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EMC Radar Consulting

atlas geophysical

Ground Penetrating Radar Survey

of

Four areas of Dunfermline Abbey

The South Aisle, Memorial Chapel, North Transept and North East Dais

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 12th century until the demolition of the East end of the building began in 1560 as part of the religious reformation in Scotland. 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 its predecessor and to locate, if possible, the site of as many large tombs as possible.

A first Ground Penetrating Radar (GPR) 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.

In 2017 a second stage survey covering three areas towards the east end of the current parish church, namely the central area of the church from the door of the Vestry to the Altar and two external areas thought to lie above the Lady Chapel of the former Abbey Church. 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 complete coverage of the remaining areas of the Lady Chapel not surveyed in 2016. The Lady Chapel is known to have contained royal graves.

In 2019, a third survey was carried out over an area to the south of the existing church which provided evidence of the remains of a rectangular structure, large enough to potentially be the remains of the South Transept.

The objective of the current survey is to investigate four additional indoor areas which could not be surveyed in earlier years due to the position of fixed pews. These four areas are the South Aisle, the Memorial Chapel lying to the east of the South Aisle, the North Transept, and the North East Dais.

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SURVEY STRATEGY

Use of Ground Penetrating Radar (GPR)

GPR operates on the same principles as conventional radar except that it uses a wide 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 signals are received by another antenna. The amplitude of the returning signals 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. Interpretation of the data rests primarily on pattern recognition within the data.

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

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 detection 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.

Features such as wall foundations may be identifiable within 2-dimensional data provided that sufficient vertical remains exist. In a site such as this one where extensive reuse has taken place over the centuries, identification of a specific built structure such as a chapel is normally made on the basis of patterning in the horizontal data. This could be the remains of wall foundations, the outlines of floors subsequently built over or potentially the distribution of a mixture of partially destroyed material used as the foundation either for another later structure or simply to level the ground.

In the previous surveys two frequencies of antenna were deployed, 400MHz for optimal definition and 250MHz for its greater depth capability. There is no benefit to be gained from using higher frequency antennas than these due to the depth of the medieval burials relative to the floor of the current parish church and the relatively lossy soils within a site for which retention of groundwater was sufficiently a concern of the church architect, William Burn, that he used pitch beneath the church floors as protection.

For consistency with the previous surveys this investigation was carried out along a North/South axis. This optimises the potential detection of any graves existing within the survey area.as well as any linear features running parallel to the primary axis of the current parish church.

Equipment

The equipment used for these surveys was a GroundVue 3_1 with a 250MHz antenna and a 400MHz antenna. The equipment was deployed on a hand towed skid to minimise offset from standing structures such as pillars, radiators and other fixtures.

The antennas used contain a dual array for narrowed signal beam and are screened in order to comply with European legislation to control the level of stray radiation. This also reduces the effects of external interference from objects above ground.

Site Conditions

As the parish church floor is flat and even, surface conditions were very good. As in previous surveys, the soils are not entirely suited to GPR investigation due to clay content. This is exacerbated where subsurface moisture is present.

Site Coverage

In order to maximise the information obtained by the GPR, survey lines 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 20mm along the line of travel of the radar was set. The data were collected to a probing depth of 100ns (equivalent to 5m in dry conditions, c. 3.9m in the site conditions) for the 250MHz survey and 80ns (equivalent to 4m in dry conditions for the 400MHz survey. 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, including both the soil and any clay or water content.

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.

Curve fitting on a spot check basis gave a transmission velocity of 0.1m/ns in all areas. Below 3.5m depth in area 3, a velocity of 0.08m/ns was measured indicating increased moisture at depth.

All data has been translated at the velocity of 0.1m/ns. There will therefore be some understatement of depth where voids are present (for which the transmission velocity is 0.3m/ns) and a slight overstatement of depth where moisture is present.

Fieldwork

The surveys, all of which were indoors and therefore unaffected by the weather, were carried out on 17th and 18th August 2022.

SURVEY RESULTS

Data Display

All 2-dimensional data is presented from South (on the left) to North (on the right). All horizontal time slices extracted from 3-dimensional data are presented with West at the top of the page and North to the right 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 (Figure 1).

Colour has been used to illustrate the 3-dimensional data from which horizontal time slices have been extracted (Figure 1). On this colour scale black indicates a high signal amplitude (positive or negative) and therefore the greatest difference in material composition from the immediate environment. For the remainder of the colour range the darker the colour, the greater the difference between the feature and its surrounding environment. White denotes continuity with or similarity to the adjacent subsurface environment.

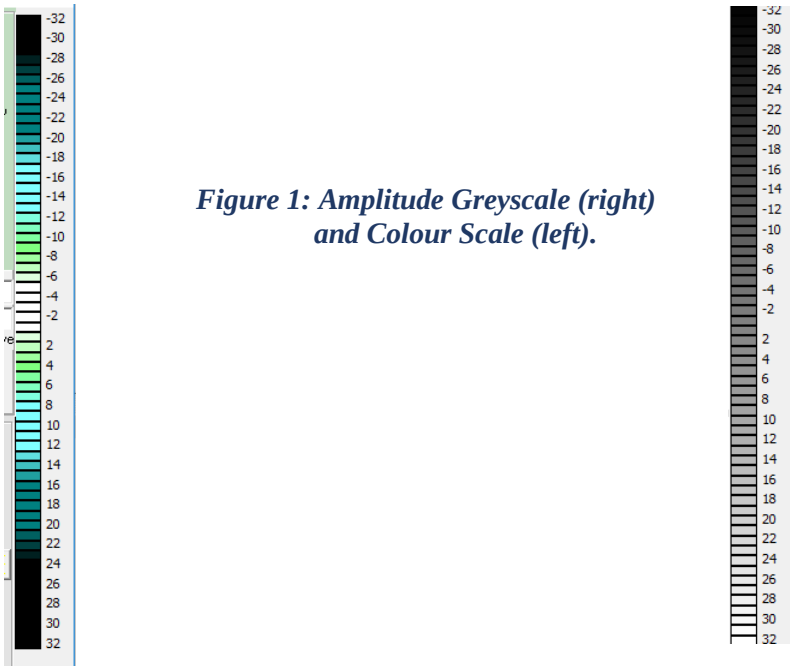

Figure 1: Amplitude Greyscale (right) and Colour Scale (left).

Area 1: The South Aisle

As this area is narrow, one survey reference line was laid out along an East/West orientation (Figure 2). A second parallel line, Line 2, was also used in the wider western section (Figure 3). Where a marker 1 or 2 has been placed on the 2-dimensional data, this indicates the position at which the radar crossed this survey reference line. The position of the survey lines were defined by measurement from fixed features as shown in Appendix B.

Figure 2: The South Aisle, from the Memorial Chapel looking to the West. Survey line 1 is visible to the right of centre.

Figure 3: The position of survey line 2 (white), parallel to and to the south of line 1 (yellow).

Each of the two surveys was completed by surveying from south to north beginning at the east end and working westwards with each line 0.25m distant from the previous one. A total of 58 lines per survey were recorded.

2-Dimensional Data: Area 1

The 2-dimensional (2D) data for both the 250MHz and 400MHz surveys have 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 displayed South to North and has been aligned to survey reference line 1 so that the x = 0 position (distance travelled by the radar) lies along this line. Negative distances are to the South and therefore closer to the church wall, Positive distances lie to the North of the parish church, closer to the main body of the church.

The 2-dimensional data from this area are characterised by strong signals from the modern floor construction, at least one near surface feature giving rise to echo effects and evidence of layering towards the western end (Figure 4). Although some possible medieval remains are visible, there is no strong evidence of substantial structures which might date to the medieval period, and it is probable that most of the visible structures date to post medieval activity and relate to the present parish church.

Area 1 250MHz 2-Dimensional Data

In Figure 4, the regular shape of the echo in line 63, its narrow width and proximity to the top of the radargram suggest ringing from the metal border to the carpet. In contrast the irregular form of the echo in line 117 and the fact that it starts from a feature directly above is suggestive of its origin being an irregularly shaped feature below the floor. The strength of signal suggests this may contain metal.

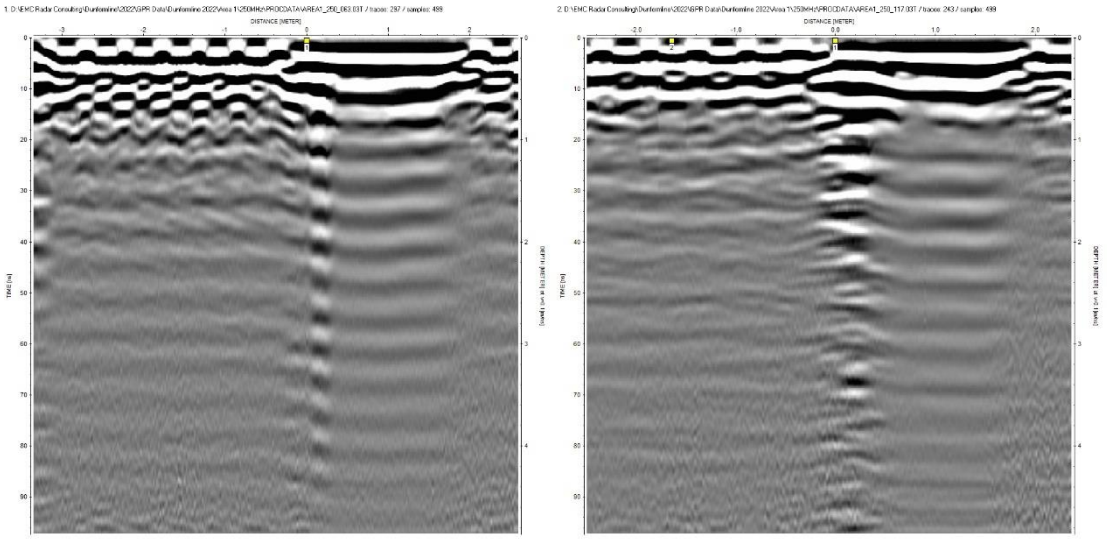

Figure 4: Survey lines 63 (y=0.5m) and 117 (y=14m) illustrating typical 2-dimensional data from the South Aisle.

To the right of the columns of ringing there is an area of near surface signal (strong black and white banding reaching from line 1 to x = 2m) below which fainter echo effects are visible. This is indicative of lost signal below the near surface feature and indicates either unsuitable soil, eg clay, combined with water in this location or possibly some form of impermeable membrane. This effect was observed previously, notably outside the present church on its south side in the 2019 survey.

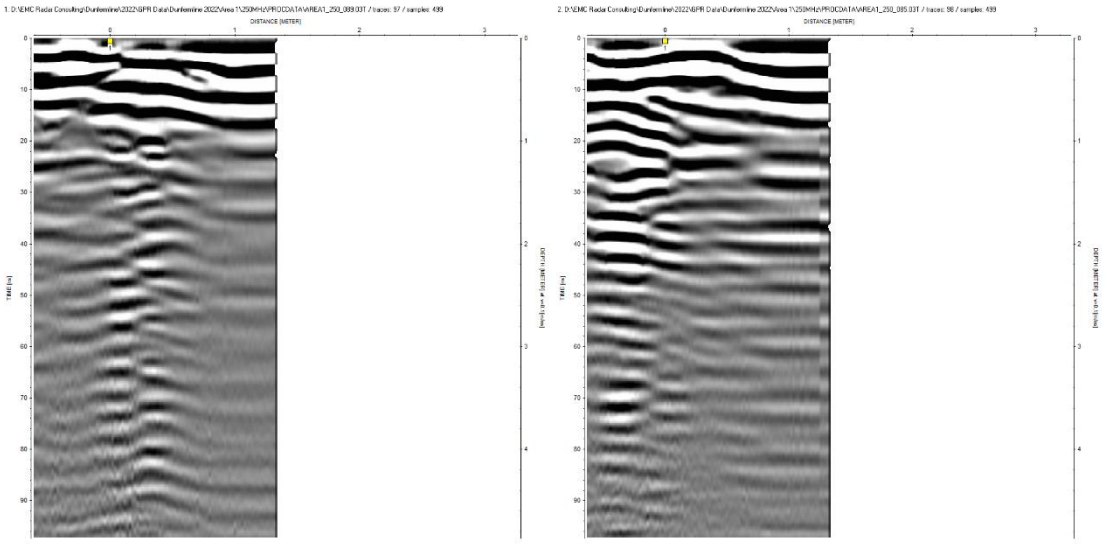

Figure 5: Survey lines 89 (y=7m) and 85 (y=6m) illustrating the data from the central area of the South Aisle)

The shorter survey lines in the central area of the South Aisle differ from those in Figure 4. Although echo effects are present and there are near surface features, it does appear that there are lower constructions also (Figure 5). There does not appear to be any continuity between individual lines.

3-Dimensional Data: Area 1

The 2-dimensional (2D) survey lines from both surveys have been incorporated into a 3-dimensional (3D) data block based on their relative positions along survey line 1. Time slices, horizontal plans, have been extracted from this data block based on the change in signal patterns visible in the data. West is at the top of the page for all the time slices.

Area 1 250MHz 3-Dimensional Data

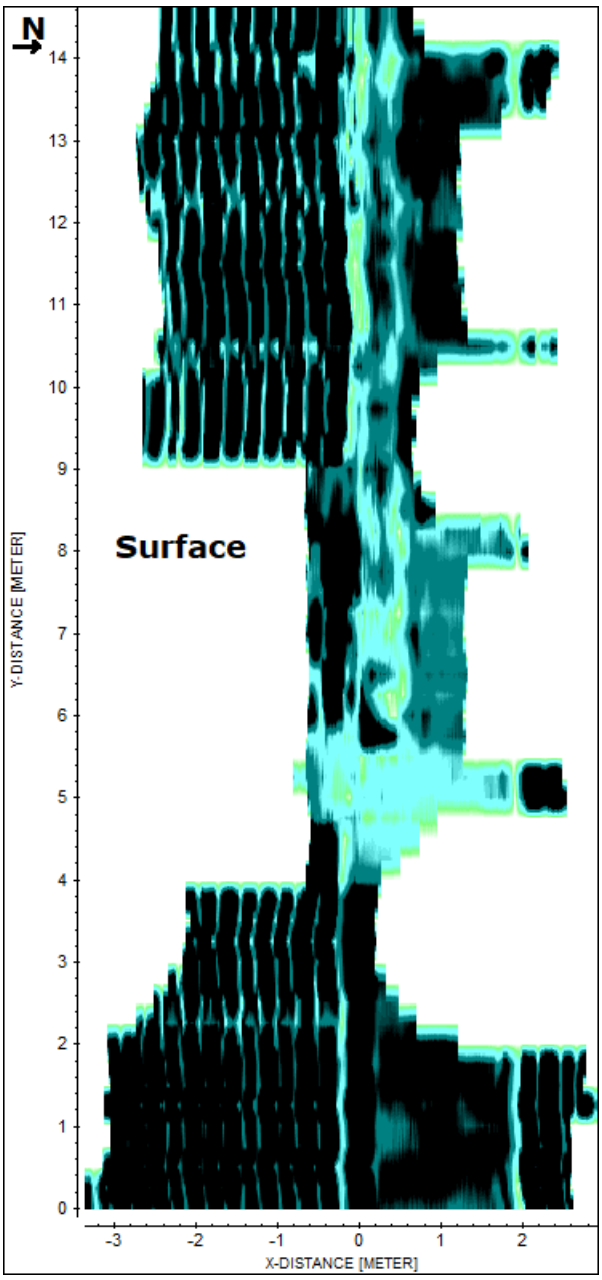

Figure 6: Surface Time Slice.

The surface time slice shows the effects originating at modern floor level, notably the construction of the floor to the left (Figure 6). It is likely that the areas to the right represent air gaps close to the floor surface. The linear feature (running East/West) ending by the large pillar on the North side marks the metal edge to the carpet. These features are worth noting because of the near surface echo effects emanating from them which affect the data lower down.

Time Slice at c. 73cm Depth

The first change in patterning occurs at c. 73cm (Figure 7). The echo effects from the modern floor are clearly visible on the left hand side of the image. A different pattern of rectangular anomalies is visible between reference line 1 (x =0) and 1.3m to the north (Figure 7).

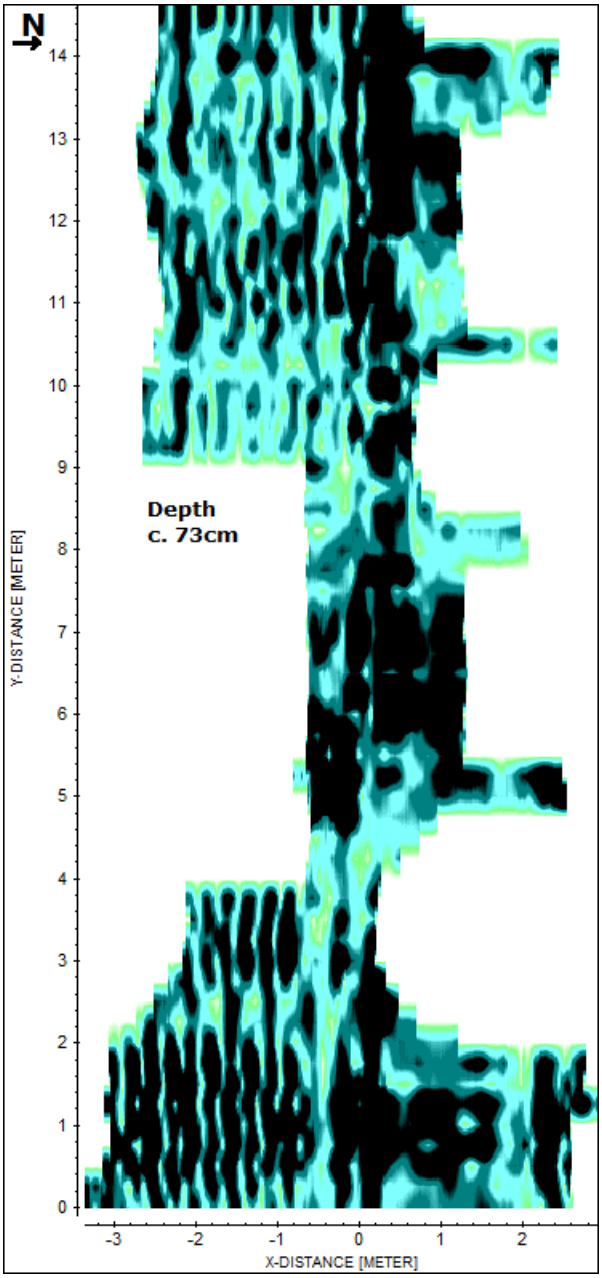

Figure 7: Time Slice at c. 73cm depth

These features are aligned East/West, but it is not immediately apparent what they represent. From observation, it is known that there are underlying structural remains in some locations, usually separated from the floor above by an air gap, not necessarily of uniform depth. At this depth the 2D data appears to form the top of a near surface feature, potentially a void from its association with ringing (cf Figure 4). Echo effects would not normally disguise a solid underlying feature such as a wall. The probability is that these signals relate to voids below the present Abbey church.

Time Slice at c. 85cm Depth

The main change at this depth lies in the middle of the survey area, on the left hand side where a rectangular anomaly of c. 2m in length is more clearly outlined next to the visual display (Figure 8).

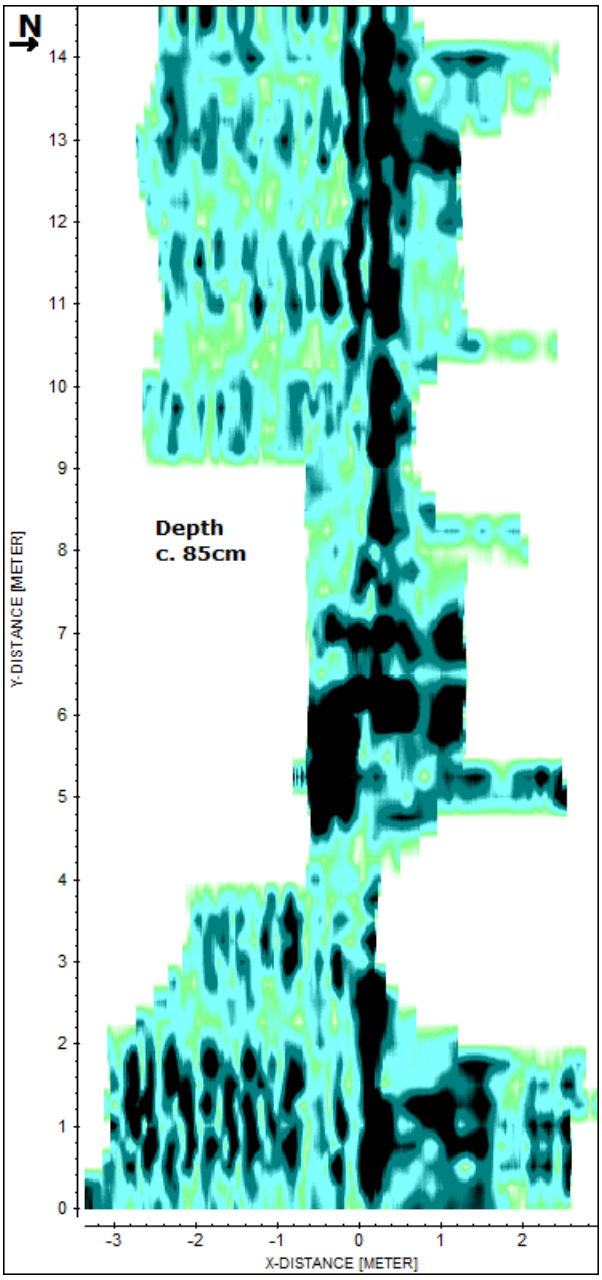

Figure 8: Time Slice at c. 85cm depth.

Comparison with the 2-dimensional data suggests that this is the underside of the same feature visible in the previous time slice and corresponds to the near surface material in Figure 5 (line 85) from which echo effects are visible. It is unlikely to be of any antiquity and may relate to the display unit it lies next to.

The rectangular features to the right of this feature correspond to the areas of strong near surface banding beneath which there is a loss of signal. As for the previous time slice, these are likely to be modern features, potentially involving voids.

The East/West line at the eastern end of the area corresponds to ringing effects from the metal edge to the carpet.

Time Slice at 1.15m depth

By this depth there appears to be a single structural system lying along an East/West orientation in the western half of the survey area (Figure 9).

Cross checking with the 2D data suggests that this is more likely to be a number of differently shaped objects, but they may be the components for a non-uniform feature. The blocks adjacent to the display unit appear to be associated with that feature (cf Figure 5, line 85). The blocks to the west appear more continuous. In all cases there are associated echo effects suggesting that there is an air gap present, but the strength of signal also suggests that there may be metal parts also (cf Figure 4). If the structures were entirely metallic, the radiowaves would not be able to penetrate them.

In the NE corner the linear feature is an echo effect from the metallic edge of the carpet. The irregularly shaped feature appears to be the underside of a void lying directly above the area of no signal penetration (cf Figure 4). A void is not sufficient to explain the lack of further depth penetration so that there must be a material impermeable to electromagnetic radiation present.

It should be noted that where voids exist, the depths quoted for the time slices will be understated. A known void examined during the survey varied from 20cm to 70cm in depth. Since radiowaves travel three times faster than the calibrated velocity for this survey, the effect based on these measurements would be of the order of 7cm to 93cm in the locations of the voids.

The general nature of these features suggests modern adaptations rather than features of archaeological interest. It would probably be useful to discuss the position of known adaptations with the Church personnel to confirm this and to identify these features in the time slices.

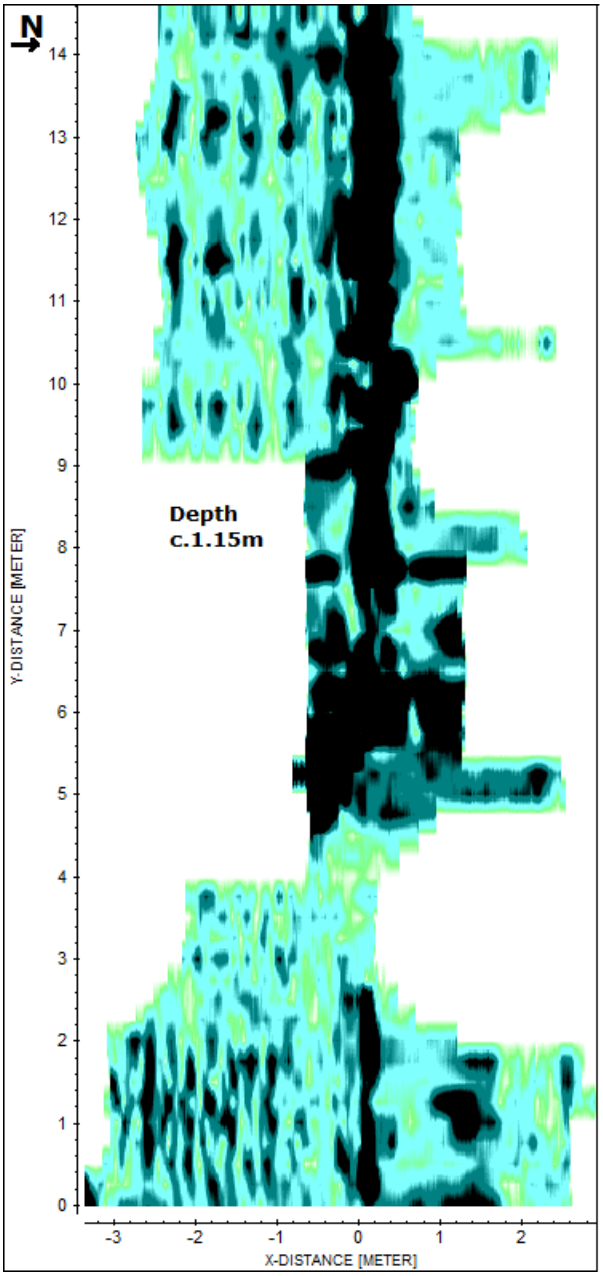

Figure 9: Time Slice at c. 1.15m depth.

Time Slice at c. 1.41m Depth

This time slice resembles the previous one but provides a clearer picture of the principal features (Figure 10). There appears to be one more or less continuous linear feature (oriented east/west) which may continue towards the north at y = c. 6.5m and a separate feature immediately adjacent to the display unit.

Comparison with the 2D evidence as well as the previous time slice suggests that these are more likely to be features of the current Abbey church.

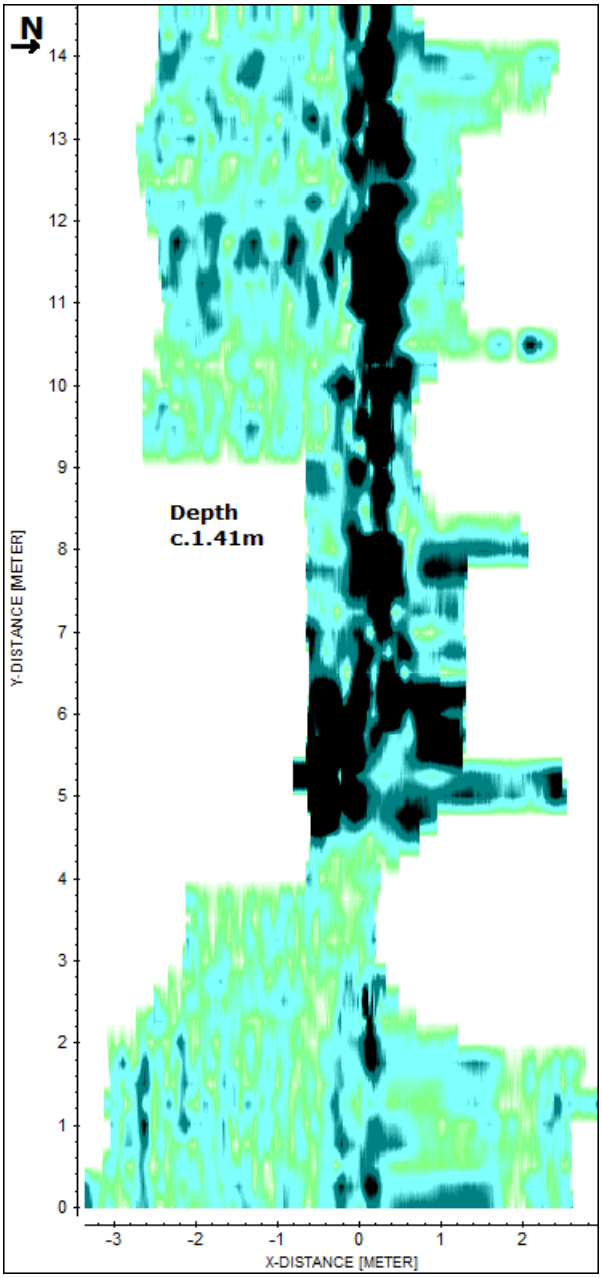

Figure 10: Time Slice at c.1.41m depth

Time Slice at c.1.62m Depth

The primary features visible in this time slice resemble those visible in the previous time slices. There are three additional areas of strong signal, two to the south of the central section and one abutting the western edge of the largest pillar (Figure 11).

All of these, except for the one centred on (x=0.3m, y=9.25m), appear to be ringing (echo effects) from features closer to the surface. The sole exception could be a partial layer of material, but its position and short length make it impossible to be sure. There is a possibility that this is also ringing.

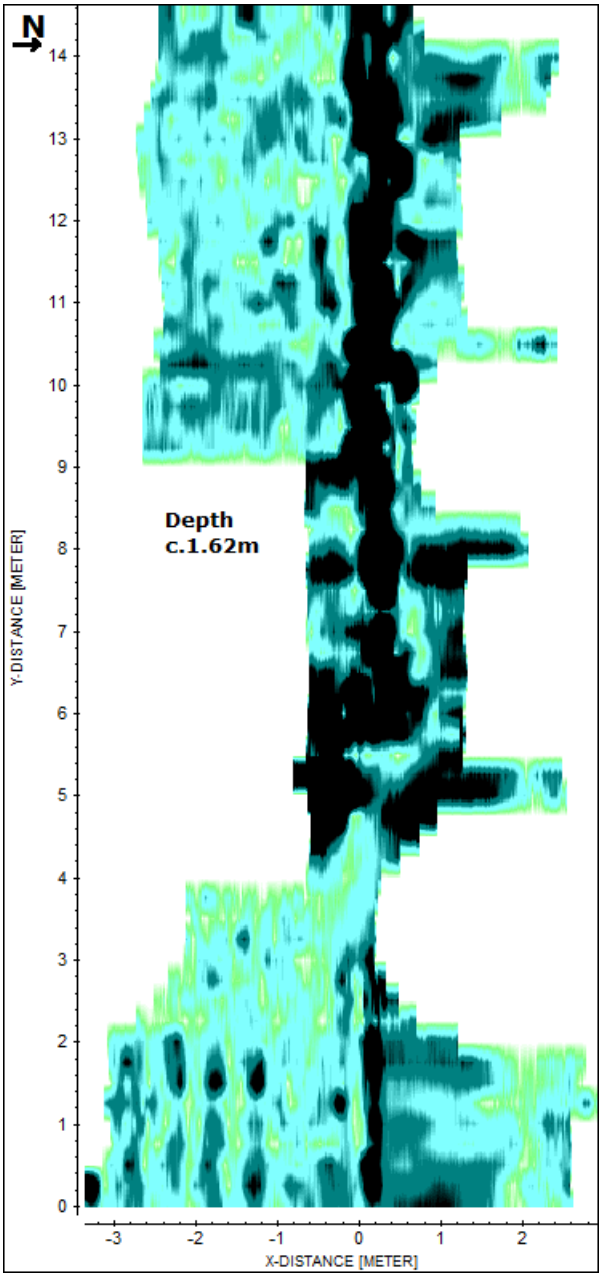

Figure 11: Time Slice at c. 1.62m depth

Time Slice at c.1.97cm Depth

The overall pattern at this depth is similar to that of the previous time slices (Figure 12). Minor changes include a greater density of strong signal in the central area, the suggestion of two possible linear features oriented North/South and some additional material in the western part.

The two linear features running North/South are not real. They are background echo effects which are visible due to the loss of real signal in this area.

The extra material in the western end does appear to be anomalous material and the pattern may therefore be significant. However, all of these are small, do not extend in the vertical direction and it is therefore impossible to determine what they represent.

The inference is that this is an area where any medieval remains have been mostly removed or destroyed and re-used as the base of the current building.

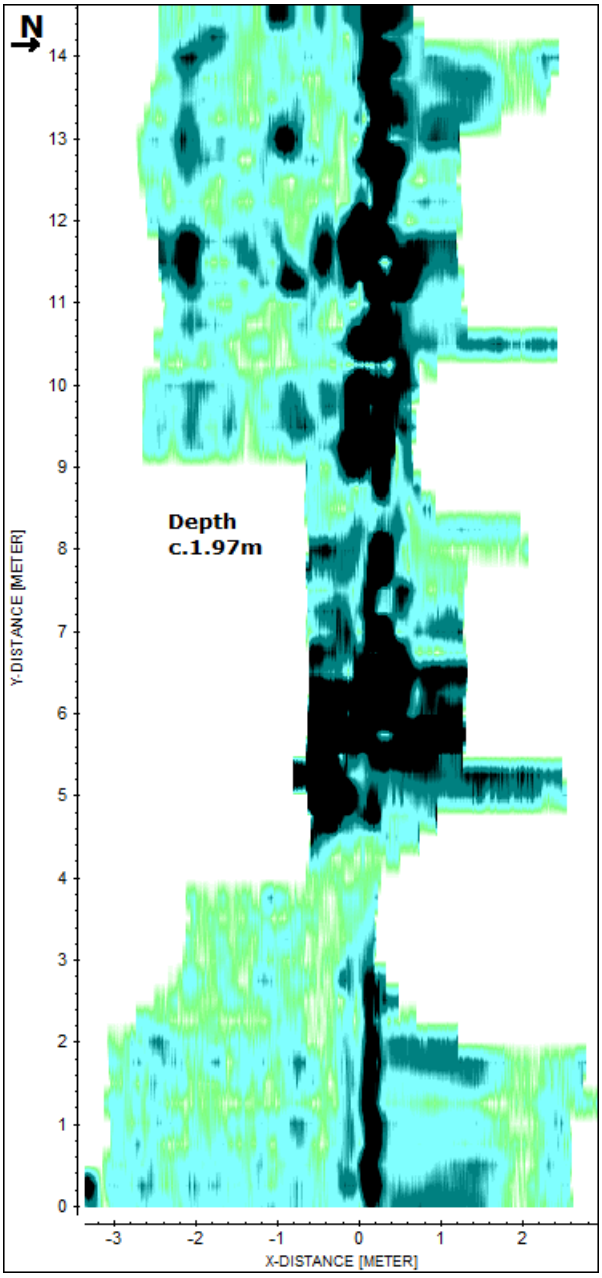

Figure 12: Time Slice at c.1.97m depth.

Time Slice at c. 2.11m depth

The principal difference between this time slice and the previous ones is the addition of a right angled feature around (x=-1, y=10.25) which might also extend as a linear feature towards the south although the signal returns are weaker along this line (Figure 13). There is still a scatter of anomalous remains in the western section.

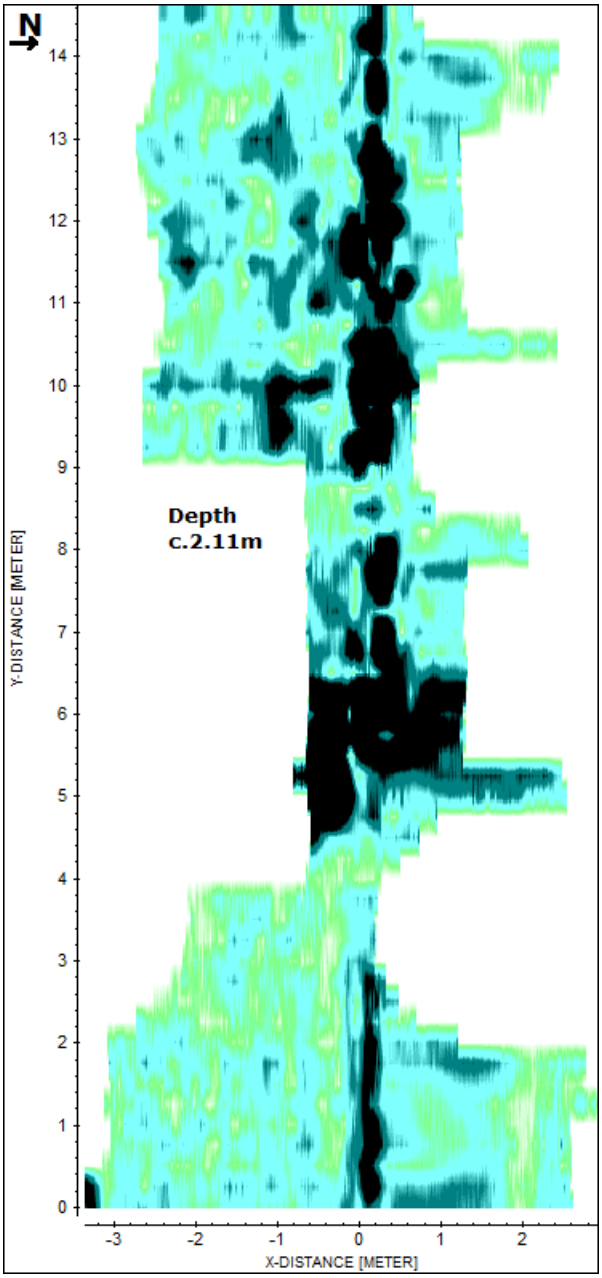

Figure 13: Time Slice at c. 2.11m depth.

The right angled feature in the western section appears to be real signal return although the amount of material is limited. It is not an echo effect, and it bears no relation to the more modern structures. The East/West leg is visible in survey lines 100 to 102 and the North/South part appears as a thin layer in line 102. It is likely that this is material from the earlier Abbey church. The fainter line leading southwards toward the current church wall also appears to be genuine remains. This corresponds to what appeared to be layering in the 2D data. Figure 14 illustrates the cross section of the East/West leg of the right angled feature.

Time slices below this depth show repeated echo effects. There is no obvious other material. There is a possibility that the strong signals from the ringing might mask less strong signal returns from real features if these were not substantial in size. Cross checking with the 2D data has not revealed any such features

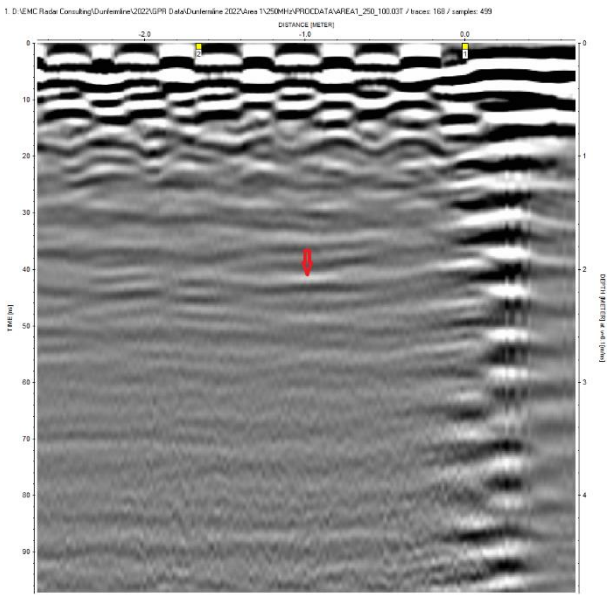

Figure 14: Survey line 100 illustrating the cross section of the East/West leg of the right angled feature in Figure 13.

Area 1 400MHz 2-Dimensional Data

As expected, the 400MHz data are similar to that of the 250MHz survey. The images are less broad brush in appearance due to the higher frequency which allows better definition. Figure 15 shows sample data from the area which corresponds closely to the 250MHz data set.

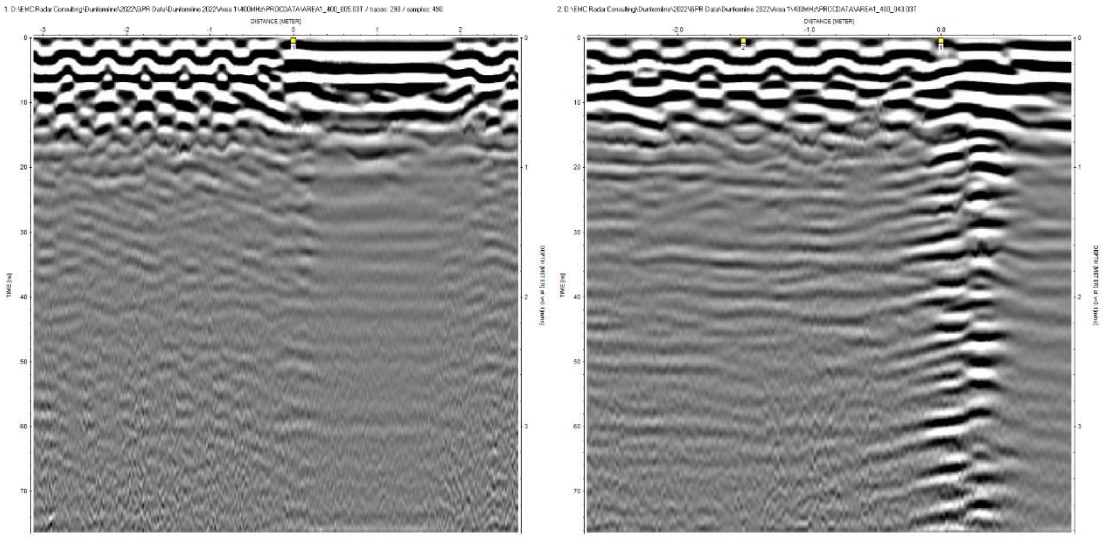

Figure 15: Survey lines 5 (x=75cm) and 43 (x=10.25m) illustrating typical data from the South Aisle

The effect of the floorboards is clearly visible, particularly in line 5 which is at the east end of the area. Two strong columns of signal dominate line 43 but there are also signs of disturbance in the area beneath the floorboards which, although fainter than the ringing, do not correspond to the signals above. Instead there is evidence of layering, particularly between 30ns and 40ns (1.5m to 2m).

Area 1 400MHz 3-Dimensional Data

Time Slices at c.75cm and c.1m Depth

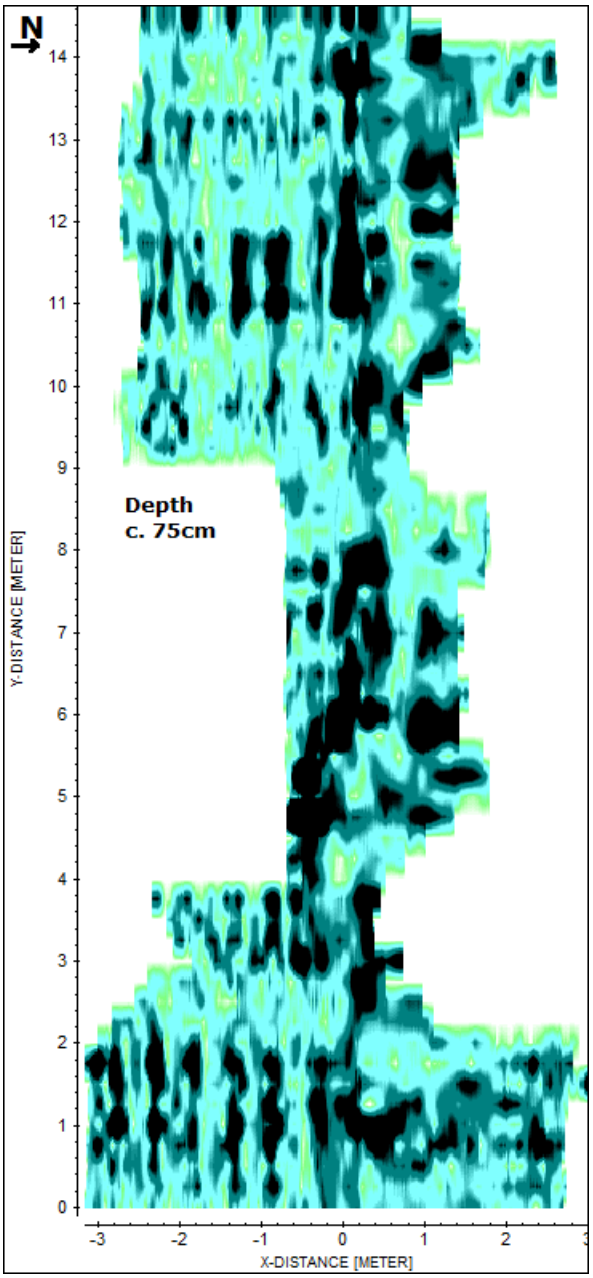

Figure 16: Time Slice at c. 75cm depth.

The c.75cm time slice differs primarily from that of the 250MHz survey is in its finer definition of the anomalous areas, all of which correspond to the lower frequency survey (Figure 16, cf Figure 7). The primary reflections are from the floor structure and near surface, and therefore presumably modern features.

The time slice at c. 1m depth is very similar. It refines the definition of the linear East/West feature(s) and the feature adjacent to the display unit (Figure 17).

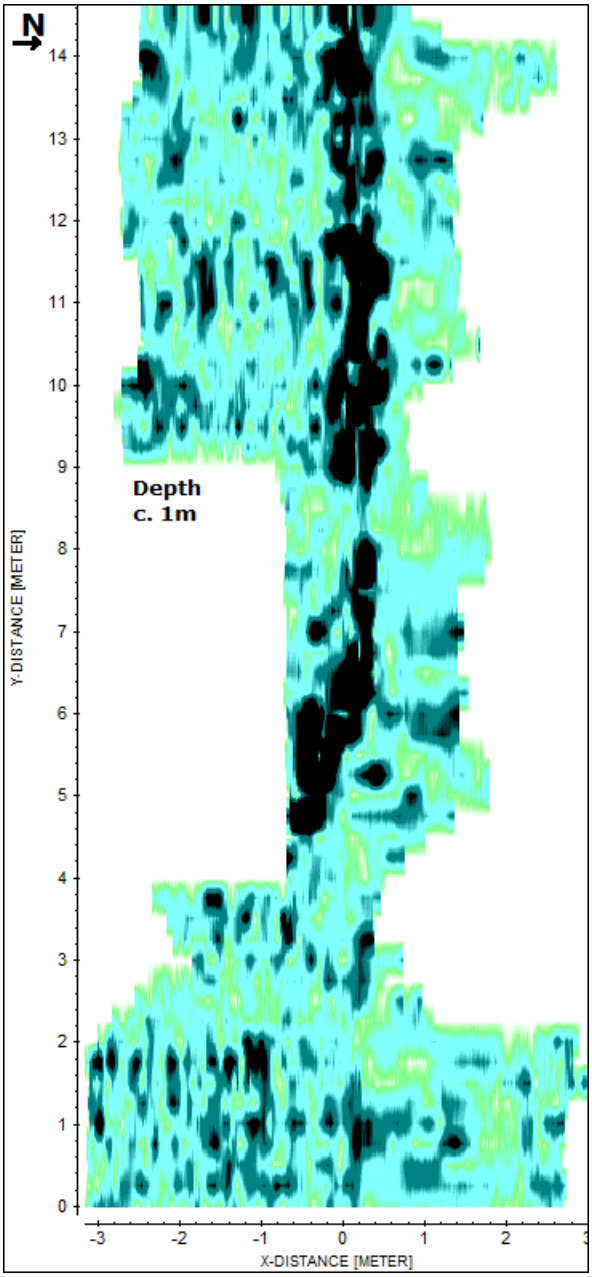

Figure 17: Time Slice at c. 1m depth.

Time Slice at c.1.65m Depth

The first real difference from the 250MHz results occurs at c. 1.65m depth where a near rectangular shape can be seen to the south of the near surface linear feature previously observed (Figure 18). At this depth the linear feature is represented by ringing. The rectangular shape represents real returns from archaeological features. Its position corresponds to the angular shape visible in the 250MHz survey at a depth of c. 2.11m (Figure 13). The difference in detection is due to the relative wavelengths and reflects the ability of the smaller wavelength to detect smaller features.

Figure 19 shows the vertical information from the 2D data along two of the relevant survey lines. The area of layering visible in line 43 also corresponds to this feature (cf Figure 15).

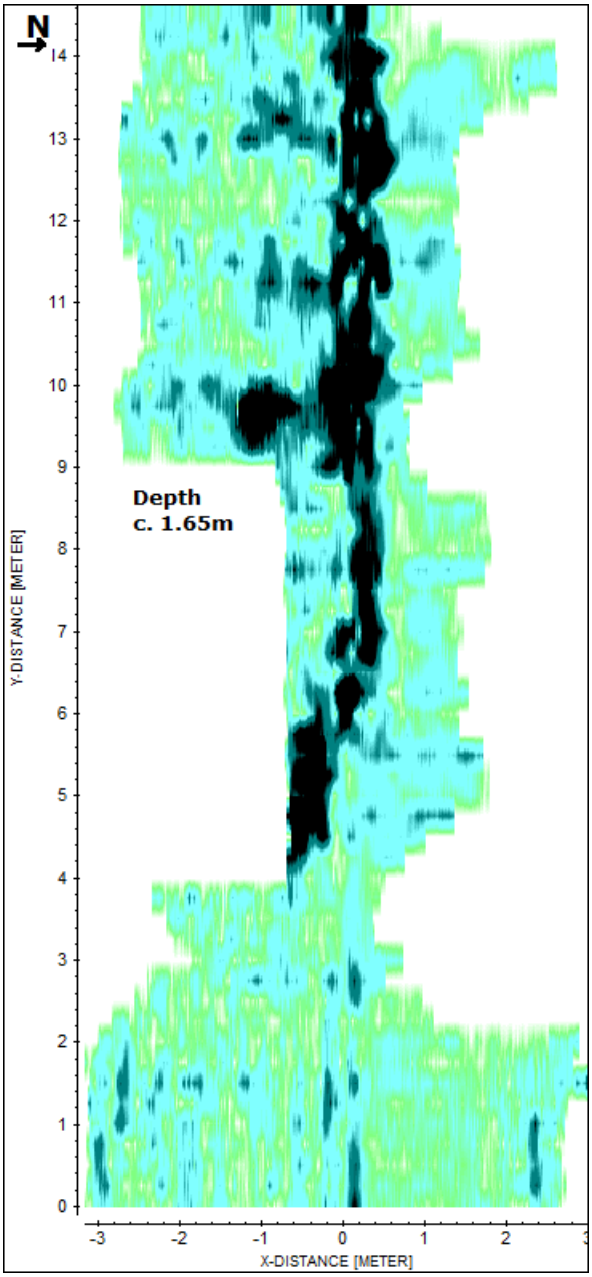

Figure 18: Time Slice at c. 1.65m depth.

The signal patterning in 2D suggests that these remains are not intact which corresponds to the partial outlines seen horizontally. Although this does not resolve the issue of whether this is material in situ or re-used as levelling material, the juxtaposition of a column of material immediately adjacent to a surface does suggest the former (Figure 19, line 40).

The material visible along x = 11.25m and x = 13.25m is less substantial than the block to the East of these features but is similar in nature and extent both from the 2D and 3D data patterning. It represents archaeological remains, potentially material which originated in a larger feature or features and likely to be building material in origin. It is difficult to judge whether this forms a single large feature or a series of smaller ones.

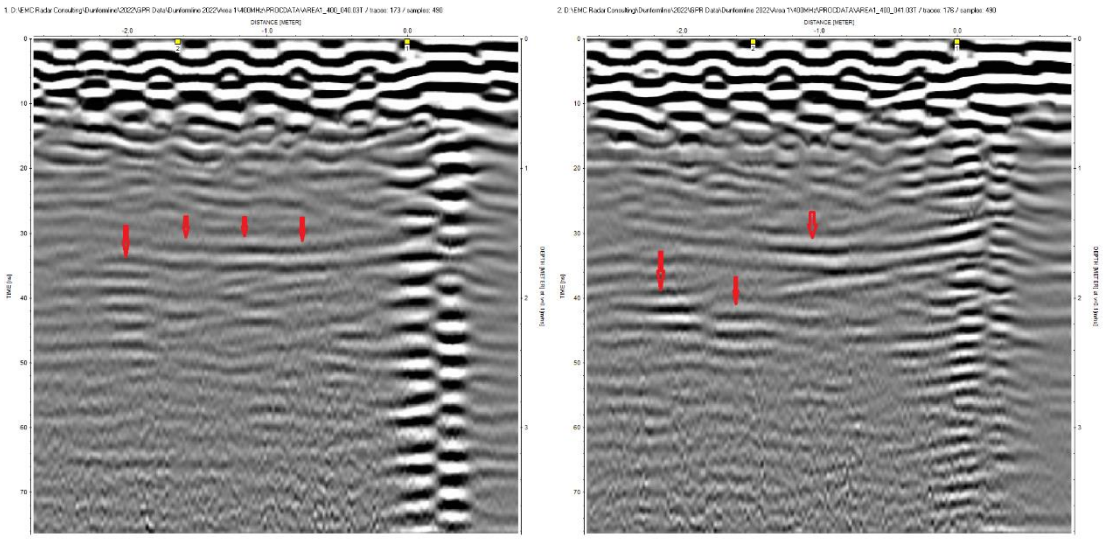

Figure 19: Survey lines 40 (x = 9.25m) and 41(x=9.5m). The red arrows mark archaeological material at the c. 1.65m depth and some of those lying below.

The presence of underlying material at 1.65m depth in the 400MHz survey when the 250MHz reached 2.11m before similar material was observed is due to the disparity in wavelengths. There are three reasons for the difference. Typically a radar can detect objects of 0.1λ or larger where λ is the wavelength. Also to distinguish one object from another requires the 2 objects (or features) to be separated by a full wavelength. The implication is therefore that the layered material is smaller and thinner than the material depicted by columns. Lastly, both antennas measure depth in terms of their wavelengths, and it would therefore be surprising if they came to the exact same depths.

There are two other implications from comparing the two time slices at Figures 13 and 18. Firstly it is possible that archaeological material is being obscured by the strength of the echo signals. It is also possible that many of the fainter signals visible in the time slices may also represent archaeological material whose presence is represented by paler colours because of the strength of the signal returns from the more modern features. It is not possible to eliminate the ringing which makes it difficult to recognise any medieval features lying in a West/East direction since this is the dominant orientation of the echoing features.

Time Slice at c.1.77m Depth

Although this time slice is also dominated by ringing from near surface material there are indications of a larger spread of material in the western part of the survey, potentially archaeological material. Examination of the three main areas (all to the south of the line of echo effects) in vertical section confirms that this is probably correct (Figure 21). Assuming this is so, it looks as though placing the more modern near surface facilities must have revealed the edge of the underlying archaeological remains or even cut through them.

The features visible vary from layer type signals to short stumps of columns and it is reasonable to assume that they are what remains following destruction before the current Abbey church was built.

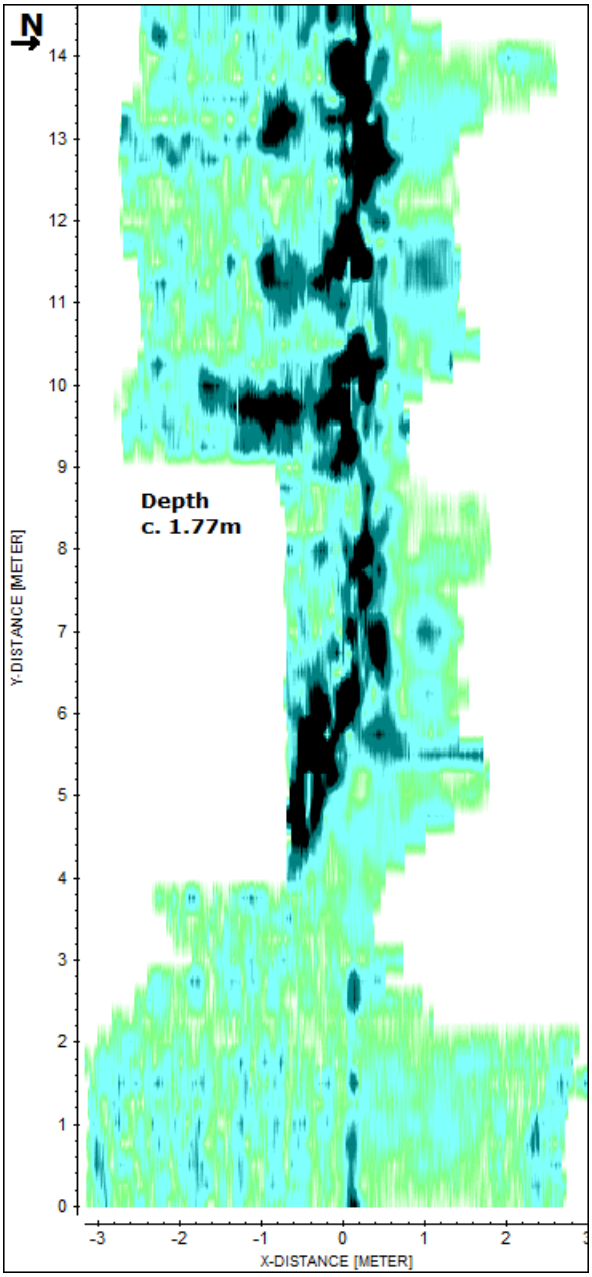

Figure 20: Time Slice at c. 1.77m depth.

Not all of the signals indicating anomalous material at this depth are as strong as those indicated in Figure 21. This may mean lesser quantities or possibly a different material. The likelihood for those visible in Figures 20 and 21 is building materials. In this context it is worth noting that there was evidence of a destroyed and levelled rectangular area directly to the south of the current church wall at a depth of 91cm in the 2019 report.

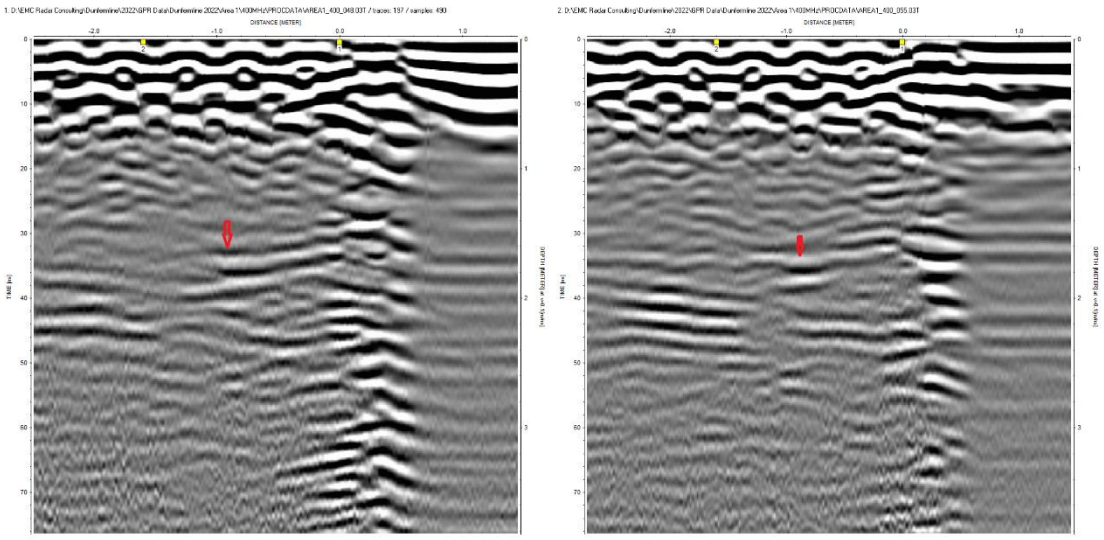

Figure 21: Survey lines 48 (y=11.5m) and 55 (y=13.25m) showing features adjacent/close to the echo effects from the modern features above. There are similar features below.

Time Slice at c. 2m Depth

More similar material becomes visible in the south western section of Area 1 by 2m depth, corresponding to the lower signals visible in Figure 21. These lower elements extend further to the south although there is still proximity to the line of echo effects between y=11m and y = 12m (Figure 22).

Although the spread of material looks as though it might represent a floor, assuming that these features are still in situ, the y-co-ordinates of these areas align with those visible centred around y=9.5m (cf Figure 19), y=11.5m (cf Figure 21) and y=13m. This suggests that even if there were a floor across the full area, there was something structurally different about these three lines which resulted in the survival of partial remains. The three patches of strong signal to the south of these lines also all centre on x = -2m which also suggests a relationship.

Beyond this observation, the lack of obvious patterns in the data and the scarcity of the remains make it difficult to draw any further conclusions as to the nature of the archaeology in this area. It may be possible to relate the GPR results in this area to other source material in spite of the restricted area of patterning in the radar data.

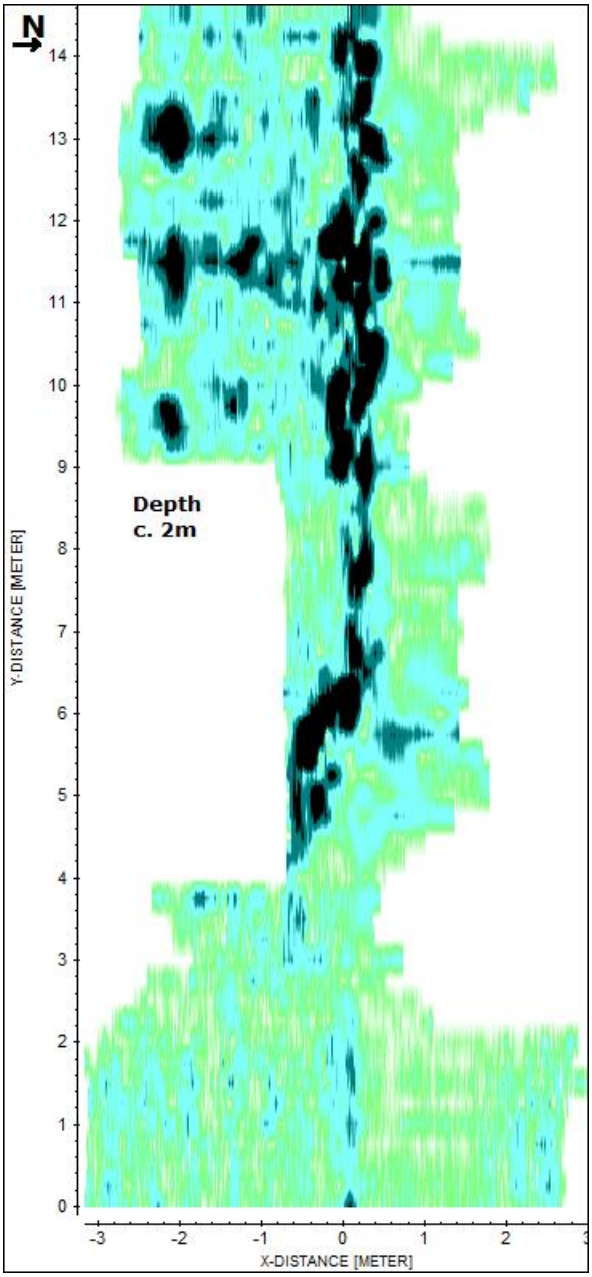

Figure 22: Time Slice at 2m depth

Time Slice at c. 2.31m Depth

The three lines of pattern observed in Figures 20 and 22 continue to evolve at this depth (Figure 23). The partial nature of the remains and the change in shape of the features again suggest historical destruction.

There are other areas at this depth which may contain archaeological remains e.g. to the north of the line of echo effects at y = 5.75m. Comparison with the 2D data does not provide a clear distinction between ringing or real artefact in this area as the strong echoes dominate the short length of survey line.

The majority of the dark blue lines visible in the east end of Area 1 are continuing echo effects (notably from the carpet edge) but there are also some real remains, for

example along y = 3m. These are too ephemeral for a serious attempt at interpretation of what they might have previously represented.

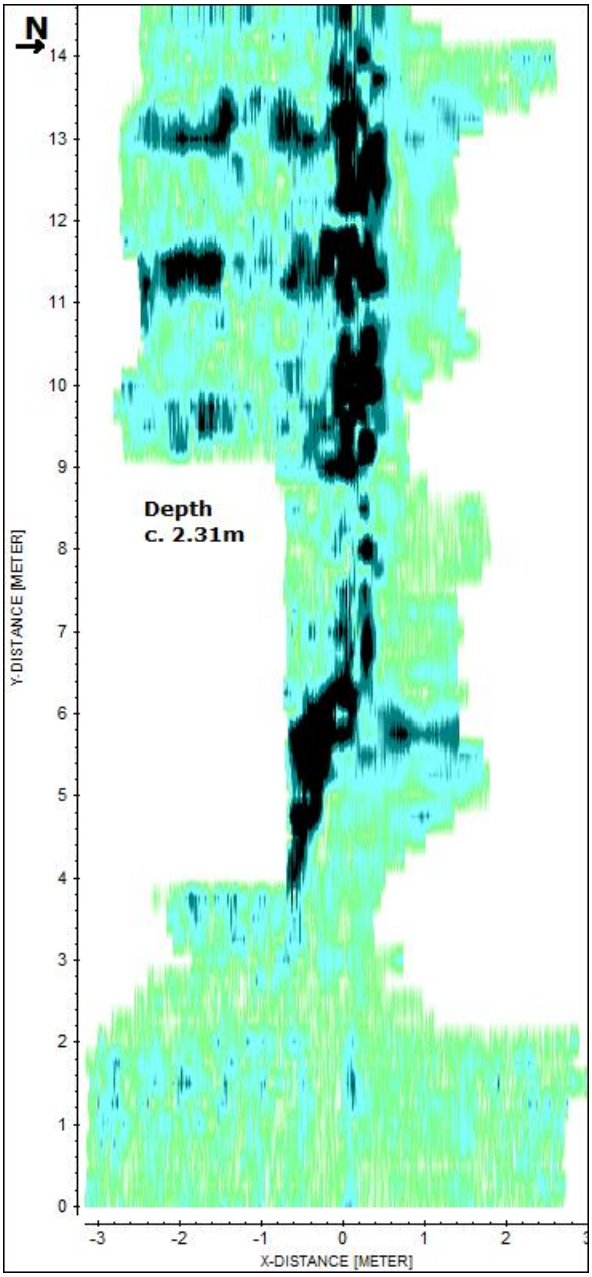

Figure 23: Time Slice at 2.31m depth

There are no significant changes below this depth.

Area 2: The Memorial Chapel

Two parallel survey reference lines were laid out along an East/West orientation, tape 1 to the north and tape 2 to the south (Figure 24). As with Area 1, where a marker 1 or 2 has been placed on the 2-dimensional data, this indicates the position at which the radar crossed this survey reference line. Tape 1 aligns approximately with survey reference line 1 in Area 1. The position of the survey lines were defined by measurement from fixed features as shown in Appendix B.

Figure 24: Survey Reference lines in the Memorial Chapel Reference line 1 to the left, line 2 to the right.

Each of the two surveys was completed by surveying from south to north beginning at the east end and working westwards with each line 0.25m distant from the previous one. A total of 32 lines were recorded using the 250MHz antenna and 34 lines using the 400MHz antenna. The difference in number results from working with different sized antennas across the steps at the East end of the chapel.

2-Dimensional Data: Area 2

The 2-dimensional (2D) data for both the 250MHz and 400MHz surveys have 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 displayed South to North and has been aligned to survey reference line 2 so that the x = 0 (distance travelled by the radar) position lies along this line. Negative distances are to the South and therefore closer to the church wall, Positive distances lie to the North, closer to the main body of the church.

The 2-dimensional data from this area are characterised by echo effects from the fitting of the floorboards and also from a few near surface features but the impact is less than in Area 1 for most of the survey runs.

Area 2 2-Dimensional Data: 250MHz

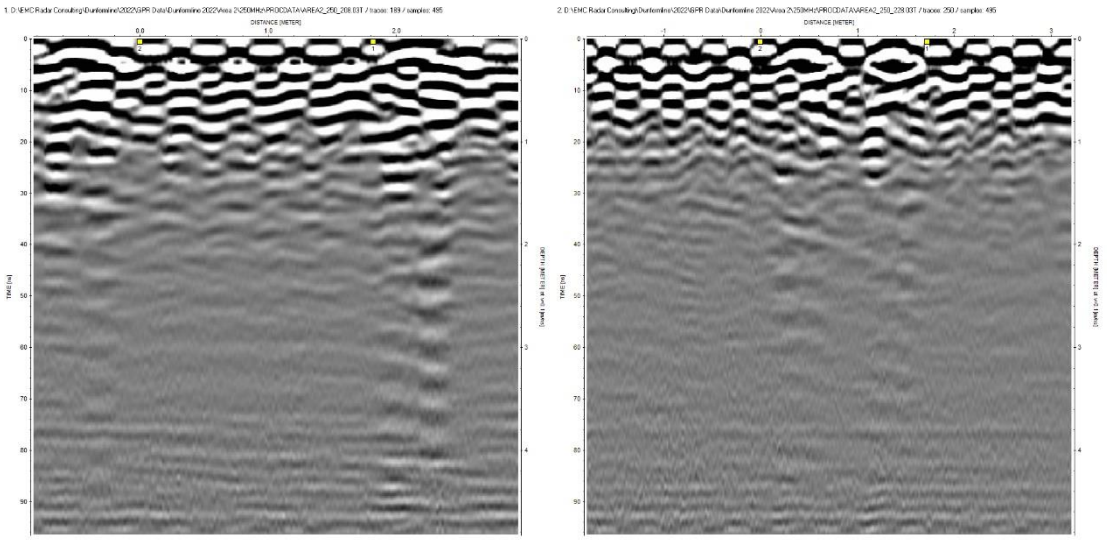

Figure 25: Survey lines 208 (y=3.25m) and 228 (y=8.25) showing typical data from the Memorial Chapel area.

The columns of echo effect in both survey lines in Figure 25 relate to the metal edges of the carpet, the gap between the two edges being wider towards the steps than in the main body of the chapel (cf figure 24). There are additional bands of ringing towards the foot of both radargrams. The horizontal nature of these suggests background ringing from the antennas which is normally only seen where there is loss of signal penetration. The close packing of the top of the radargrams shows the composition of the floor. There are other signals present, eg in line 208 between the two columns of ringing.

3-Dimensional Data: Area 2

The 2-dimensional (2D) survey lines from both surveys have been incorporated into a 3-dimensional (3D) data block based on their relative positions along survey line 2. Time slices, horizontal plans, have been extracted from this data block based on the change in signal patterns visible in the data. West is at the top of the page for all the time slices.

The position of the step where data could not be obtained due to the relative sizes of the antenna and the steps shows as a blank area and is marked. The depth of the step was 15cm or 3ns at the calibrated velocity. The block of data at the East end in each time slice is therefore slightly less deep than the remainder of the time slice. This has not been adjusted as it was not considered material.

Area 2 3-Dimensional Data: 250MHz

Surface Time Slice

The surface time slice has been included to illustrate the elements of the floor composition which give rise to echo effects lower down . These affect all areas except for a band in the centre of the survey area (Figure 26).

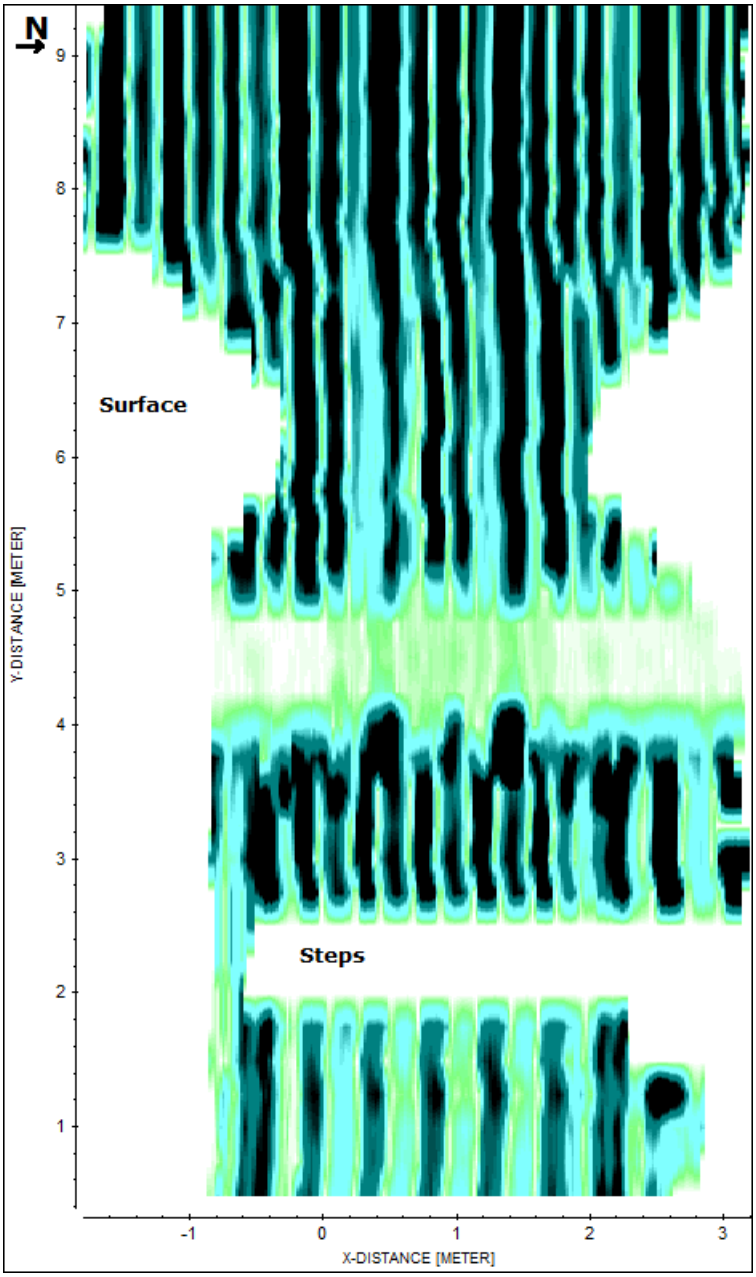

Figure 26: Surface time slice showing the surface variations which give rise to echo effects lower down.

Time Slice at c. 54cm Depth

The dominant features at this depth are the echo effects. However, there are also near surface features visible in the central section. These consist of two large blocks of strong signal to right and left and four broad short linear features in between (Figure 27).

The two central broad linear features coincide in the 2D data with the edges of the carpet. The metal edges to the carpet set up echo effects. Both the outer and inner broad linear features originate in a near surface object at this depth, but these objects also give rise to echo effects below. The resulting pattern is a double column of echoes (Figure 28). It is very likely that the physical features these represent relate to the current parish church.

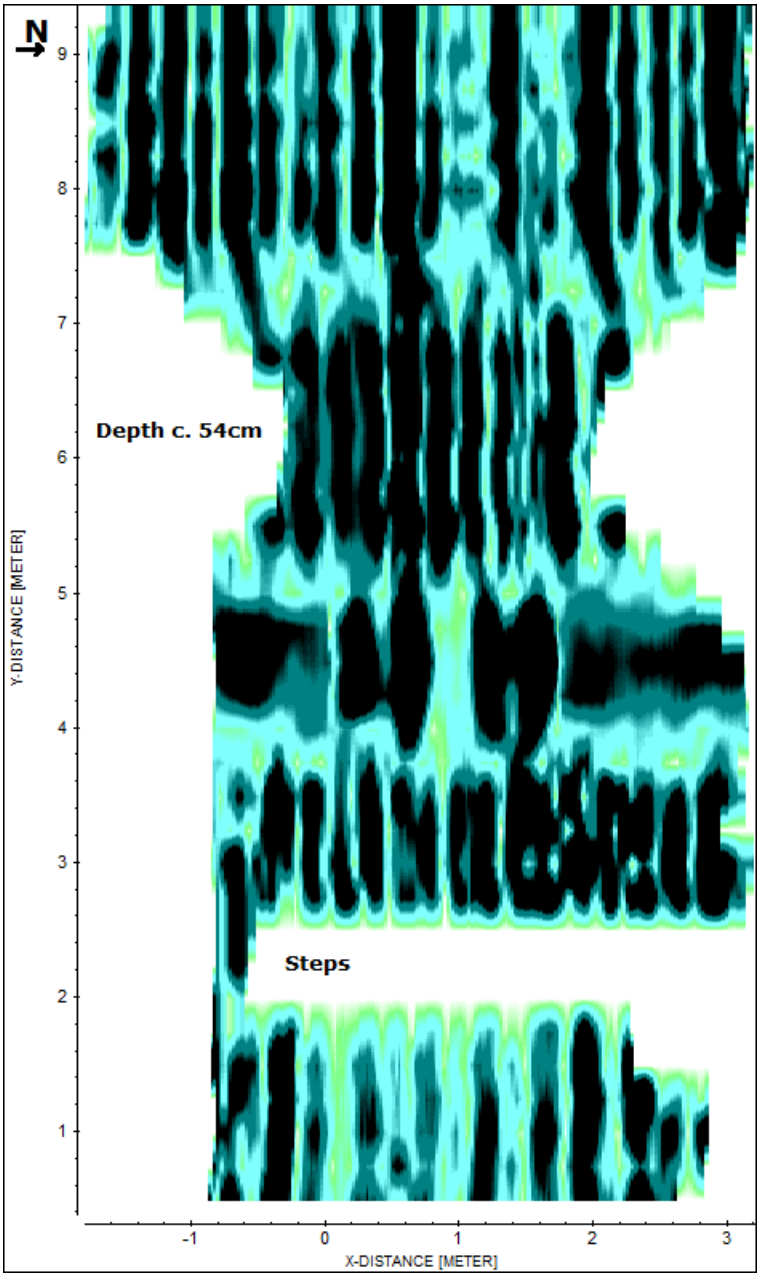

Figure 27: Time slice at c. 54cm showing near surface features in the central section.

The broader, larger areas of strong signal to right and left of the central section can also be seen in Figure 28. There is nothing visible below these other than background ringing from the antennas which implies signal loss. It is possible that there is voiding below the floor at this depth but whatever it overlies is unsuited to GPR signals. The typical reason for this would be clay content in the soil combined with moisture but a membrane or metal are also possible.

Time Slice at c. 1.15m Depth

This time slice shows the underside of the near surface material visible in the previous time slice (Figure 29).

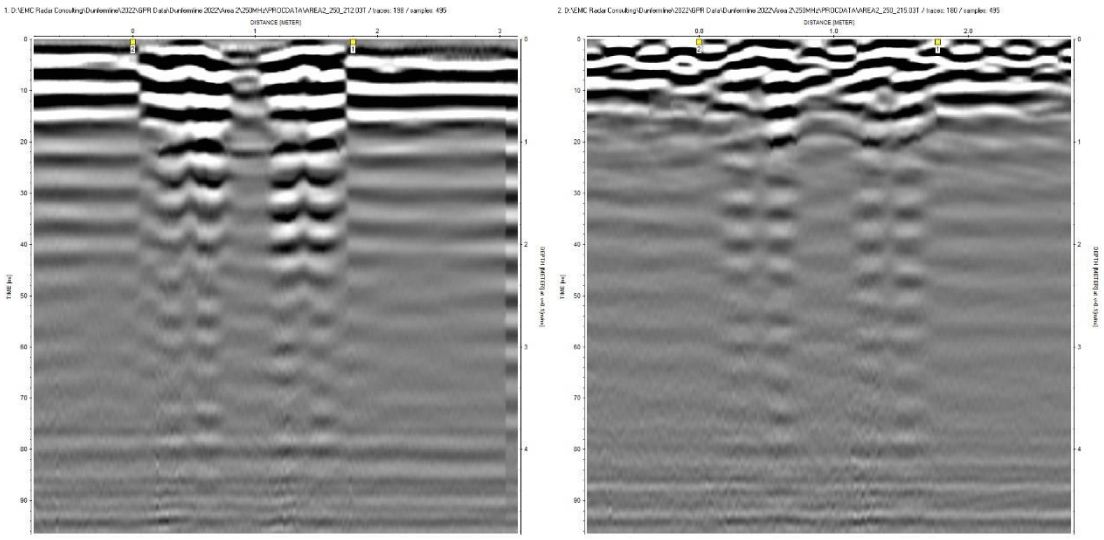

Figure 27: Survey Lines 212 (y=4.25m) and 215 (y=5m) showing the near surface configuration giving rise to a double column of echo effects below.

The principal features are:

- a number of linear features beneath the raised area at the east end of the chapel, possibly extending into the area immediately beyond the steps;
- continuation of the same four central features as in the previous time slice; and
- one linear feature and an area of shorter features forming the outline of a rectangle.

Taking the central area first, the two central rectangles (in the same location as the previous pairs of linear features) are double columns of ringing from near surface features as can be seen in Figure 28 at this depth.

The two outer areas are much reduced in size and appear to be echo effects from above. This may indicate that the near surface features include an air gap. The ringing below this level is background ringing, suggesting lossy material is present, preventing any visual clues to what lies below.

The linear feature in the western end is formed from a column of variable depth. There are no echo effects below and it is likely this is structural (Figure 30). Potentially this could be archaeological remains from the medieval chapel although it is impossible to date it from the GPR data alone. Also it does lie immediately below a near surface anomaly which might mean that it is an echo effect.

The area of shorter features to the south of the linear feature just discussed, although partial in nature, is very regular in outline, lying between x = 0.3m and 0.6m and from y = 7.75m to 9m, forming a rectangle of a similar length to its neighbouring line. The 2D data reveals the southern half of this feature (x = 0.3m) to be similar in nature to the adjacent structural linear feature. Both features lie beneath the southern edge of near surface features. If this is significant, it would indicate they are of modern date rather than archaeological remains. The other half of the outline appears to be similar in nature to a series of regular columns visible across the remainder of the area and is therefore undoubtedly of relatively recent construction.

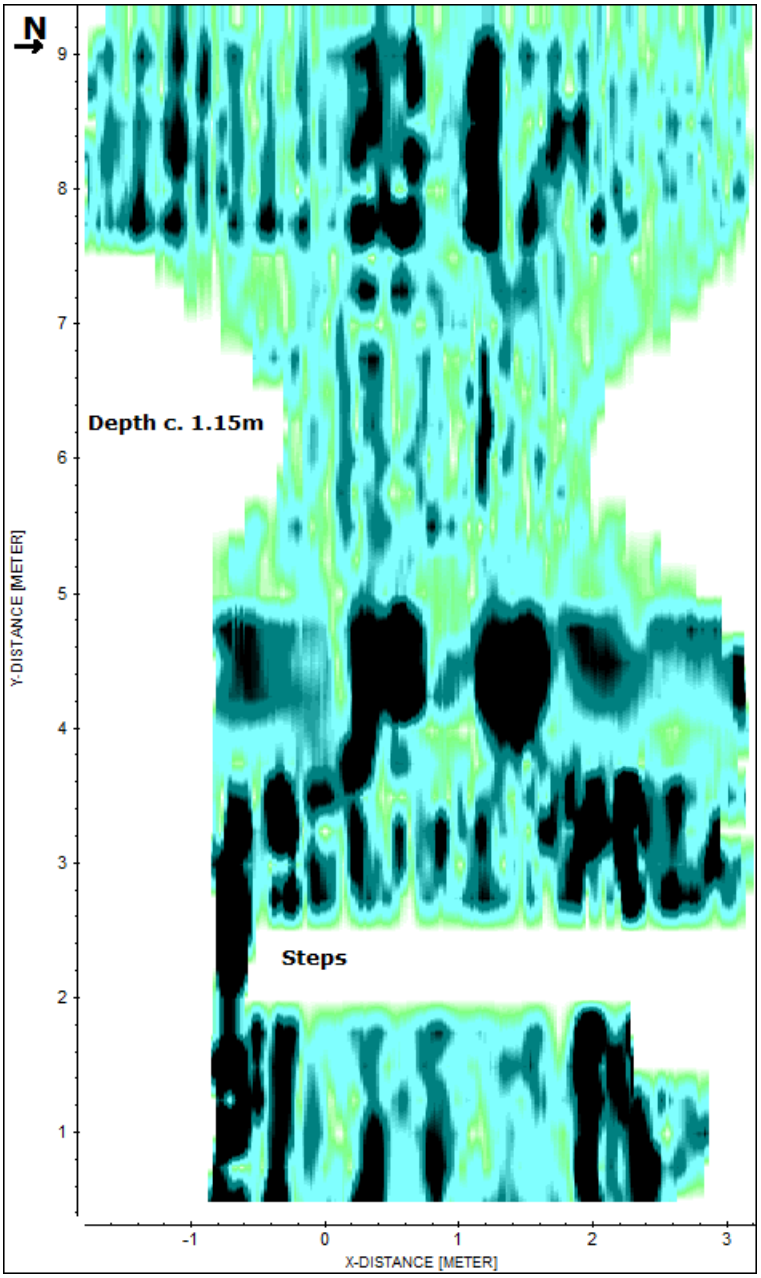

Figure 29: Time Slice at c. 1.15m depth

There is also what appears to be structural material underlying the eastern end of the chapel (Figure 31). On the north side there is a bridge shaped feature, directly underlying another closer to the surface, centred on x = 2.2m. The two lower branches of this feature are visible as two lines, one straight, one partially curved in Figure 29, leading from the East towards the West. Although this might be archaeological remains, it mirrors another feature closer to the surface. The feature continues to the West of the steps, terminating at c. y = 3.7m. The overall shallowness of the combined feature suggests that this may be a construct of the modern church.

The dark lines which border the southern side of this area of the church include similar material to that on the northern side (see Figure 31) which also tends to suggest that these features may belong to the current parish church.

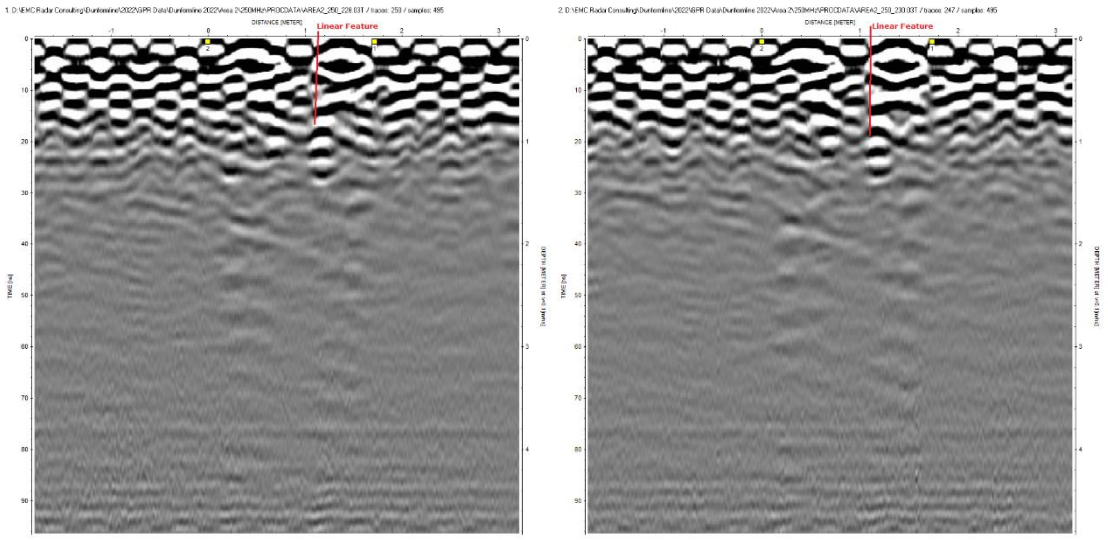

Figure 30: Survey lines 228 (y=8.25m) and 230 (y=8.75m) showing the linear feature in the west end of the chapel.

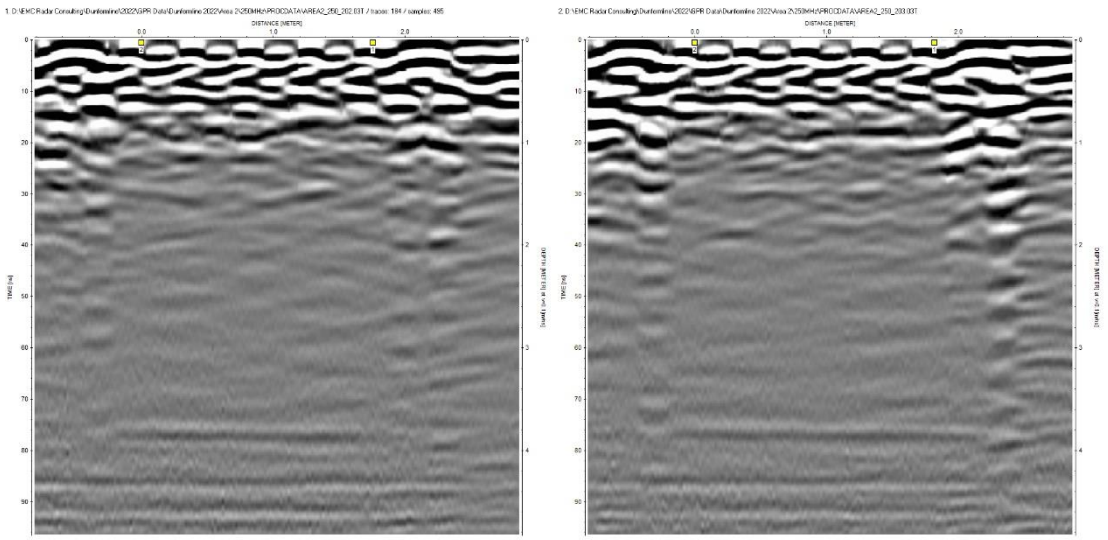

Figure 31: Survey lines 202 (y=1m) and 203 (y=1.25m) showing the features underlying the raised area at the East end of the Chapel.

Time Slice at c. 1.4m Depth

The main change at this depth is the irregularly shaped area of strong signal between 2.6m (immediately to the west of the unsurveyed area of the steps) and 3.75m on the y axis, centred around x = 2m. The linear feature to the south of the steps has also become more dominant than in the previous time slice.

The irregularly shaped feature, from comparison with the 2D data is composed of a short length of column which is close to but separate from the overlying material and therefore may indicate archaeological material. An example can be seen in Figure 25, line 208 at x = 2m (also Figure 33). Alongside this are small remnants of material. The impression is of a damaged section of construction, possibly a wall or partial floor, oriented East/West surrounded by remnants of associated material.

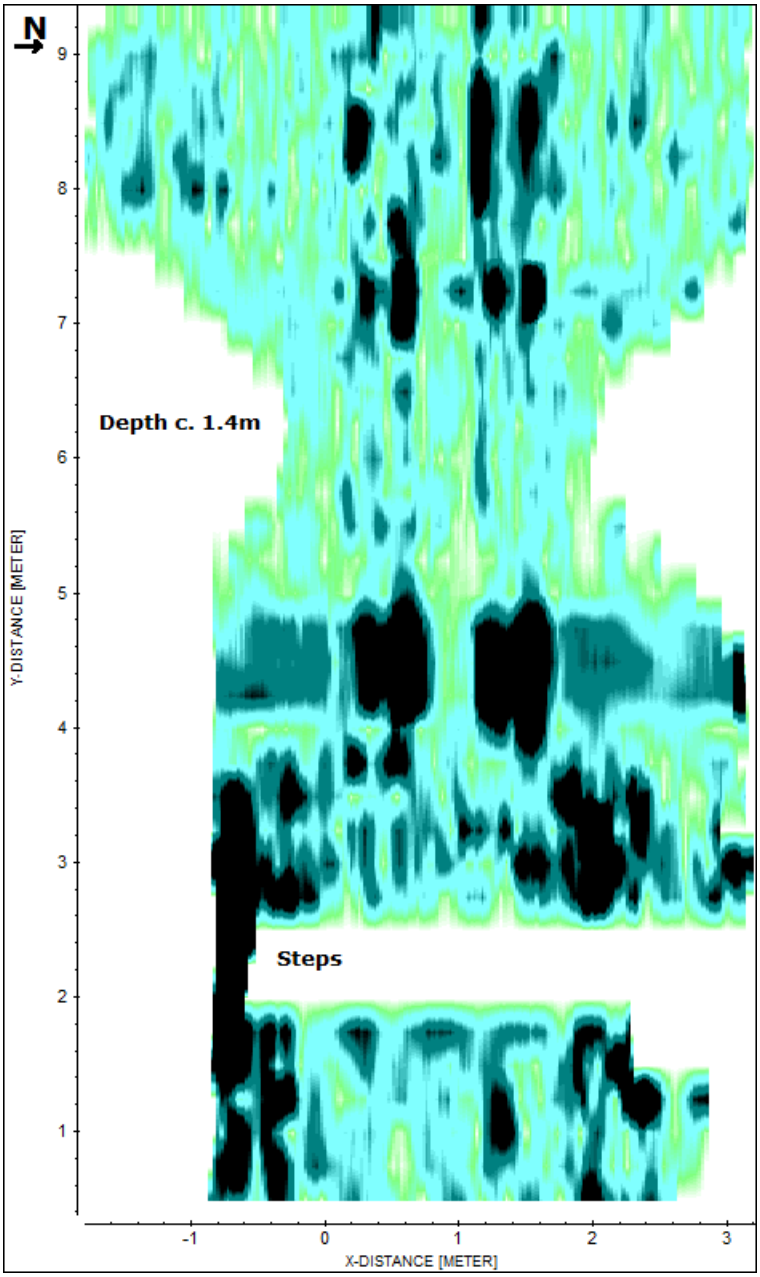

Figure 32: Time Slice at c. 1.4m depth.

The linear feature to the south of the area is more complicated. The apparent continuity across the unsurveyed area of the steps is not real. The short lengths of signal have been inserted to keep the y distances to scale. The portion of this feature to the east is structural material which corresponds to that observed in the previous time slice as is the material from y = 3.25m onwards. There is a short stretch of potentially archaeological material immediately adjacent to the steps on their western edge at y = 2.75m to 3m. Again, the extent of the potentially archaeological material is too restricted to identify its nature beyond commenting that the change from black/white banding to white/black banding in the lowest two signals could potentially be the top and bottom of a discrete object. The reversal of positive/negative polarity usually indicates the entry of signal into and out of a uniform material returning to its surrounding environment.

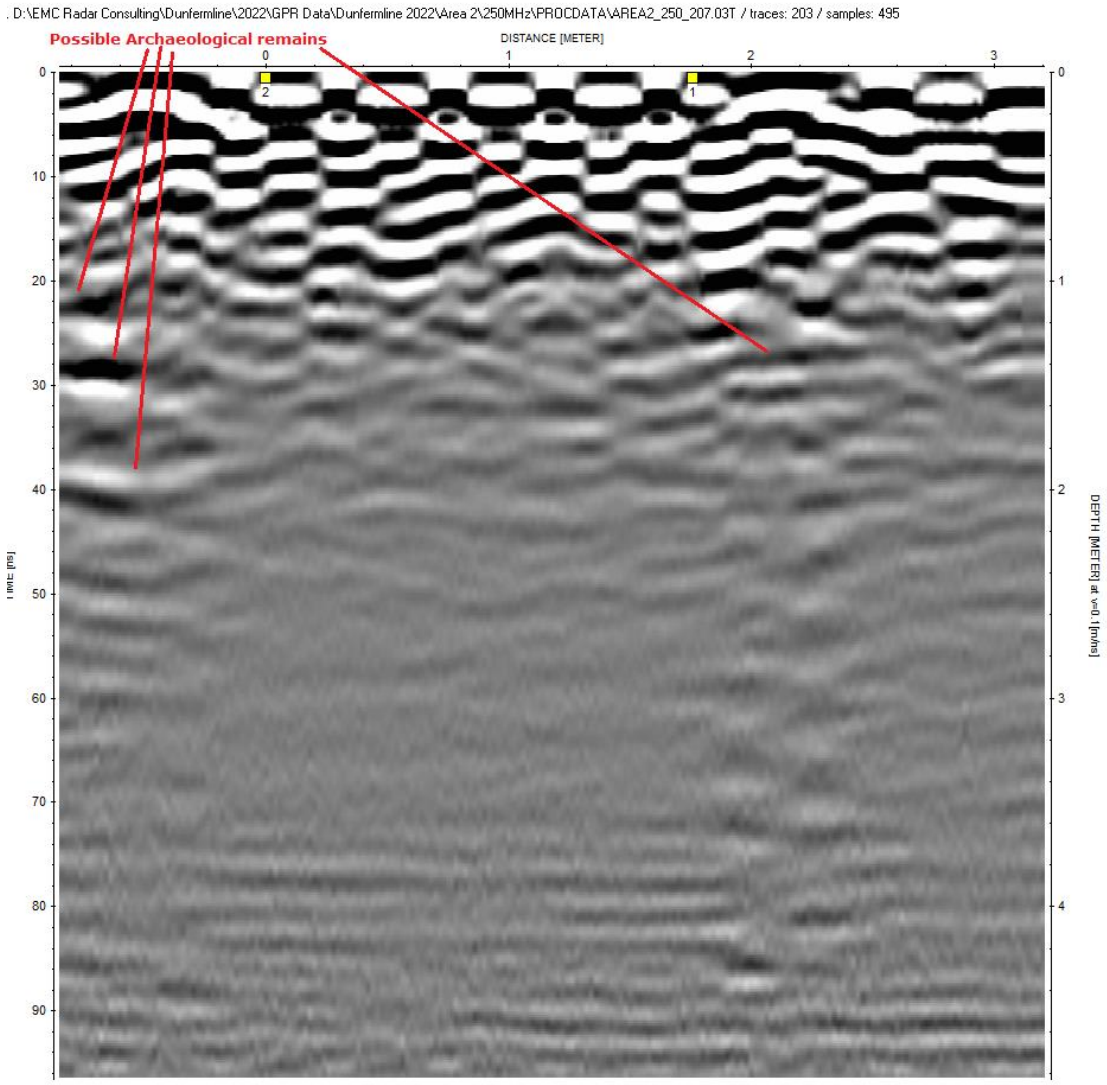

Figure 33: Survey line 207 (y=3m) showing potential archaeological material corresponding to the "linear feature", also part of the irregular feature, both from Figure 32.

Time Slice at c. 3.16m Depth

The next major change in patterning occurs around c. 3.16m depth. Most of the signals visible are echo effects. A new structure is visible in the NE corner of the chapel in the form of one right angled feature with a linear feature to the south (Figure 34). Comparison with 2D data confirms that these features are also echo effects from structures in the near surface.

Below this level there are changes in patterning, but these reflect echo effects from multiple near surface features in the layers above. Given the scarcity and small size of potential medieval remains, it is possible that there are others within this data set effectively obscured by surrounding echo effects.

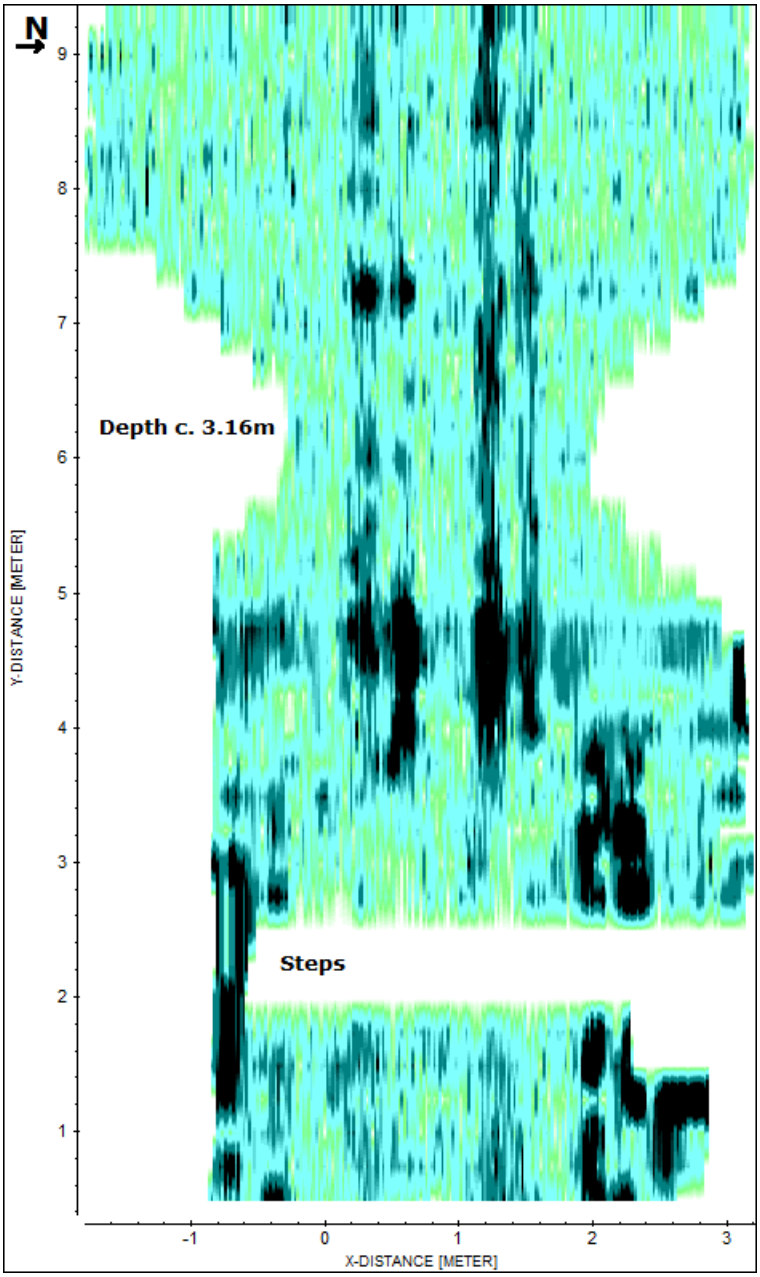

Figure 34: Time Slice at c. 3.16m depth (echo effects)

Area 2 2-Dimensional Data: 400MHz

The 2D data are very similar to the 250MHz data set showing a crowded near surface, relatively few deeper anomalies and echo effects set up from the near surface. The higher frequency data is sharper in definition. Typical data is shown in Figure 35.

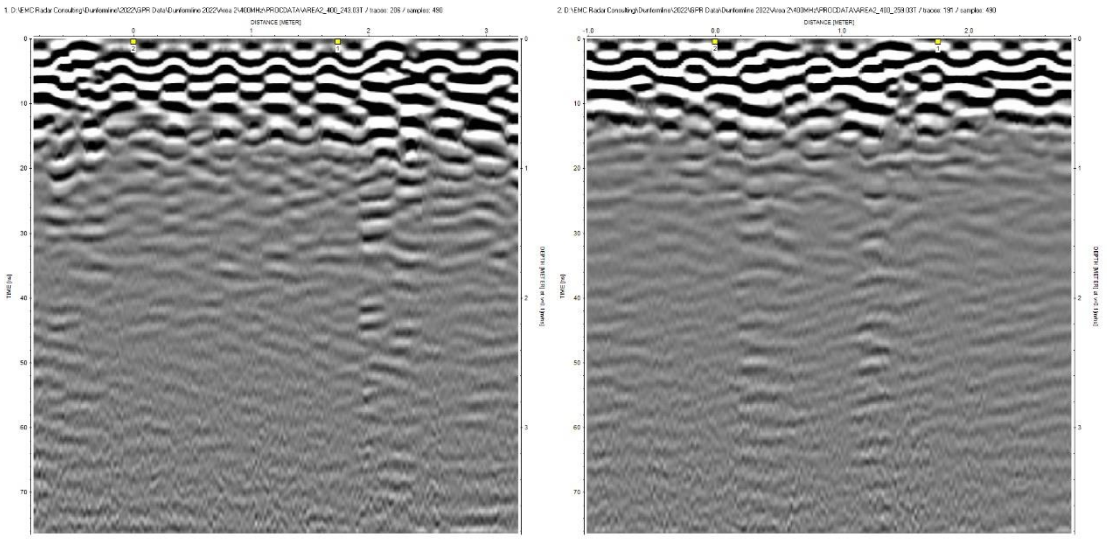

Figure 35: Lines 243 (y=3.25m) and 259 (y=8.25m).

Area 2 3-Dimensional Data: 400MHz

The smaller size of the 400MHz antenna meant that it could be fitted more easily into the step down from the raised eastern end of the chapel. The extra survey lines result in a better coverage than could be achieved with the 250MHz antenna. The only line lost is at y = 2.25m. This shows as a thin white line in the time slices.

Step height is 15cm (or 3ns). This has not been adjusted in the time slices as it makes an immaterial difference to the patterning.

Surface Time Slice

The surface time slice has been included to illustrate the elements of the floor surface composition which give rise to echo effects lower down. The dominant signals are primarily from the metallic edge of the carpet. The effect is greater in this data set due to the shorter wavelength of the radar. The effect of the floorboards is also visible in all areas except for a band in the centre of the survey area.

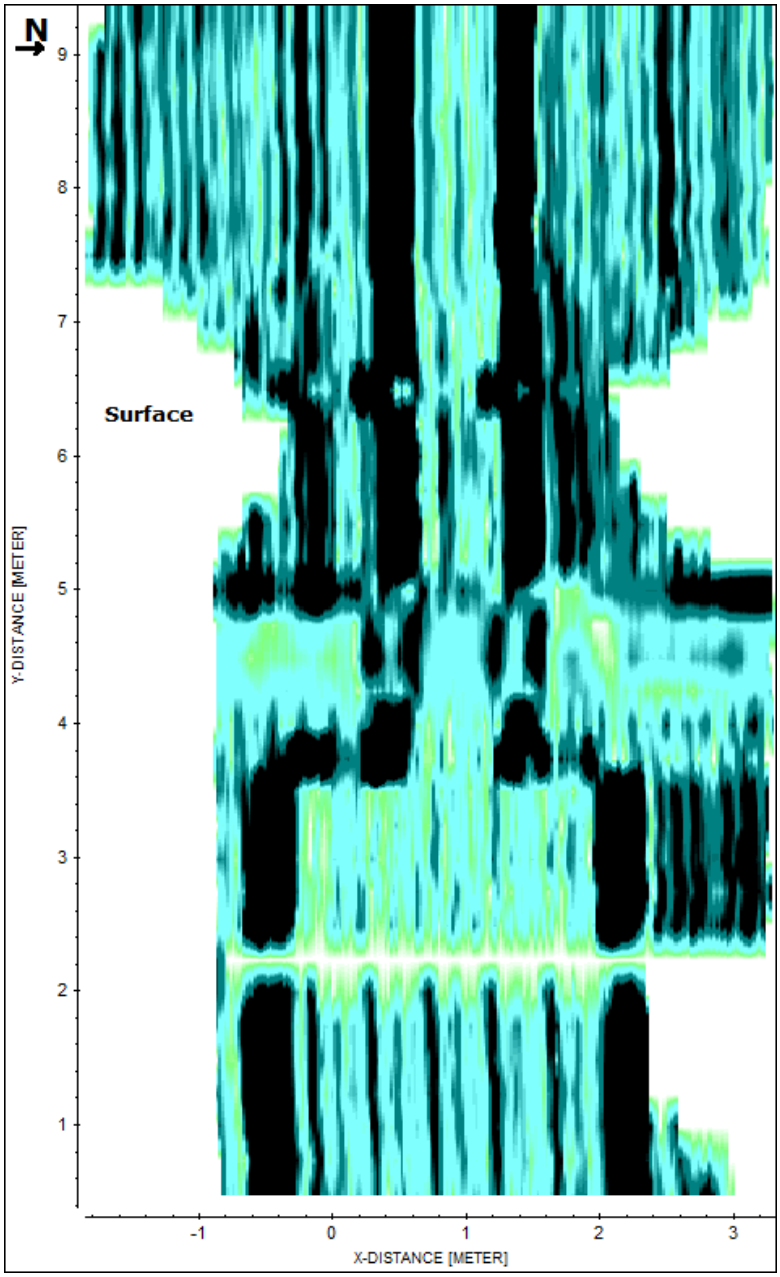

Figure 36: Surface Time Slice.

Time Slice at c. 80cm Depth

The crowded near surface includes the position of an air gap which shows clearly at c. 33cm depth (not illustrated). Most of the signals visible at 80cm depth are signal returns either from near surface modern features, including the floor boards, or echo effects from the same. In addition two rectangular features have appeared in the central section between y = 4m and y = 5m (Figure 37, cf Figures 29 and 30 in the 250MHz data).

These two features correspond to two near surface air gaps. The top and bottom of each can be clearly seen and there is ringing below both, a common feature of a defined underground void. The reversal of polarity as the signal enters and leaves the void is clearly visible cf the white/black reversal to black/white in Figure 38. Approximate dimensions are 90cm long by 45cm wide and 32cm deep. Their

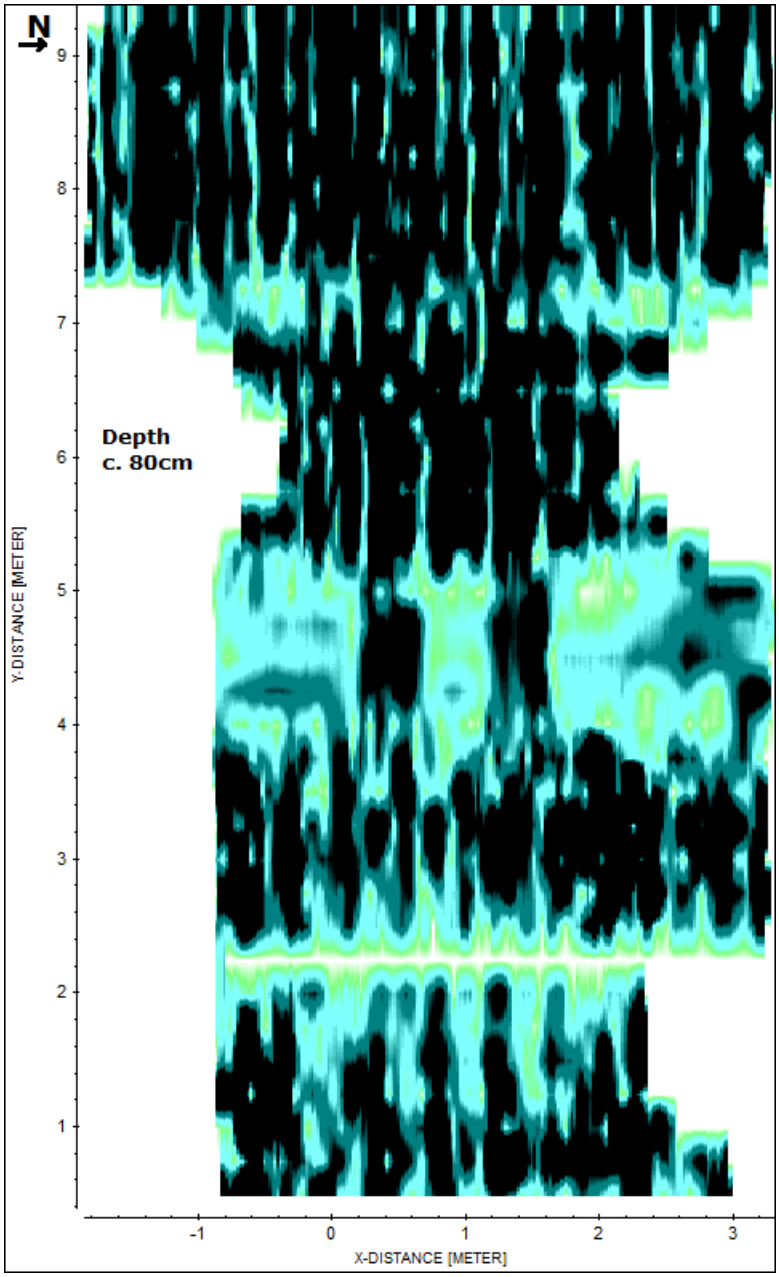

Figure 37: Time Slice at c. 80cm.

proximity to the surface makes it likely that these are modern features. The better definition in this data set also explains the double feature in the 250MHz data which, being less detailed, was less easy to analyse.

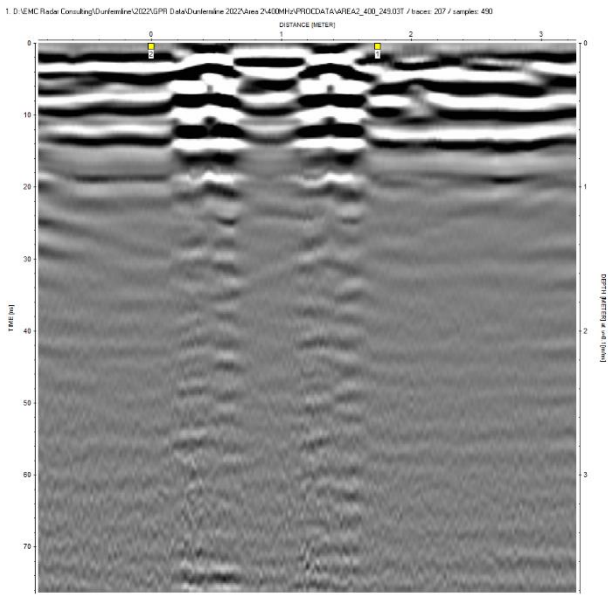

Figure 38: Survey line 249 (y=4.5m) showing 2 voids directly below the floor and their associated echo effects.

Time Slice at c. 1.59m Depth

There is one short linear feature, running East/West between y = 2.75m and y = 3.5m and centred on x = 2m which stands out clearly at this depth (Figure 39).

Comparison with the 2D data confirms this as pre-dating the modern church. The strength of signal is not a constant throughout the line. Survey line 241 (y = 2.75m) is both fainter and less substantial but has a thin layer of additional similar material directly to the north. This can also be seen in the time slice. The implication is of archaeological material, probably building remains, destroyed and either re-used or quite possibly left in situ to form part of the base of the present Abbey church.

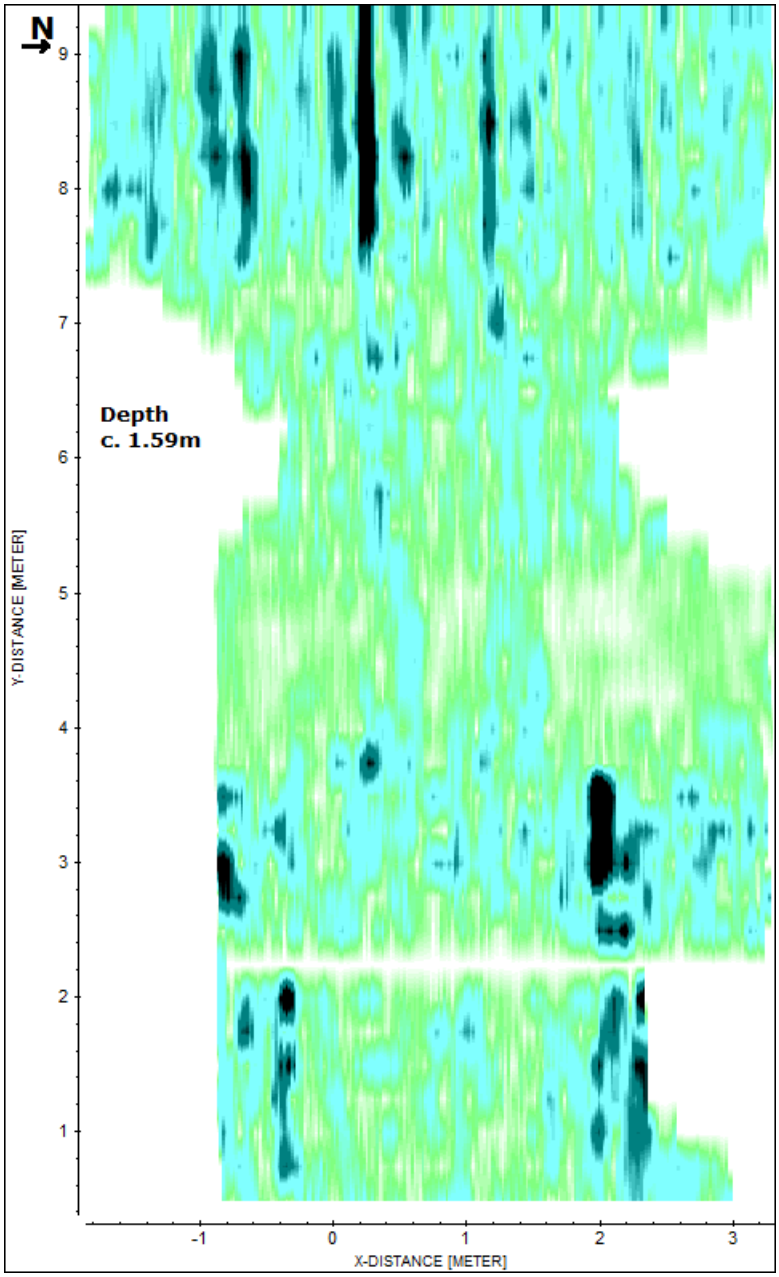

Figure 39: Time Slice at c. 1.59m depth

Time Slice at 1.88m Depth

The most obvious change at this depth is a rectangular feature in the SW corner centred on (-0.78, 8.4). The maximum length of this feature is c. 1.5m, assuming that the grouped areas are all part of one larger unit (Figure 40).

Comparison with the vertical view of the 2D data reveals this to be a thin double signal. The material does not appear to be associated with the near surface features but is not substantial and varies in both halves. The impression is either of two redeposited items of material, anomalous in the context of their current environment or of two badly damaged elements of the same feature. They may be of archaeological interest, but it is impossible to say what they actually represent.

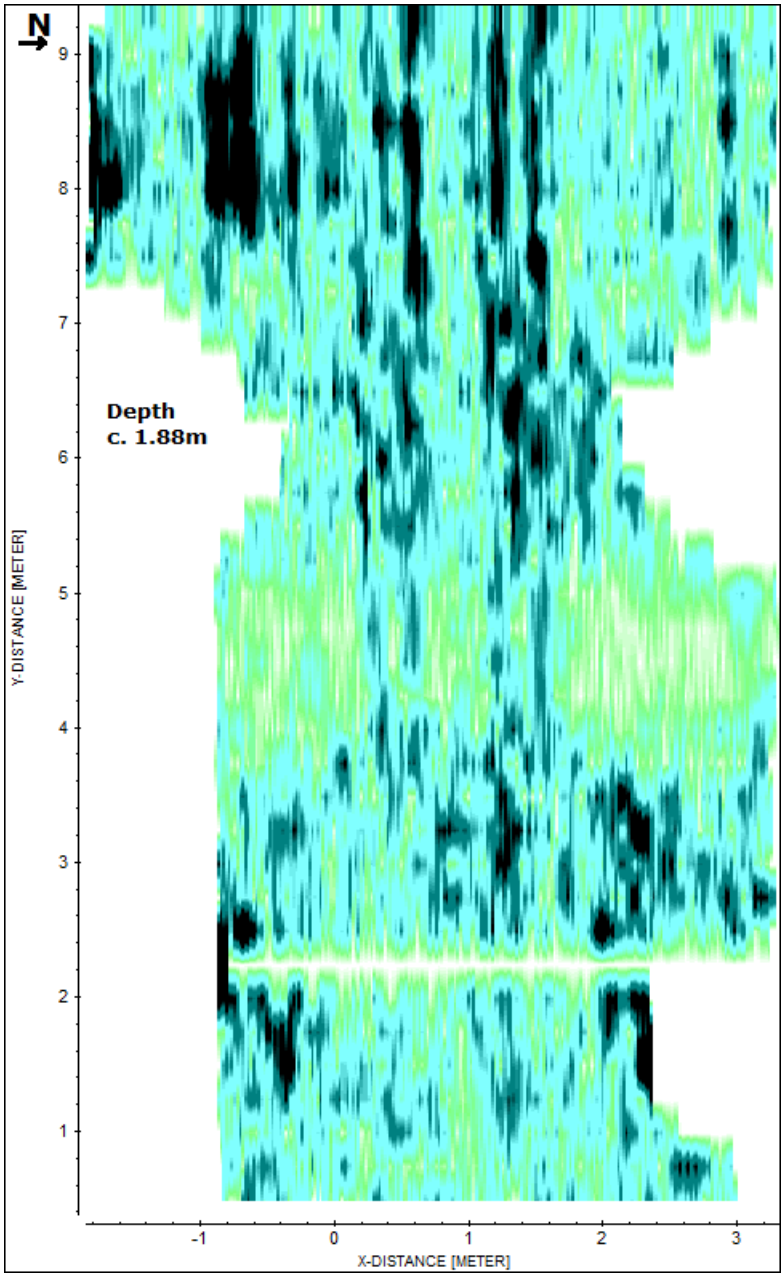

Figure 40: Time Slice at c. 1.88m depth

The material between y = 1m and y = 2m in the north side of the east end is an echo from material very close to the current floor and therefore of no great significance. The thin line between y = 1.8m and 2.6m on the south side may be more complicated but there is insufficient coverage (due to the position of the church wall) to determine what this might represent.

Time Slice at c. 2m Depth

A number of rectangular features are visible at this depth alongside some of the ringing observed previously (Figure 41). When compared with the (vertical) 2D data, the rectangular features in the SW of the survey area are mostly composed of small irregularly shaped signals. This is consistent with pockets of anomalous material

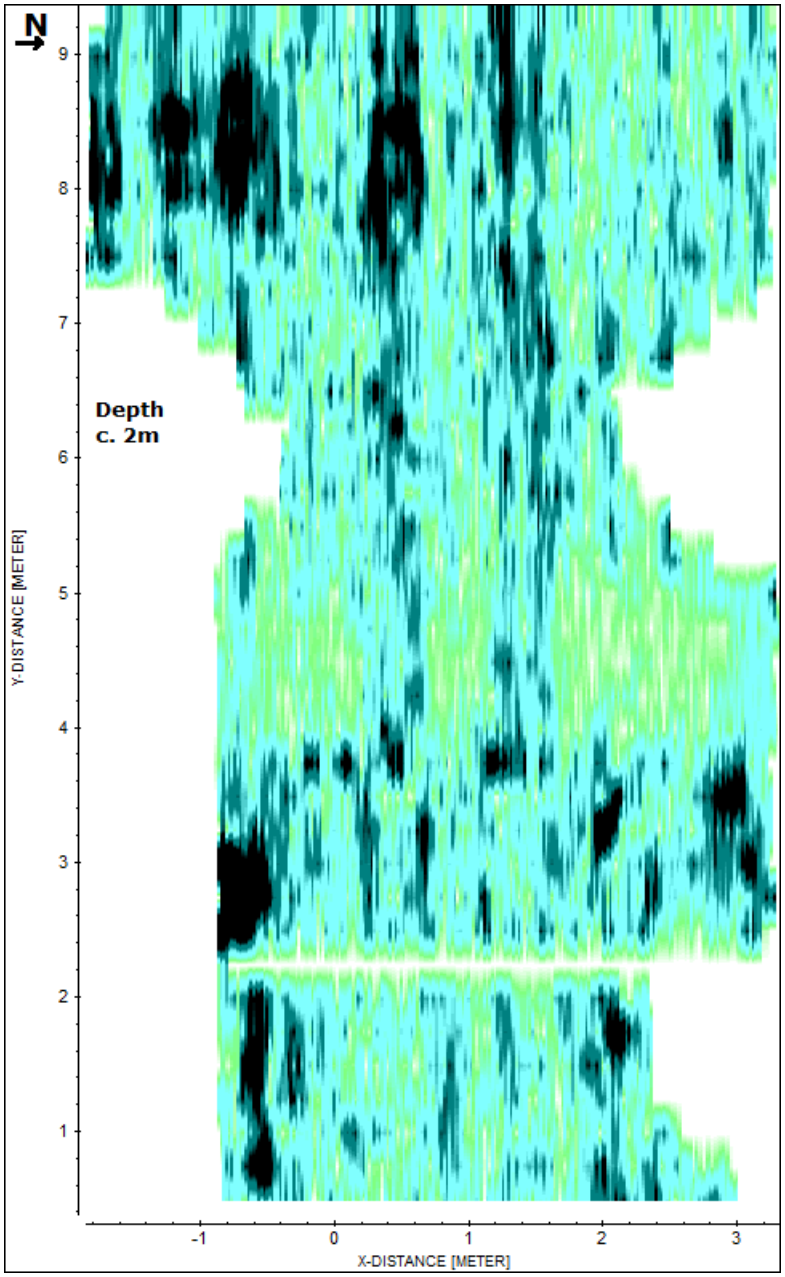

Figure 41: Time Slice at c. 2m depth

which have been damaged rather than an intact structure. There is no consistency in shape of the individual signals making up the features apparent in the time slice. It is not possible to date them by radar, but they do not appear to be connected to the near surface features and are therefore potentially connected with the medieval Abbey church. In the case of the area centred on x = -0.7m, some of the signals form parts of small columns which could contain echo effects.

The shape immediately to the West of the steps on the South side of the survey area may possibly be due to echo effects. However, the only obvious source for this is very close to the floor and does not appear to recur with consistent regularity as would be expected so this may also indicate archaeological material.

The smaller areas to the north of this feature, lying in a band defined by y = 2.6m to 3.8m appear to be archaeological material but they are small in size and there is little

continuity and no consistency in shape. This again suggests partial destruction.

The linear feature visible running East/West in the SE corner of the survey area does represent real anomalous material even though it lies below near surface features. It is not clear what this represents, and the implications of damage are visible in the time slice.

Time Slice at 2.15m Depth

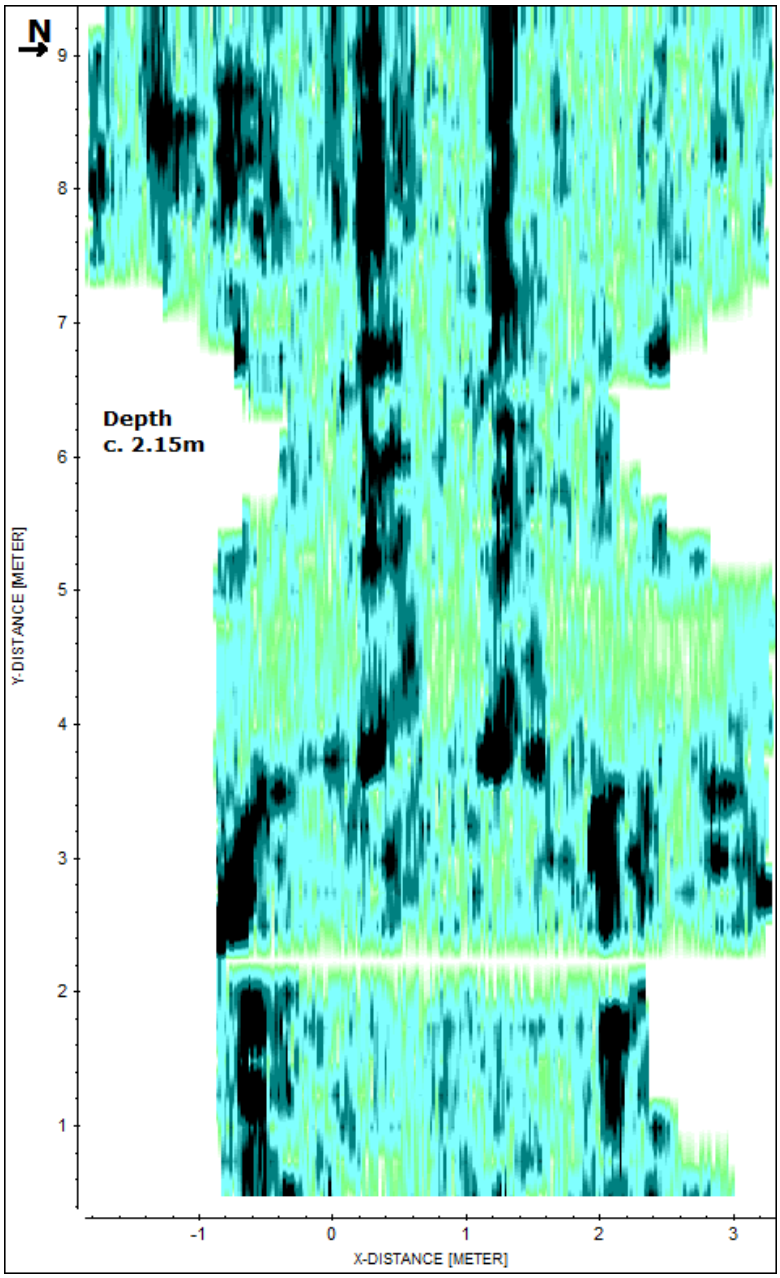

Figure 42: Time Slice at c. 2.15m depth

The patterning of this time slice reflects the ringing from near surface modern features (Figure 42). There are, however, some continuities from the previous time slice which may be reflections from real archaeological material. In the SW corner of the survey area, this comprises an irregularly shaped area around x = -0.7m and another centred on x = -1.2m. The former is similar in nature to the material at 2m being

composed of small objects and a few possible echo effects. The latter has lesser amplitude (fainter) than it appears in the time slice but does seem to contain irregularly shaped anomalous material.

The small features towards the north between y = 2.6m and 3.8m also appear to be continuations of the material observed in the previous time slice. Although the pattern of the linear feature in the SE corner now appears to be divided into three sections, this also appears to be a continuation of the structure above.

It is not possible to distinguish the material along the south wall between y = 2.5m and 3m from the echo effects immediately adjacent.

Time Slice at c. 2.55m depth

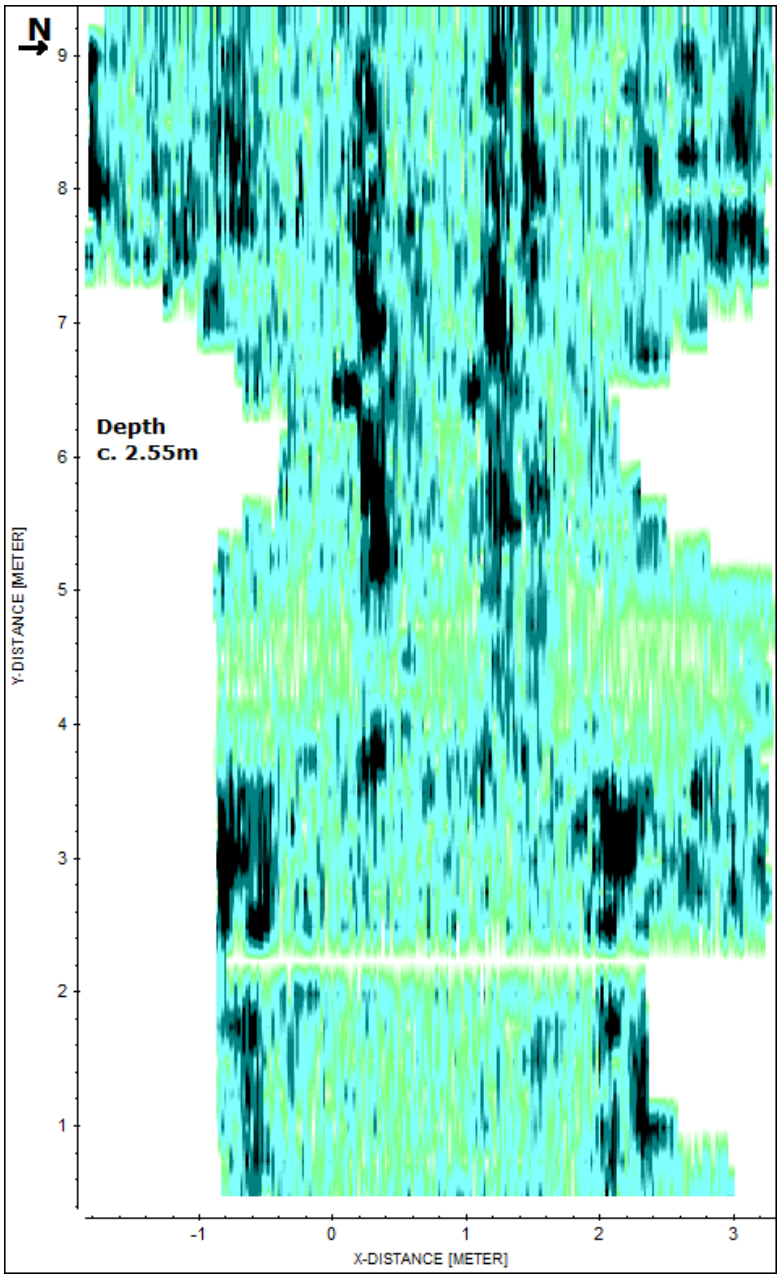

Figure 43: Time Slice at c. 2.55m depth

Ringing again dominates this final change in patterning but there are also slight indications of continuity from several real features observed in the last two time slices (Figure 43). Of the three features in the SW corner (to the south of the outline of echo effects) the partial outline next to the south wall is clearly visible, the middle one has disappeared and the third is also a partial outline. The linear feature in the SE corner is barely visible and the shape of the feature on the other side of the steps no longer follows the outline formed by echo effects and is therefore visible again.

Both vertical and horizontal data confirm that there are faint traces of the same material in the SW corner observed in previous time slices. This suggests that these are the remains of constructions rather than voids. Partly this is a question of feature depth. The transmission speed of radiowaves in air is c. three times that through soil and building materials and this would represent a significant size of void. However the pattern of traces left at this depth would not be typical of a void and the only potential echo effects lie within the feature above. There is therefore an implication of partial destruction of a feature of the medieval Abbey church.

Within the band defined by y = 2.3m to 3.6m, there are two near rectangular features. Against the south wall, this is primarily caused by echo effects. Note that radar signals form the shape of a cone, so it is possible for the signal to appear larger at depth. There is also a very small amount of anomalous material visible in line 243 at this depth (cf Figure 35).

The short rectangle to the north centred on x = 2.16m, although it lies beneath a near surface feature from which ringing emanates, does contain archaeological material which does not pertain to the modern church.

The linear feature in the SE corner of the survey area contains faint traces of archaeological material in both vertical and horizontal planes.

Time Slice at c. 2.69m Depth

There are indications at this depth of both deeper remains and the possibility of remains disguised by the echo effects from above at this and other depths. In Figure 44, those signals corresponding to actual anomalous material have “M” marked beside them and those corresponding to echo effects are marked with “R”. Most of the potential archaeological material lies westwards of the y = 3m line. Echo effects exist across the full area, mostly corresponding to the surface time slice (Figure 36).

This is again a depiction of partial destruction, presumably in advance of the construction of the new church. It is not possible to be completely sure that the little that remains are in situ but, given the depth, it is a distinct possibility.

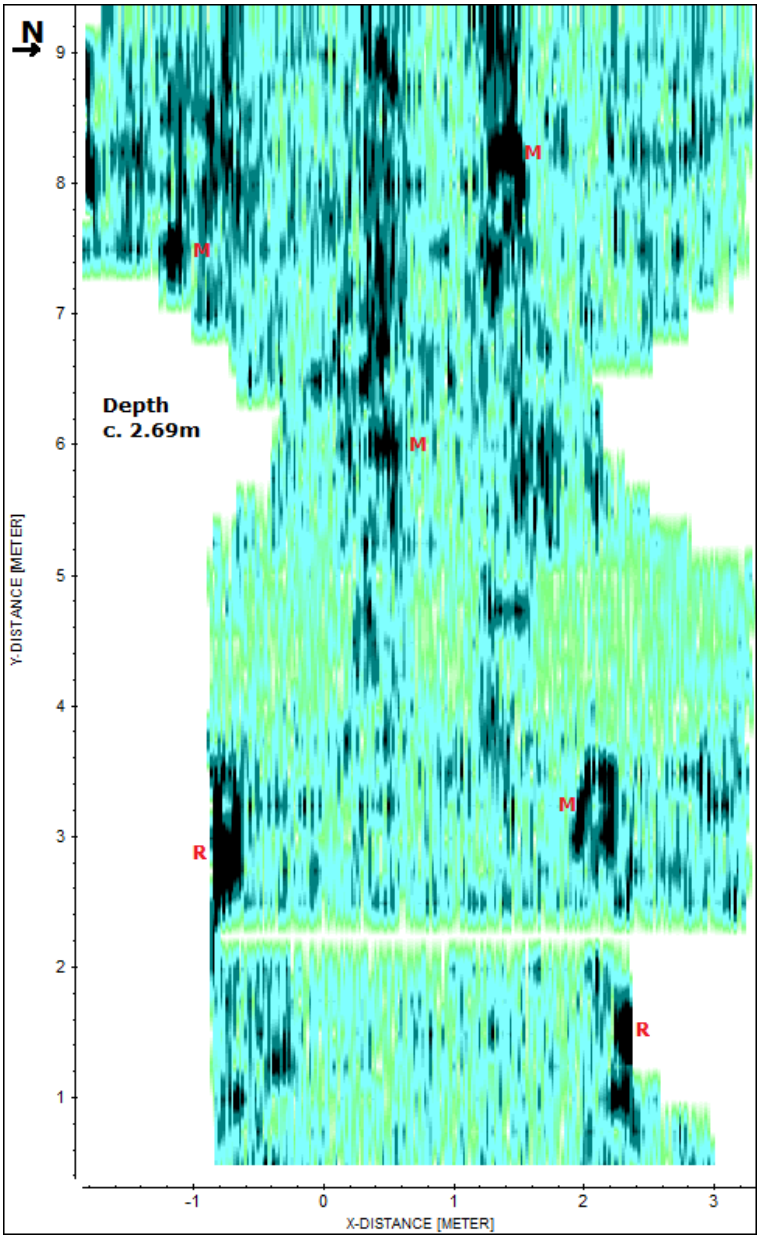

Figure 44: Time Slice at c. 2.69m depth

Area 3: The North Transept with an extension

Two parallel survey reference lines were laid out along an East/West orientation, across the North Transept with tape 1 to the south and tape 2 to the north (Figure 45). As with Areas 1 and 2, where a marker 1 or 2 has been placed on the 2-dimensional data, this indicates the position at which the radar crossed the relevant survey reference line. Gaps in the data indicate where a surface obstacle (e.g. pillar base, radiator etc) had to be worked around. The position of the survey lines were defined by measurement from fixed features as shown in Appendix B.

Figure 45: Survey Area 3, viewed from the North door. Tape 2 is in the foreground, tape 1 towards the South.

2-Dimensional Data: Area 3

The 2-dimensional (2D) data for both the 250MHz and 400MHz surveys have 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 displayed South to North and has been aligned to survey reference line 1 so that the x = 0 (distance travelled by the radar) position lies along this line. Negative distances are to the South and therefore closer to the centre of the church. Positive distances lie to within the North transept, towards the North door.

A total of 20 lines were recorded using the 250MHz antenna and 21 lines with the 400MHz antenna. The difference is due to the larger size of the lower frequency antenna.

Area 3 2-Dimensional Data: 250MHz

Typical 2D data for this area shows a crowded shallow subsurface, a considerable number of echo effects both at depth and close to the floor, a number of signals below the immediate subsurface and at least one area of lost signal (Figure 46). The area of lost signal is less extensive than that observed in the Memorial chapel.

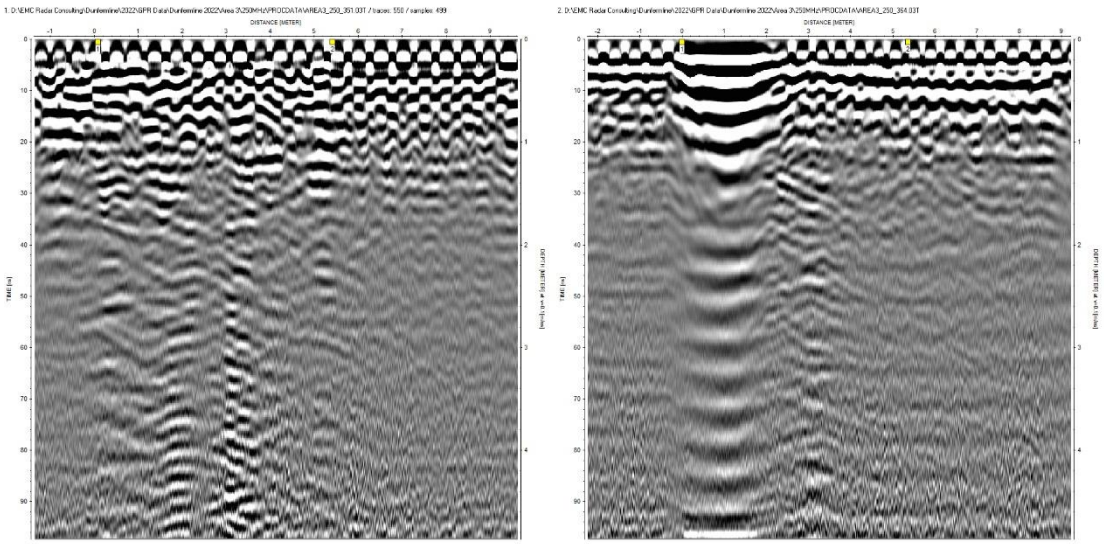

Figure 46: Survey lines 351 (y=1.4m) and 364 (y=3.9m), typical 2D data from the North Transept and its extension towards the South.

Area 3 3-Dimensional Data: 250MHz

The 2-dimensional (2D) survey lines from both surveys have been incorporated into a 3-dimensional (3D) data block based on their relative positions along survey line 1. Time slices, horizontal plans, have been extracted from this data block based on the change in signal patterns visible in the data. West is at the top of the page for all the time slices.

Surface Time Slice

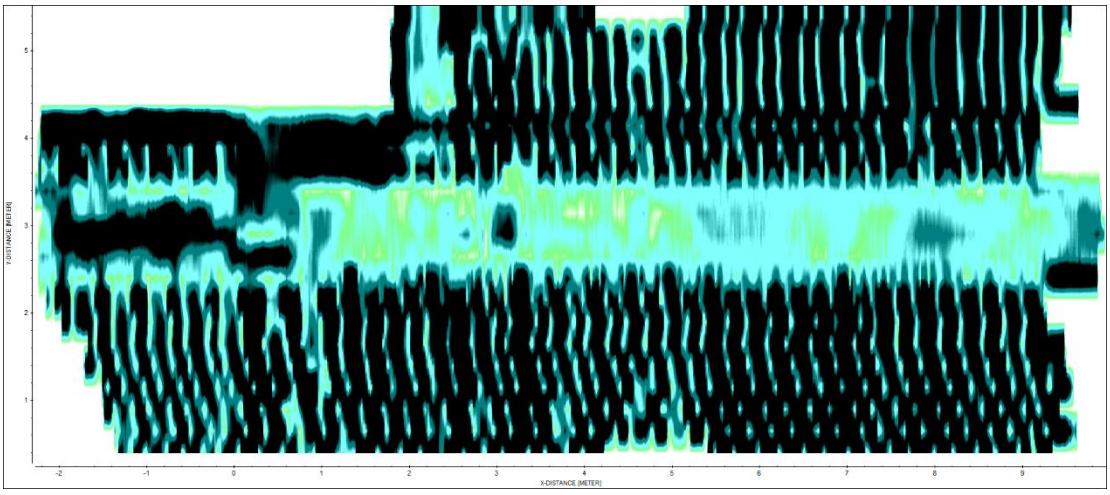

Figure 47: Surface Time Slice

The surface time slice is included to demonstrate the elements of the floor construction which result in echo effects lower down.

Time Slice at c. 89cm depth

This time slice shows a discontinuous linear feature oriented North/South down the middle of the survey area (Figure 47). The various elements line up along y = 2.9m which implies they are connected. Comparison with the vertical data indicates that

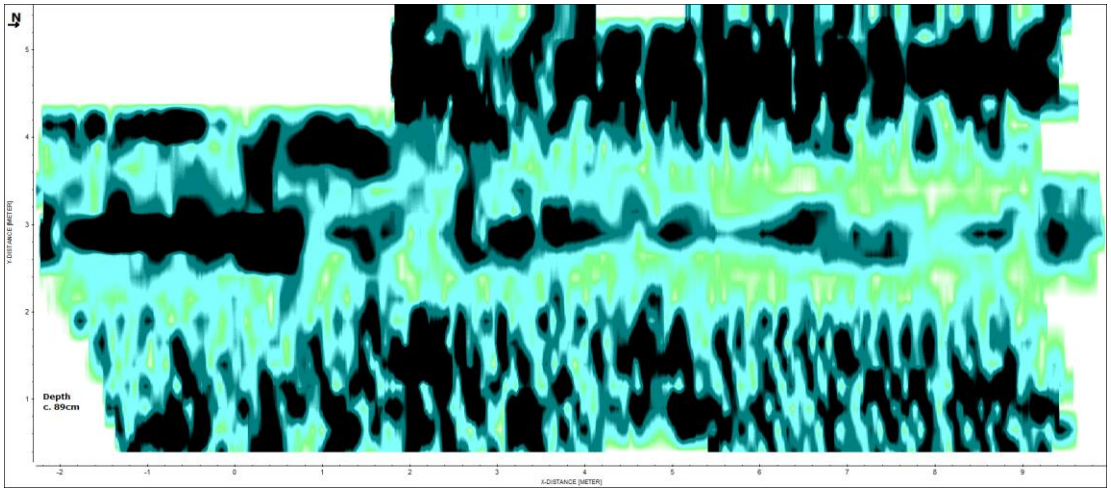

Figure 48: Time Slice at c. 89cm depth

the first portion of this, between x = -1.9m and 0.78m cannot be distinguished from the feature in a similar position, visible above in the surface time slice and they are likely to form the same feature (Figure 49). The 2D data also suggests that this feature may contain a void, from the echo effects below.

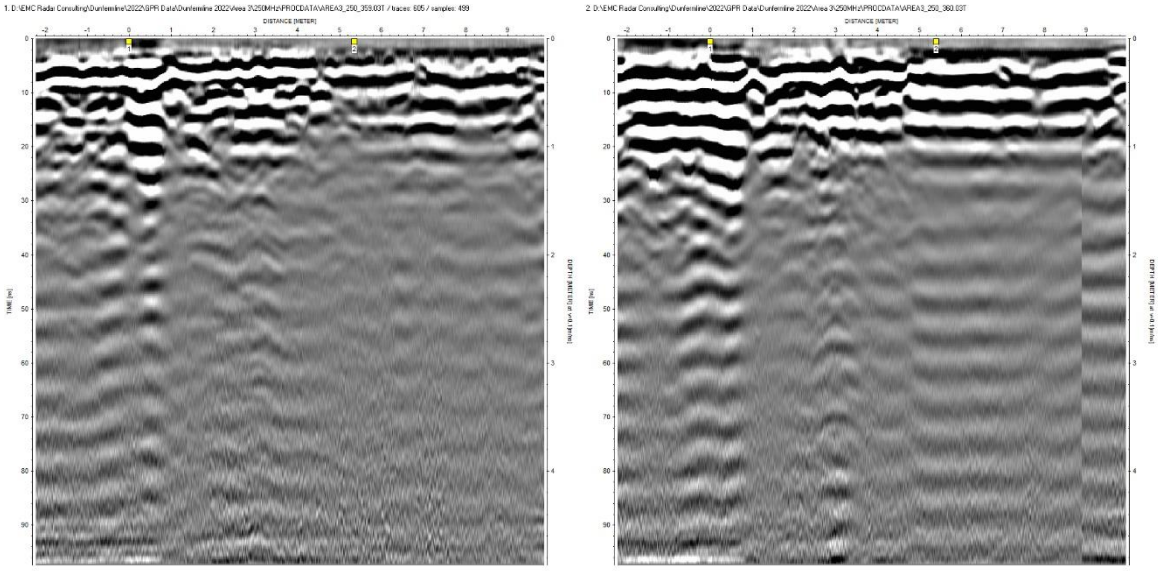

Figure 48: Survey Lines 359 (y=2.65m) and 360 (y=2.9m).

Survey line 359 suggests that there is a near surface void between x = 0 and 1m. There are echo effects repeating below this. Line 360 is rather different. The first metre of deposit forms the subsurface of the current church. Most of it is characterised by strong black and white banding which is not uniform. The first section from the start to x = 1m may well be a void but the signals visible below 30m are real (rather than echoes) and strong enough to disguise any ringing. The next section, up to x = 4.6m is less regular in appearance and also has underlying material, including a smaller feature which gives to rise to echo effects. The final section from x = 4.6m to the end is strongly suggestive of a void and all of the signals below are echo effects. This area is reminiscent of parts of the South Aisle and also the central area of the Memorial Chapel (cf Figure 15, line 5 and Figure 38).

Time Slice at c. 1.86m Depth

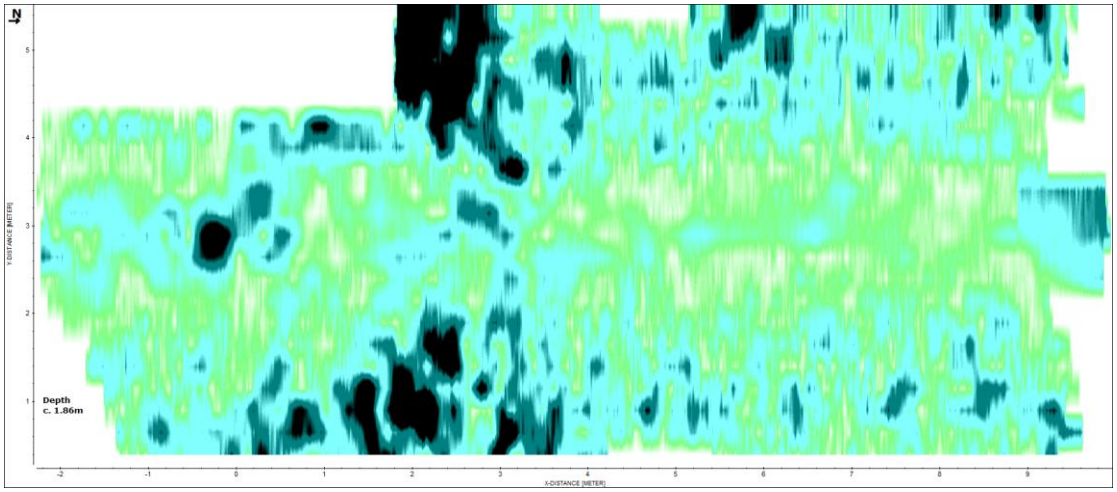

Figure 50: Time Slice at c. 1.86m depth

At this depth there are two main areas of strong signal: a roughly rectangular area in the SW corner (where it meets the edge of the carpet) and a series of roughly shaped features approximately opposite along the eastern edge (Figure 50). One further small area is visible, centred on (-0.24, 2.8).

The 2D data suggests that this material is sufficiently deeper than the near surface material to be of archaeological interest. Line 351 in Figure 46 illustrates that the irregular outlines of anomalies along the eastern edge lie below the near subsurface. These are not echoes but new material. Both vertical and horizontal patterning is of a scatter of anomalous material. The irregularity suggests damage in the past prior to the construction of the present church or possibly post depositional intrusion. There is some ringing visible in the 2D data, but this begins below the 37ns (1.86m) depth.

On the West side of the survey area the first metre of strong signal is an echo effect from the surface which is probably generated by the metallic edge of the carpet. The next part of the anomaly is also the result of ringing from the near surface but may also contain other material at this depth. The remaining small areas along the western edge appear to be potential archaeological material (Figure 51).

The remaining dark area of signal, towards the south is an echo effect which appears to originate at c. 1m depth from the floor.

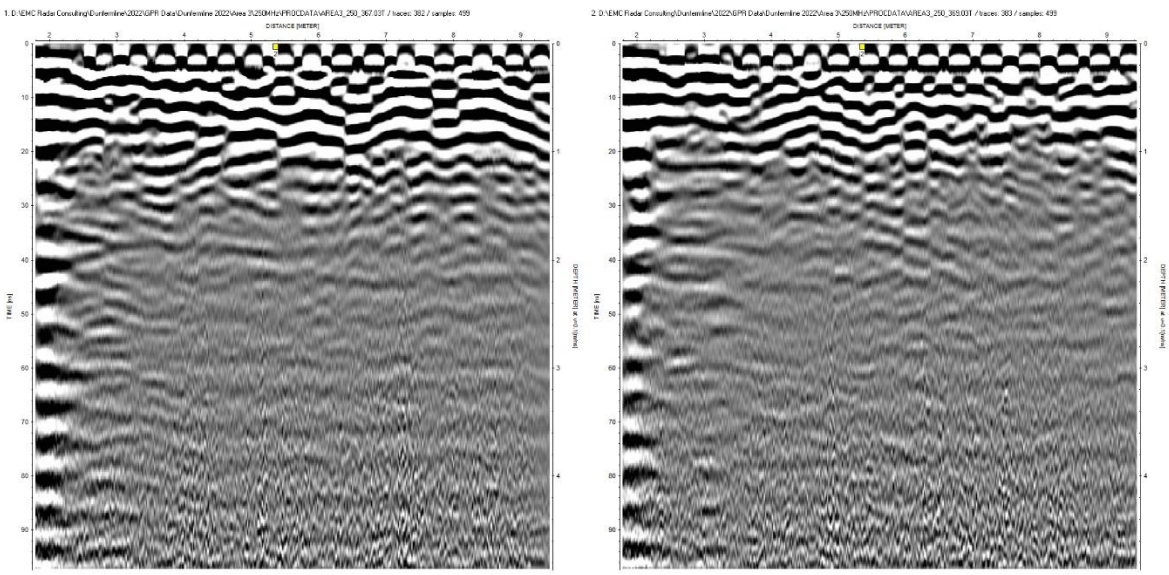

Figure 51: Survey lines 367 (y=4.65m) and 369 (y=5.15m)

Time Slice at c.1.98m

The overall pattern of this time slice is very similar to that of the previous one. The main differences are a rectangular outline (with North/South axis) by the North door and the extension of the previous areas of strong signal returns (Figure 52).

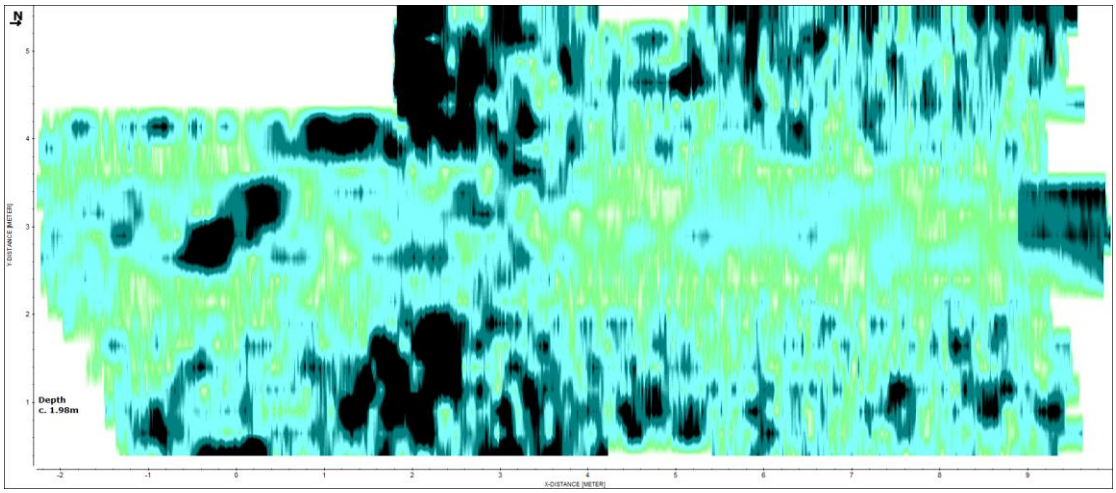

Figure 52: Time Slice at c. 1.98m depth

The rectangular feature by the door results from a disjoint in the data which is not due to the movement of the radar across the floor but to the insertion of a near surface structure and echo effects below this. This is therefore the echo of a more modern structure connected with the north door.

The North/South rectangle from x = 1m to 2m along the western edge is ringing from what appears to be a substantial feature immediately below the floor. This feature can also be seen in the surface time slice (Figure 47).

Looking along the western edge of the survey area, the smaller elements do represent anomalous material but without any obvious overall pattern either within the 2D vertical or the horizontal data.

The thin rectangle next to the SW corner is again showing as ringing from the surface. The thinner line immediately adjacent (and to the north) appears to be layered material. The small rectangle immediately beyond that (to the north) is also possible archaeological material. A definite area of disturbance is visible at x = 5.9m which might be the remains of a burial (see Figure 51 around x = 3m at a depth of c. 40ns (2m). As can be seen from the time slice, it is impossible to define the area originally covered.

More interesting is the area previously visible along the eastern edge, directly opposite. This also shows signs of disturbance over a slightly more coherent area. The disturbance is obvious and includes echo effects (not from above) in at least one survey line (Figure 53).

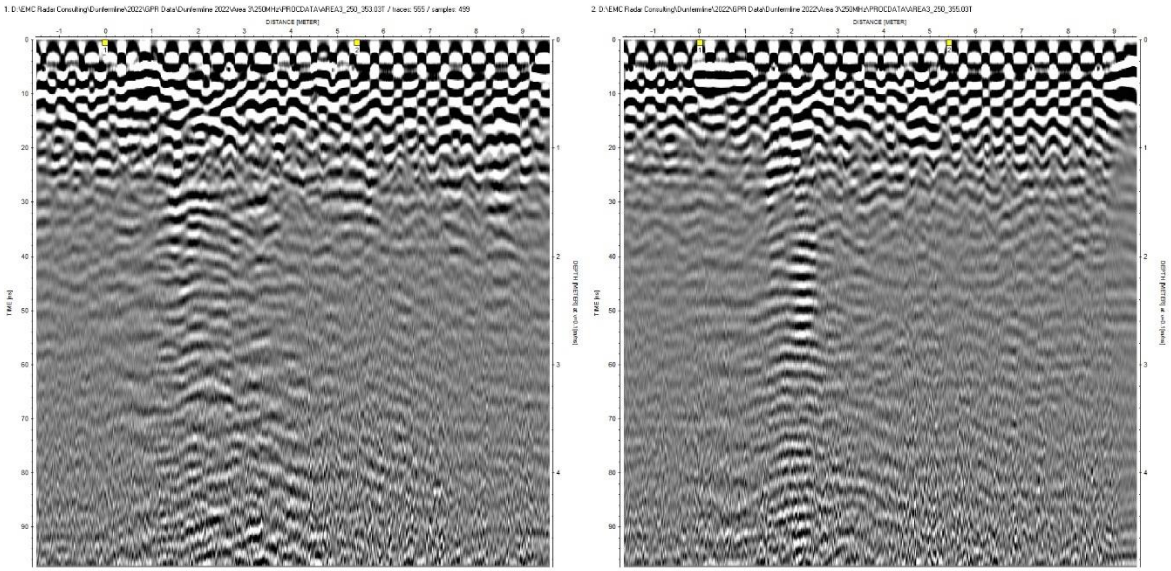

Figure 53: Survey lines 353 (y=1.15m) and 355 (y=1m65) showing an area of disturbance (both lines) with associated internal ringing in 355).

The single patch of strong signal in the southern quarter has now become two adjoining patches, both of which are the result of echo effects from the near subsurface.

Time Slice at c. 2.65m Depth

At this depth there are four obvious areas of ringing and two of potential burials, as evidenced by subsurface disturbance. The echo effects are seen in the rectangular area by the north door, the first metre of West/East rectangle at the SW corner, the North/South rectangle from x = 0.4m to 1.7m along the western edge, the two adjacent areas in the middle of the southern section. All have been identified in shallower time slices and confirmed in this one by comparison with the vertical data.

The entire group of anomalies along the eastern edge are composed of disturbed material, implying the existence of burials. None shows a complete outline or central air gap which makes them look unlike the remains of a royal or prestigious burial. The images are consistent with burials in earth which may have been disturbed post deposition. If this is the case there has been an attempt to reinstate the remains, such as they were, resulting in mixing in of soil from the surrounding environment (Figure 53).

The group of scattered strong signals on the western edge directly to the north of the

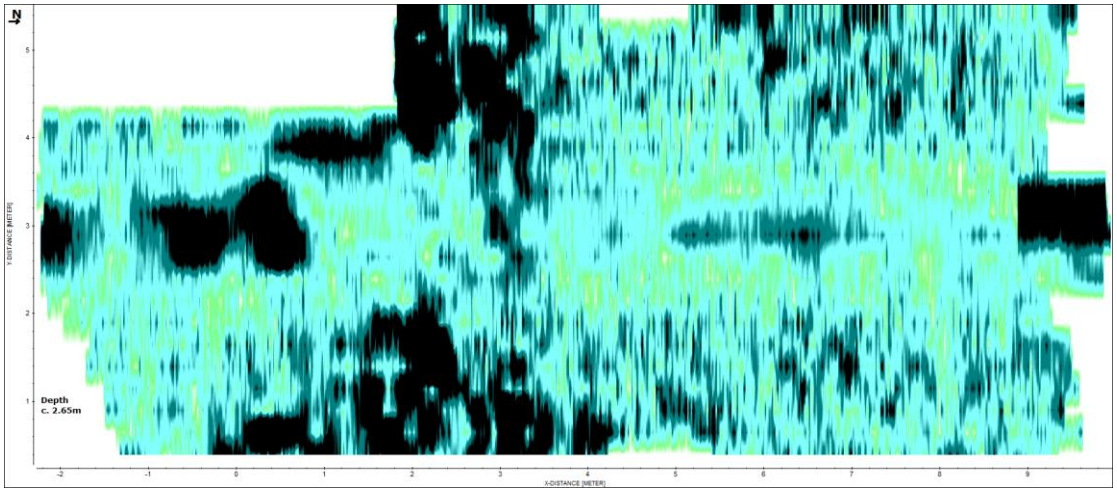

Figure 54: Time Slice at c. 2.65m depth showing a mixture of echo effects and of disturbance likely to indicate burial locations.

rectangular feature identified as ringing again represents disturbance and implies disturbed burials. This is also true of the smaller groups of strong signal return further towards the north door (See Figures 46 and 51).

This raises a potential question as to the nature of the rectangular near surface feature in the SW corner of the survey area, lying along a North/South axis. It is both large and distinctive cf line 364 in Figure 46. Although it lies very close to the surface, it could potentially be related to the adjacent burials if, for example, there had originally been an entrance of some sort. The echo effects suggest a large air gap in association with some form of material impermeable by radiowaves such as metal. It is not possible to determine from the radar data alone whether this is speculation or a possibility.

Time Slice at c. 2.9m Depth

A mere 25cm deeper, the outline of some of the remains visible on the eastern edge have resolved into more extensive areas including a partial rectangular shape lying in an East/West orientation.

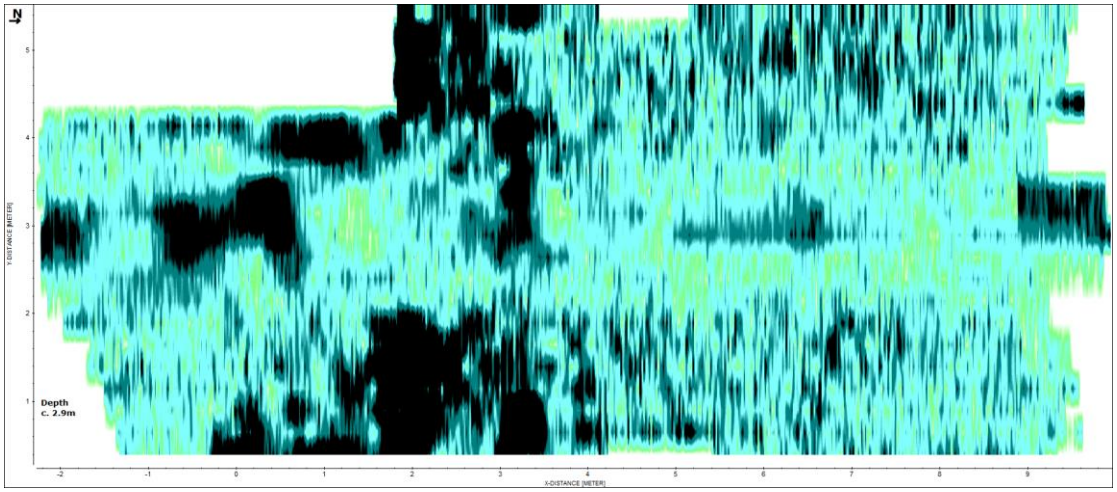

Figure 55: Time Slice at c. 2.9m depth

The rectangular feature centred on x = 2m cut by the eastern edge and the smaller one lying to the north of it contain material consistent with burial in soil (cf Figure 53). Although they show in the time slices as separate, the 2D data suggests that they may be linked. The larger area shows a considerable degree of disturbance above this level (Figure 53). Typically this may be caused either by repeat burials in the same location, one on top of the other, or by investigation of the burial some time after interment. In either case, the pattern is caused by disruption of the packed earth which can introduce other materials (typically air but also remains of any other material in the vicinity) or mixed levels of soil with different chemical composition giving rise to different electromagnetic responses. This burial (or burials) being indoors and protected from the weather would not have the equalisation effect of rainwater passing through which tends to remove the air pockets and to settle the ground. Even so, the same type of patterning can be found in present day cemeteries although how long the pattern lasts in an outdoor context has not been determined.

The material to the south of this area, also lying on the eastern edge, does not extend sufficiently into the survey area to be sure that it is a similar feature. On the northern side, the scatter of material between x = 4m and 7m resembles a compacted version of the probable burial but, if it is, lacks the depth of later intrusion as the disturbance is much less (Figure 53). If this were a burial area, these properties would imply greater age and lesser post depositional disturbance. Unlike the probable burial, there is less substance at lower depth. The evidence is essentially ambiguous as this could simply be a reflection of levelling ground in advance of building the present Abbey church.

The butterfly shape in the southern central portion of the survey area represents echo effects from near surface features, in the case of the northern half from a probable void (cf Figure 49). As previously, the rectangle lying along an East/West axis bordering the SW corner of the survey area is also the result of echo effects as is the North/South rectangle by the North door (cf Figures 51 and 49 rhs). This is also true of the North/South rectangle along the western edge between x = 0.35m and 1.4m, the feature from which signal below the near surface is blocked (cf Figure 46, rhs).

This leaves two other main features, both oriented East/West, the first centred on x = 2.67m from y = 4.2m to the western edge of the survey area and the second centred on x = 3.2m from y = 2.8m to 4.3m. There are two smaller possible extensions directly to the West of the latter. It is not clear what the first of these represents but there is real buried material directly alongside the echo effects from the feature at the SW corner. The feature closer to the central area also contains ringing but the depth at which this starts varies being shallower at the west end than at the east where it includes a feature very similar to the rectangle lying North/South along the western edge. In Figure 56, line 361 is typical of the eastern end of this feature and line 363 shows the proximity and apparent connection to another area of blocked signal in the near surface. It appears likely therefore that these features were once part of the same structure. If this is correct, the gap between the two in the time slice implies destruction prior to the construction of the present church. (Figure 55).

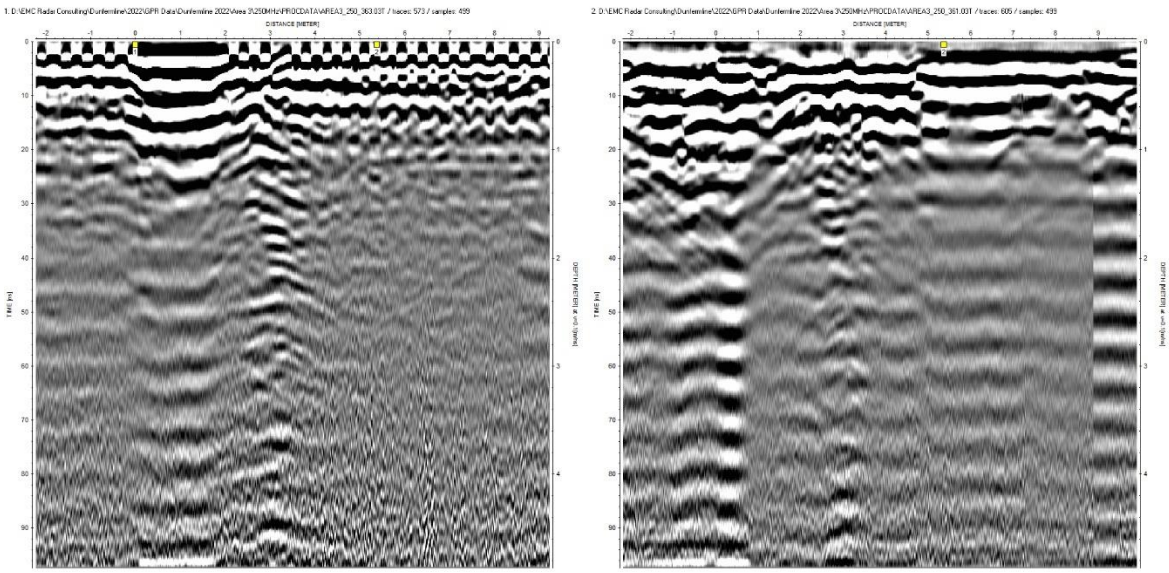

Figure 56: Survey lines 363 (y = 3.65m) and 361 (y = 3.15m)

Time Slice at c. 3.3m Depth

At this depth, the main features follow essentially the same layout as the previous two, the principal difference being the patterning from the presumed burial area along the eastern edge. The respective evidence for identification as archaeological material or echo effects is unchanged.

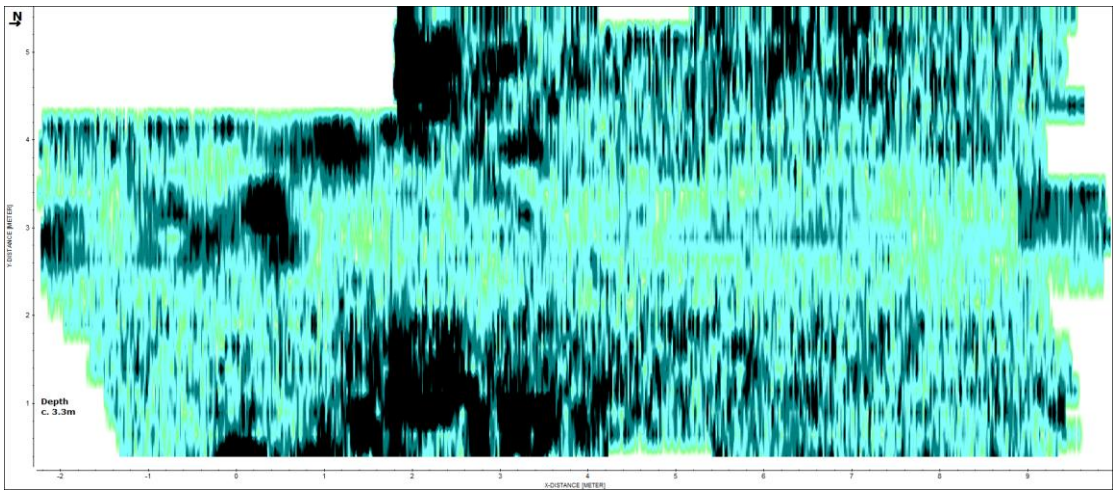

Figure 57: Time slice at c. 3.3m depth

Below this level a similar outline is observable albeit less clear from cumulative echo effects.

Area 3 2-Dimensional Data: 400MHz

The 2D data collected using the 400MHz antenna in Area 3 follows a similar pattern to the 250MHz data set with a crowded shallow subsurface; evidence for possible archaeological remains in the east; at least one area where radiowaves have been unable to penetrate beyond the near subsurface; and considerable ringing. Figure 58 shows typical output.

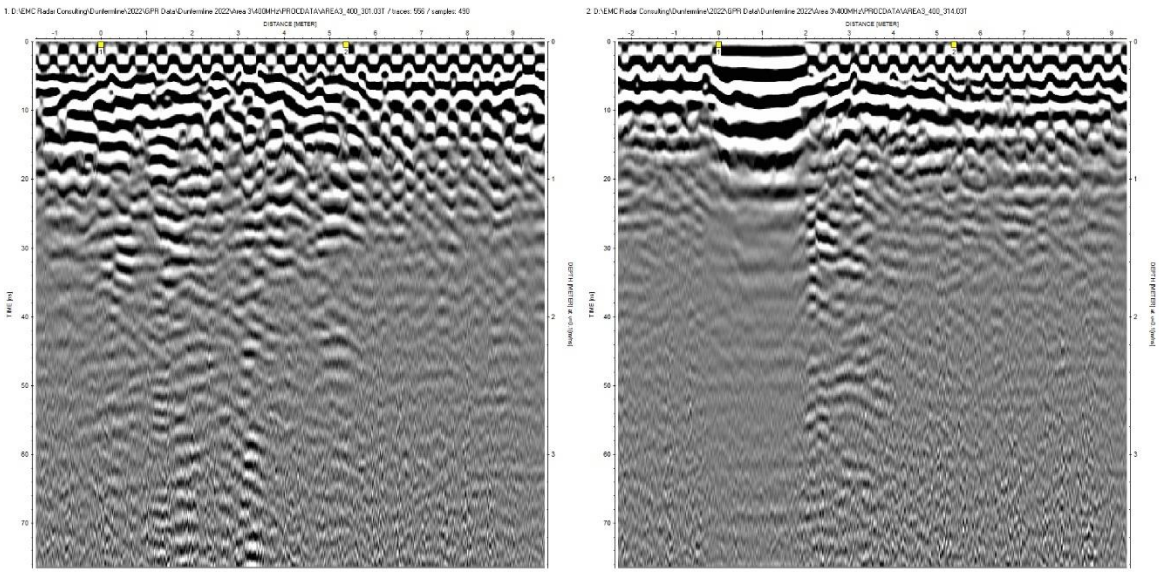

Figure 58: Survey lines 301 (y = 65cm) and 314 (y = 3.9m)

Area 3 3-Dimensional Data: 400MHz

Although the 3D 400MHz data highlights the same general areas as that generated with the 250MHz antenna, the variation in patterning is not as great. This may be because the depth reach of this antenna is considerably shorter. In part this is due to the shorter wavelengths emitted but it is also affected to a greater extent by the lossy components of the soil composition, probably the clay element. This effect will increase with depth as soil moisture increases.

Surface Time Slice

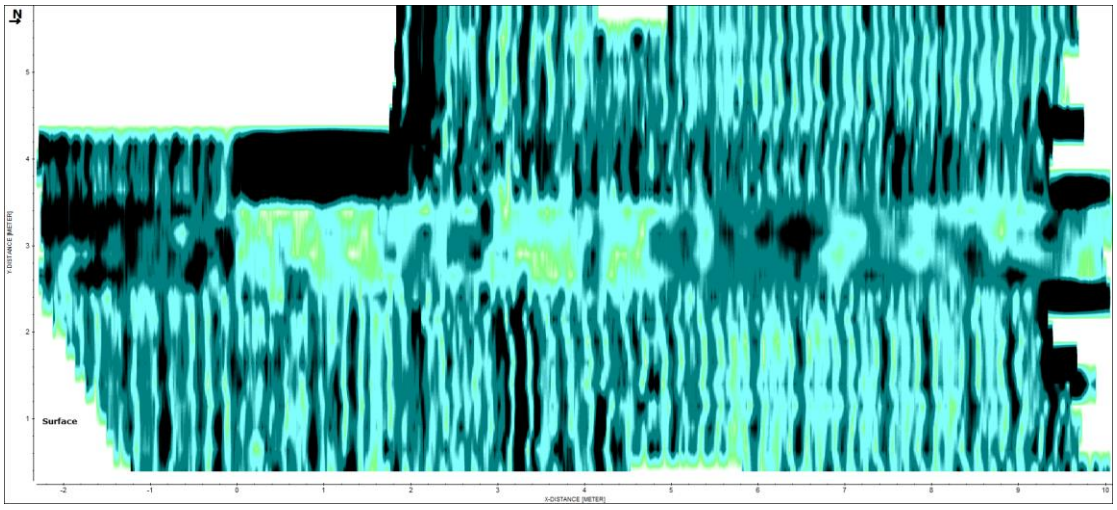

Figure 59: Surface Time Slice

The surface time slice is included in order to identify near surface features likely to cause echo effects at depth. These include the North/South rectangular feature along the western edge, the smaller West/East rectangle at right angles to the western edge, four positions around the North door, one irregular feature in the centre north sector

and the floorboards. The pattern is consistent with that recorded with the 250MHz antenna, allowing for the difference in wavelengths (cf Figure 47).

Time slice at c. 88cm Depth

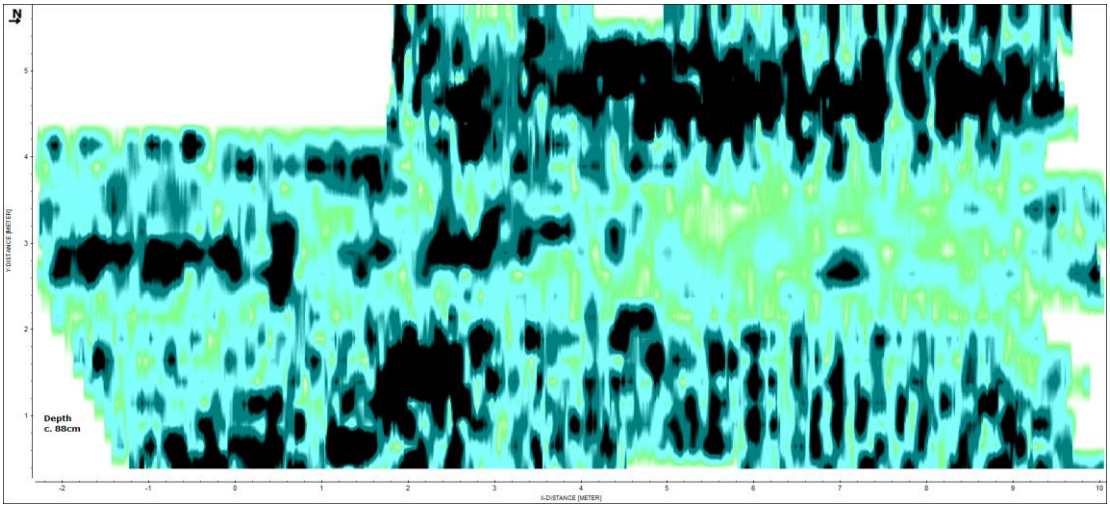

Figure 60: Time slice at c. 88cm depth

This time slice highlights the western edge of the survey area except for the rectangular feature aligned East/West along the SW edge seen in the lower frequency survey. A number of disparate areas of strong signal return mark the centre of the survey area from south to north. This is the first indication of the probable grave seen in the 250MHz data. There is a suggestion of additional material towards the south but, as for the western sector, this whole eastern section suffers from ringing from the floorboard spacing above (Figure 60).

Comparison with the 2D data confirms that all of this material lies relatively close to the underside of the floor. None of it appears to be the result of ringing and any visible echo effects emanate below this depth. The type of material represented here varies from potentially disturbed ground on the eastern edge between x = 1m and 3m to constructions below floor level e.g. the central North/South line and much of the material along the western edge. It therefore seems likely that most of this material may relate to the operation of the present Abbey church.

There are two exceptions. The first is the area between x =1m and x = 3m which relates to the potential burial material observed in the 250MHz time slices at greater depth. The second is at x = 4m to 5.55m where there is a distinctive bridge type outline visible between x = 3.7m and 5.4m (Figure 61). This is the lower end of a single object. The banding above reverses at this depth indicating radiowaves entering one material and exiting lower down. The gap appears to be c.8cm (calculated at a velocity of 0.1m/ns).

Time Slice at c. 1.26m Depth

At this depth the signals along the western edge have thinned out. With the exception of the ringing visible along the SW edge from y = 4.4m westward, this appears to be the beginning of anomalous material potentially unrelated to the modern floor and its immediate subsurface. From comparison with the 2D data, there are two large features centred on x = 5m and from 5.5m to 6m (cf Figures 61 and 62). The width of the banding and the echo effects below the more northerly of these two suggest that these may contain voids. The outline bridge shape previously commented on suggests

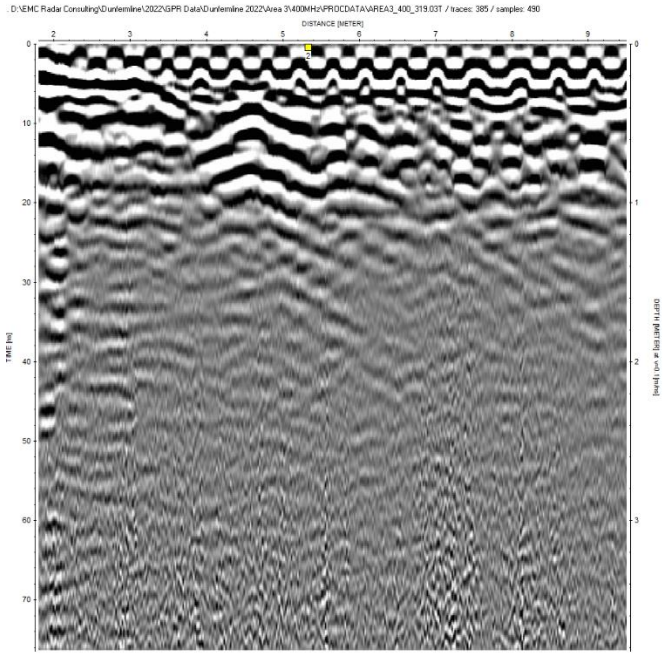

Figure 61: Survey line 319 along y = 5.15m

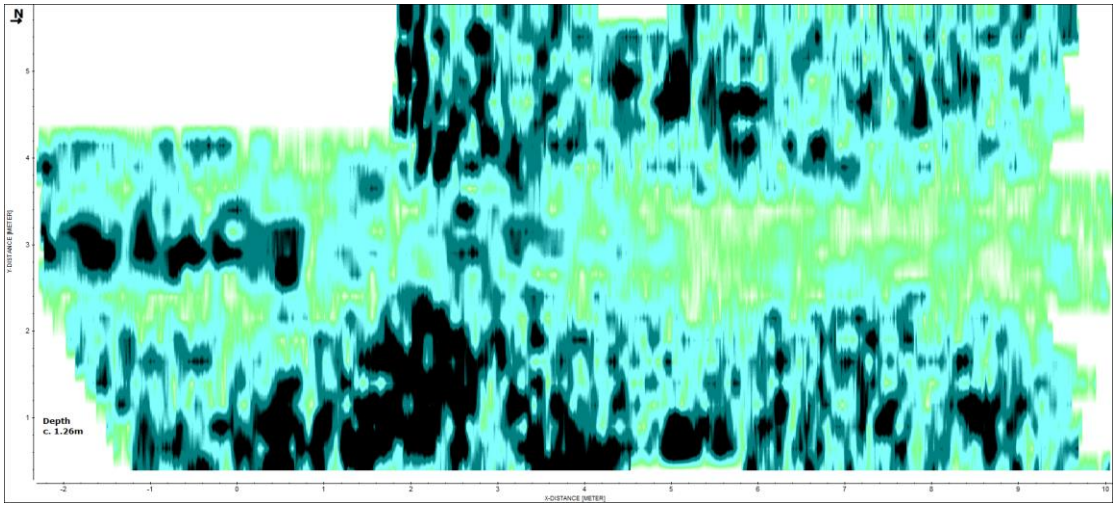

Figure 62: Time Slice at c. 1.26m depth

a surrounding structure of some sort (Figure 61).

In the central section of the survey area, the line of anomalous material reaching to c. x = 0.5m, consists of regular layers of materials. In contrast, from x = 2.5m to 3.5m, there appears to be a greater depth of buried material (Figure 63). This suggests that there is a near surface feature, possibly a grave, in this vicinity, given the break in continuity of signal above and what could potentially be a substantial void. If this identification is correct, the top of this grave lies close to the modern floor. The actual depths involved in any void will be three times as large as depicted since all data is displayed at the more general transmission speed of 0.1m/ns as opposed to the transmission speed of radiowaves in air of 0.3m/ns. Also note the proximity of the feature in line 313 from x = 0m to 2m. This may be related to the possible burial although a relationship to the modern floor cannot be ruled out (cf also Figure 58 line 314).

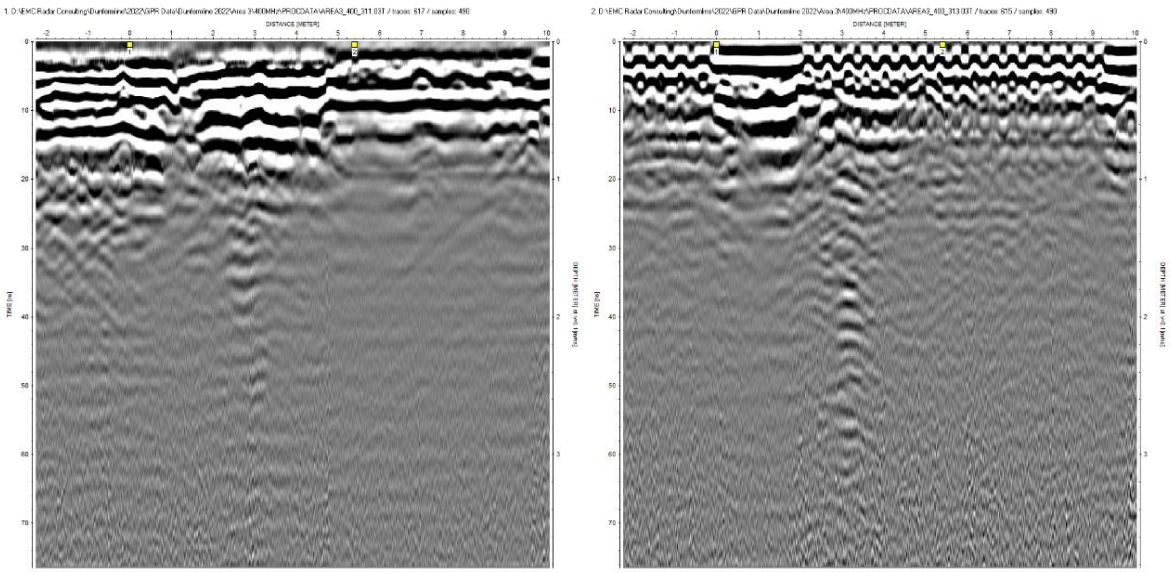

Figure 63 : Survey lines 311 (y=3.15m) and 313 (y= 3.65m).

Along the eastern edge the 2D data shows a considerable volume of anomalous material at this and lower depths, consistent with the possibility of there being at least one grave (centred on x = 2m) and possibly more. Although there is very little material visible at x =5m for example, the 2D suggests this as a possibility and that the material lying between these two features contains material which gives rise to echo effects below (cf Figure 58, line 301).

Time Slice at c. 1.5m Depth

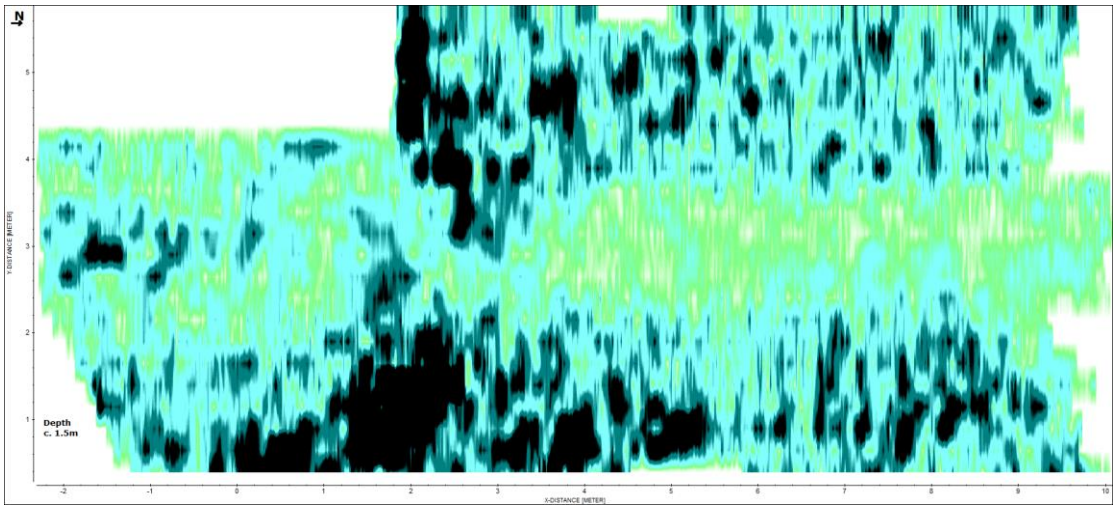

Figure 64: Time Slice at c. 1.5m depth

The same basic pattern can be seen at this depth. The changes are primarily to do with the spread of potential burial material in the eastern section of the survey area. The area of potential burials extends from x = 1.2m to 5.9m. The material beyond x = 5.9m appears to be echo effects from the floor construction (Figure 58, line 301).

Along the western edge, the first linear feature along the south side of the SW corner, is a mixture of anomalous material and some echo effects. It does not appear to be a complete single feature formed by ringing as it does in the 250MHz survey. Tracing it back towards the East, it appears to be part of a burial along with the adjacent

signals. This group of signals corresponds to the burial visible in Line 314 (y = 3.9m) in Figure 46. The group is centred on x = c 2m. The dark area at x = 3.4m to 3.9m may be part of the same feature. This is not clear as there is no great depth of small anomalies below. The signals closest to the western edge are mostly echo effects from the floor above.

Time Slice at c. 2m Depth

This time slice shows the distribution of anomalous material at depth. It highlights the two areas where the material residue and distribution suggests that there may have been graves (Figure 65).

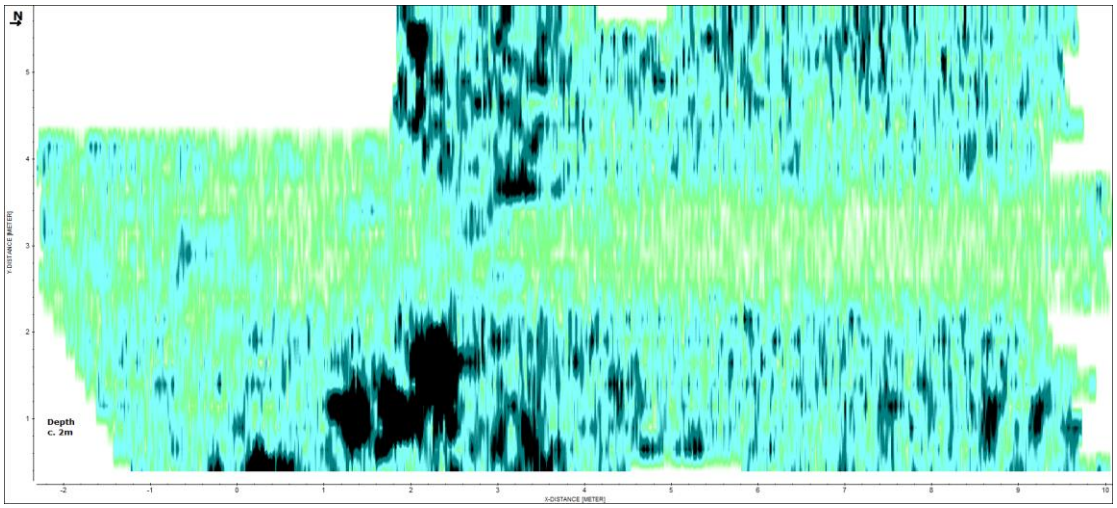

Figure 65: Time Slice at c. 2m depth

Neither of the two areas resembles either a rectangle, series of rectangles or even the shape of a medieval coffin. Rather they are scatters of anomalous material across a specific area. This absence of visible boundaries suggests burial in earth rather than within a vault or similar solid structure where any air or gas present would normally fill the outline of the container. Without investigating, it is difficult to be sure what the anomalous material present is. The irregularity of these features would be consistent with the breakdown of the human remains over a long period of time in which case the strong signals could correspond to pockets of air. Alternatively, given that it is known that Burn used pitch as a precaution against the moisture content of the soil, it is possible that the radar is identifying this as the anomalous material.

Another possibility is that the burials have been disturbed by deliberate excavation before some form of reinstatement has been made. This would typically result in mixing of materials and air throughout the layers investigated.

Time Slice at c. 2.5m Depth

This time slice is particularly interesting because it suggests that, at least as far as the grave centred on x = 2m on the eastern border is concerned, there may have been a vault. Although the signal pattern is patchy, a distinctly rectangular outline is visible (Figure 66). If this does mark the remains of a vault, some of the strong signals are also from construction materials and the graves have undoubtedly been broken into which will have contributed to the dispersed pattern of the evidence.

Comparison with the 2D data reveals that this area of strong signal is a mixture of real material and echo effects from above. For example, line 304 (y= 1.4m) is represented by signals from a strong column of ringing, emanating from above (c. 1.5m) at x = 2.2m. This implies a metal object directly above this position.

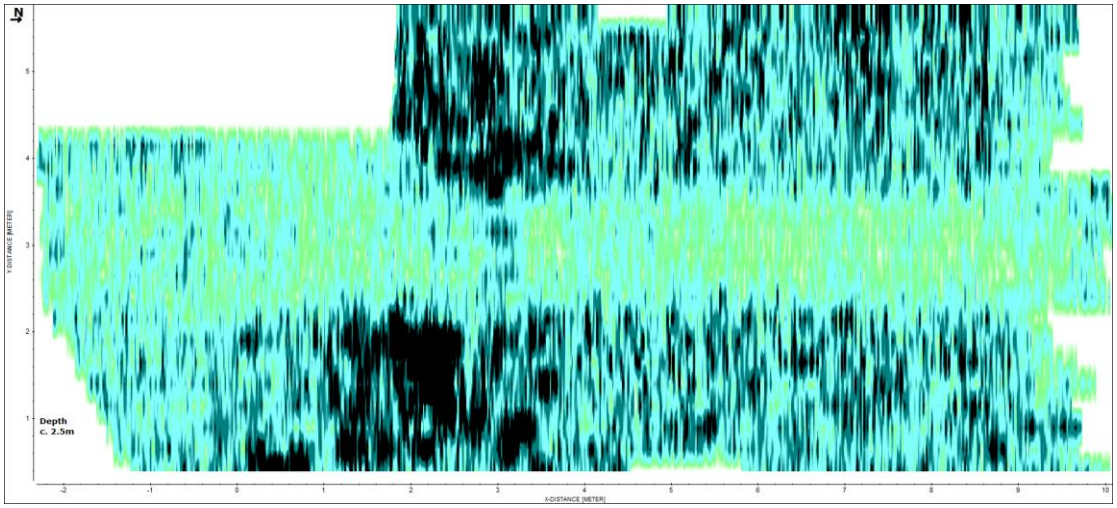

Figure 66: Time Slice at c. 2.5m depth

The remaining signals beyond x = 4m along the western edge do not appear to contain any significant patterning.

Along the western edge from x = 2m to c. 4m, the 2D data confirms material related to the possible grave immediately adjacent to the SW corner. From line 317 (y = 4.65m) to the final line along the western edge the width this possible grave narrows to 3m. There is no significant patterning in the signals to the north of this area.

Time Slice at c. 3.82m depth

This is the last time slice in the 400MHz data. By this depth, there is no longer signal penetration, and the images are echo effects from various layers above.

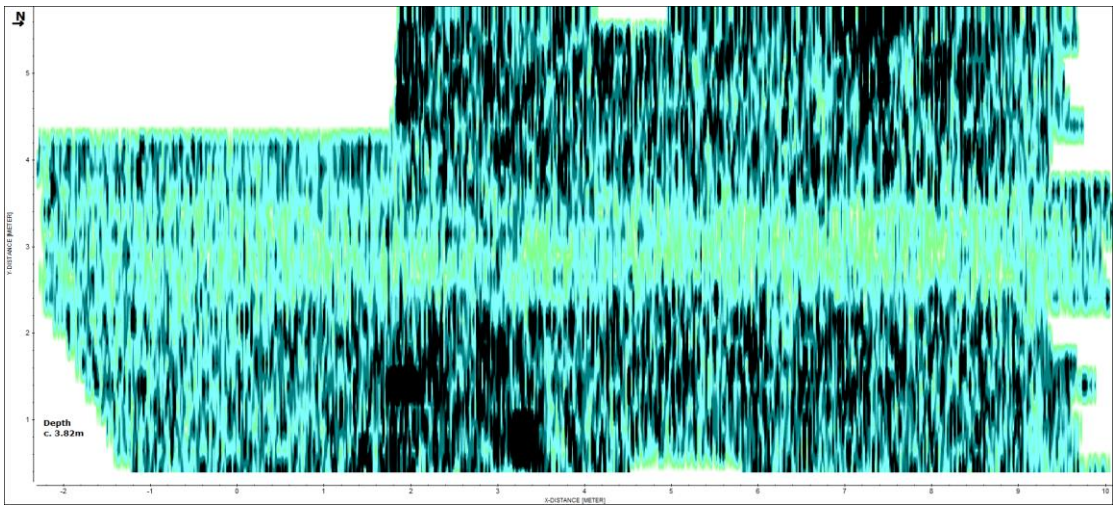

Figure 67: Time Slice at c. 3.82m depth

However there are two distinct images whose centres lie at (1.9, 1.4) and (3.2, 0.8). The first is a square, the second a rectangle. It is unlikely that these objects are present at this depth and the 2D data does not suggest this. It is more likely that they are included in the material higher up but their outlines disguised by other strong reflectors in their vicinity. For an object to be distinguishable from nearby objects, there has to be a wavelength between them. In these ground conditions for a 400MHz antenna, that distance is 25cm.

In the vertical plane, the square covers the base of two columns of ringing (Figure 68). The first of these lies at a depth of c. 3m. The second is the example cited in the previous time slice, visible on line 304 (y = 1.4m).

The rectangle also represents the base of a column of ringing in the vertical plane (Figure 68). It appears to begin at a depth of c. 2.7m. There is a 10cm variation in depth between lines 301 (Figure 58) and 302 (Figure 68).

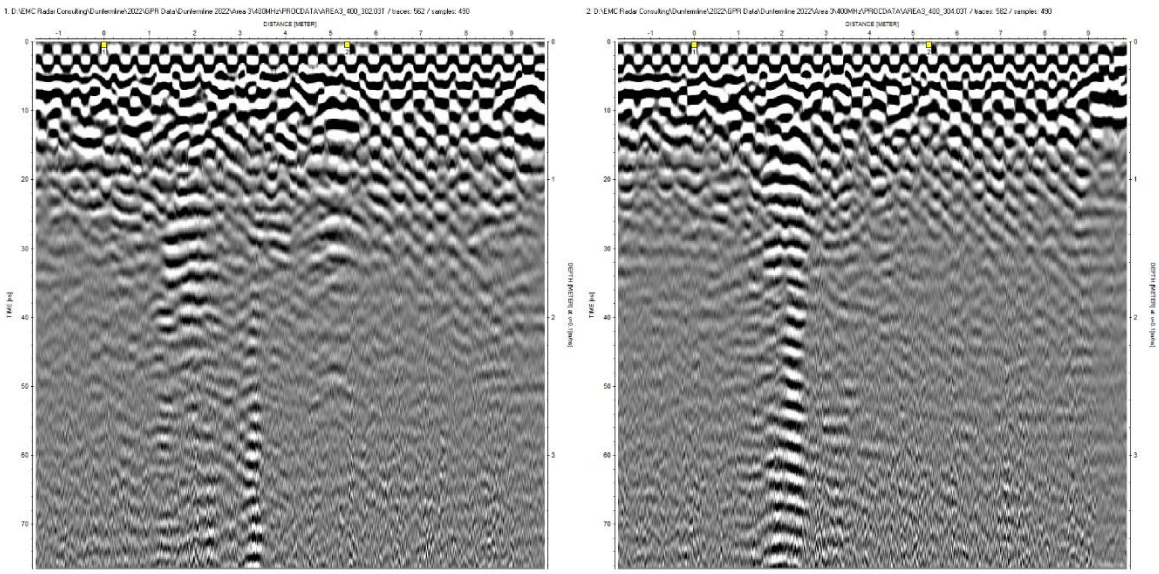

Figure 68: Survey lines 302 (y=0.9m) and 304 (y=1.4m) showing the echo effects visible at the base of the data.

The echo effects are relatively strong which suggests either a void (possibly with the later addition of pitch) or metal. The variation in depth implies mixture of materials throughout the possible burial area, either from repeat interments or intrusion into the burial space.

Area 4 The North East Dais

As this area is also narrow, one survey reference line was laid out along an East/West orientation (Figure 69). Where a marker 1 has been placed on the 2-dimensional data, this indicates the position at which the radar crossed this survey reference line. The position of the survey lines were defined by measurement from fixed features as shown in Appendix B.

Figure 69: Area 4 viewed from the East.

2-Dimensional Data Area 4

The 2-dimensional (2D) data for both the 250MHz and 400MHz surveys have 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 displayed South to North and has been aligned to survey reference line 1 so that the x = 0 (distance travelled by the radar) position lies along this line. Negative distances are to the South and therefore closer to the pulpit and the central area of the church. Positive distances lie to the North, closer to the position of the organ. Both surveys collected a total of 37 files.

Area 4 2-Dimensional Data: 250MHz

As the area is very narrow, some of the 2D files are very short and therefore provide

limited information on their own. Typically this area is mostly devoid of deep signals although there are a few subsurface features including echo effects. Typical data is shown in Figure 70. Line 404 has both echo effects at the start and real stratigraphy later on. In line 424, only echo effects are visible beneath the near surface of the present Abbey church.

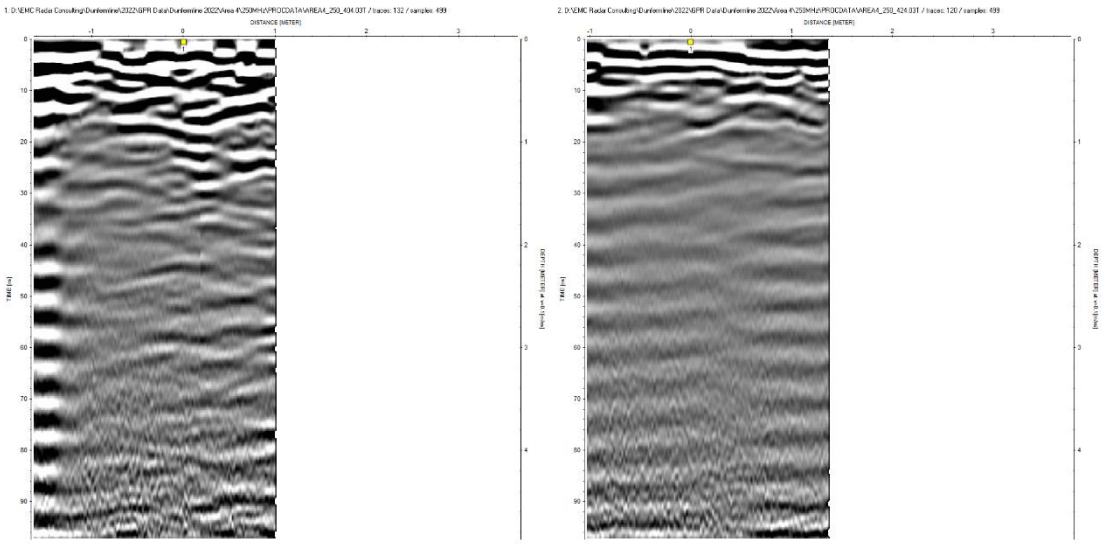

Figure 70: Survey lines 404 (y=1.4m) and 424 (y=6.4m).

3-Dimensional Data Area 4

The 2-dimensional (2D) survey lines from both surveys have been incorporated into two 3-dimensional (3D) data blocks based on their relative positions along survey line 1. Time slices, horizontal plans, have been extracted from this data block based on the change in signal patterns visible in the data. West is at the top of the page for all the time slices and North to the right hand side.

Area 4 3-Dimensional Data: 250MHz

The time slice data is again heavily influenced by echo effects from the floor above and, as in the other areas, there are places where signals are blocked in the near surface.

Surface Time Slice

The surface time slice is presented so that echo effects from the surface can be identified and discounted from other time slices. The main effects are from the floor boards but there are also two features in the west of the sector as well as a possible feature or features in the SE (figure 71).

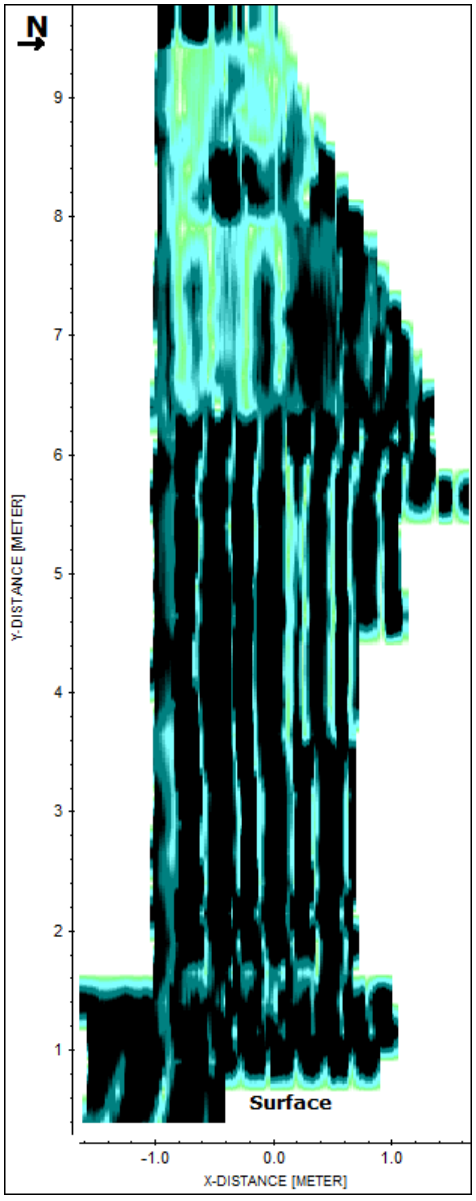

Figure 71: Surface Time Slice showing potential sources of subsurface echoes.

Time Slice at c. 56cm Depth

There are two main areas containing strong signals, the west and east ends of the survey area. The scattered signals in between are mostly related to the flooring above.

Comparison with the 2D data in all areas other than the rectangle at (-0.3,7) are part of the near surface layering and therefore of relatively modern date.

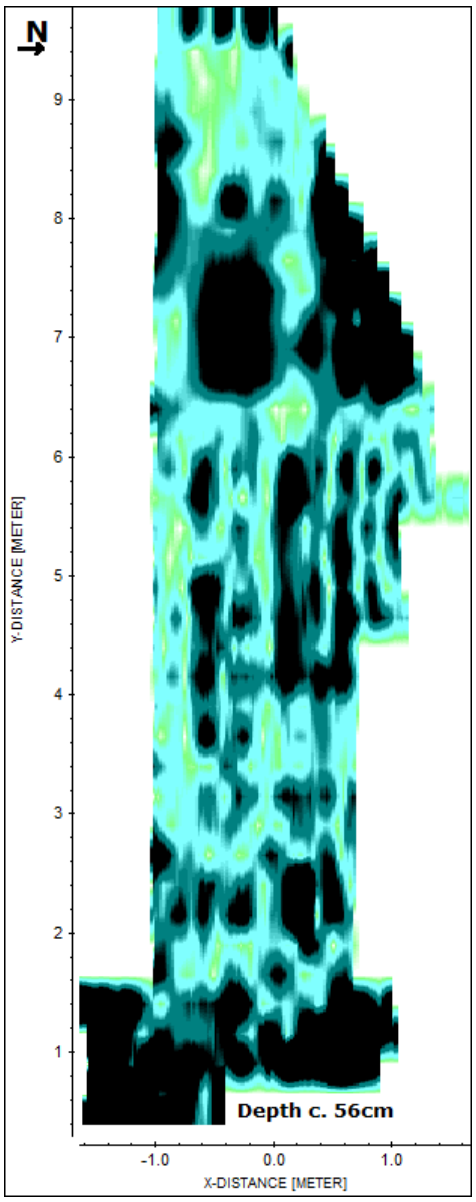

Figure 72: Time Slice at c. 56cm

It is likely that this rectangle is also a relatively modern feature from its position but, viewed vertically, it is a recognisably separate structure within the layers with a top and bottom, revealed by the reversal of signal polarity from black/white/black to white/black/white as the radiowaves enter and then leave the feature (Figure 73). The top and bottom layers are marked by red arrows in the figure.

All of the signals below are ringing from the feature above. This means that any archaeological features are not visible as the radiowaves have been unable to penetrate below.

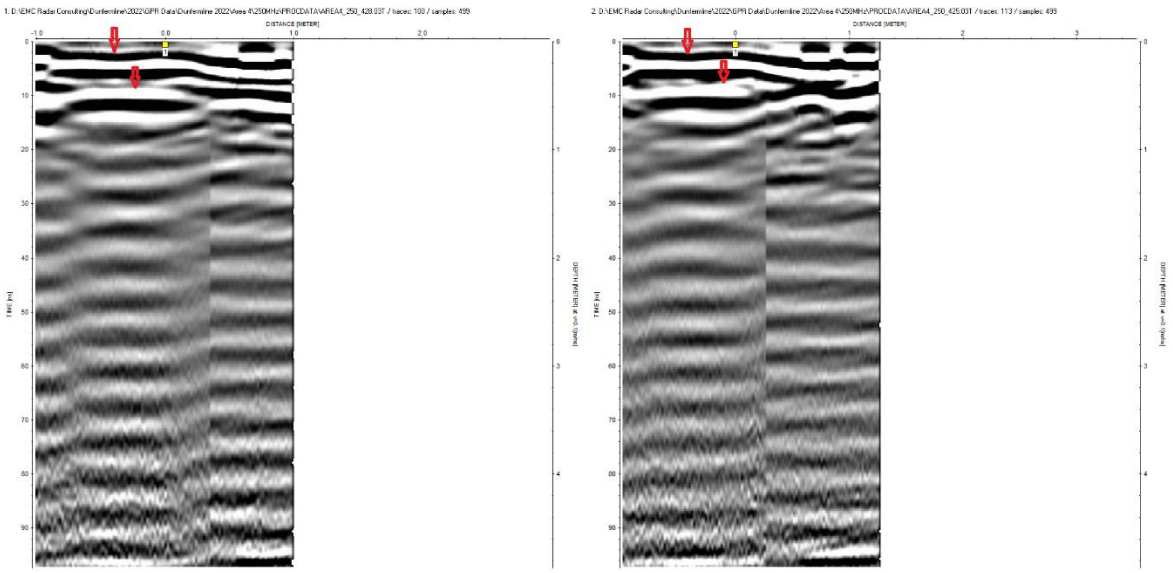

Figure 73: Survey lines 428 (y=7.4m) and 425 (y=6.65m)

There is also a marked discontinuity in the data, occurring only in the subsurface. This suggests that the feature has been cut into the modern layers. The heavy ringing below suggests that this feature may be a void. Through soil or construction material, the internal depth of the feature would be 33.5cm. In air, it would be 1.05m.

Time Slice at c. 1.05m Depth

The pattern changes slightly by this depth. There are three small rectangles along the western edge and, at the eastern end, a scatter of material with a linear feature in the SE corner (Figure 74).

The three rectangles are actually visible in the previous time slice which suggests that these are probably recent constructions. Looked at in the vertical plane, the central one (-0.4, 9.65) has buried material below it, the other two do not. The echo effects from the central rectangle are extremely strong so that although it is not clear what this represents, a void is a distinct possibility.

The linear feature in the SE corner is an echo effect from the near surface. This can be seen both in the surface time slice and, in vertical profile, in Line 204 in Figure 70..

The remaining material in the NE corner does not form a coherent pattern either in the vertical or the horizontal plane. It is very close to the surface of the dais and although there is definitely layered material, it does not conform to the size or shape of a grave. This makes it likely that it is part of the construction of the present Abbey church.

Comparison with the other time slices does not show the type of consistency or variation visible along the edges of Area 3, for example. There is also a visible break in the subsurface in the data which suggests relatively modern intervention (cf Line 204 in Figure 70. A break such as this can occur when the radar passes over a surface irregularity but if that were the case, the discontinuity would be visible from the surface. That is not the case here.

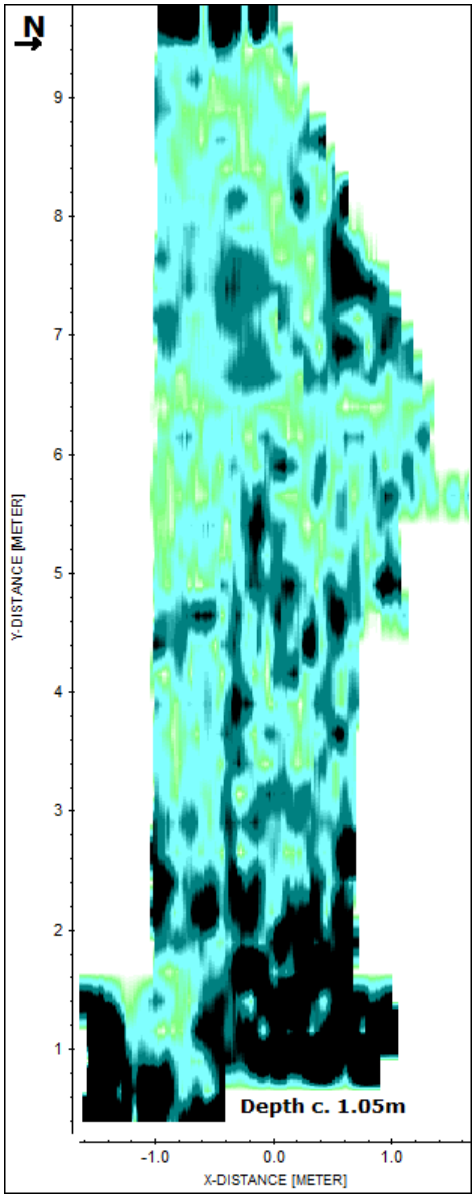

Figure 74: Time slice at c. 1.05m depth

Time Slice at c. 1.3m Depth

The primary anomalies at this depth are, from West to East, the three rectangular features along the western edge, the large rectangle at (-0.3,7) and the cluster of features at the east end (Figure 75).

As previously, the linear feature in the SE corner is ringing from a near surface feature. The other objects do not have any individual continuity. For example, there is buried material visible in lines 403 (y = 1.15m), 404 (y = 1.4m), and 405 (y = 1.65m) but the apparent continuity in the time slice is not reflected in the individual vertical views. There is a short column of what might be a part of a wall visible in line 404 at x = 0.2m (cf Figure 70) but it does not appear in either line 404 or 405 although other discrete material does. It seems unlikely that this represents any significant feature.

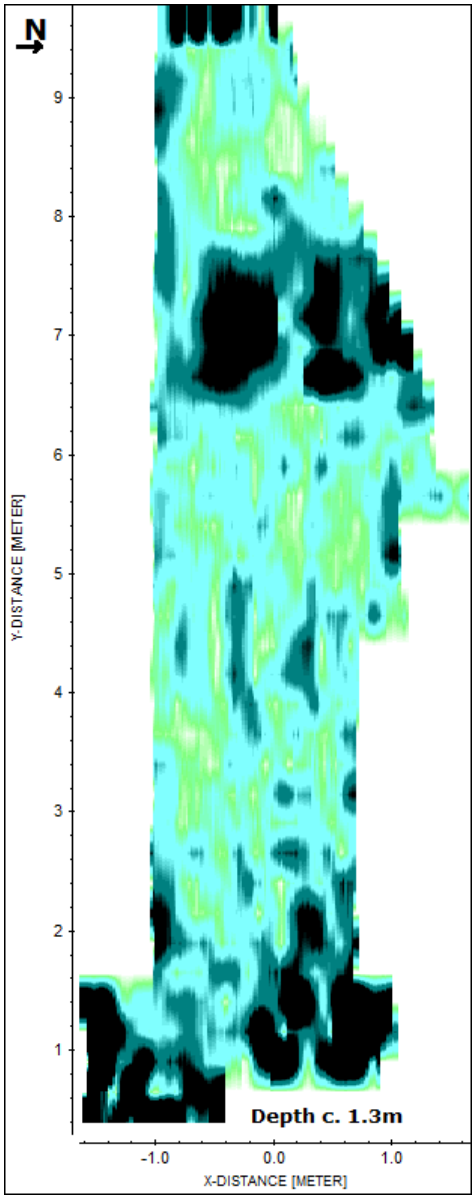

Figure 75: Time Slice at c. 1.3m depth

The signals returned from the area of the large rectangle are echo effects from the feature above, described in the 56cm time slice.

There is buried material below the central small rectangle at the west end. This is flanked at this depth by its neighbours although they do not have similar deposits beneath them. There is a possible reversal of polarity directly below and ringing further down, implying an object containing another void.

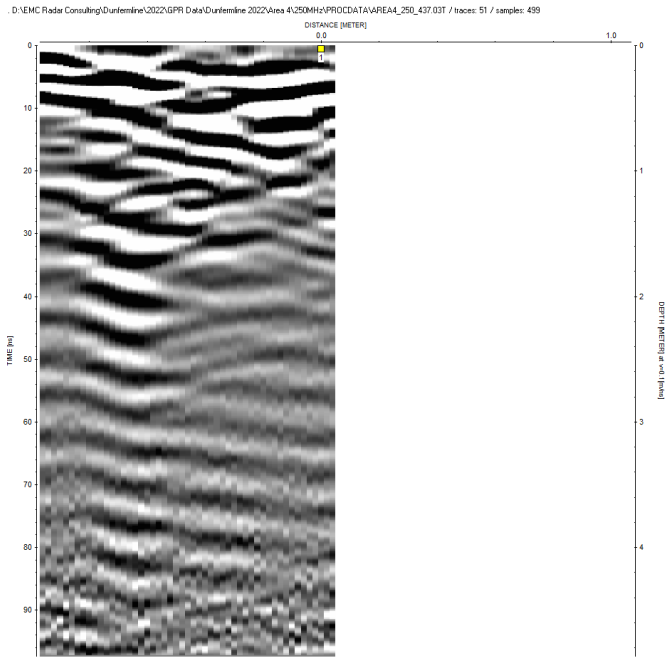

Figure 76: Survey Line 437 (y=9.65m)

Time Slice at c.2m Depth

The principal changes at this depth are the reduction of the three small rectangles to two, a line joining the large rectangle to the feature below the northern edge of the dais, and the disappearance of most of the strong signal returns at the east end (Figure 77).

The small rectangle at the west end at x =-0.66m (lhs in Figure 77) represents the buried feature visible in Figure 76. There is no obvious patterning for the second small rectangle in the vertical plane and it is likely this is just echo effects from above.

The bridge between the large rectangle and the feature to the north of it is a function of the subsurface discontinuity. At this depth all of the signals are echo effects, so this is of no significance.

At the east end of the survey area all of the signals on the south side are echo effects at this depth although there appears to be real material centred on x = -1.1m at a deeper level. The small patch of signal at (0.53, 0.9) lies on the north side of the subsurface discontinuity and represents part of an area of disturbance, potentially therefore part of a burial although the section covered is too short for this finding to be completely justified.

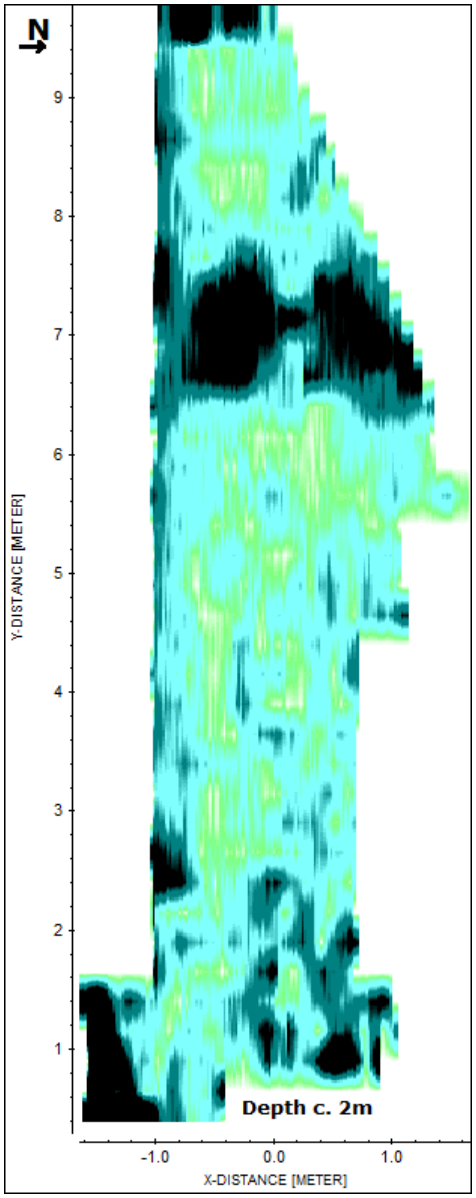

Figure 77: Time Slice at c. 2m depth

Time Slice at c. 2.55m depth

This time slice represents a mixture of echo effects from above and some real signal returns which are likely to represent features of medieval origin (Figure 78).

All of the signals at the western end of the survey area are echo effects at this depth with the possible exception of the western end of the triangular feature visible between y = 6.5m and 8.5m. The part of this feature which represents an extension from its outline in Figure 77 contains a partial layer signal. Coverage is insufficient for any further interpretation.

At the eastern end, the linear feature in the SE corner continues to be mainly echo effects. The horizontal line which meets it in the SE corner is not ringing. It is a substantial feature, potentially a possible void (Figure 79). It is possible that this feature is post medieval and related to the position of the organ on the north side of the survey area, its position being that of the clear indent on the right hand side of the time slice (Figure 78).

The rectangular feature in the NE corner is a disturbed area on the far side of the subsurface discontinuity (Figure 80). This could potentially be part of a burial, but its full extent is unknown.

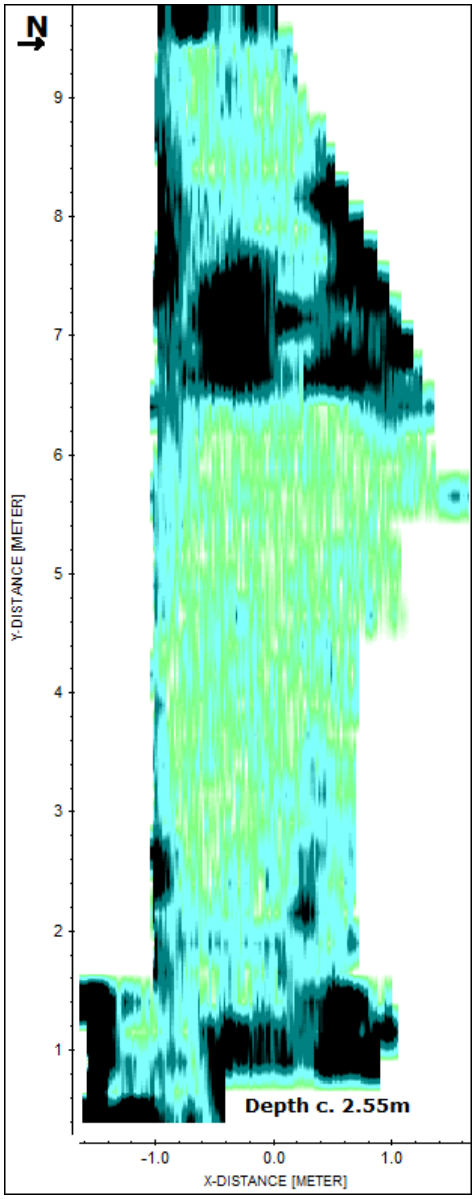

Figure 78: Time Slice at c. 2.55m depth

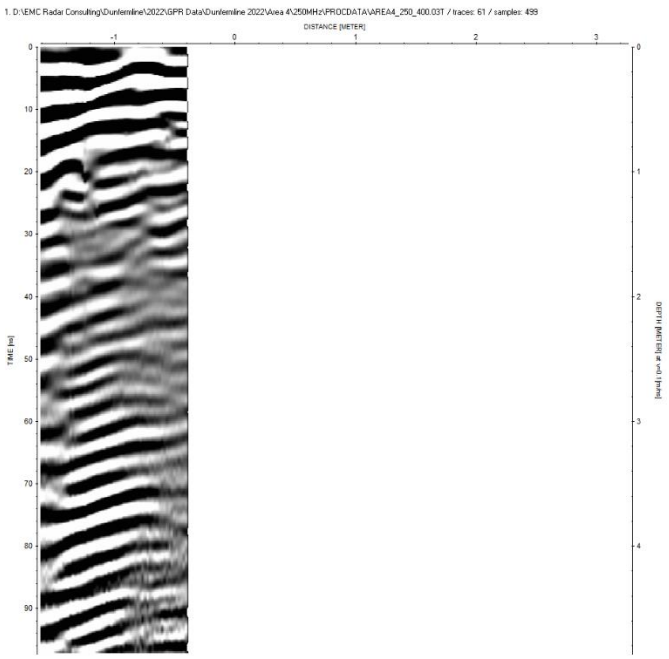

Figure 79: Survey line 400 (y=0.4m)

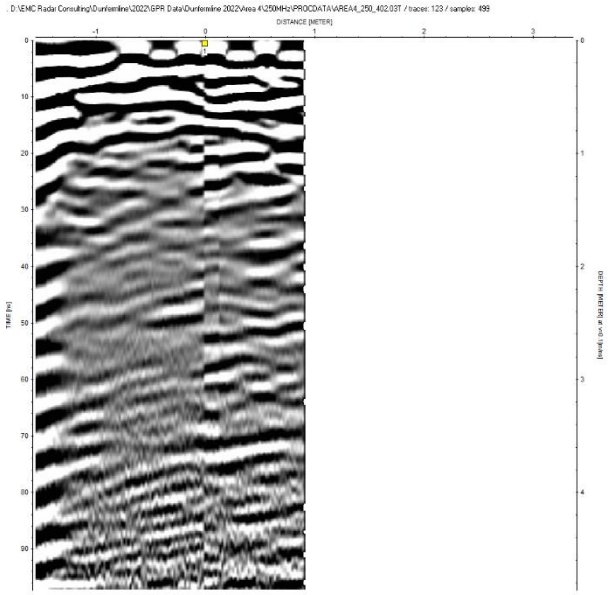

Figure 80: Survey line 402 (y=0.9m)

Time Slice at c. 2.8m Depth

This time slice is mainly composed of echo effects but does include some minor areas of real signal returns which, at this depth, are likely to be medieval in date (Figure 81).

All of the "features" in the western area of this time slice are echoes from higher up. At the east end, the vertical line in the SE corner is an echo effect as before. The horizontal line which meets it remains part of the substantial feature referred to in the previous time slice. The near circular feature appears to be, in part, a construct of the subsurface discontinuity but possibly also some minor layer changes (cf Figure 80 at line 1). Any remains here are not likely to be of any great size but the outline, although incomplete may be real enough. The fragment of strong signal in the NE corner is part of a disturbed area but too partial to be sure what it relates to.

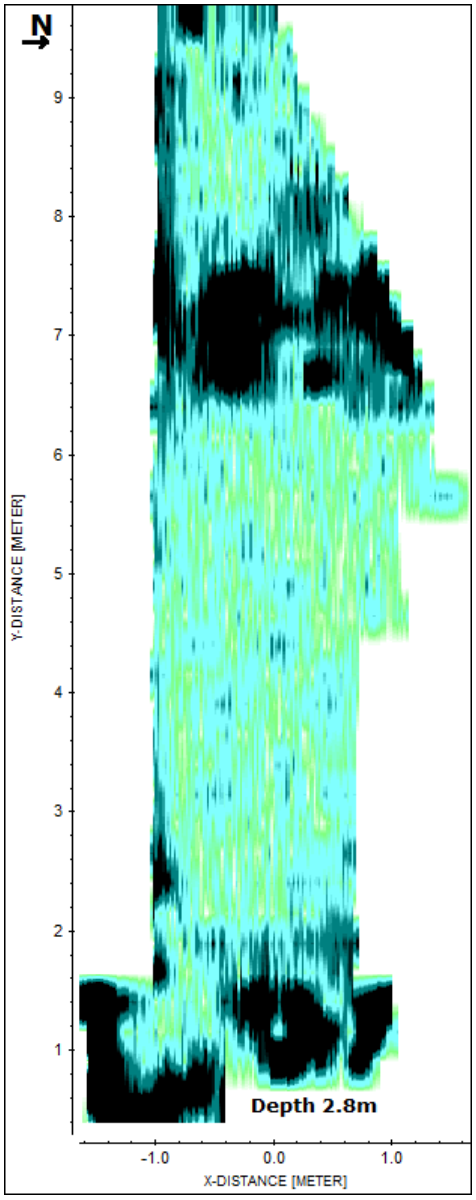

Figure 81: Time Slice at c. 2.8m depth

Area 4 2-Dimensional Data: 400MHz

The 2D data in Area 4 contain more near surface material than deep features. Survey lines 453 and 483 are typical of the output (Figure 82).

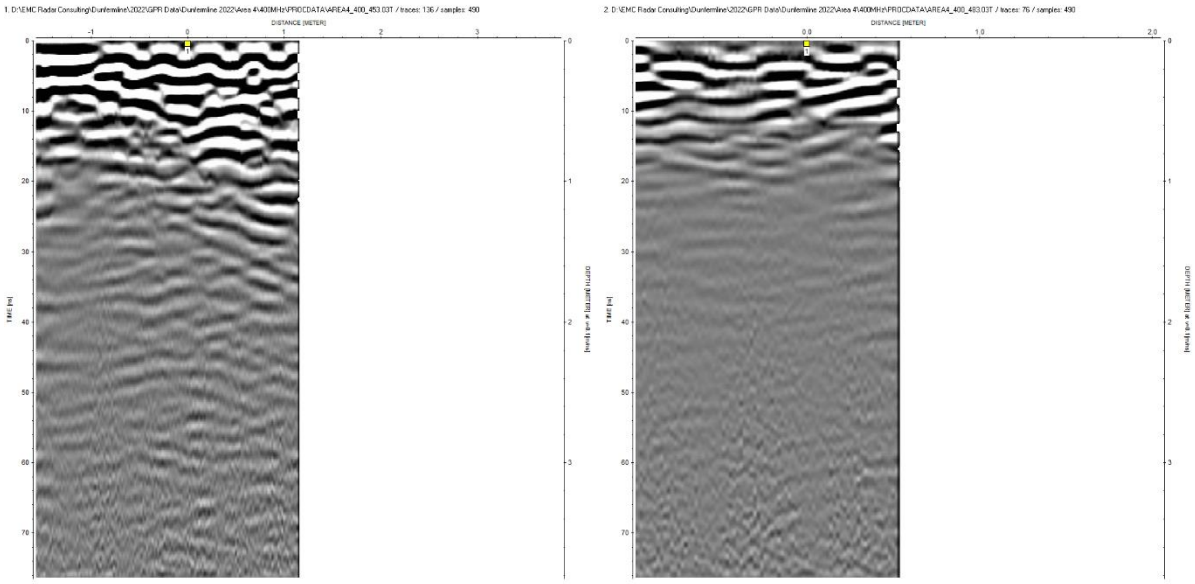

Figure 82: Survey lines 453 (y=1.15m) and 483 (y = 8.65m)

Area 4 3-Dimensional Data: 400MHz

The surface time slice has been included for completeness although it does not highlight the potential for ringing lower down as clearly as the 250MHz data from area 4 or both frequencies in the other three areas.

Surface Time Slice

The surface time slice indicates that there are two main areas were ringing can be expected. These are along the south and east sides of the survey area. Ringing from the construction of the floorboards is also indicated and a few discrete features at the western end.

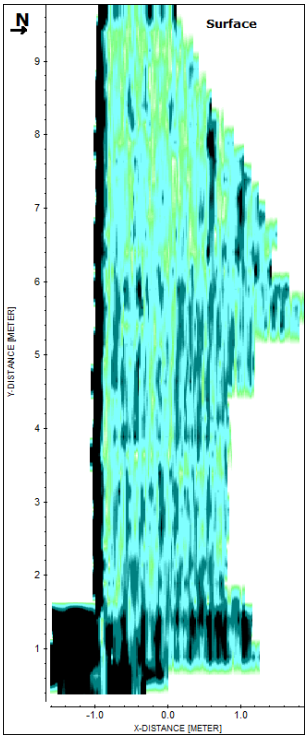

Figure 83: Surface Time Slice

Time Slice at c. 52cm Depth

This time slice shows major reflectors in the east end and around y = 7m towards the west. There are a number of other minor reflections, many of which relate to the construction of the floor (Figure 84).

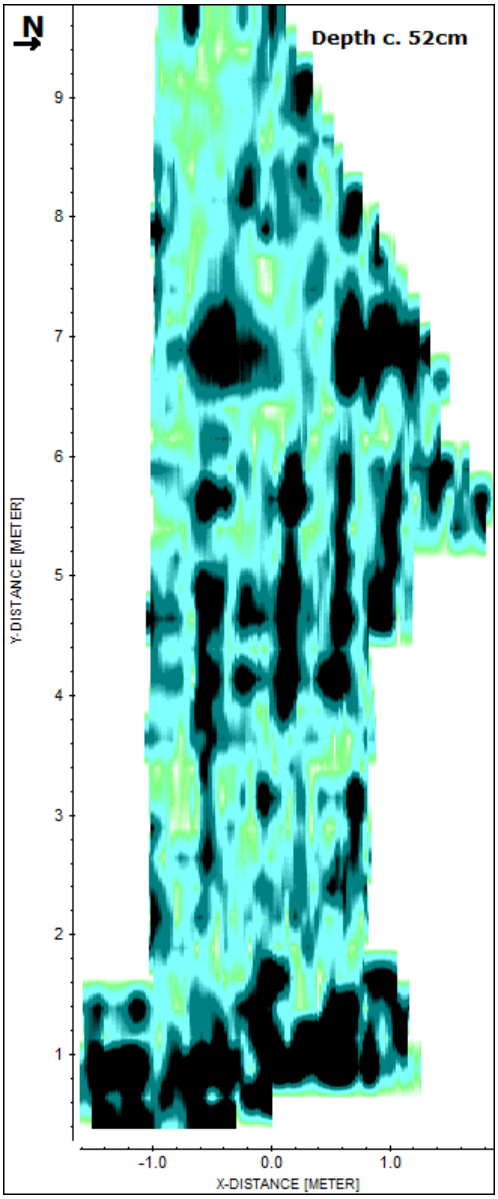

Figure 84: Time Slice at c. 52cm depth

At this depth, all of these reflections are from near surface construction. Some, however, do cover other deeper material. This is not the case in the area around x = 7m.

Between 4m and 5m there is some deeper material lower down, but the total depth is less than 1m. At the east end, the depth of underlying material increases towards the north side. The patterning does not reveal what these objects might be either in the vertical or the horizontal plane but they do cover other material deeper down.

Time Slice at c. 68cm Depth

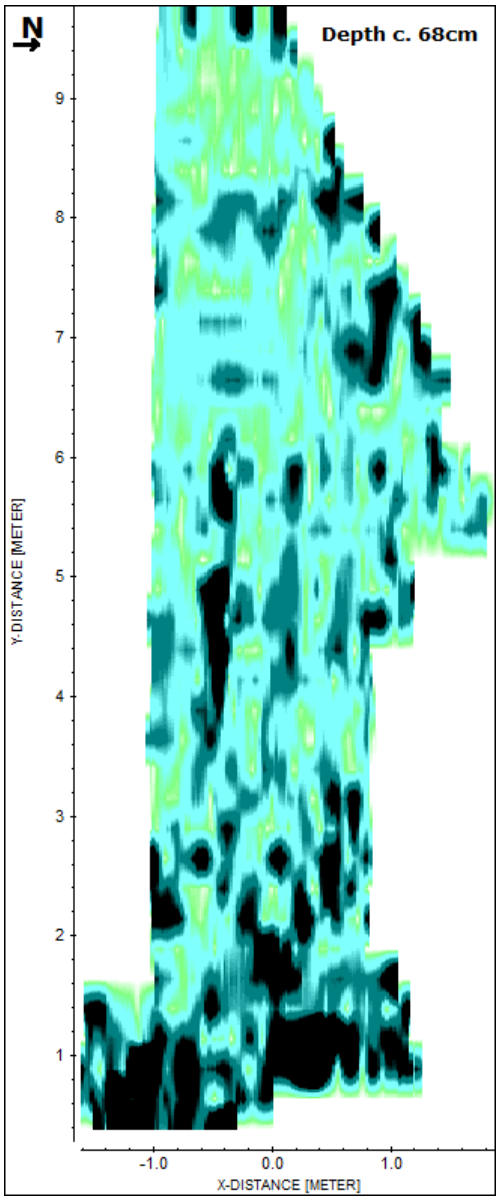

Figure 85: Time Slice at c. 68cm depth

The pattern of remains changes by this depth but seems relatively random. There are three small rectangular deposits along the western edge, linear features on the north edge at y = c. 7m and another between y = 4m and 5m and a square outline surrounded by at least 3 rectangular features at the east end (Figure 85).

The material forming the 3 small rectangular deposits is directly below the construction of the floor, but it is not clear what this represents. It does, however, corroborate the evidence from the 250MHz antenna that there is some form of buried material at this location.

The linear feature located towards the north side around 7m on the y axis does not

appear to be anything significant in the vertical section. Nor does the linear feature between 4m and 5m on the y axis.

The material at the east end of the survey area appears to be a jumble of different features. The vertical profile looks as though it is a pit sloping down from south to north (Figure 86 and line 453 in Figure 82).

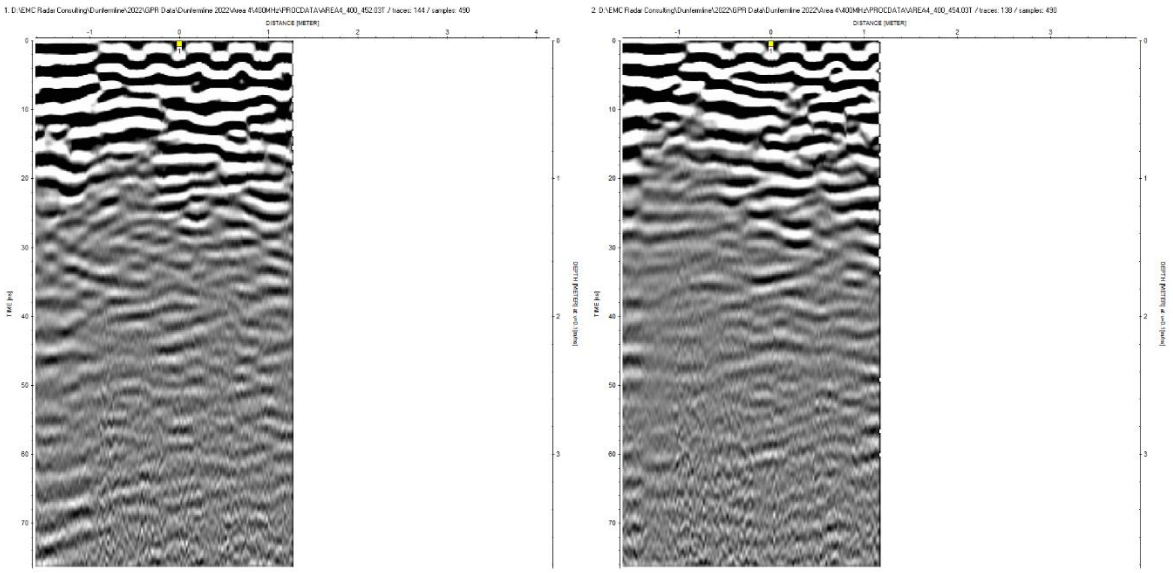

Figure 86: Survey lines 452 (y = 0.9m) and 454 (y = 1.4m) showing the outline of a disturbed area, a possible pit sloping from left to right

Time Slice at c. 95cm Depth

This time slice, although clearer in individual feature outlines, has no easy interpretation (Figure 87). The western end contains a series of discrete lines which overlie a short length of buried structure centred on x = -0.4m. The buried structure is two columns of signal close together (Figure 88) which could be archaeologically significant, but it is not possible to be certain due to the limited view.

In the east end of the survey area, the first group of irregularly shaped signals correspond to layer signals which lie directly below the floor construction but are no more susceptible to interpretation than the signals at the west end.

Further to the east are a group of small mostly rectangular shapes. Viewed in the vertical plane these correspond to the area of disturbance (possible pit) observed previously sloping down from south to north. The contents of the pit appear to be mixed materials. As with the 250MHz, the rectangular outlines might imply disturbed burial rather than a pit.

The linear feature aligned East/West in the SE corner is ringing from the near surface. It is not possible to define any individual element within this grouping in spite of the apparent clarity of the time slice. It seems likely that this is material from the medieval church, potentially left in situ even when constructing the present abbey church. The material remains are not, however, undamaged and this could be

displaced material used for backfill. The brief and deep appearance of regular rectangular outlines are the only evidence suggesting burial place rather than backfilled pit.

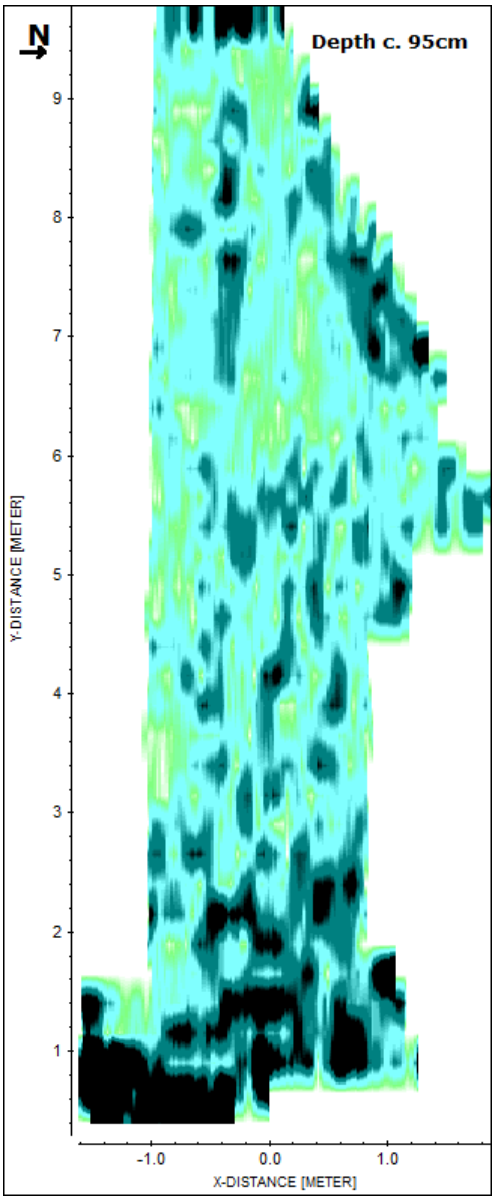

Figure 87: Time Slice at c. 95cm depth

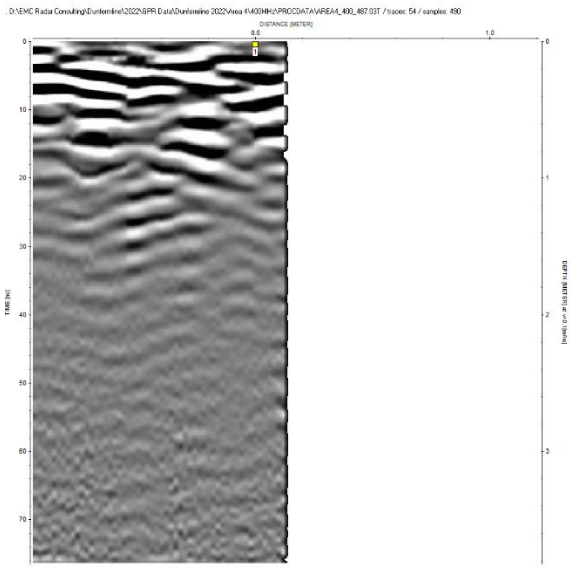

Figure 88: Survey line 487 (y=9.65m) showing the series of features at c. 95cm depth at the west end of the survey area, overlying a double column of signal.

Time Slice at c. 1.13m Depth

This time slice is similar to the previous one, the main differences being the reduction of the small rectangles to two in number (cf Figure 88) and changes in the shape of the features at the east end (Figure 89).

The features in the east end are a continuation of the previous time slice. The rectangular outlines suggest possible burials rather than the backfilled pit suggested by the vertical profile higher up.

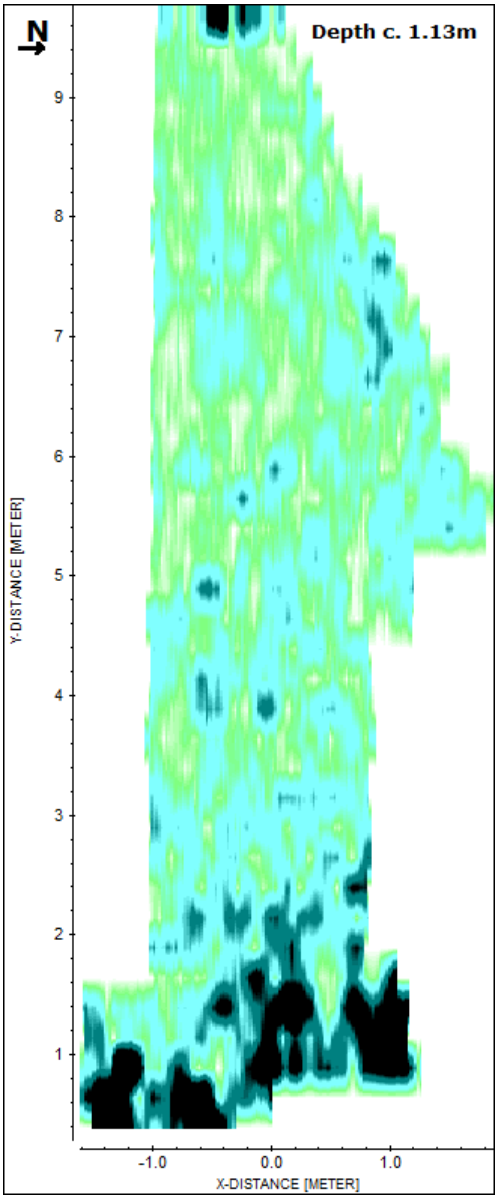

Figure 89: Time Slice at c. 1.13m depth

Time Slice at c. 1.27m Depth

The material below the floor at this depth is the same as in the previous two time slices. At the east end, the buried material is more sparsely distributed but the basic outlines fit either interpretation. The regularity of the outlines left suggest potential burials but it could also be argued that the denser remains lie to the north fitting the apparent pit profile. The East/West line visible in the SE corner, is again echo effects (Figure 90).

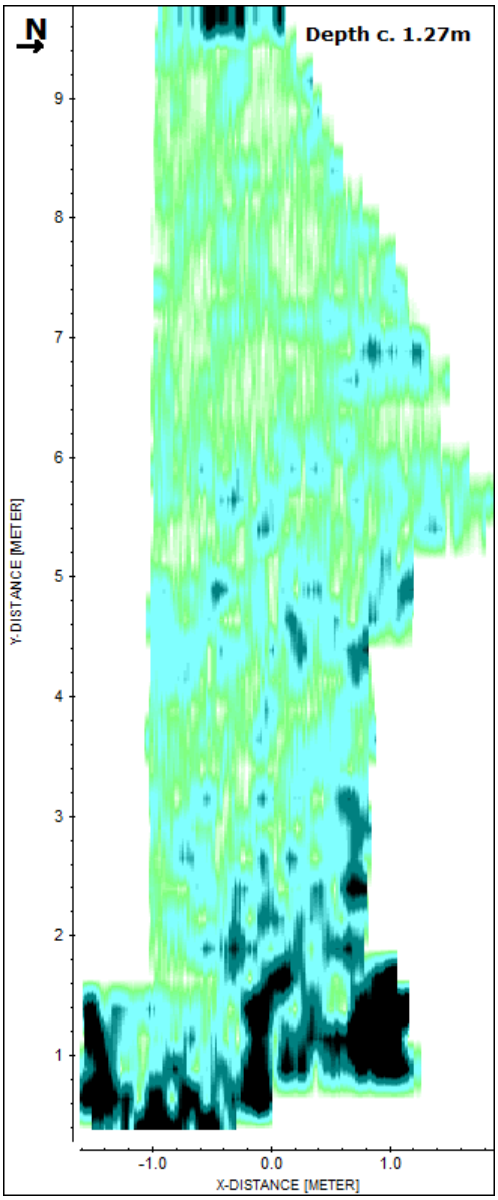

Figure 90: Time Slice at c. 1.27m depth

Time Slice at c. 1.77m Depth

At this depth the radar is nearing its depth limit, as determined by the soil in the subsurface which as in previous investigations, is relatively lossy. The addition of extra gain on the data results in an enhancement also of the echo effects above. This is the reason for the reappearance of the fainter signals in the time slice (Figure 91).

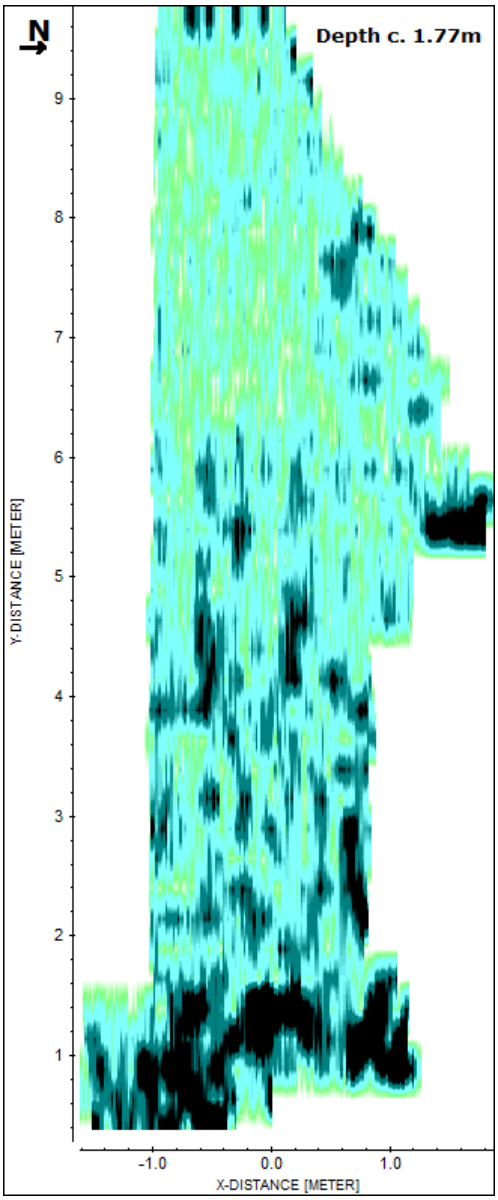

Figure 91: Time Slice at c. 1.77m depth

At the east end, the features from line 1 (x = 0m) onwards are material remnants from the feature previously described. The features lying between x = -1m to 0.8m are the beginnings of a large set of signals observed also in the 250MHz data (see Figures 78 and 79). Although this could represent a void, the increased width of banding in the vertical plane suggests the presence of moisture. Moisture slows down the transmission velocity of the radiowaves. It may also account for the irregularity of outlines at this depth if the absorption is not uniform across the area.

The other new feature at this depth is the triangular one located around y = 5.4m.

Comparison with the 2D data suggests a thin layer of anomalous material.

Time Slice at c. 1.95m Depth

Most of this time slice is composed of echo effects. There is still material present in the NE corner. The linear feature at the eastern edge of the SE corner is due to echo effects. Next to it is the top of the large feature seen also in the 250MHz data set (cf Figure 79). Although it is not clear what this is due to its incompleteness, the outline in the time slice resembles the shape of a lead coffin. There are echo effects visible below in the 2D data. Unfortunately there is only c. 1m of length visible and a definitive conclusion cannot be drawn.

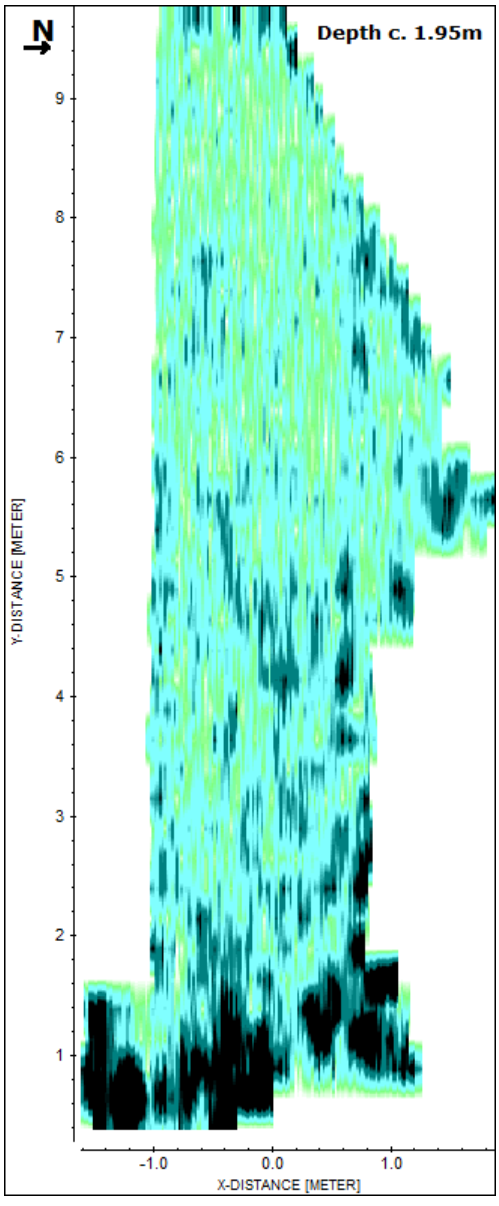

Figure 92: Time Slice at c. 1.95m depth

The area in between north and south at the east end does not seem to correspond to anything major in the 2D data. However there are faint traces of a layer change, and it is possible that these features are the result of greater moisture content.

Conclusions and Recommendations

Area 1: the South Aisle

The surveys of this area have revealed a number of near surface constructions which appear to relate to the current church. Echo effects suggest that there are air gaps present and possibly some related metal.

The 250MHz data has detected a series of anomalies in the SW corner of the South Aisle which may be remains of the medieval building. These are few in number and limited in area and depth. It is possible that the linear features and the sole right angled feature may give a clue to the layout of the medieval church in this area, but it is not certain that this material has been left in situ (Figures 20, 22, 23).

The 400MHz data provides greater detail of the material in the western corner which is more extensive than the 250MHz. The regularity of this material as imaged in the 400MHz survey suggests that it may well be in situ. Both surveys imply considerable destruction around these features and throughout the rest of the area. The installation of the features pertaining to the modern church may also have had an impact both physically and by obscuring the data through echo effects.

Area 2: the Memorial Chapel

As in Area 1, the picture which emerges from both surveys is primarily one of destruction both from the incompleteness of the outlines of the remains in both planes and from the lack of overall patterning. It seems likely that some if not all of these remain in situ, if only because of their depth. The typical outline is rectangular or linear but none of these stretches to more than a little over a metre in length nor do they appear complete in their outline. The few archaeological remains can be seen in Figures 29 to 33 and 39 to 43.

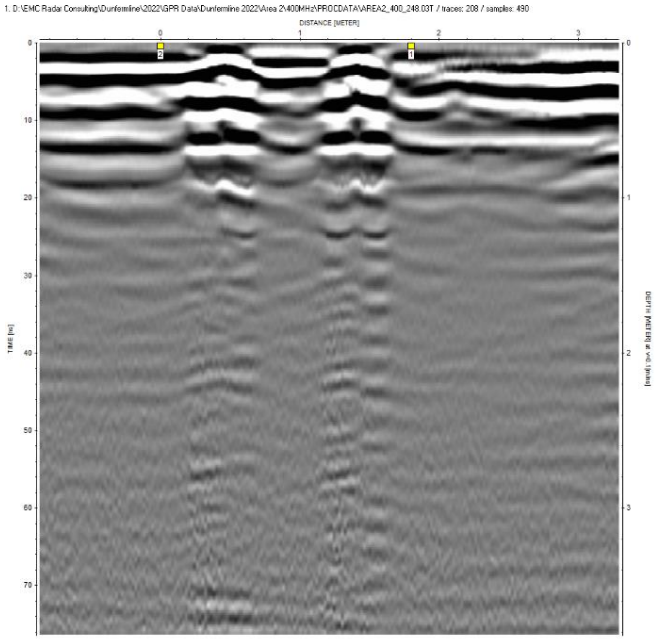

Figure 93: Line 248 at y = 4.25m

There is no obvious signs of wall remains which is surprising, given that lines 212 (400MHz) and 248 (250MHz) for which y= 4.25m pass over the remains of an East/West wall which can be observed through a hatch in the floor. In line 212, the wall section observed passes beneath the area of lost signal (Figure 28, lhs). Since radiowaves transmit through wood, air, soil and building materials, this suggests that there is another impermeable material on the underside of the floor in this position. Line 248 shows exactly the same pattern i.e. ringing from the two air gaps and loss of signal on either side (Figure 93).

There are other indications in Area 2 that there may be archaeological material being disguised by its proximity to echo effects combined with the relatively small size of what remains. Figures 42 and 44 both contain good examples. It therefore seems likely that other archaeological remains may be undetected, particularly in the central area i.e. within the band defined by y = 4m to 5m in the Area 2 time slices.

Area 3: North Transept and Southern Extension

There are two distinctive areas of possible archaeological remains, one to the East and the other to the West, and the full extent of neither is visible. Both are visible from the earliest time slices (Figures 50 and 52 respectively).

Although bearing signs of post depositional destruction and possibly intrusion, the North Transept appears to contain at least one major grave and possibly more. The archaeological material does not seem to be based on burial vaults, individual or otherwise. Instead it resembles burial in the soil, possibly successive burials. This may have more to do with the preparation of the site for the present church than the original methods of interment.

The patterning in each area is incomplete which may be a reflection of the age of the burials or of their post interment treatment or of other materials, e.g. pitch filtering in from above at the time of the construction of the new church. It may also mark post interment investigation with or without deliberate destruction.

There is an association between the small areas containing large blocks of signal at near surface level and nothing but echo effects underneath (such as Figure 46 rhs) and some of the areas of disturbance. Given that metal is one of the most effective barriers to transmission of radiowaves, it may be that these are or were entrances to a subsurface vault. There is no way of being able to prove this beyond direct investigation so this interpretation may be pure speculation.

Area 4: North East Dais

Much of the material beneath the NE dais lies in the near surface and therefore relates mostly to either the construction of the dais or adaptations made more recently. There is, however, archaeological material present including the possibility of burials at the east end of the survey area. Figures 85 and 87 suggest that what appeared to be a random distribution of material, potentially associated with a pit, may actually be burials. Figure 92 contains an image which could potentially be part of a lead coffin. Unfortunately it is right on the edge of area 4 so it is not possible to verify this from a

complete outline and the possibility remains of a less exciting target having been uncovered.

There is also a relative shallow feature, composed of a number of short lines of anomalous material at the extreme west end of Area 4 which contains buried material lower down. It is not possible to say what this feature might represent since it may continue to the west and the view afforded the radar is very limited.

Both antennas suffered a degree of loss of depth penetration which appears to be due to soil moisture at depth.

Recommendations

If possible, the patterning of potentially medieval material in the SW sector of Area 1 should be followed up with other sources such as the layout of similar Benedictine Abbey churches and documentary or pictorial evidence (see Figures 18 and 20). This may not be possible due to the restricted nature of the GPR data.

Area 1 appears to contain mostly post medieval structures below the floor. It might be useful to enquire as to what structures, if any, are known to lie in this area to confirm these findings.

Within the Memorial Chapel, the evidence of underlying medieval deposits is very limited and appears to have been at least partially destroyed. It would be interesting to investigate whether or not the partial remains correspond to written evidence or early plans from the Abbey. It would also be useful to determine, if possible, the significance of the rectangular outlines visible in Figures 41 and 42 even though they are relatively small.

Of the four areas, the North Transept gives the clearest indication of potential medieval remains. This includes areas in which the signal patterning resembles burials in open ground. At least one of these, on the east side of the area, although incomplete due to the position of the current church structure, looks as though it might have been sufficiently extensive for one or more royal burials. However there is scant evidence for the outline of anything resembling a vault. Currently the GPR data does not sit comfortably with documentary burial evidence or the evidence of Burn's discoveries during his involvement in constructing the new church. It is recommended that the various strands of evidence should be compared and further followed up where possible.

It is recommended that there is a follow up on the possibility of confirming the existence of the burials at the east end of Area 4. Guidance on some of the near surface material might also be useful to improved interpretation of the history of this area. There is a lesser probability of enhancing the interpretation of the material at the West End but it may be worth attempting.

Acknowledgements

This report was written, on the basis of the GPR survey, by Erica Carrick Utsi of

EMC Radar Consulting working in conjunction with Alexander Birtwisle of Atlas Geophysical Ltd. The authors were also responsible for carrying out the GPR survey.

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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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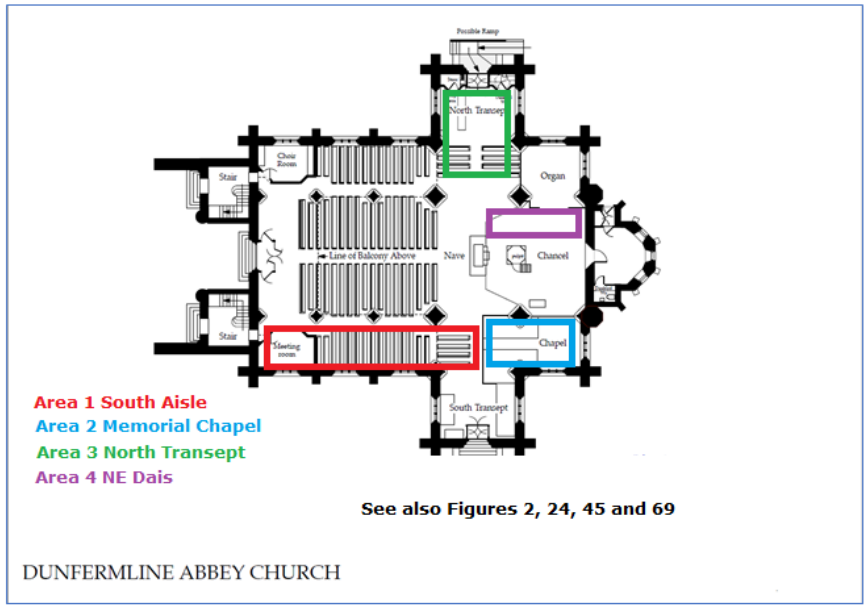
Appendix A: Areas surveyed



Plan based on that drawn up by Tod and Taylor, Architects, Edinburgh in January 2005.

Appendix B Survey Reference Line Positions

Area 1 South Aisle Line 1	Distance from	To Line 1
	Main Pillar	76 cm
	Second Pillar (to the W of Main Pillar)	1m 16cm
	Third Pillar (to the W of Second Pillar)	1, 15cm
	Line 2 (South of Line 1 where space available)	1.6m

See also Figure 3.

Area 2 Memorial Chapel	Distance from	To Line and Line Position	Distance
	North Pillar	Line 1 East end	6m
	North Pillar	Line 1 West end	3.6m
	South Pillar	Line 2 East end	6m
	South Pillar	Line 2 West end	3.6m
Both lines are offset from the pillars by 72cm. Tape 1 aligns approximately with survey reference line 1 in Area 1.			

See also Figure 24.

Area 3 North Transept and Extension

Two reference survey lines were laid out parallel to each other from pillar to pillar on both sets of pillars as seen in Figure 45 and Figures B1 to B4 below. Line 1 is south of line 2.

Figure B1: Line 1 West end of tape

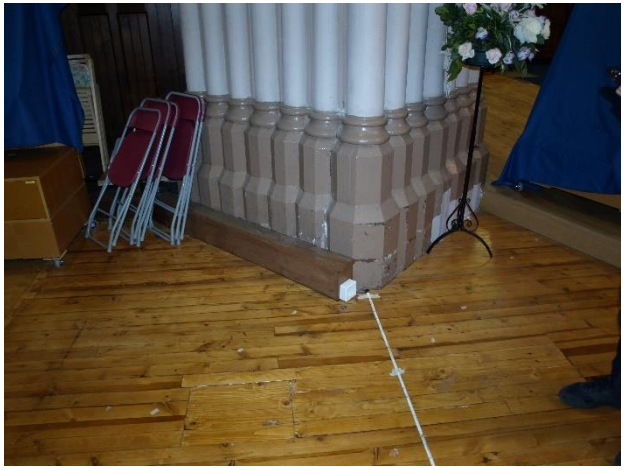


Figure B2: Line 1 East end of tape

Figure B3: Line 2 East end of tape

Figure B4: Line 2 West end of tape

Area 4 NE Dais

Area 4 NE Dais Line 1	Distance from	To	Distance
	Centre of pillar	West end of line	3.75m
	South side of vestry door	West end of line	11.2m
	Vestry wall	East end of line	40cm
	Centre of pillar	East end of line	6.21m
	NE corner of Bruce grave	East end of line	6.38m

See also Figure 69, Figures B5, B6 and B7 below.

Figure B5: Pillar
Measurement to end of tape not shown.

Figure B6: South side of Vestry door

Figure B7: NE corner of Bruce Grave