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Pencaitland House, East Lothian: Ground Penetrating Radar Survey

# **Data Structure Report**

# Report No. 1107

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## SURVEY OBJECTIVE

The purpose of the Ground Penetrating Radar (GPR) survey was to identify the subterranean remains of the former Pencaitland House. From previous intrusive investigation there was known to be at least one cellar located within the survey area and it was hoped that it would be possible to identify this.

The area identified for GPR investigation was divided in two by a wall (of later date) and also contained a certain number of impenetrable shrubs. The major investigation was therefore carried out on the west side of the wall and a more limited survey on the eastern side.

### SURVEY STRATEGY

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

GPR operates on the same principles as conventional radar except that it uses a wider frequency range, a shorter pulse, and a much shorter range of detection. The radar generates a short pulse which is transmitted into the ground via an antenna. The return signal is received by another antenna. The amplitude of the returning signal provides information about changing ground characteristics with depth. The use of the radar does not affect underlying deposits: it is non-destructive.

GPR identifies possible cellar locations by detecting anomalous material (e.g. a void between two surfaces with/without the addition of backfill) relative to the surrounding environment, measured on the basis of the electromagnetic response of the materials involved. The identification of a cellar as opposed to any other subterranean feature is dependent on pattern recognition. Since similar patterns may be generated by more than one type of buried feature, it is possible for the anomalies identified by the radar to be due to other structures.

It is also possible for ground conditions, typically wet clay, to mask the existence of buried features through attenuation of the signal. It is not always possible to detect specific targets if adjacent anomalous material obscures the spatial patterning of the target sought. Soil conditions for this survey were good. Although the soil was damp at the time of the survey, there is no evidence of significant signal attenuation. Calibration runs indicate that the soil is free-draining and therefore unlikely to contain clay to a significant extent.

### Equipment

The equipment used for this survey was Utsi Electronics' Groundvue 1 for which the central operating frequency is 400MHz & the effective maximum range 5m in dry conditions. The radar uses bow-tie antennas for close ground coupling and arrayed antennas for narrowed signal beam.

### **Site Conditions**

Ground conditions for the survey were generally good: mown grass and a gravel drive. There was one area where it was difficult to extend the survey runs for the full

length. Immediately adjacent to the wall dividing the properties of the West and East Houses, there is a raised mound, partially covered by shrubs. It was not possible to cover the whole of this area due to the difficulty in travelling over the highest point and also to the impenetrability of the lower growing shrubs. It was also not possible to approach the wall too closely due to the position of an oil tank surrounded by its own protective wall.

### Site Coverage

The primary site investigation was carried out in the area, designated as Area 1, between the two existing houses. Two parallel lines, running in an approximate East/West direction, were defined between grid points 1 & 2 (line 1) and between grid points 3 & 4 (line 2). Grid point 1 is c. 2m to the west of the East House (currently unoccupied), measured from the point on the external house wall immediately adjacent to where the curvilinear external wall joins the house. Grid point 2 is the equivalent position 2m to the east of the West House. The total length of line 1 was 30.9m. It was not possible to survey the full 30.9m due to the position of the wall dividing the two gardens, the oil tank and also the position of the curvilinear wall adjacent to the West House.

Area 1 was covered by 44 parallel survey transects, spaced at intervals of 0.5m, beginning at 6m to the west of the East House and running approximately North/South. A part transect, run 45, was later added at 0.5m to the east of run 1. This transect could not be extended as far as line 1 due to the position of the oil tank and its surrounding wall.

A more limited investigation was carried out in the second designated area, Area 2. Two parallel lines, running in an approximate North/South direction, were defined between grid points 5 & 6 (line 3) and grid points 7 & 8 (line 4). Line 3 corresponds with the eastern edge of the boundary to a previously cultivated plot: grid point 6 is 1 boundary stone's length to the north of the SE corner, grid point 5 is 7m to the north. Line 4 is 4m to the West of Line 3 (i.e. towards the existing boundary wall) and parallel to it.

Area 2 was covered by 14 parallel survey transects, spaced at intervals of 0.5m, running approximately West/East.

Precise positional information to identify the location of the survey grids was collected by CFA and will be applied to the GPR data.

## **Survey Parameters**

The Groundvue 1 surveys were carried out using an impulse of 1 nanosecond, a scan time of 60 nanoseconds and a sampling interval of 5cm. In the soil conditions of this site, a scan time of 60 nanoseconds corresponds to a depth of approximately 3m.

## Calibration

GPR depths are measured in nanoseconds time. 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 borehole data. Calibration by the wide angle reflection and refraction (WARR method) was carried out in both areas. The WARR method is used to compare the known speed of transmission of the electromagnetic waves in air with the unknown speed of transmission through the ground. It is achieved by drawing the receiver and transmitter antennas apart while the radar continues to transmit. A simple curve-fitting computer programme is then used to compare the two speeds.

Three calibration runs were completed in area 1 and a further two in area 2. The results do not deviate markedly from the expected transmission speed for dry soil, 0.1m/ns, indicating that the soil was not retaining significant volumes of water. A velocity of 0.1m/ns has been applied to both data sets, as the variation from this (in area 2) is not significant.

Area	Run	Dielectric Constant (Er)	Speed of Transmission
1	46	9	0.1m/ns
	51	9	0.1m/ns
	52	9	0.1m/ns
2	55	11	0.09m/ns
	56	10	0.095m/ns

### Fieldwork

Fieldwork was carried out on 15<sup>th</sup> August 2005.

### SURVEY RESULTS

### **Radar Output**

The radar output was processed as follows: Background removal applied; Time based gain added; and Bandpass Butterworth filter (200MHz to 600MHz) applied.

### Area 1: 2-Dimensional Data

Area 1 is the main area between the two existing houses. All radar transects are depicted as running from line 1 to line 2 i.e. site North to South.

Typical output is shown in Figure 1 (transects 11 and 33). Much of the area appears to be relatively densely packed with strong anomalous signals, probably indicating the presence of building remains. The existence of discrete surfaces is indicated by continuous black/white banding across the plots. Repeat signals in the vertical direction indicate the presence of standing remains although there is also some ringing (repeated echo effects) from near surface objects. Areas of interference patterning suggest the possibility of backfill, again containing significant amounts of building materials. The general impression of the output is relatively chaotic. This is not unusual for an area where one or more buildings have been destroyed and the ground subsequently levelled for later re-use.

The survey was carried out in a series of parallel transects so that a 3-dimensional data set could be formed. It is generally easier to understand the source of GPR patterning in the horizontal rather than the vertical plane. A series of horizontal timeslices has therefore been extracted from the 3-dimensional data.

### Area 1: 3-Dimensional Data

All of the time slices for this area are presented with site East at the top of each image i.e. as though the viewer were standing beside & in front of the occupied West House, facing the unoccupied East House. A larger than usual number of timeslices has been generated due to the high volume and complexity of the buried remains.

The series of timeslices is shown in Figures 2 to 14. The approximate depths represented are 10cm, 20cm, 30cm, 40cm, 50cm, 60cm, 70cm, 80cm, 90cm, 1m, 1m35, 1m65 and 2m.

In the **10cm** timeslice, the black curvilinear feature marked "A" corresponds to a densely packed surface close to the current ground surface. In the 2-dimensional data, the ringing (echo effects) associated with this type of hard surface are clearly visible: see Figure 15. The principal problem with ringing is that it can mask other signal returns with a genuine depth association. The dark area in the lower right hand side is a similar but much smaller feature.

The area of strong signal return marked "B" consists of a similarly dense surface but appears to correspond to possible building remains. Area "C" corresponds to the position of the current gravel drive and probably therefore relates to the construction of the drive. Although there are underlying signals consistent with building construction, at this depth this appears to be a levelled surface. Area "D" also appears to relate to the levelling of the site, rather than underlying construction: compare the area before marker 1 on Figure 16: transects 19 and 24 are typical.

In the **20cm** timeslice, area "A" becomes more extensive: the footprint appears as a square/rectangular surface combined with a curvilinear feature. Taking into account the ringing pattern visible in the 2-dimensional data (which is indicative of a hard surface close to the present day one), this suggests a possible former road/drive, possibly connected to a small building of more recent date than the original house. The ringing in transect L24 (Figure 16) is typical.

In the NE (top left) corner, a linear feature has appeared which appears to be a utility: the trench and trench sides are clearly visible. The construction is not typical of modern utilities which typically depict disturbance in the area of the trench and then, as depth increases, the line of the utility. This appears to be a channel marked by the position of solid material on either side of the trench.

The utility trench is still clearly visible in the **30cm** timeslice. In the SE (top right) corner, the dark line running approximately East/West is the continuation of the existing wall observable on the East side of the current boundary wall between the East and West Houses. Note that since the data has not been topographically corrected, that this raised area is not at the same level as the remainder of the timeslice. The strong signal returns associated with Area "A" are beginning to

resolve into 2 separate features, as described above (at 20cm). This is also observable in the 2-dimensional data. It seems that the footings for the two constructions may be similar. The remaining dark areas appear discontinuous both in 3-d and in 2-d (the central portion of transect 11 in Figure 15 is typical). The 2-dimensional data suggests that these are areas of backfill i.e. containing quantities of building materials used to produce one or more level surfaces.

The possible utility trench is still visible in the **40cm** timeslice although its central portion is not visible. A new linear feature is just visible along the x = 0 line i.e. survey line 1. This does not correspond to a feature above ground: the survey base line was chosen with reference to potential area coverage and accuracy of long term recording. This line meets another at right angles at c. y = 20m. It appears likely that these lines correspond to part of the outline of the former main house. The separation of the two features forming area "A" is much clearer at this depth.

As in the previous timeslice, the dark mottled area between x = 3m & x = 10m; y = 1m and y = 8m, corresponds to an area of densely packed signals. This is likely to be either backfill or a surface made up of many individual densely packed elements. The wall beneath the small mound in the SE (upper right hand) corner is still visible: a growing spread of adjacent building material accompanies it on both sides, suggesting that the mound is based on the wall, augmented by rubble.

Both the possible utility trench and the 2 right-angled probable walls are clearly visible in the **50cm** timeslice. Between y = 10 and y = 12.5 along line 1, there is a gap which does not appear to relate to the intrusive trench and may therefore be an entrance to the former building. The mottled area (noted above) is virtually unchanged but has resolved into a triangular shape. The signal pattern in the former area "A" has become much more diffuse and appears at this depth to relate to the 2 right-angled possible walls. This would imply that there are underlying building remains *in situ* in this area, effectively masked in the 2-dimensional data by the hard surface above them. If this is a correct interpretation, it also dates the possible road/drive and the small building to post-destruction of the main house. There has been at least one such building: at the time of the survey mention was made of a former garage.

Although the pattern of the signals in the SW sector of the survey area is relatively diffuse (consistent with backfill often associated with post-destruction debris), the overall outline is similar in shape to the relevant end of the house footprint in the old Ordnance Survey 1-inch map. In the SE corner (top rhs), the raised area adjacent to the dividing wall between the 2 existing properties appears to consist primarily of building rubble.

The **60cm** timeslice is very similar to that at c. 50cm: the beginnings of possible room outlines are visible in the southern sector (rhs). Along survey line 1 (x = 0), a split has appeared so that the strong signal returns are aligned on either side of what appeared previously to be the limit of the building. This central line now appears as less dense relative to the materials on either side.

There are a number of interesting changes in the **70cm** timeslice. Along the line of the trench previously described as being a possible utility, a line of dark signals

indicates the position of the potential utility itself. This line is only partial, running from (x = 2.7, y = 13) to (x = 4.9, y = 20.5). It is completely missing from the NE sector, presumably removed subsequently. In the 2-d data, there are at least 2 closely spaced hyperbolae, indicating more than 1 construction within the same defined space. Alternatively, this could represent two base slabs to the same construction, provided that they were sufficiently small.

There is a large, mostly rectangular area near to the middle of the western sector of the survey area whose footprint measures approximately 4.2m by 2m although the shape is irregular. The 2-dimensional data at this point shows clearly that this upper surface continues in the horizontal direction but that beneath it lies another deeper surface. Measured at 0.3m/ns (the velocity of transmission of radio waves in air), the distance between the two surfaces is between 1.6m and 2m. It is also clear that the floor/cellar ceiling gives a stronger electromagnetic response and is measurably thicker than the surrounding floor area. There are some signals between the possible cellar floor and ceiling, indicating that the area is not completely devoid of contents. Figure 17 shows the results from transects 36 and 37. From run 37 onwards the pattern is relatively regular from one transect to the next. The first transect to show the returned signals from the possible cellar is run 36: the irregularity relative to subsequent runs suggests that there are some major differences in construction. This may be a reflection of an entry point.

The split observed along survey line 1 where, at higher levels, an apparent limit to the former building lies, is more exaggerated. There is a considerable quantity of building remains in the eastern sector and relatively little to the west.

In the southern sector, a number of dividing lines suggests a possible room layout. Although the dark areas between y = 20 & y = 24 are within the area where ringing is visible, these reflections do seem to represent underlying construction since some signal variation is discernible in the 2-dimensional plots.

The **80cm** timeslice is very similar in content to the 70cm one. By **90cm**, however, a new linear feature has appeared along the line y = 20.5m (transect 41). As Figure 18 illustrates, this is a continuous surface which is probably linked to a similar feature visible in the southern third of the profile. This latter signal appears to curve upwards: in reality the current ground surface dips and this is almost certainly a level feature. Some of the wall construction is also visible in this and the following transect profile.

The cellar is clearly visible in both timeslices. The possible northern edge to the main house is indicated only by a few metres of signal, to either side of survey line 1, in the general vicinity of the eastern edge but nowhere else. A stronger parallel line has appeared along the x = 4m line with a central break. It is possible that this represents an earlier phase of the house and that a c. 4m extension to the north is of later date.

By **1m** depth, two parallel lines with a slightly bowed shape towards the north have taken over as the northern limits of the house. Compared with the shallower patterning, this also suggests phased development of the main house. The signals representing the cellar continue to be strong reflections relative to their surrounding area, indicating a complete difference in material. This is as expected i.e. the

difference in the cellar relative to its surrounding environment is what makes it a suitable GPR target.

The linear feature, which first appeared in the 90cm timeslice, is also clearly visible in this one. The northern edge appears to join the house outline and it is reasonable to assume they are related features.

Below 1m depth, the changes in patterning are much less frequent. The **1m35** timeslice is almost identical to the previous one, at 1m. In defining these depths, it needs to be remembered that transmission velocity varies with the medium through which the radio waves are travelling. The timeslices represent a cross section in time, but not necessarily space. The physical cross section will have been distorted by the radio waves crossing the air void in the cellar at three times the speed that they pass through the ground. In addition, since the GPR data has not been contoured, there is also a slight distortion where the modern surface rises (in the SE corner) or dips (in the SW corner).

By **1m65** there are relatively few features still visible. There is a faint outline of a moderately large square/rectangular building whose northern edge lies close to the x = 4m line. Some remnants of signal are visible from the area of the cellar. The two areas of strong reflected signal to the south are likely to be ringing, echo effects from features lying above. Beneath the mound in the SE (top right hand) corner, there is a spread of building material. By **2m**, only the latter three features are visible.

### Area 2: 2-Dimensional Data

Area 2 lies in front of the unoccupied East House, to the east of the existing boundary wall between the two houses. The 2-dimensional data suggests that there are major building elements still *in situ* in this area. Figure 19, comprising the first and last profiles, illustrates this.

### Area 2: 3-Dimensional Data

The time slices are presented with North at the top of each image. The relatively limited area investigated is dominated by one linear feature, which crosses at an angle in the eastern part of the survey area. This feature becomes visible within the first 10cm of deposit as a triple series of parallel lines.

By the depth of the **25cm** timeslice (Figure 20), two of these signals have amalgamated into the relatively thick linear feature visible in this timeslice: the third line is still separately visible to the east. A dark triangle to the west indicates a hard surface close to the present day surface. The thin line marking x = 3.5 is a reflection of a modern feature, the line of stone marking the edge of a cultivation bed.

The linear and surface features appear to join up in the **40cm** timeslice (Figure 21). This subsequently resolves into a series of parallel lines, with the suggestion of a corner to the north and a curvilinear feature curling towards the north & south in the **55cm** timeslice (Figure 22). The **65cm** timeslice (Figure 23) is similar except for the gradual disappearance of an anomaly apparently at the centre of the circular feature. In the 2-dimensional data, this appears to be a fraction of a compacted surface close to

the present ground surface and the likelihood is, therefore, that this is ringing (echo effects) caused by the surface above. As such, the feature is likely to post-date the destruction of the main house.

By **93cm** most of these features have disappeared, visible only as minor reflections: see Figure 24. The main linear feature and a short anomalous area near the base line (survey line 4) remain. The 2-dimensional data suggests that both are related to building construction. By the **1m50** timeslice, these, too, are diminishing (Figure 25).

### **Conclusions & Recommendations**

### Area 1

The detailed findings in each timeslice have been described above. The area is relatively complex but there is good evidence for the following features, annotated on Figure 26:

- A possible cellar (A);
- A small square/rectangular building which post-dates the destruction of the main house (B);
- A large linear feature of relatively solid construction which may have served as a the conduit for a former utility (C);
- A possible former road/driveway which post-dates the destruction of the main house (D);
- Partial continuity of an existing wall from the garden of the East House into that of the West House beneath the small mound in the garden of the latter (E);
- Other *in situ* building remains (F);
- Possible evidence of extension of the main house towards the north (G);
- Levelling of the site following the destruction of the main house (H).

### Area 2

The more limited investigation in Area 2 confirms that there are building remains buried in this area also. It is not possible to interpret the patterning but it is evident that there are significant building remains *in situ*. If a fuller ground plan is required, this part of the GPR survey could be extended.



Figure 1: Typical Output from Area 1 - Transects 11 & 33

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Figure 2: Area 1 10cm Timeslice



Figure 3: Area 1 20cm Timeslice



Figure 4: Area 1 30cm Timeslice



Figure 5: Area 1 40cm Timeslice



Figure 6: Area 1 50cm Timeslice



Figure 7: Area 1 60cm Timeslice



Figure 8: Area 1 70cm Timeslice



Figure 9: Area 1 80cm Timeslice



Figure 10: Area 1 90cm Timeslice



Figure 11: Area 1, 1m Timeslice



Figure 12: Area 1 1m35 Timeslice



Figure 13: Area 1 1m65 Timeslice



Figure 14: Area 1 2m Timeslice



Figure 15: Transects 16 & 30

1. C:\Pencd\PROCDATA\L19\_\_\_\_\_.02t / traces: 822 / samples: 256



Figure 16: Transects 19 & 24



1. C:\Pencd\PROCDATA\L36\_\_\_\_\_.02t / traces: 673 / samples: 256

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1. C:\Pencd\PR0CDATA\L60\_\_\_\_\_.02t / traces: 363 / samples: 256

Figure 19: Area 2, Transects 60 and 73



Figure 20: Area 2 25cm Timeslice



Figure 21: Area 2 40cm Timeslice



Figure 22: Area 2 55cm Timeslice



Figure 23: Area 2 65cm Timeslice



Figure 24: Area 2 93cm Timeslice



Figure 25: Area 2 1m50 Timeslice



Fig. 26 - Interpretation Plan.