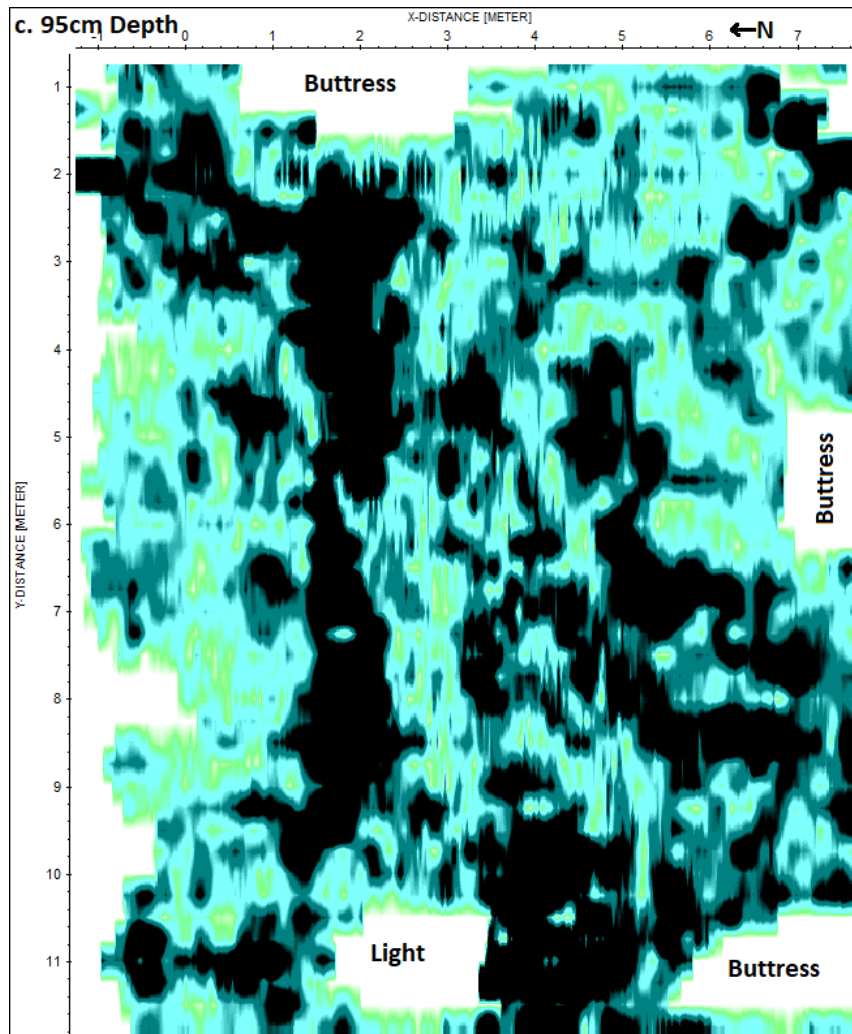




*Figure 41: Time Slice extracted at c. 69cm Depth (250MHz, Area 3).*

### **Time Slice at 95cm Depth (c. 23.8ns)**

By this depth a possible East/West linear feature has developed running from the buttress on the West wall of the North Transept down towards the position of the light on the current ground surface. There is no obvious wall at right angles. It is not clear whether this relates to two further graves or to a wall. The 2-dimensional evidence is not clear and could be interpreted either way. Figure 40 shows two of the cross sections across this feature. All that can be said at this depth is that both contain large areas of signal. There is no sign of the vertical dimensions of a wall although there is some (presumably) archaeological material lying directly below.



*Figure 42: Time Slice extracted at c. 95cm Depth (250MHz, Area 3).*

**Time Slice at 1.13m Depth (c. 28ns)**

This time slice is similar in patterning to the previous one with the exception of feature A, to the South of the area below the light (Figure 43). From its shape, the patterning could potentially represent a constructed feature such as a pillar base. The vertical view confirms the size of the feature in cross section but it does not assist in determining whether this is construction material or another material. The relevant signal block is outlined in red in Figure 44.

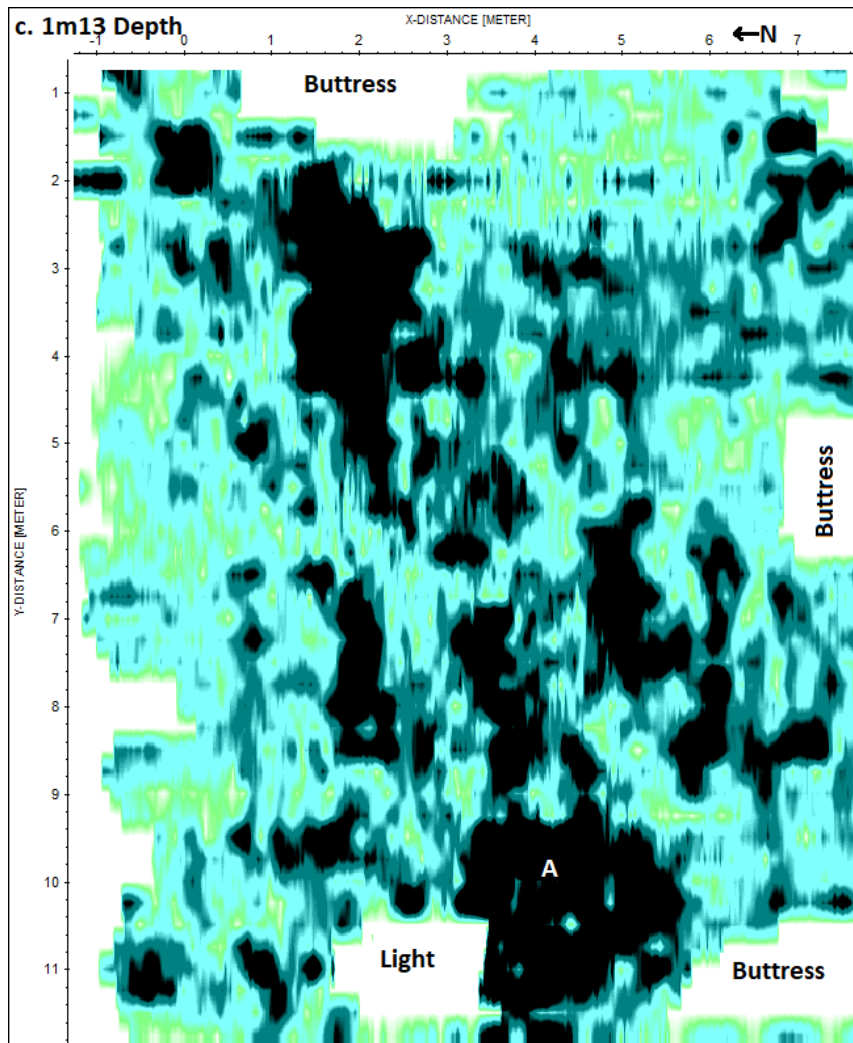


Figure 43: Time Slice extracted at c. 1.13m Depth (250MHz, Area 3).

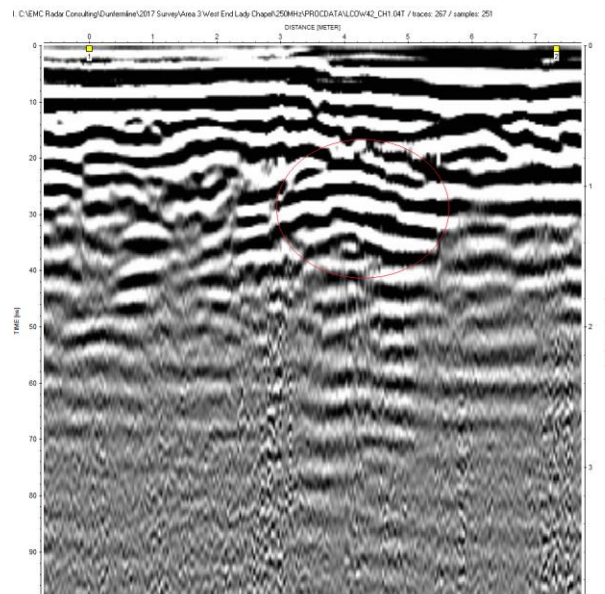
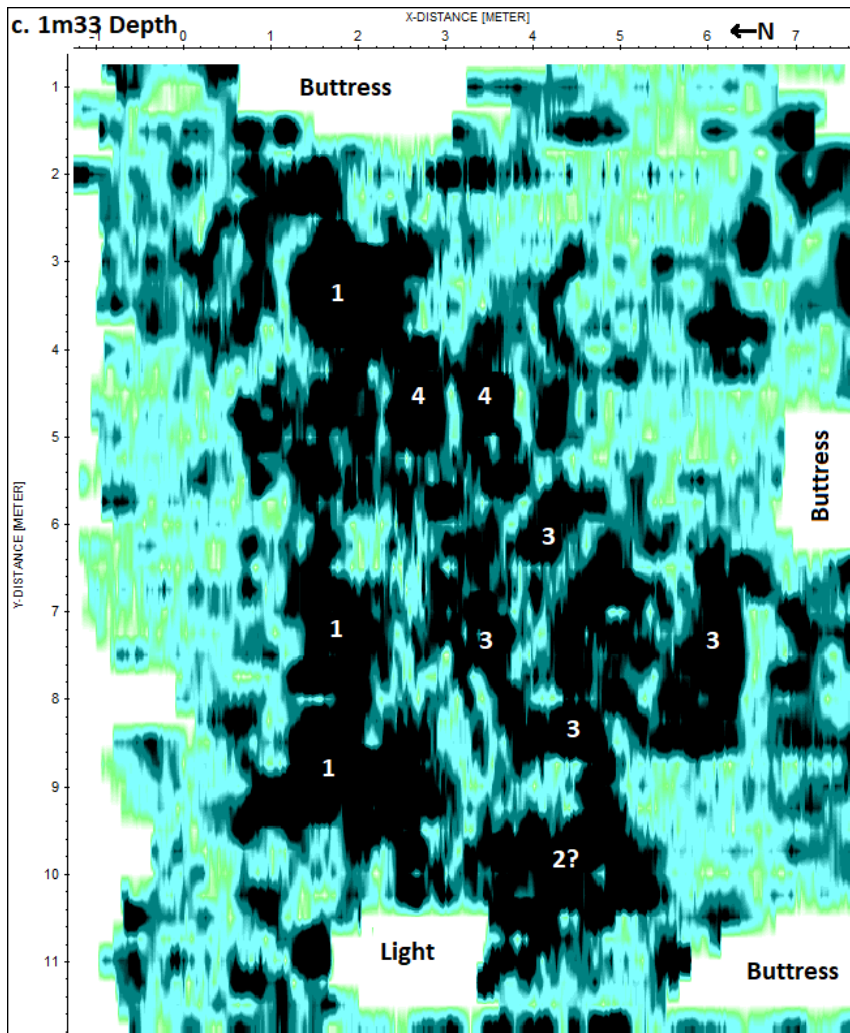


Figure 44: Survey line 42 showing a cross section of feature A from Figure 43 (250MHz, Area 3).

### Time Slice at 1.33m Depth (c. 33ns)

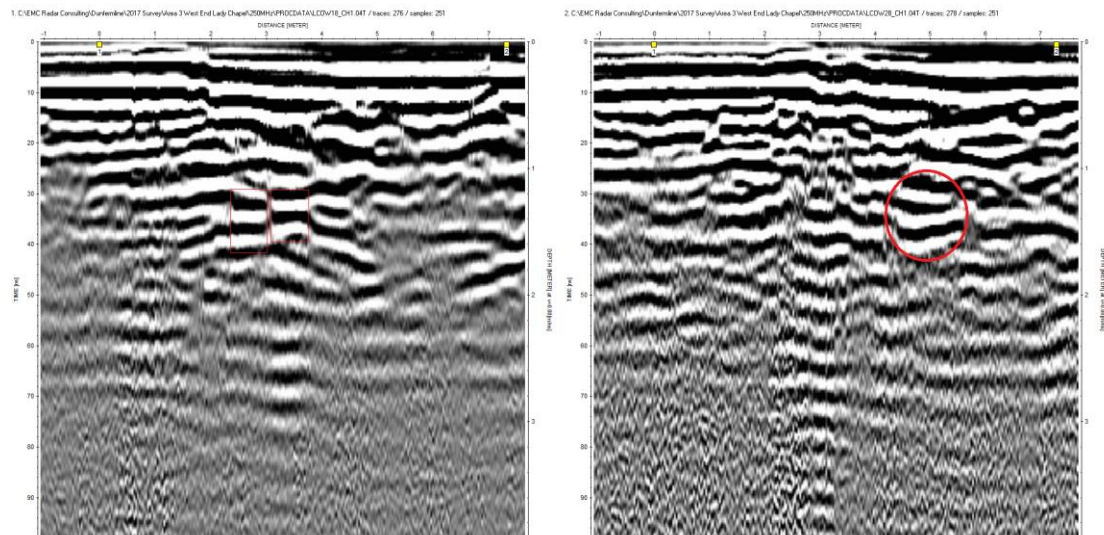
All of the time slices in this data set are relatively poorly defined and it is difficult to find meaningful patterning in them. This one is no exception. There is an approximate East/West line running from the buttness at the East end of the survey area (the buttness on the West wall of the North Transept) towards the unsurveyed area occupied by a light at the surface. This is marked 1 in Figure 45.



*Figure 45: Time Slice extracted at c. 1.33m Depth (250MHz, Area 3).*

Viewed in the 2-d data, line 1 is composed of large squared off blocks of signal, closely surrounded by other material. An example has been ringed in red in survey line 28 (Figure 46). It is possible that this is masonry of some sort, but it does not resemble the wall evidence from Area 2, for example. On the basis of this data set, another material cannot be ruled out. Within line 28, it is noticeable that there is more than one anomalous material present, if only from the presence of echo effects directly to the North of this particular feature, raising the possibility of metal being present (Figure 46). It also seems likely that this entire area has been disturbed. This disturbance could prove challenging to the low frequency antenna which requires objects to be a wavelength apart if they are to be separately detected. On the basis of the calibrated velocity, one wavelength is c. 32cm.

There appears to be a possible right-angled corner approximately 1m before the line reaches the light but there is no continuation of the line from this point. The only potential candidate for a North/South line connecting feature 1 to the present church is the irregularly shaped feature marked 2. This is composed of very similar signals to feature 1.



*Figure 46: Survey lines 18 (lhs) and 28 (rhs) [250MHz, Area 3].*

In the angle between features 1 and 2 there is a large group of strong signals which could potentially represent the interior of a rectangular feature measuring approximately 2 to 3m long by 3 to 4m wide, some components of which have been marked 3 in Figure 45. It is far from certain that this is a single feature. Its outer edges are, however, suggestive of a rectangular feature. If this is correct then the strong signals within would be likely to represent irregularly shaped air gaps. The 2-d data does not assist in interpretation, the strong signals in this area correspond to irregular lengths of layering and it is not possible to infer the material or materials involved.

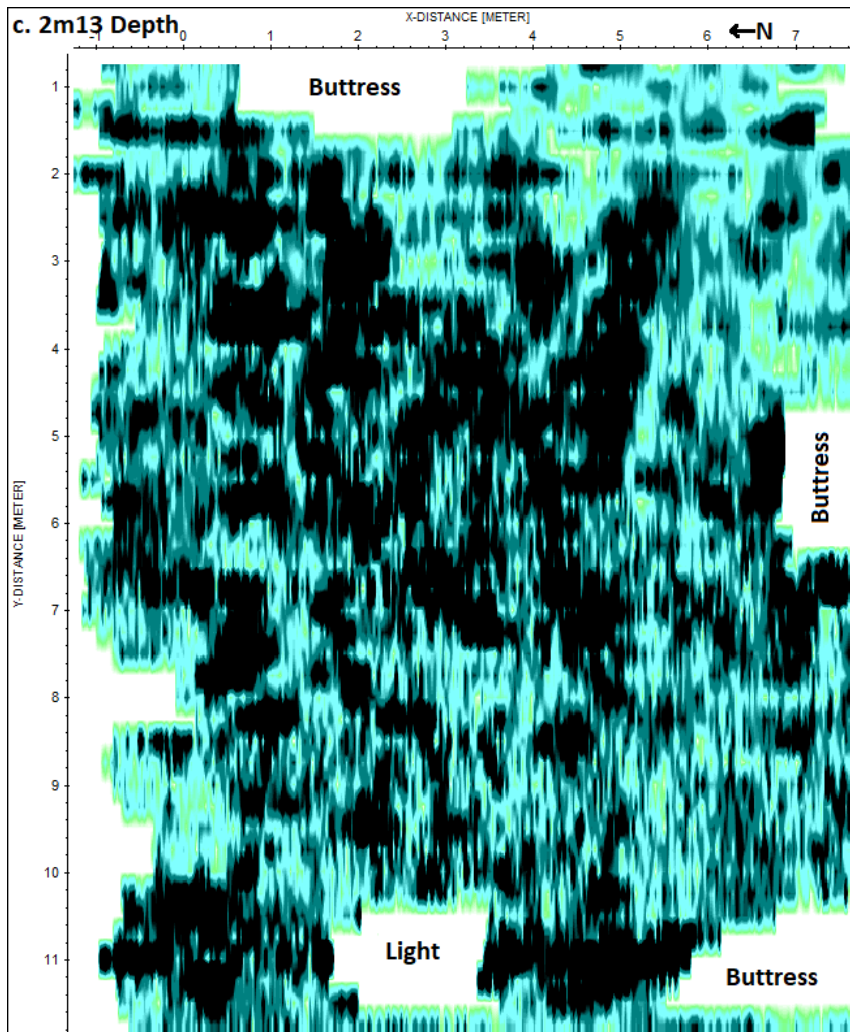
In addition to the foregoing, there are two roughly rectangular signals, further to the East, marked 4 in Figure 45. These correspond to two series of columns of signals of those marked in survey line 18, Figure 46. Again, they are closely surrounded by other material which makes their identification problematic.

The main conclusion from this time slice is that a higher frequency, shorter wavelength antenna is required to resolve some of the features. The dense packing of material makes it difficult to understand the patterning in any meaningful way.

### **Below 1.33m Depth**

Although there are visibly many deeper signals in the 2-dimensional data, it is not possible to derive meaningful patterning from them in time slice. This is in part due to the prevalence of ringing from the surface and near surface but also due to the density and probably the condition of the extant remains. Figure 47, the time slice at 2.13m is typical. There is a new line passing through the area of the light and

apparently heading towards the SW buttress. It is not a coherent structure and since the installation of the lighting has disturbed this area, it is difficult to be sure what else has been disturbed in the process. The 2-dimensional data suggests that this feature is an echo effect from above.



*Figure 47: Time Slice at c. 2.13m Depth (250MHz, Area 3).*

The effects become worse with depth due to the noise generated from the Abbey's wi-fi. This is already visible in Figure 47 but becomes more prevalent with increasing depth.

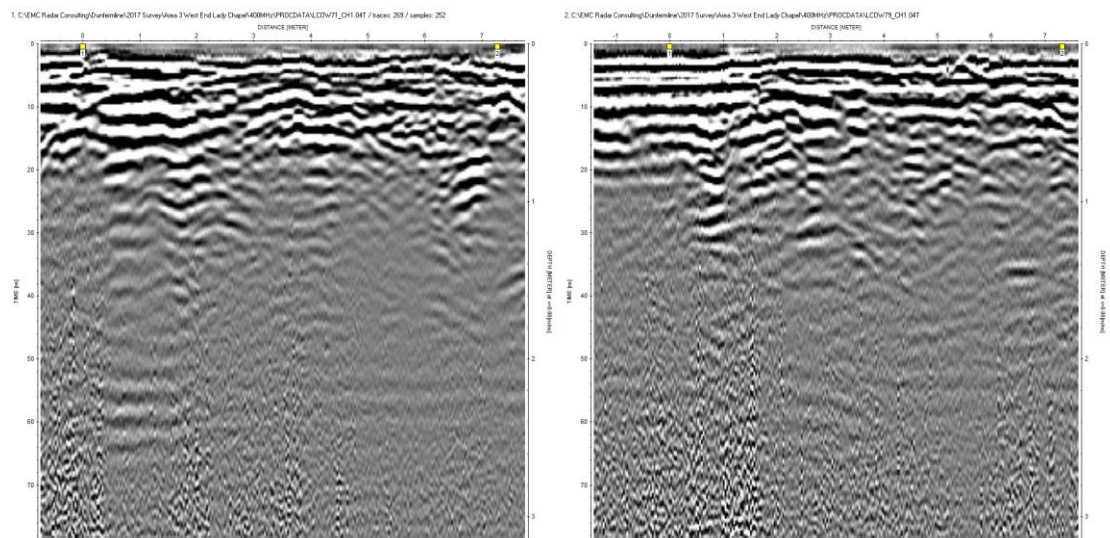
### **2-Dimensional Data: 400MHz**

The same survey reference lines were used for the 400MHz as for the 250MHz survey. The 2-dimensional data has been processed by:

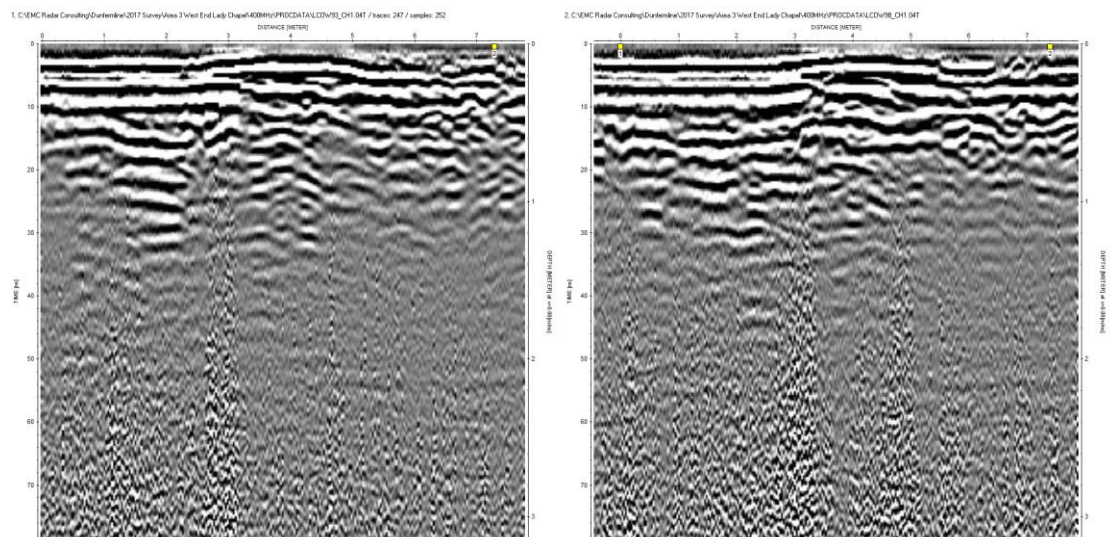
- Sender/Receiver Correction;
- Correction for Tzero;
- Constant background removal;
- Addition of gain to compensate for diminishing signal strength with depth;
- Application of Bandpass Butterworth to remove any spurious signals.

All 2-dimensional data is presented from North to South (left to right) with markers 1 and 2 on the data indicating the position of the survey reference lines. The 2-dimensional data from Area 3 is different from that of Areas 1 and 2. Although there is evidence that the soil is lossy i.e. not entirely suited to GPR, the depth penetrated by the radar is generally greater than in Area 1 but not so great as Area 2. As expected the target definition is a considerable improvement over the that of the 250MHz survey but the depth of penetration is correspondingly less.

Survey lines 71 and 79 illustrate the general pattern of subsurface material. As might be expected from the results of the 250MHz survey, there are large blocks of signal overlying generally disturbed ground and large areas of layered material not only in the immediate subsurface but also lower down. Line 71 also shows a clear echo effect from the buried block close to the surface. The upper edge of the original material occurs at c. 8ns. The echo occurs at c. 52ns.



*Figure 48: Survey lines 71 and 79 showing the density and variety of remains in the subsurface (400MHz, Area 3).*



*Figure 49: Survey lines 93 and 98 showing typical areas of layered material from Area 3 (400MHz, Area 3).*

Survey lines 93 and 98 show areas of layered material overlying a high density of other remains, another feature of this survey area.

### 3-Dimensional Data: 400MHz

The full set of survey lines has been incorporated into a 3-dimensional data set on the basis of their respective positions along survey reference line 1. Time slices, essentially horizontal plans, have been extracted from the data set on the basis of changes in patterning at the depths where these changes are observed. East is at the top of each time slice and x = 0 marks the position of survey line 1.

The 2-d data selected for illustration can be located as follows.

| Survey Line | Y position on Time Slices |
|-------------|---------------------------|
| 71          | 2.75m                     |
| 79          | 4.75m                     |
| 93          | 8.25m                     |
| 98          | 9.5m                      |

### Time Slice at c.40cm Depth (c. 10ns)

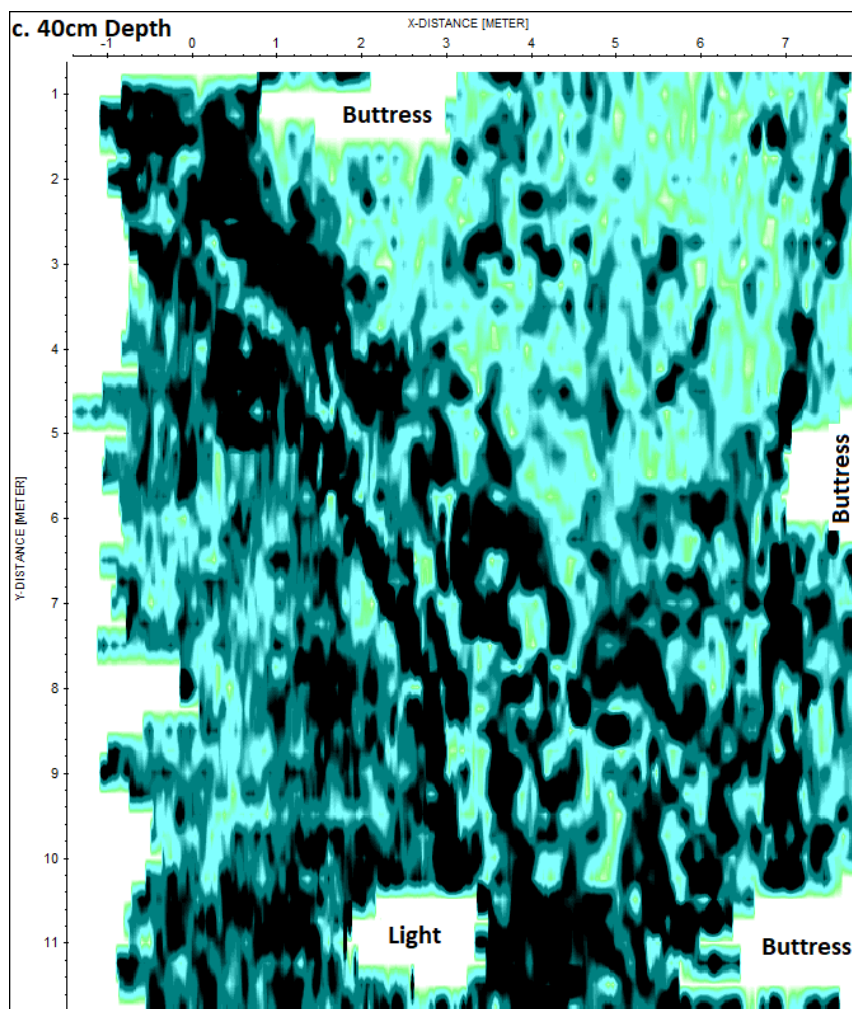


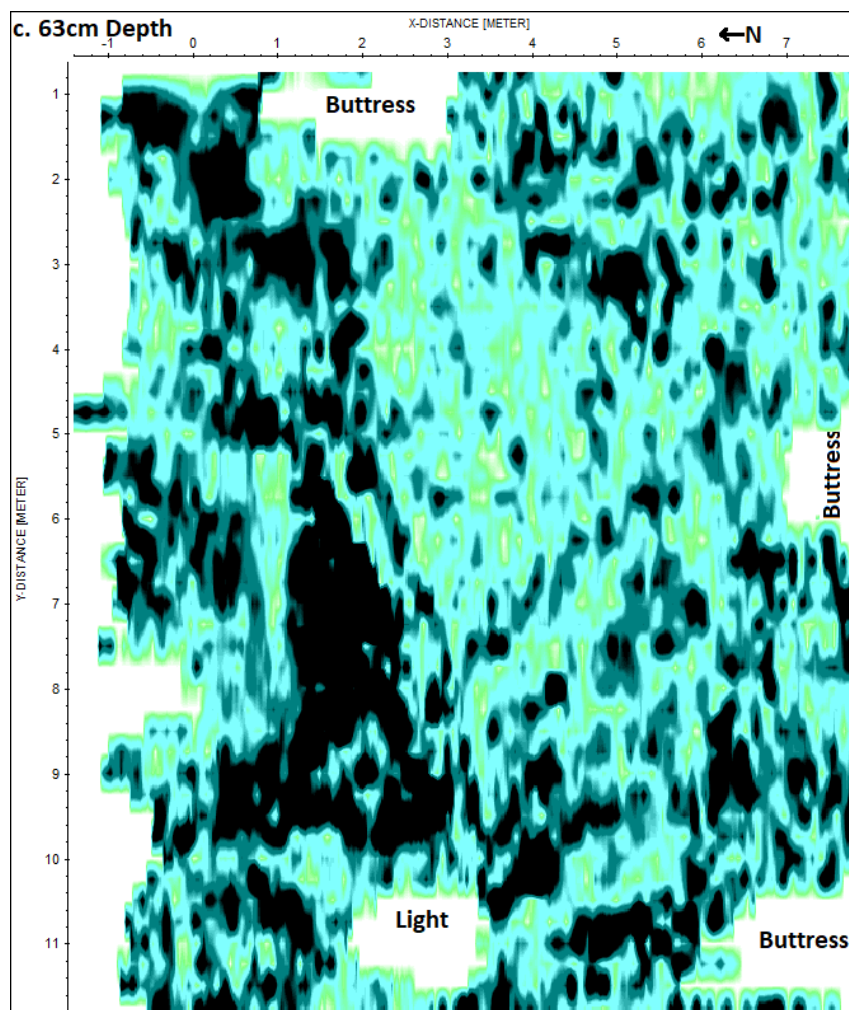
Figure 50: Time Slice extracted at c. 40cm Depth (400MHz, Area 3).



The lighting cable feed becomes visible at c. 4cm depth (not illustrated). The main feature visible at this depth is the path although traces of the lighting cable trench remain but there is also another linear feature lying very close to the church (Figure 50). This is likely to be a modern utility and very unlikely to be of archaeological significance.

### Time Slice at c. 63cm Depth (c. 15.6ns)

This shallow time slice contains two outlines which are suggestive of large graves (Figure 51). The first of these is a tapered area of strong signal lying in an East/West orientation. The shape is broadly reminiscent of air patterning within a large grave. The area covered is approximately 4.8m in length by a maximum breadth of 2.8m. It is not possible to confirm this interpretation through comparison with the 2-d data. The vertical section across this area shows strong black and white banding consistent with layers of material (cf, for example, Figure 49).

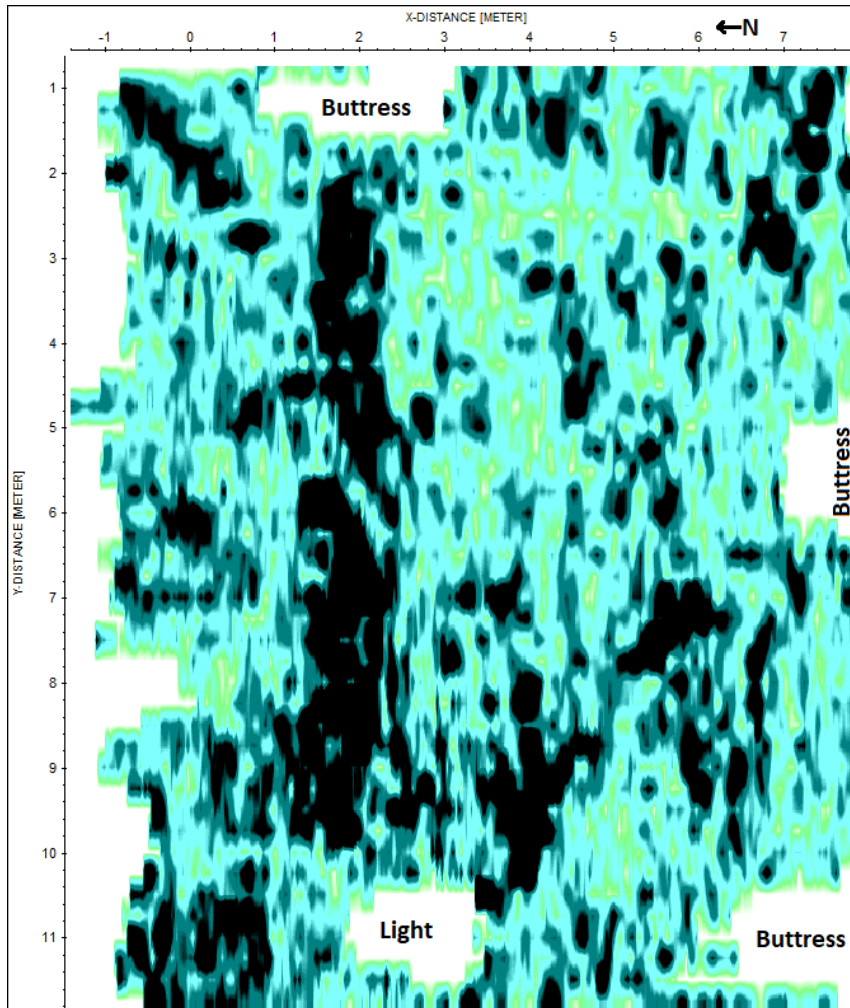


*Figure 51: Time Slice extracted at c. 63cm Depth (400MHz, Area 3).*

Directly to the East of the tapered shape lies the outline of a rectangular feature whose measurements are approximately 3m length by 2m breadth. The 2-dimensional data

shows a series of large blocks potentially consistent with building material of survey line 71, Figure 48.

**Time Slice at c. 78cm Depth (c. 19ns)**

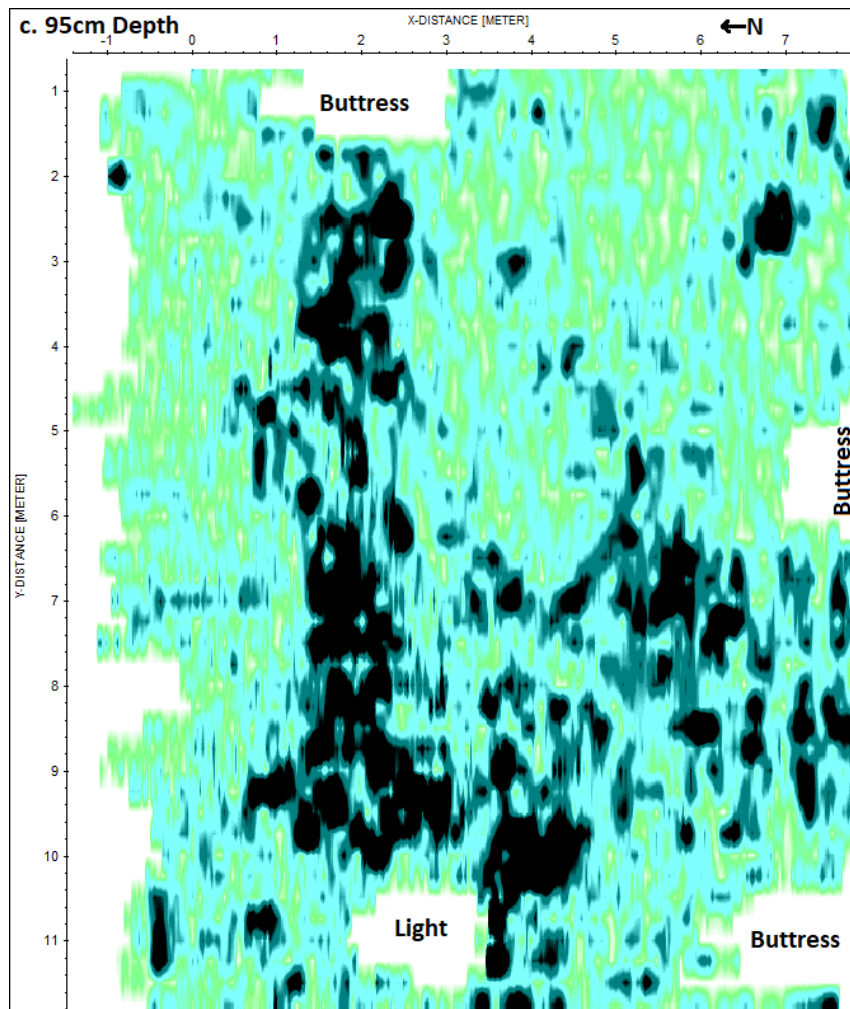


*Figure 52: Time Slice extracted at c. 78cm Depth (400MHz, Area 3).*

This is the first time slice in which the straight line, presumably the northern boundary to the Lady Chapel becomes visible (Figure 52). In addition to this there are a few large patches of anomalous signal. The straight line does appear to be a wall as it shows in the vertical data as a short column and is continuous from one data line to the next. The dark patches are difficult to interpret. They could be broken masonry or oddly shaped voids. The 2-d data shows these as short irregular layer signals.

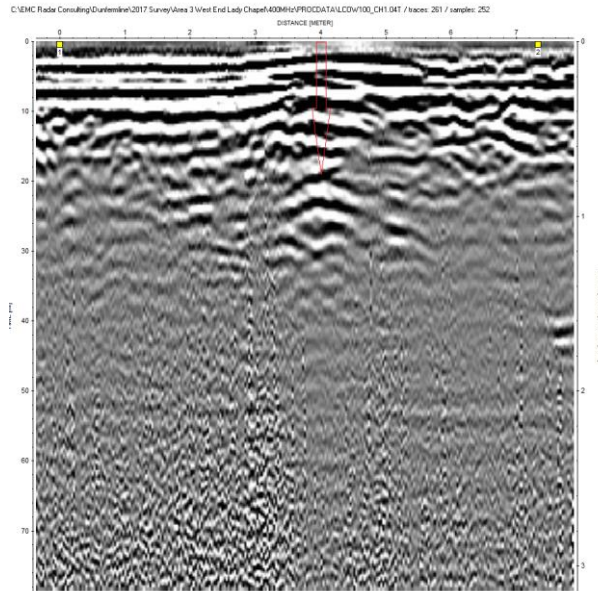
In the NW corner there is the eastern half of a rectangular feature which is a potential grave. At this depth the vertical section shows a layer directly above two short columns of signal.

## Time Slice at c. 95cm Depth (c. 23.8ns)

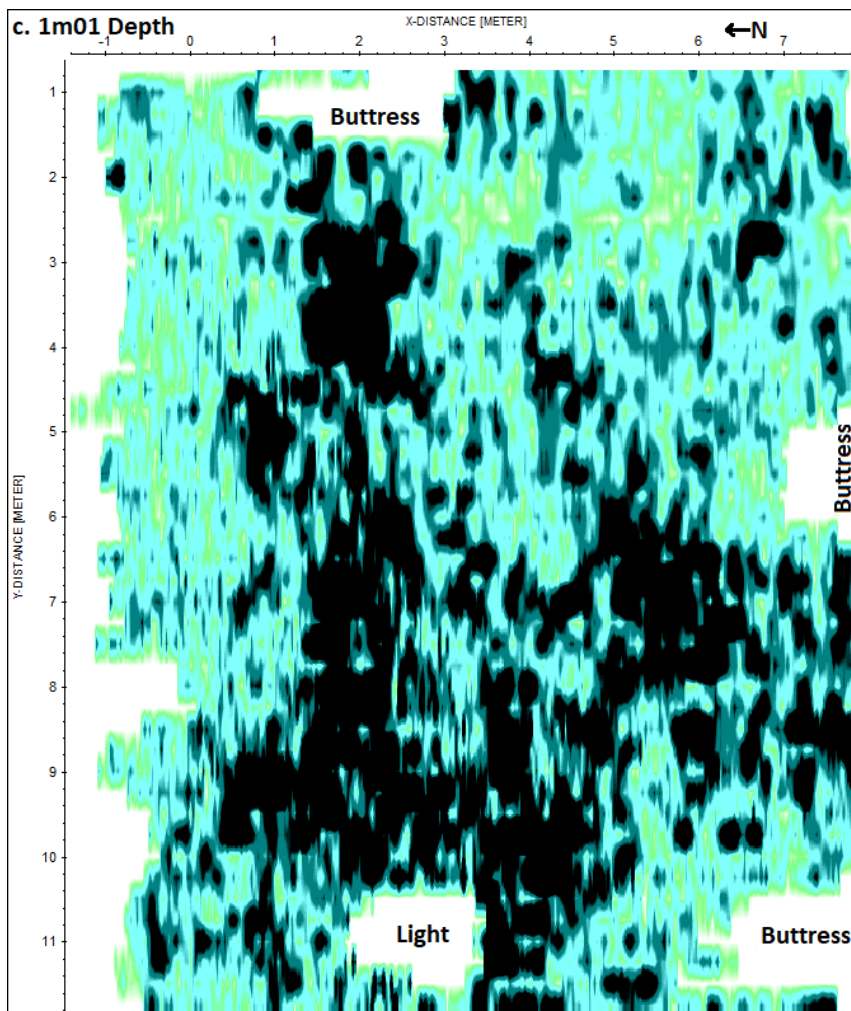


*Figure 53: Time Slice extracted at 95cm Depth.*

The outer wall of the Lady Chapel shows very clearly at this depth, including a right angled bend forming part of the western section (Figure 53). The square area of dark signal to the South of the western section of wall and adjacent to the blank space left around the light is construction in situ. It forms a small arch directly above two other objects. The hyperbolas suggest undamaged material in situ (Figure 54).



*Figure 54: Survey line 100 showing the arch above other material in situ.*  
**Time Slice at c. 1.01m Depth (c. 25.3ns)**



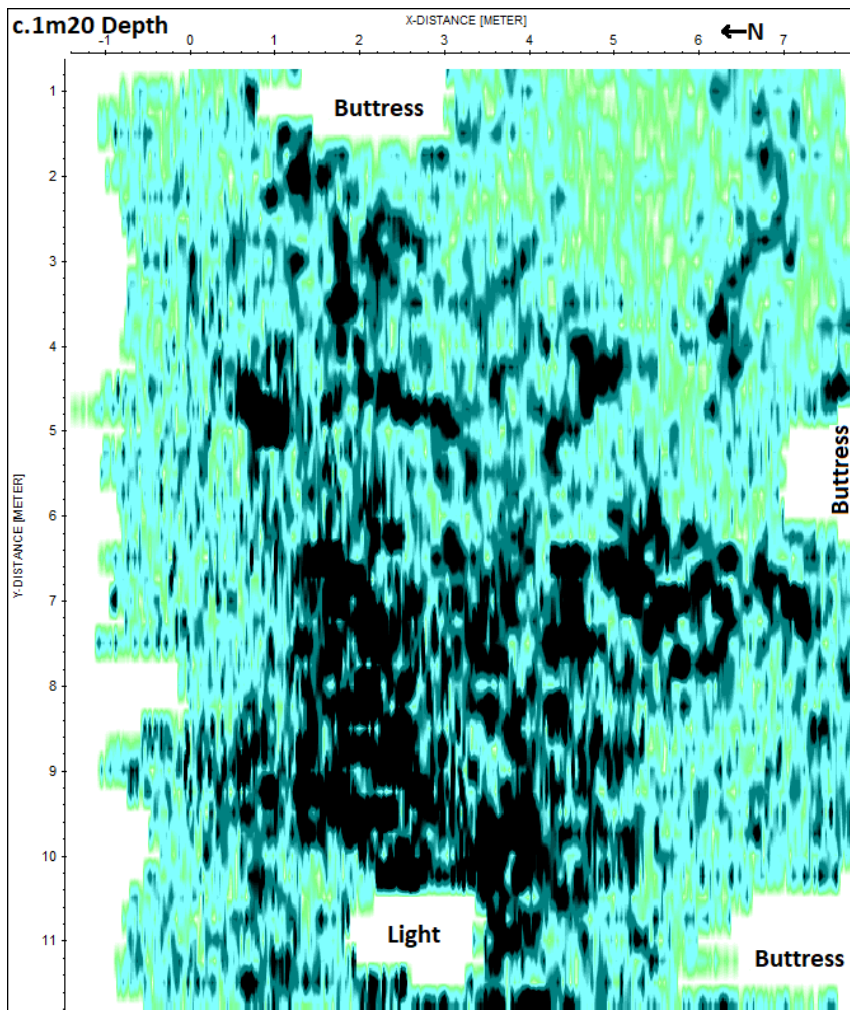
*Figure 55: Time Slice extracted at 1.01m Depth.*

The northern and western edges of the boundary wall of the Lady Chapel are clearly visible at this depth. In addition, there appears to be a North/South dog-leg towards the western end of the survey area. The dog-leg appears to be made up of construction material, but the structure is not coherent and the overall impression is of damaged and disturbed structural material.

The dark areas inside the boundary wall cannot be easily interpreted as neither in time slice nor in section is the patterning clear. The overall impression is of heavily disturbed material.

### Time Slice at c. 1.2m Depth (30ns)

At this depth the western end of the boundary wall is still visible. The remaining strong signals are distributed across the area without obvious meaningful patterning. It is likely that this is also a reflection of disturbance within the ground at this level. The speckled pattern around the main signals is interference from the Abbey's wi-fi system.



*Figure 56: Time Slice extracted at 1.2m Depth.*

### Below 1.2m Depth

Although there are real signals below this level, there is no trace of patterning which

could be related either to structural material or to graves. There are a number of very small squares and/or rectangles which occur within the time slices which could potentially indicate a feature of interest but the size of these is small relative to the size of an adult burial and the material around them does not resemble a recognisable structure. No further time slices have been extracted.

## **Conclusions & Recommendations**

### ***Area 1***

The results of the two surveys in this area are enigmatic. The 2-dimensional data generated using the 250MHz antenna did not appear to contain evidence of any substantial graves. In the time slices, however, there were significantly shaped areas of sufficient dimension to be considered graves, in some cases, potentially large graves, features 1 to 7 inclusive (Figure 4). It may be significant that some of these features lie side by side in a coherent North/South line although this does not necessarily correlate with the position of the Lady Chapel.

The main problem with this interpretation is the relative proximity of these features to the surface which calls the potential dating into account but there is also reason to doubt the interpretation of at least some of these features as graves. There is a wide variation in evidence between the features themselves which could be the result of differences in construction or in the impact of later destructive processes. It could also mean that at least some of them have been misinterpreted. There may also have been a potential impact from both the construction of the modern church itself and from subsequent alterations such as the installation of the organ, for example. There is also not complete agreement in the evidence of the 2-d and 3-d data sets and also discrepancies with the data from the 400MHz survey.

In general, the 400MHz data correlates well with the 250MHz data but the notable exceptions are the absence of certain potential graves, notably features 1, 2 and 5 (cf Figures 4, 14 and 16). Features 3, 4, 6 and 7 remain good candidates for graves although all of them lie relatively close to the modern floor.

The 400MHz survey has also shown up a number of short parallel lines which may be related to the construction of the former Abbey Church.

### ***Area 1 Recommendations***

The floor plan in the time slices needs to be compared with historical information to see if either the dimensions can be said to match known missing graves or whether alternative explanations for features 1 to 7 inclusive can be found (Figures 4, 14 and 16). The GPR results should also be discussed with the current custodians of the church to eliminate the possibility that these are existing known features relating to the more modern church and, in particular, the installation of the organ. The use of relatively low frequencies makes it difficult to determine the internal structure of these various features and it may be difficult to reconcile the GPR findings with information currently available.

Although the subsurface appeared to be dry, the soil beneath this area was surprisingly lossy in comparison with the data collected in 2016 from beneath the North Transept and the Vestry. This is probably related to the construction of the current church and the way in which the earlier site was prepared in advance of construction. It would be interesting to discover whether there are valid reasons given in historical accounts of the construction which could explain this. If practical, it may also be helpful to obtain a small soil sample to determine its electromagnetic properties.

Area 1 does suggest that the layout of the former East end of the Abbey relative to the current church is critical in understanding the GPR evidence. A plan of the current church is essential to relate the evidence from the various time slices in the different areas. This can be done by inserting time slices into the drawing. It is anticipated that this will enhance the overall results of the surveys and potentially increase understanding and interpretation of the results.

### *Area 2*

The primary result of surveying this area is the discovery of two walls which potentially define the exterior of the Lady Chapel. Both were originally substantial and neither remains complete. The current church seems to have been placed in a deliberate manner over the remains of the former East end of the Abbey (cf Figure 35). There appears to be some changes in the line and extent of the boundary wall visible in the 400MHz data at a shallow depth which is not visible in the 250MHz data, including a dog-leg in the northern side (Figure 32). However, once the depth of what appears to be the original wall is reached, the two data sets agree.

The boundary wall and other areas of strong signals all provide evidence of destruction through observed irregularities in the shape of the various features. There also appears to be a spread of structural material notably towards the North of the boundary wall although this may simply be damaged structures in situ (Figure 30).

There are two false eastern boundary lines visible on various time slices (e.g. Figure 25) which appear to have formed from features containing excess moisture. However, it may be worth paying some attention to these as they could indicate the replacement of an earlier structure with backfilled earth. Figure 29 is also relevant here since it shows an alteration in the boundaries or possibly an earlier structure and is not the result of excess moisture being retained.

There are a number of survey lines which show groups of complete hyperbolas. This implies the existence of a structure or group of smaller structures, potentially shaped and presumably undamaged. This, taken alongside the sparse evidence for potential air gaps at lower level suggest that there are mediaeval graves within this area (see Figure 27, 28, 30, 37 and 38). Although the evidence for air gaps is minimal, this is potentially consistent with backfill during the construction of the current church and also weather effects on the area post the destruction of the East end of the former Abbey.

There is a large grave at a shallow level within the angle of the NE wall of the church and the eastern wall of the North Transept (Figures 32 and 33). It is not possible to

date this using GPR, beyond the observation that it appears to pre-date the construction of the current Abbey church. The position of this grave implies that it may be worthwhile surveying the eastern edge of the North Transept if this is possible.

Overall the depths at which the archaeological remains appear are relatively shallow. Although this would be expected given that the area has not been built up in the same manner as the church, it does throw into question the dating of some of the observed remains. GPR cannot be used to date archaeological remains except in a relative sense based on their relative positions.

As in the previous survey, the soil was not wholly suited to GPR, but Area 2 was slightly more suitable than Area 1. In spite of the observed damage, Area 2 also appeared to be potentially less re-worked than Area 1.

### *Area 2 Recommendations*

The time slices showing the position of the external walls of the former Lady Chapel should be compared with a plan of the current Church (assuming that one can be obtained) in order to define the relationship of the two buildings, confirm if possible the boundaries including phasing, if applicable, and to place the potential graves within the context of the former Abbey Church.

Based on the comparative qualities of the GPR data in Areas 1 and 2, it is worth giving consideration to how the subsurface inside the church was constructed, should any relevant records exist.

The possibility of surveying the eastern edge of the North Transept (in the area of the present day shop) should be discussed in case this is a possibility.

### *Area 3*

This area was characterised by high levels of disturbance. The result of this was a high density and relative incoherence of archaeological remains to the extent that the 250MHz antenna in particular struggled with target definition. The destruction appears to extend down into the potential layers of mediaeval burial (Figure 45). There is also evidence of utilities in the area so that there is also recent intrusive development present. There was evidence of post depositional destruction in Area 2 but not to the same extent.

There appear to be shallow graves present in the area: see Figures 41 and 51. As found in Area 2, it appears that the current church has been aligned with the former Lady Chapel. The 250MHz data suggested and the 400MHz data confirmed that the northern boundary of the former Lady Chapel wall aligns with a buttress of the current church wall. See Figures 52 and 53.

A single possible pillar base was found (figure 43).  
Fig 43 – pillar base?



The target definition of the 400MHz antenna was able to resolve more features and parts of features than the lower frequency antenna. However, the density of extant remains still posed a problem in interpretation of the time slices in general. Even using the 400MHz antenna did not entirely resolve the western boundary of the Lady Chapel cf figure 55.

### ***Area 3 Recommendations***

The next step required is to acquire a plan of the current church into which the time slices showing principal features can be inserted. This would enable the various sets of time slices to be related to one another which might enable interpretation, for example resolving the issues around the location of the Lady Chapel walls.

Since it will not be possible to excavate in this area (so far as is known), historical evidence should be searched for any information concerning pillars or other structures within the Lady Chapel to see if these correlate with the findings of this survey.

### ***General Comments***

As was the result of the 2016 surveys, the 250MHz proved the best target detector for soil and depth penetration but was not always able to resolve targets optimally. It was worthwhile using a second frequency since the 400MHz, even without the additional depth capability proved useful for target definition, particularly in Area 3.

Although there is some uncertainty attaching to the identification of the various graves whose position was detected in this series of surveys, it is likely that a better overall picture of the subsurface can be obtained if the results from each of the areas investigated (Areas 1 to 3 in this report, the Vestry & the North Transept) can be combined. This requires a suitable digital plan of the current church since all of the time slices can be located relative to the church.

If the interpretation is correct, it is possible that some of these graves may have been used for royal burials. However, it is far from certain that they remain intact since the related air gaps are not large enough for internal air reflections to be generated.

### **Acknowledgements**

This report was written, on the basis of the GPR survey, by Erica Carrick Utsi of EMC Radar Consulting working in conjunction with Dr Oliver O'Grady of OJT Heritage. The authors were also responsible for carrying out the GPR survey.

EMC Radar Consulting and OJT Heritage would like to thank Dr Michael Penman for his assistance with the practical aspects of the survey and for dealing with visitors to the Abbey during the survey.

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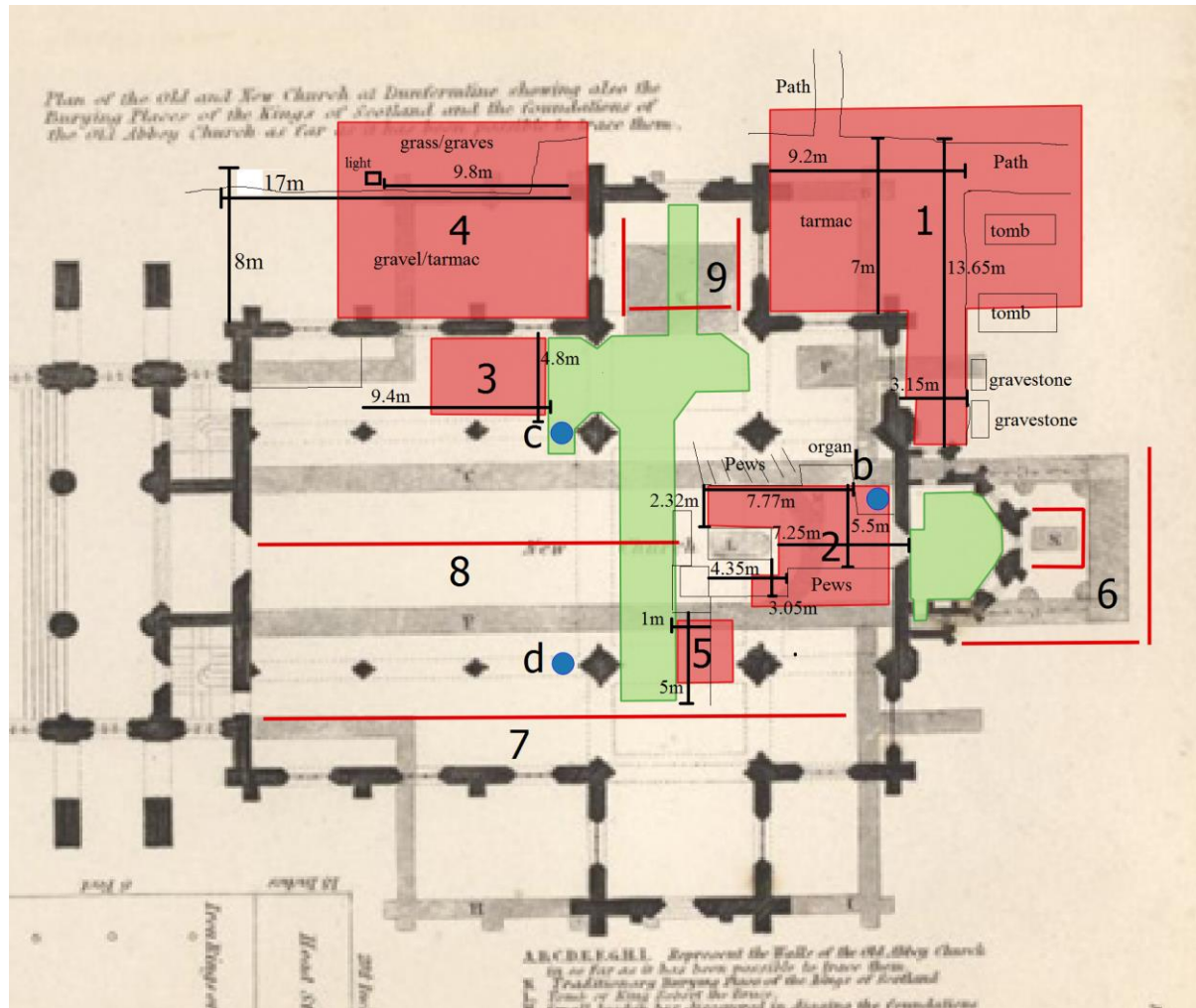
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### **Further Information**

Any queries arising from the content of this report or the GPR survey to which it refers should be addressed in the first instance to Mrs Erica Carrick Utsi, EMC Radar Consulting.

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CB6 3TD  
Tel: 01353 741033  
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### Appendix A: GPR Survey Areas



The areas in green were surveyed in 2016.

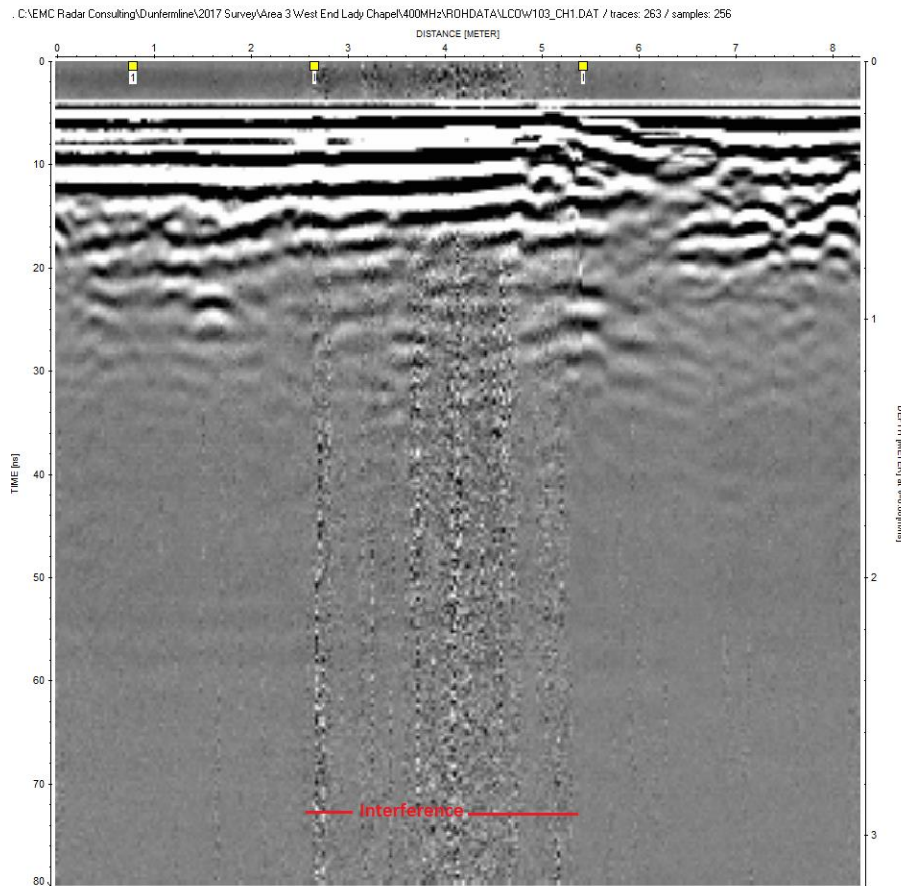
Areas 1, 2 and 4 were surveyed in 2017.

Red area no 2 is Area 1 in this report.

Red area 1 is Area 2 in this report.

Red area 4 is Area 3 in this report.

## Appendix B: Example of external interference on raw GPR data



### **Band of external interference showing on raw GPR data.**

The effect of this interference is random, it varies with every survey line so that some are more badly affected than others. The reason that the effect of this interference increases with depth is because the radar data is enhanced with depth in order to compensate for signal losses which also increase with depth. It is not possible to enhance the radar data without enhancing the interference.