Ground Penetrating Radar Survey of an Area within

Kilspindie Golf Course

for

CFA Archaeology Ltd

17 July 2008

CONTENTS

SURVEY OBJECTIVE

This survey had two objectives. There is historical evidence for the existence of a cave, used for smuggling in the past, lying below the headland to the north of Kilspindie golf course. The blocked entrance to this cave has been identified. Aerial photographs have revealed the location of a double ditched enclosure, thought to be an Iron Age Fort, on the headland above, immediately adjacent and to the East of the cave entrance

The first survey objective was to identify the extent of the cave within a total survey area of 40m by 120m (see Figure 1). The second survey objective was to examine the extent of subsurface remains from the possible Iron Age fort.

SURVEY STRATEGY

Use of Ground Penetrating Radar

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 distinguishes between adjacent materials on the basis of their electromagnetic characteristics. The strength of the signal returned to the radar is a measure of the degree of difference between adjacent materials. It is not possible, however, to distinguish the precise nature of the materials involved. Any attempt to do so must recognise two potential pitfalls:

- the possibility that there may be an equally valid alternative explanation for the strength of signal return; and
- where the electromagnetic properties of a given target are similar to those of its immediate environment, it is unlikely that the radar will detect any difference resulting in the potential for concealed material.

The expected targets for this survey were air gaps in at least some sections of the cave and differential soil deposits in the ditches of the fort. Air and rock have very different electromagnetic responses. Voids therefore represent excellent targets for the radar. Although there is a difference in the electromagnetic response of rock and associated soils, this difference t is not necessarily substantial.

Equipment

The equipment used for this survey was Utsi Electronics' Groundvue 2 which has an operating frequency range of 30MHz to 100MHz and a maximum depth of penetration of over 30m in dry conditions.

Before the survey was carried out, the maximum depth of penetration was expected to be of the order of 13m which necessitated the use of a low frequency radar. The

survey results show that there are no anomalous signals below c. 5m in depth and a higher frequency, higher definition radar could have been used, had this information been available prior to the survey.

Site Conditions

Ground surface conditions for the survey were good along the fairway & poor in the rough grass, closer to the cliff edge. The conditions were not sufficiently poor to prevent the survey being completed. It was not possible to survey close to the cliff edge for safety reasons.

Site Coverage

Survey reference lines were established as illustrated in Figure 1: line 1 to the East; lines 2, 3 and 4 parallel to line 1 and at distances of 60m; 30m and 120m respectively.

Each area was surveyed along a series of parallel lines in an approximate East/West orientation at intervals of 1m between adjacent transects.

Survey Parameters

Areas A, B & C were initially surveyed using a time sweep of 320ns (approximately equivalent to 16m in dry conditions) to allow for the maximum possible depth of 13m. From this survey it became apparent that there were no anomalous signals below c. 5m depth and the time sweep was reduced to 160ns (approximately equivalent to 8m in dry conditions) for the remaining survey. Areas D, A & B were surveyed using a time sweep of 160ns. The sampling interval along the line of travel of the radar was 10cm for all surveys.

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.

Two calibration runs were completed, using the Wide Angle Reflection & Refraction (WARR) method. The antennas were drawn apart during transmission. This results in a signal curve through the ground and an associated signal curve through the air. Since the speed of transmission through the air is known, a simple curve fitting programme can be used to calculate the speed of transmission through the ground. The results of both calibrations were consistent and gave an average speed of 0.1078m/ns which is consistent with the dry nature of the site. This velocity has been used to calibrate depths in this report.

Where a void exists, the transmission speed of radio waves is approximately three times as fast i.e. c. 0.3m/ns. Since the speed of transmission is approximately three times that in soil or building materials, the GPR data presents a distorted view both in vertical section and in horizontal time slice where voids exist. This will have had a major impact on the data in the area of the cave. In the vertical 2-dimensional data, the depth of voids is 3 times that indicated.

Time slices are extracted at their common time. Where a void has been crossed, the area indicated by the void will be considerably lower in depth than its apparent surround. This does not, however, negate the process of void detection. It is the reason that apparently horizontal views are referred to as time slices rather than horizontal slices at a given depth. The time taken for the signal to reach the material and return to the radar receive antenna is the common factor.

Fieldwork

The survey was carried out on 26th & 27th June 2008.

SURVEY RESULTS

Radar Output

The radar output was processed as follows for Areas A & D:

Geometric correction for Sender/Receiver distance;
Correction for Tzero (transmission along cables); and
Bandpass Butterworth filter (30MHz to 150MHz) applied.

For Areas B & C, data processing was:

Geometric correction for Sender/Receiver distance;
Correction for Tzero (transmission along cables);
Background removal;
Time based Gain compensation; and
Bandpass Butterworth filter (30MHz to 150MHz) applied.

The reason for the difference in processing the data sets is due to the extreme shallow position of the fort remains in Areas A & D. Any additional processing, such as background removal, results in the elimination of the near surface features and has therefore not been applied to this data set. It is possible that the processing applied to areas B & C has reduced the visibility of the fort remains in this area. The processes chosen for areas B & C have been selected in order to optimise the signal responses from the voids below the cliff since the data from the remaining 2 areas can be used to investigate the remains of the fort.

All 2-dimensional data is illustrated running from Marker 4 to Marker 2 to Marker 3 to Marker 1 i.e. from West to East, as depicted from left to right across the page. Time slices extracted from 3-dimensional data are shown with North at the top of the page.

The Survey Results from the Area of the Fort

Aerial photographs show a double ditch covering the full extent of all four survey areas and extending beyond the survey areas to the West. Although, as explained above (in Radar Output), only the data from Areas A & D is optimised for detection of the fort remains, all four areas have been examined for definition of the fort. All four areas show some evidence related to the fort.

Area A (Runs K1 to K19 inclusive)

A total of 19 radar profiles were collected in this area, beginning at 1m to the South of the southern boundary & finishing 19m to the North of the same boundary. Typical output from Area A is shown in Figures 2 and 3 (radar profiles 4 & 9; 6 & 15).

The data show a series of shallow double ditches, at varying distances from each other, depending on the relative positions of the survey line and the concentric circles of the ditches. There is a suggestion in a number of the profiles that there may be at least one additional ditch: see, for example, Profile 4, Figure 2.

The ditches are very shallow and survive best below the rough ground on the golf course. Figure 3 illustrates the difference in survival below the rough grass (run 6) and below the fairway (run 15). It appears that the creation of the golf course has impacted on the survival of the archaeological remains.

Anomalous signals within the outline of the ditches confirm that the content of the ditches differs in electromagnetic properties from the ditch profile. This implies that backfill is present and that the backfill is not similar to the soil/rock into which the ditches have been cut. It is not possible to determine the nature and contents of the backfill on the basis of the GPR survey alone.

Area D (Runs L1 to L38 inclusive)

A total of 38 parallel traces were taken, covering all of Area D and most of Area A, beginning 1m to the North of Area D's southern boundary and continuing northwards at 1m intervals. This area was surveyed on the second day and therefore used a reduced time sweep of 160ns. The reduction in depth penetration has resulted in an improved vertical definition i.e. it is slightly better than for Area A alone. This is also the reason why Area A was re-surveyed following the completion of the Area D survey. The two aims were to achieve compatible data sets across the two survey areas and to see whether it was possible to gain a more detailed view below the fairway, where the development of the golf course appears to have impacted most strongly on the archaeological remains.

Although the vertical definition is improved, the survey results are very similar to those of Area A. The data indicates the position of two shallow ditches. The apparent variation in distance between them is a function of the position of the radar relative to the two concentric circles. As for Area A, there are indications that a third ditch may exist or that the area directly to the NW may differ from its surround. In some locations, the impact of creating a golf course has reduced the visibility of at least one of the two main ditches. Area D lies wholly beneath the fairway. Figure 4 illustrates the data from this area (runs L5 & L13).

Area B (Runs A1 to A14 inclusive; E1 to E12 inclusive)

Area B was surveyed twice: initially at 320ns (A1 to A14) and later at 160ns (E1 to E12). In each case the survey was begun at 1m to the North of the southern boundary & continued as far north as was feasible at 1m intervals. The limiting factor on the

full extent of the survey was the rough ground surface and the proximity of the towing vehicle to the edge of the cliff.

Although this area lies primarily below the rough ground, there is very little indication of the presence of shallow ditches. As discussed above, this may be in part due to the processes applied to the data (optimised for greater depth). From the first survey, only profiles A1 and A13 (both in Area B) show similar evidence to Areas A and D (Figure 5). In both cases, this is limited to a single possible ditch although profile A1 does seem to indicate some sort of platform immediately adjacent to the ditch, implying the existence of a ditch on the other side, even if this is not clearly visible (e.g. at c. 53m distance). This 'platform' features later in the time slices from the 3-dimensional data set.

The data from the second survey are, as expected, consistent with that from the first. The best evidence for the possible survival of one or more ditches comes from profiles E1 & E8 (Figure 6).

The data from Area B therefore indicates shallow remains of a former circular enclosure. The remains are not substantial and lie close to the current ground surface.

Area C (Runs C1 to C20 inclusive)

Area C lies directly south of Area B. Runs C1 to C20 inclusive were recorded starting

1m to the North of the southern boundary and continuing northwards at intervals of 1m between transects.

The data are very similar to that from Area B. There is very limited evidence for one or more shallow ditches which may, in part, be due to the processes applied to the data since this area was optimised for detection of subsurface voids. No evidence at all of the fort remains is visible in the majority of profiles: compare the data from C1 and C10 (Figure 7). The position and direction of the survey was not optimised in this area for detection of the fort, as defined by aerial photographs so that any signs of archaeological material in the GPR data are effectively a bonus.

3D Data from Areas A & D: the Fort Remains

The parallel profiles from the 160ns survey of Areas A and D have been combined into a 3-dimensional data block from which quasi-horizontal time slices have been extracted. All time slices are depicted with North at the top of the page.

A group of rectilinear features and 1 curvilinear feature appears at c. **4ns** (equivalent to 24cm below the surface, measured through dry soil): see Figure 8. These lie above the level at which the ditches can be detected. They are not within the area delineated by the ditches. Comparison of Figures 8 & 9 shows that there is an overlap between these features and the top of the ditches suggesting that these features post date the use and backfill of the ditches.

The upper levels of the ditches become visible at c. **7ns** (equivalent to 38cm in depth): see Figure 9. The areas of the ditch show as weaker (paler) signals than the

surrounding rock/soil. Two concentric rings are visible, with a partial inner ring to the West and an outer possible ring to the East. The partial inner ring may indicate that the central portion of the fort differs in nature from its surround, rather than being another ditch. An area of possible levelling off, presumably in order to create the golf course, is also visible at this depth.

This same patterning is clearly visible at depths of c. **10ns** (or c. 54cm) and **13ns** (or c. 69cm): see Figures 10 & 11. The evidence of levelling off is no longer visible at these depths and the eastern boundary appears to be merging into the underlying rock. The narrowing of the ditches with depth is also observable in these time slices.

By **20ns** (or c. 1m) the inner circle defined by the two concentric ditches appears also to be bottoming out on to rock (Figure 12).

Around **33ns** (or c. 1m78), the pattern begins to change. The double concentric rings visible in the layers above are replaced by concentric circles whose centre lies to the East of the Area. These features are not visible in the 2-dimensional data. Figure 13, the time slice at **37.5ns** (or c. 2m) illustrates the change of orientation. It seems very likely that this represents an earlier use of the site. Unfortunately it is not possible to date the two structures on the basis of the GPR survey other than relative to one another.

3D Data from Areas B & C: the Fort Remains

The parallel profiles from the 320ns survey of Areas B and C have been combined into a 3-dimensional data block from which quasi-horizontal time slices have been extracted. For this data set, "quasi" is used to acknowledge the difference in absolute depths (as opposed to time) in an area containing voids and therefore subject to differing transmission speeds. All time slices are depicted with North at the top of the page.

There is no evidence in the near surface layers of this 3-d data set of the concentric ditches visible in Areas A and D although the curvilinear feature visible at 10ns may possibly be connected to the inner ditch (see Figures 14 to 16 inclusive). This is not an unexpected result, given the position of these two areas relative to the position of the ditches, as defined by aerial photographs. The 2-dimensional data also suggests that the depth of soil above the rock is much less in this area than in Areas A & D which could potentially reduce the chances of preservation.

By **20ns** (c. 1m), the central area of the Fort becomes visible: the points marked on Figure 17 correspond to the positions of the feature resembling a platform referred to in the 2-dimensional data and the position of the possible related ditches. This area is still visible by **25ns** or c. 1.35m (Figure 18).

2D Data from Areas B & C: the Cave and other Features

All of the 2-dimensional data from areas B & C is characterised by the presence of at least two stratigraphic interfaces. The first of these may reasonably be assumed to be the change from soil to the underlying rock and can be seen in all of the 2-d data from all 4 survey areas.

The second is primarily present in the survey areas B & C. This interface lies below that presumed to be the change from soil to rock and is followed by a third stratigraphic layer change directly below. Figure 19 uses data from Area C to illustrate these second and third layer changes. The same phenomenon can be observed in profiles A13 (Figure 5), E8 (Figure 6) and C10 (Figure 7).

On the basis of the radar evidence alone, it is not possible to be prescriptive as to the materials involved. However, there are a number of characteristics which can be described, some of which suggest that this represents substantial voids within the rock.

1. There is a change of polarity from the second interface to the first. Put simply, this means that a black/white/black band becomes a white/black/white (or the reverse). The actual polarity is not important. However, the reversal of the polarity suggests that there is a single intrusive material between 2 layers of the same material. An air gap within rock is one obvious possibility.
2. From the prevalence of these interfaces in the 2-dimensional data, the areas involved are substantial. It is not possible to determine whether or not they are interconnected from the 2-dimensional data.
3. Voids sometimes give rise to echo effects, known as ringing, especially if the size of the void is a multiple of the wavelength emitted by the radar. There is no evidence of this type of ringing. However the structures visible in the 2-dimensional data are large and therefore such ringing would not be expected.
4. The signal returns from the second interface are strong. The strength of signal return is an indication of how different the two adjacent materials are in their electromagnetic properties. Air and rock have very different electromagnetic properties and a strong signal return would be expected at the interface between the two materials.
5. The third interface is generally markedly weaker than the second although signal strength varies along the line of the layer change. Although some reduction in signal strength with depth is to be expected, the attenuation is greater than would normally be the case for a reversion from air to rock. If the intrusive material is air, the lower level corresponds approximately to the level of the shoreline. Where there is an opening to the sea, the floor of any void will have been subject to the accumulation of salt. The presence of any ionised material reduces the amount of signal returned to the radar. The electromagnetic pulses pass into the ionised material as a weak electric current resulting in attenuation (loss) of signal returned to the radar. One possible interpretation of the radar data is therefore that the floor of the voids has been exposed, in some areas, to the accumulation of salt, making these areas more lossy (or signal attenuating).
6. Another possibility for the variation in signal strength along this third interface is that there is a build up of sand on the floor of the voids but that the volume of sand is insufficient to be separately identified from the underlying rock by the radar. Since the sand and the underlying rock are likely to be similar in electromagnetic properties, the variation in signal strength from air to sand to rock might appear reduced. With a greater build up of sand deposit, this would be replaced by two sets of layer

signals, the first being considerably stronger than the second set. If this is the case, the areas of stronger signal return are more likely to be rock and the areas of weaker signal return more likely to contain sand.

Although it is not possible to state categorically, on the basis of the GPR data alone, that these layers are voids, it appears very likely that they are. This is because a) as analysed above, they conform to the expected pattern of signal returns for voids within the rock and b) they lie adjacent to the known entrance to a cave.

3D Data from Areas B & C: the Cave and other Features

The first feature to become visible in this data set is a linear feature running approximately West/East across the survey area at c. **6ns** (equivalent to c. 34cm), see Figure 14. Its proximity to the surface and lack of correlation with any of the underlying features, suggests that this may be a modern feature.

By **10ns** (c. 54cm), a curved linear feature becomes visible (Figure 15). This is accompanied by a partial line directly to the north. It is possible that this feature relates to the remains of the fort. The dark areas in the **14ns** (c. 75cm) time slice appear to represent the change from soil to rock, from comparison between the 2-d and 3-d data (Figure 16). By **20ns** (c. 1m), as noted above, the central area of the fort appears to be the principal feature of the time slice (Figure 17). This is also the case at **25ns** (or c. 1.35m): see Figure 18.

The 2-dimensional data in Figure 19 indicates a depth range for the possible void stratum of between 40ns and 63ns although the depths vary both within the profiles and from 1 profile to the next. It is therefore a reasonable assumption that the top of the voids should be visible as areas of strong signal return at or around 40ns. The time slice at **41ns** (Figure 20) shows one area, to the NW, connecting to the sea front. There are also large areas of possible voids across Area C to the south and along the eastern border with survey areas A & D. Although these latter areas do not appear to connect directly with the northern coast, this may simply be because the connection occurs at a different depth i.e. the roof of the void is lower than 41ns.

Assuming that the layer changes represent voids, the time slices indicate that there are a considerable number of these, of varying size and shape. It is not always easy to define the outline of a cave from its roof, simply because of the structure of the rock at this point and the implied variation in depths of the rock/air interface.

The time slices at **59ns** (Figure 21) and **63ns** (Figure 22) are of the right depth to detect the floor of the cave. For both of these time slices, dark areas of strong signal return should represent the interface between the air and the rock below. Since radio waves pass very much faster through air gaps than through rock or soil, these quasi-horizontal plans are not in fact horizontal. They represent equal times, not equal depths. If we assume that any air gaps begin at 41ns and end at 59ns, the 59ns time slice represents depths of c. 3.2m where there are no air gaps but c. 4.9m where air gaps exist.

The radar data indicates at least 3 possible caves along the northern front, of which that to the East (x = 45m to x = 60m) is consistent with the entrance to the reported

"Smugglers' Cave". There is a very much larger series of possible caves to the south which look as though they may interconnect although the shape & size of the interconnections may or may not be sufficient to allow human access.

Conclusions & Recommendations

The GPR data confirm the existence of a double ditch surrounding a defined central area. The remains are shallow and have been reduced in certain areas by the creation of the golf course, notably directly under the fairway. The GPR data also provides evidence of previous occupation (concentric ditches on a different orientation) and subsequent occupation (features lying above the ditches).

The GPR data suggests that there is a considerable network of voids within the rock. These do not necessarily inter-connect although the time slices suggest that they may. We recommend that the 3 relevant time slices (Figures 20 to 22 inclusive) are compared with the known entrance to the cave to confirm which of the voids corresponds to the cave formerly used by smugglers.

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 Utsi, Director, Utsi Electronics Ltd.

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Appendix A: Figures

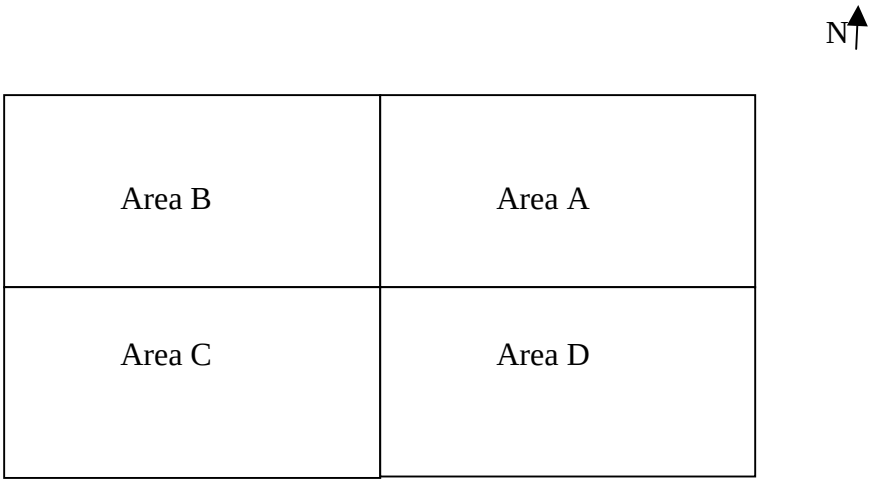

Figure 1: Sketch Plan of Survey Areas A to D inclusive

Notes

1. This sketch is not to scale.
2. Each survey area measures c. 20m (N/S) by 60m (E/W).
3. The surface of Areas C & D is fairway. Part of the surface of Areas A & B is rough grass and lies immediately adjacent to the cliff edge. As a result, the full northern extent of Areas A & B could not be surveyed for Health & Safety reasons.
4. Survey Reference line 1 is the eastern boundary of the survey areas. Survey Reference line 2 is the middle boundary of the survey areas i.e. the boundary between A & B and C & D. Survey Reference line 4 is the western boundary of the survey areas. Survey Reference line 3 lies 30m to the West of line 1 and 30m to the East of line 2 and parallel to both.
5. The entrance to the cave lies directly to the North of Area B.
6. Aerial photographs indicate the presence of a double ditched feature covering all four areas.

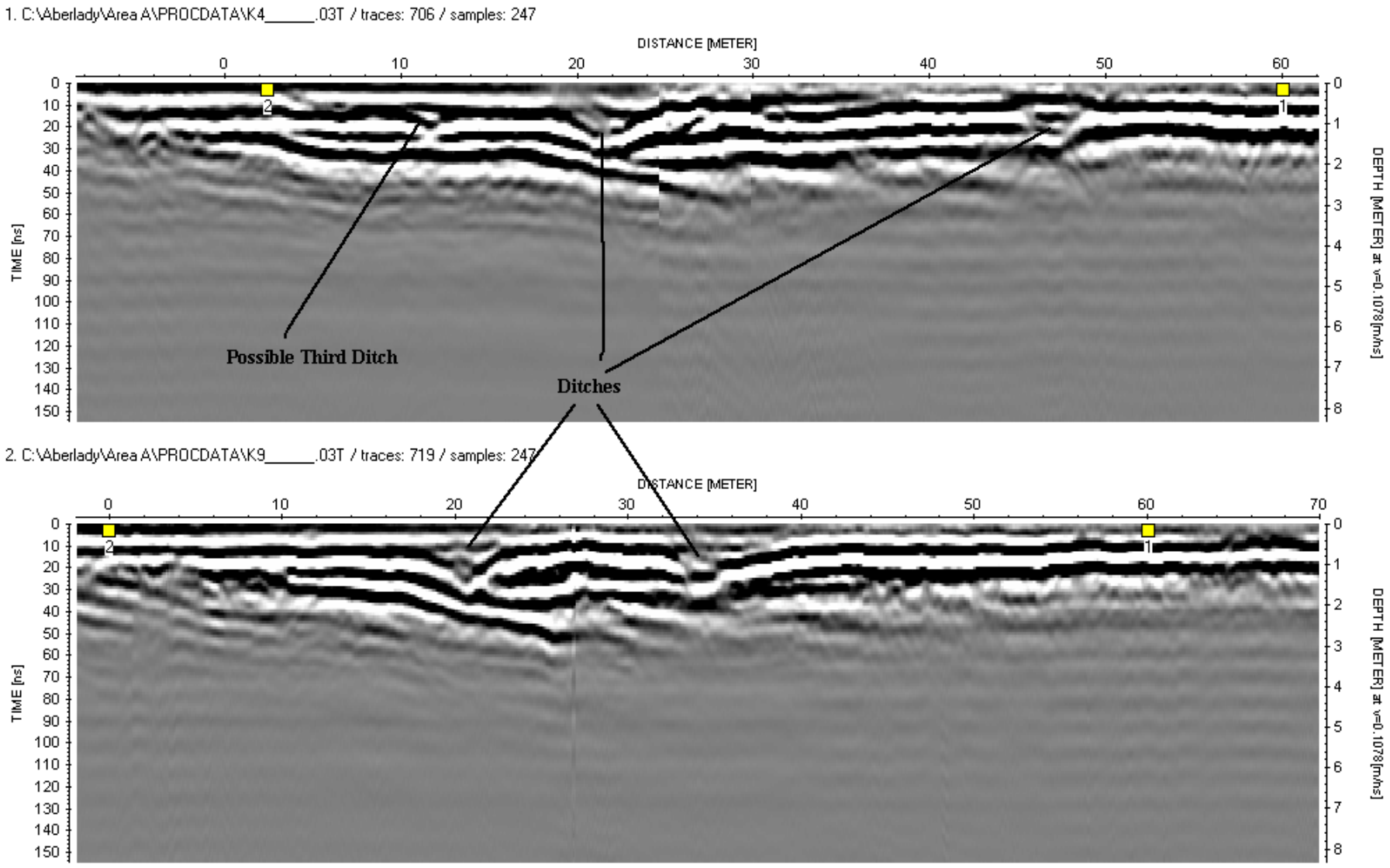

Figure 2: Profiles 4 & 9 showing the remains of shallow ditches

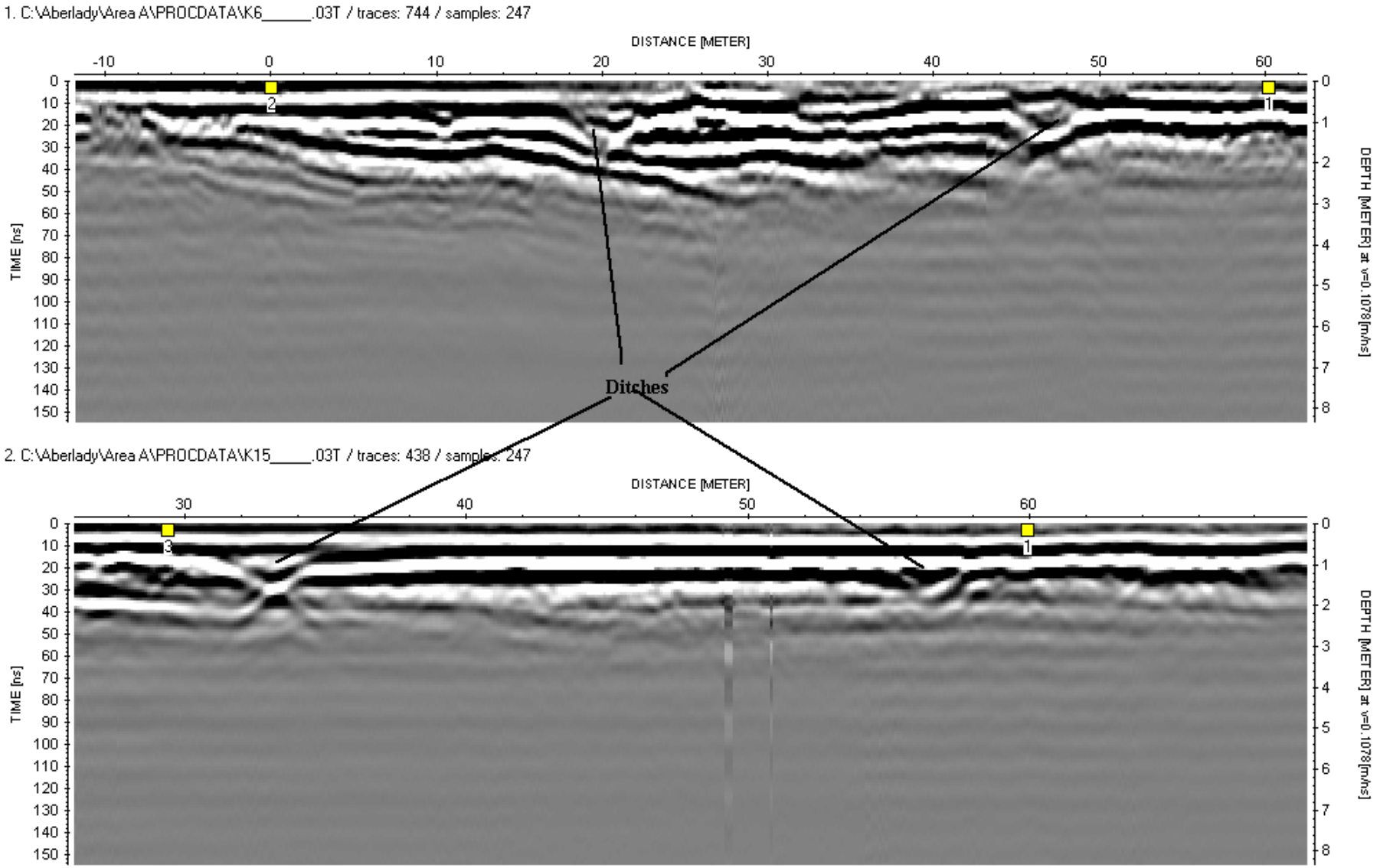

Figure 3: Area A Profiles 6 & 15 showing the difference in preservation below the rough grass (above) and the fairway (below)

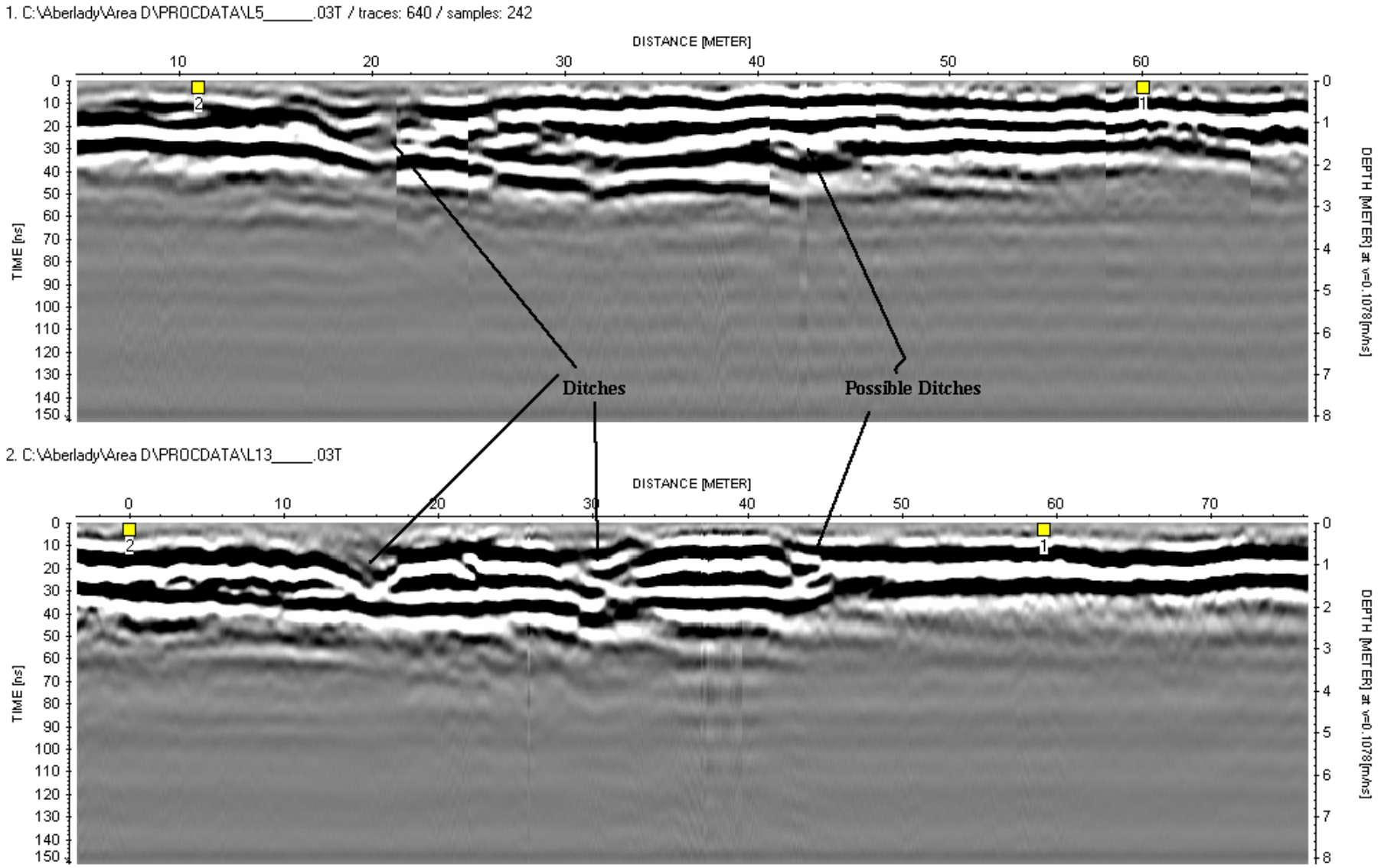

Figure 4: Area D Profiles 5 & 13 showing variable preservation of ditches

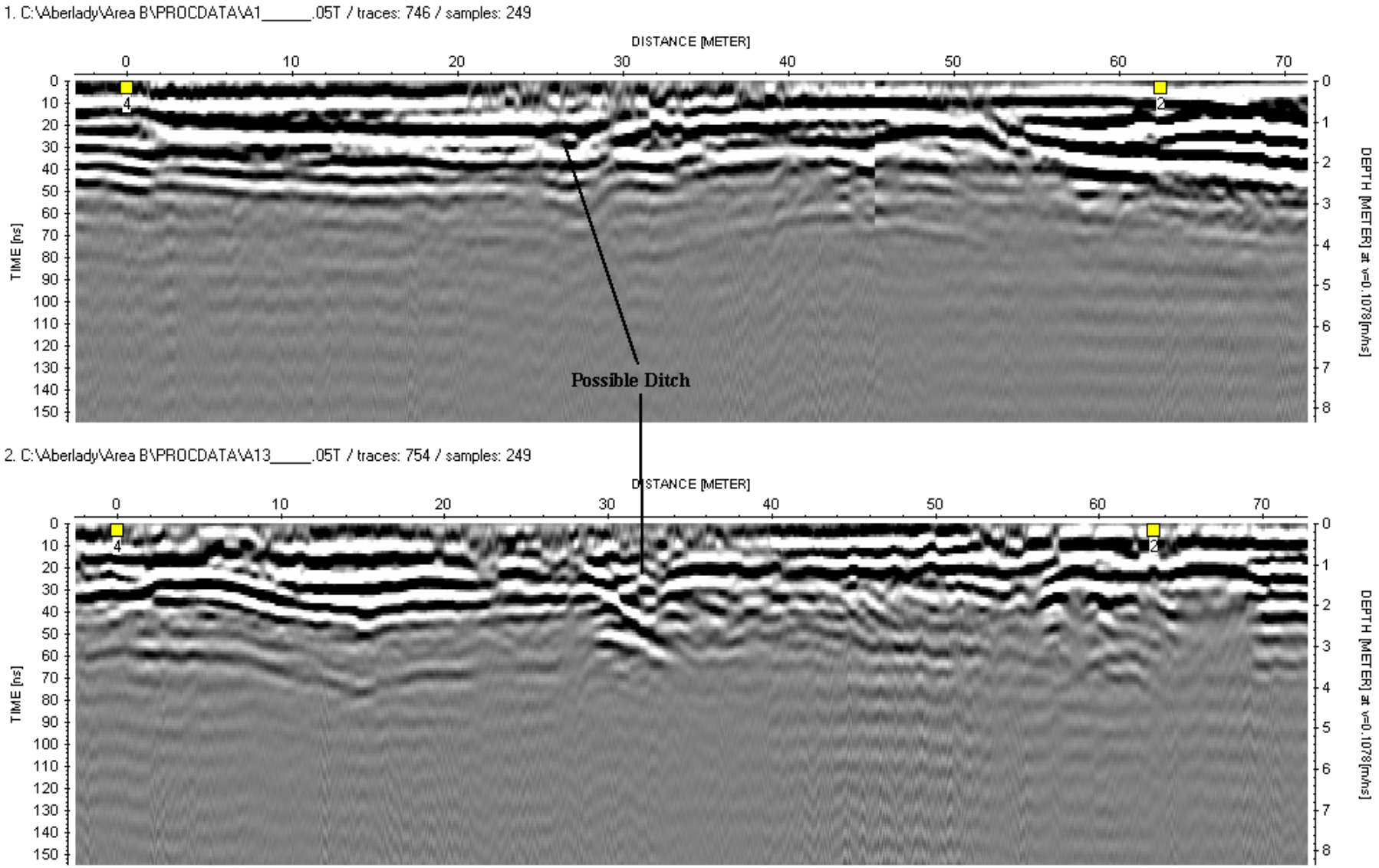

Figure 5: Area B Profiles A1 and A13 showing limited evidence for ditches

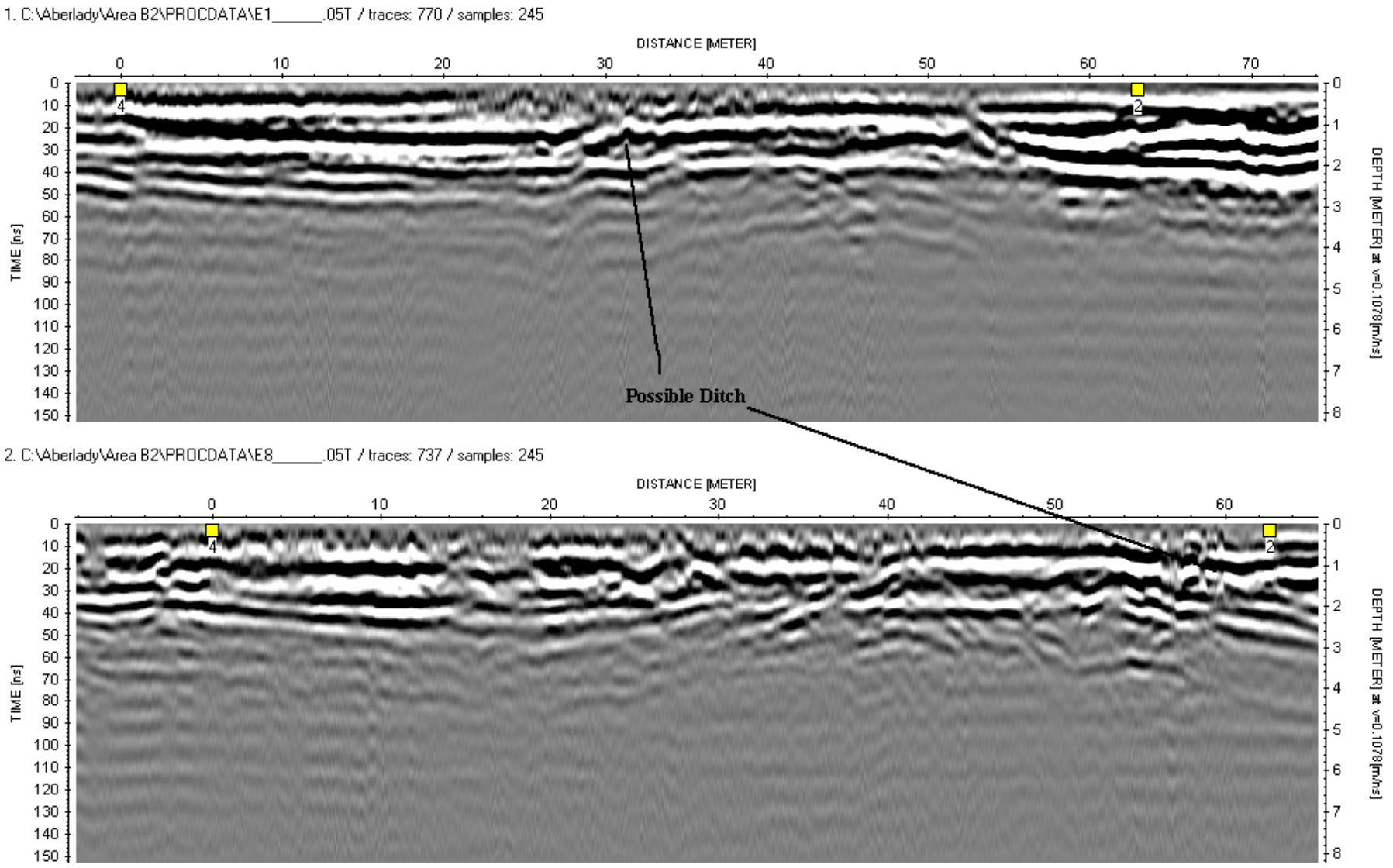

Figure 6: Area B Profiles E1 & E8 showing possible evidence for ditches

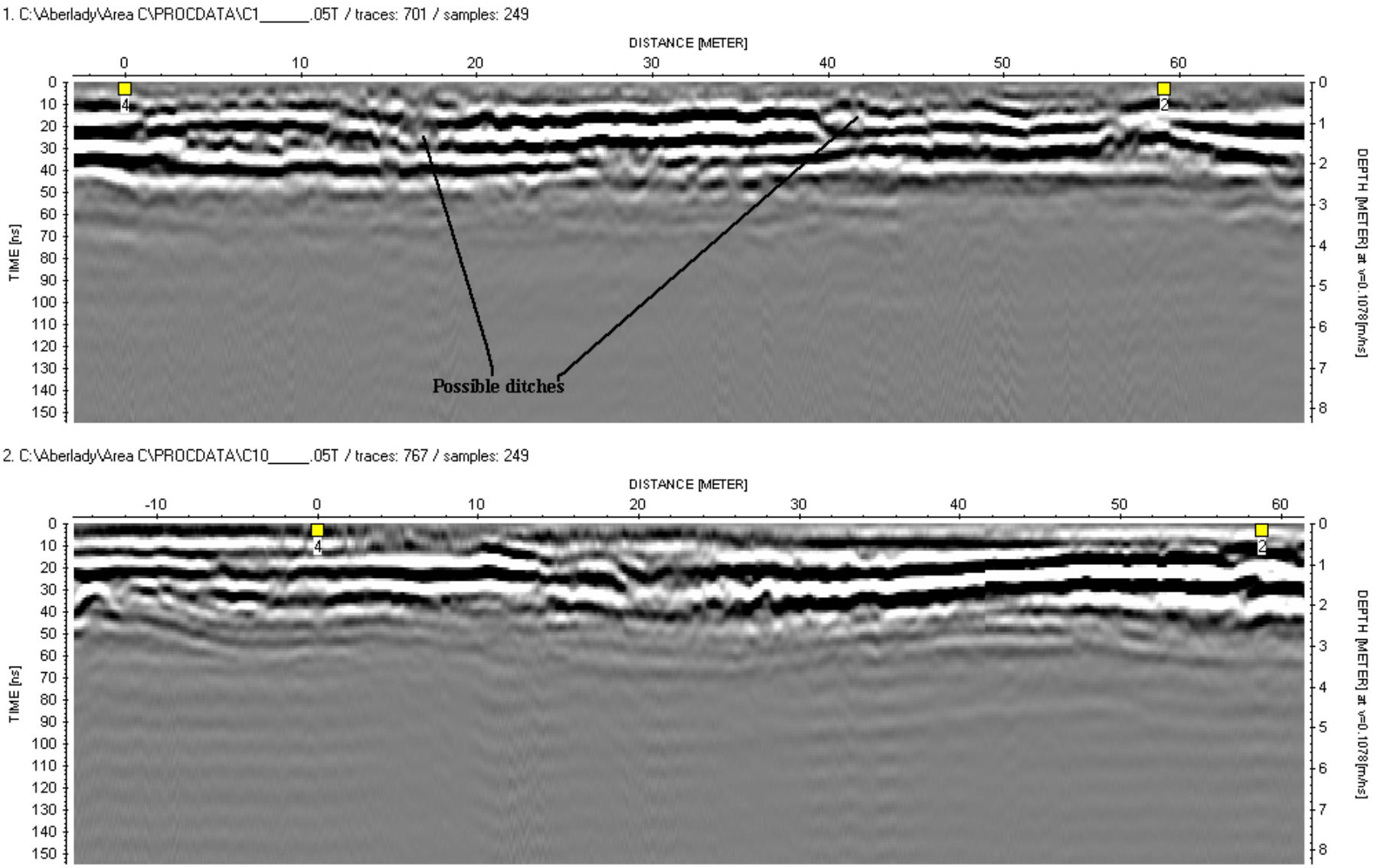

Figure 7: Area C Profiles C1 & C10 showing lack of consistent evidence for ditches

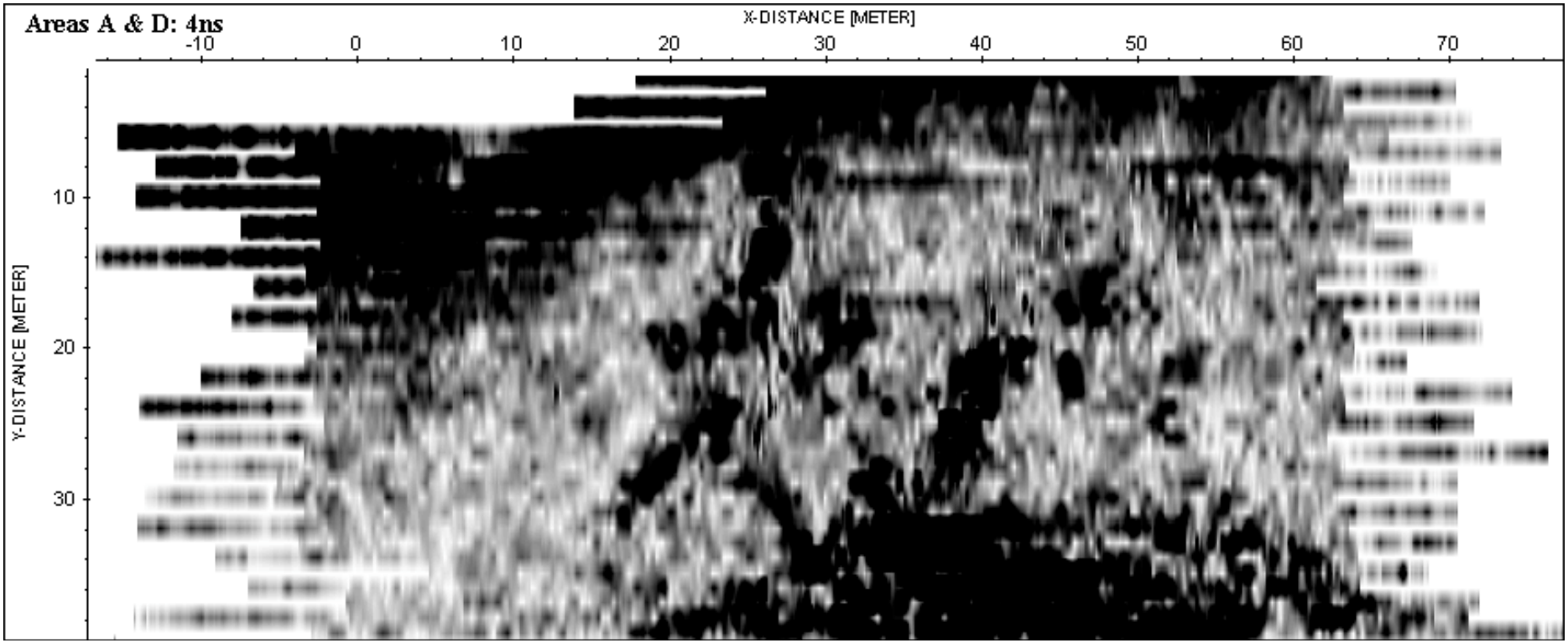

Figure 8: Areas A & D Time Slice at 4.4ns (c. 24cm)

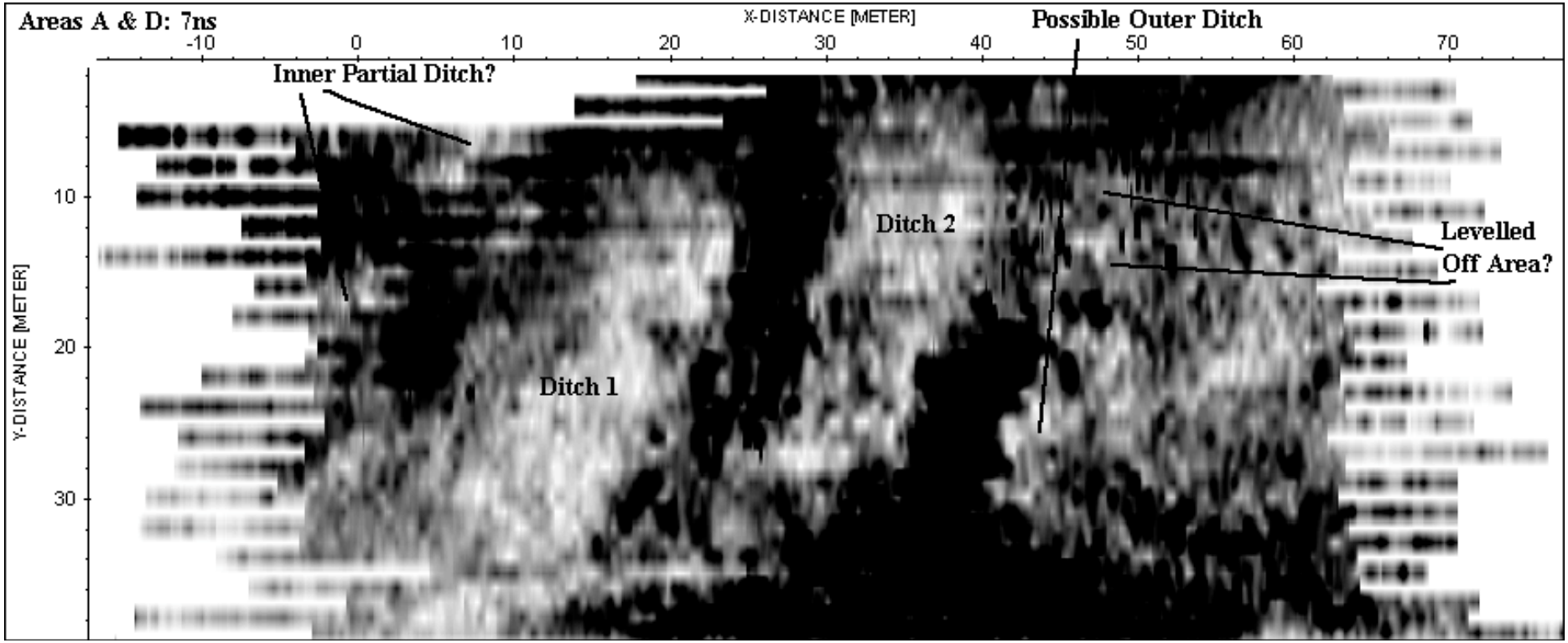

Figure 9: Areas A & D Time Slice at 7ns (c. 38cm)

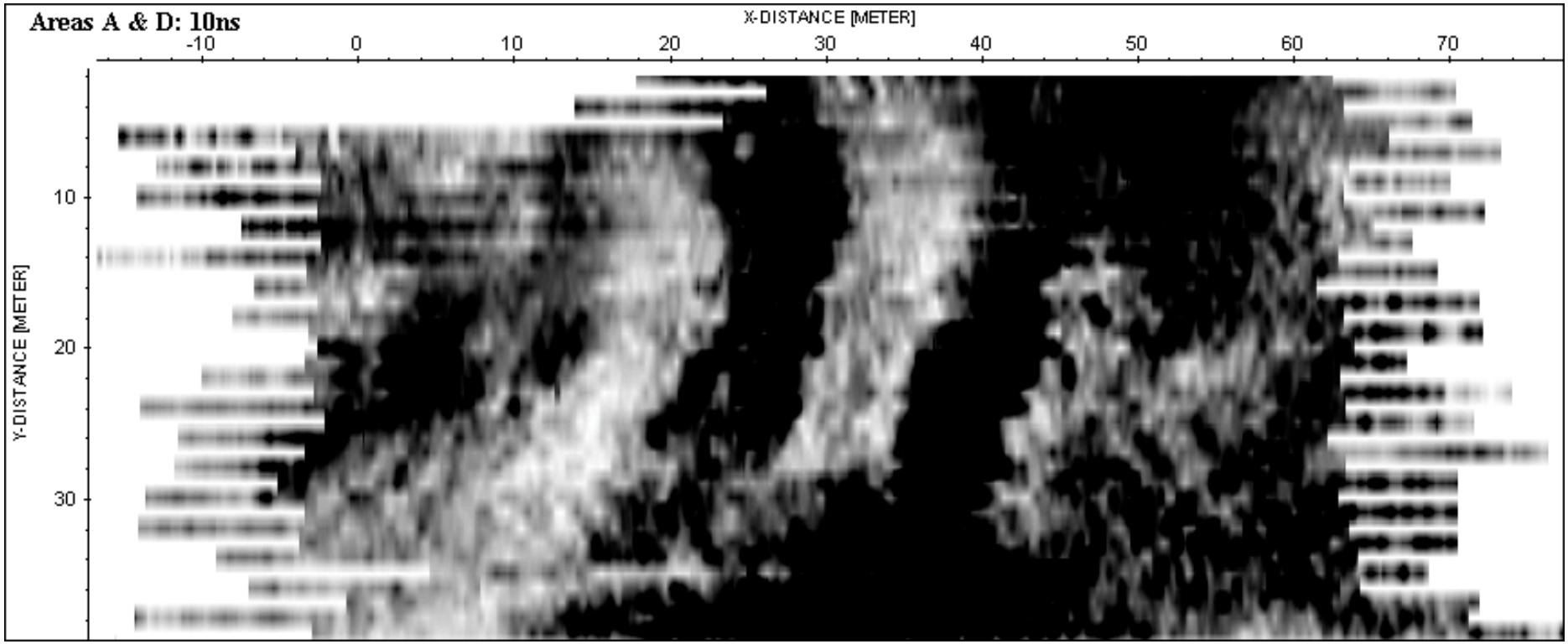

Figure 10: Areas A & D 10ns Time Slice (c. 54cm)

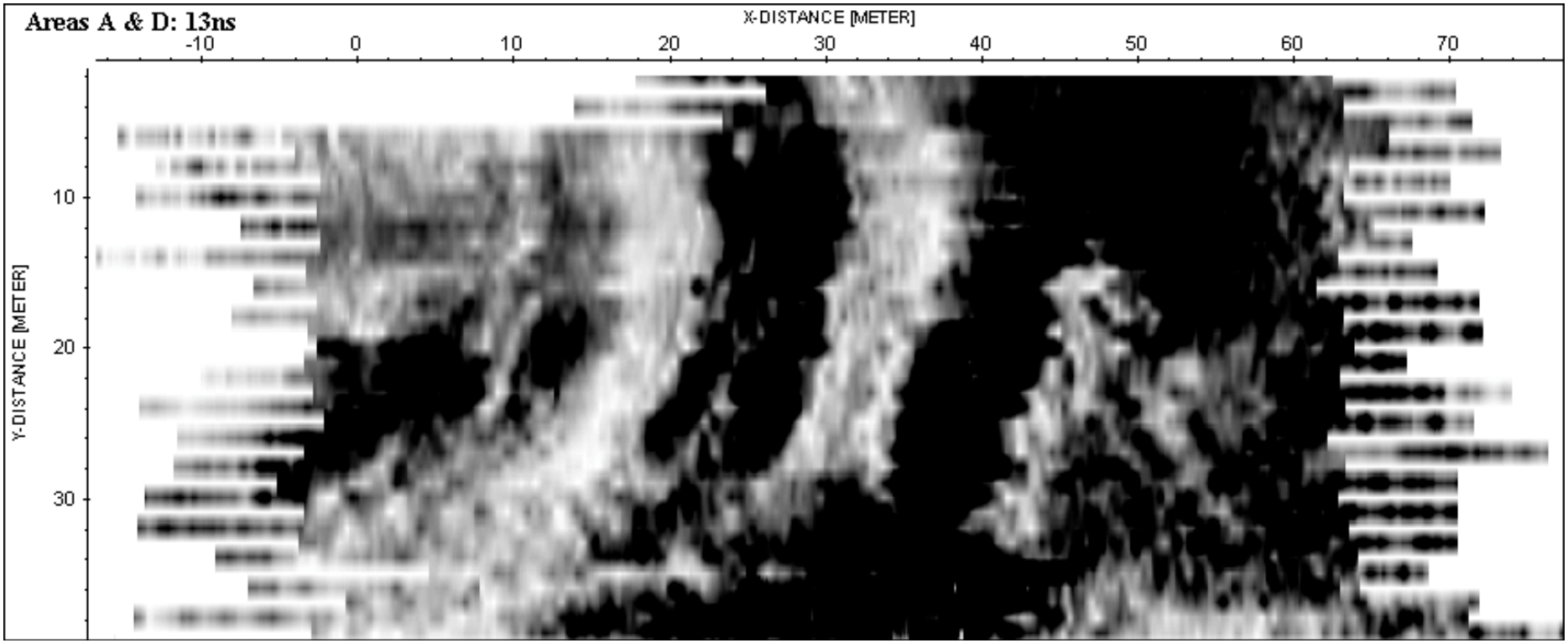

Figure 11: Areas A & D Time Slice at 13ns (c. 69cm)

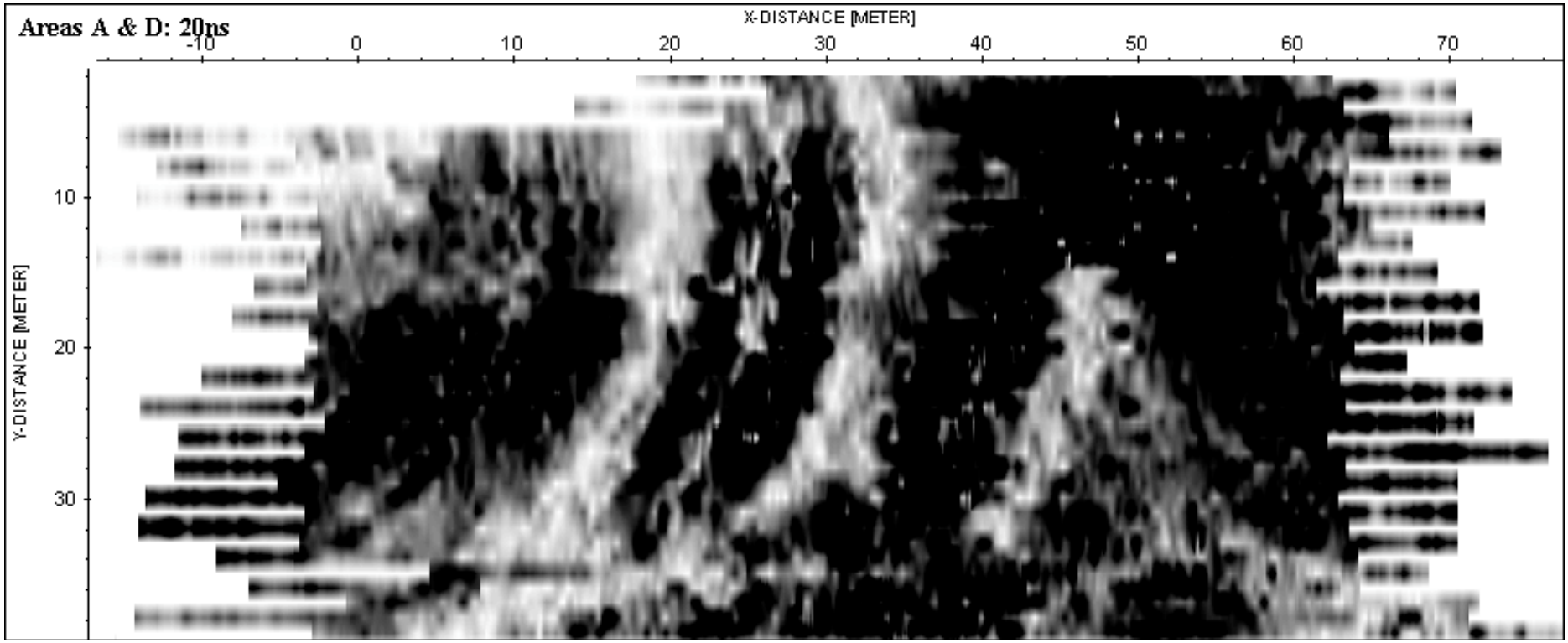

Figure 12: Areas A & D Time Slice at 20ns (c. 1m)

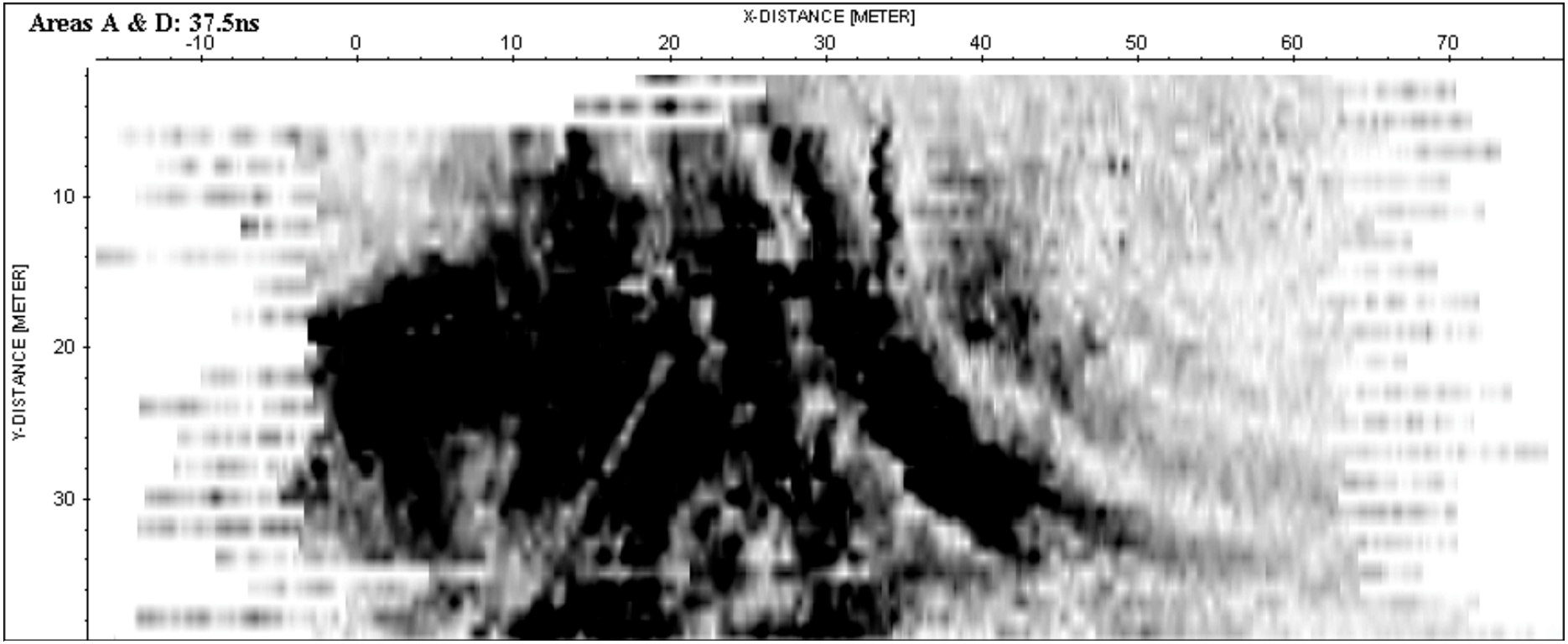

Figure 13: Areas A & D: Time Slice at 37.5ns (c. 2m) showing underlying circular feature facing East

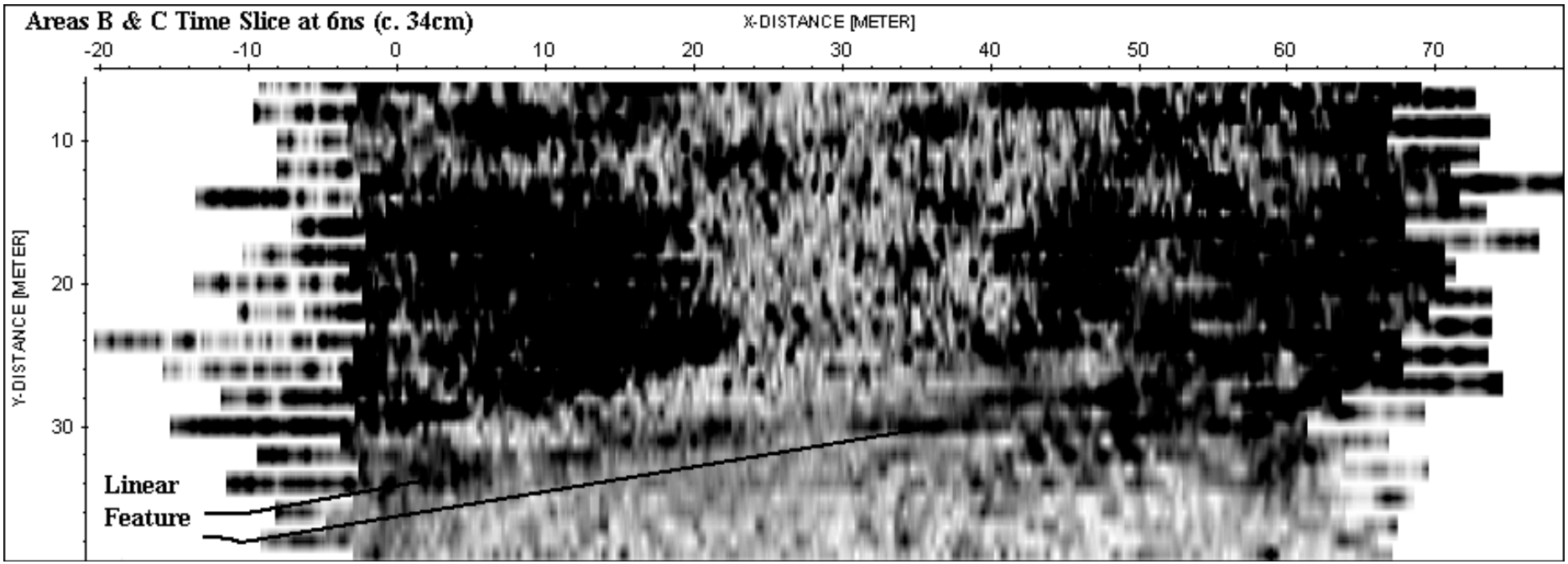

Figure 14: Areas B & C Time Slice at c 6ns showing near surface linear feature

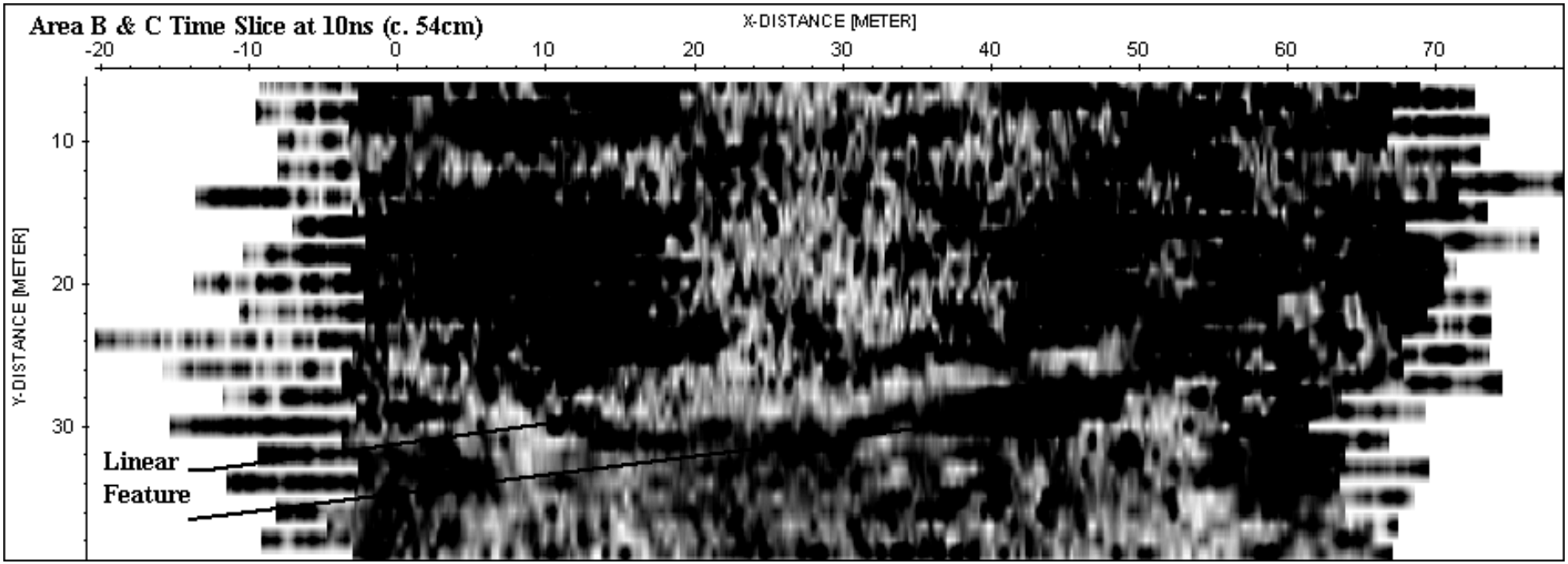

Figure 15: Areas B & C Time Slice at 10ns showing curvilinear feature

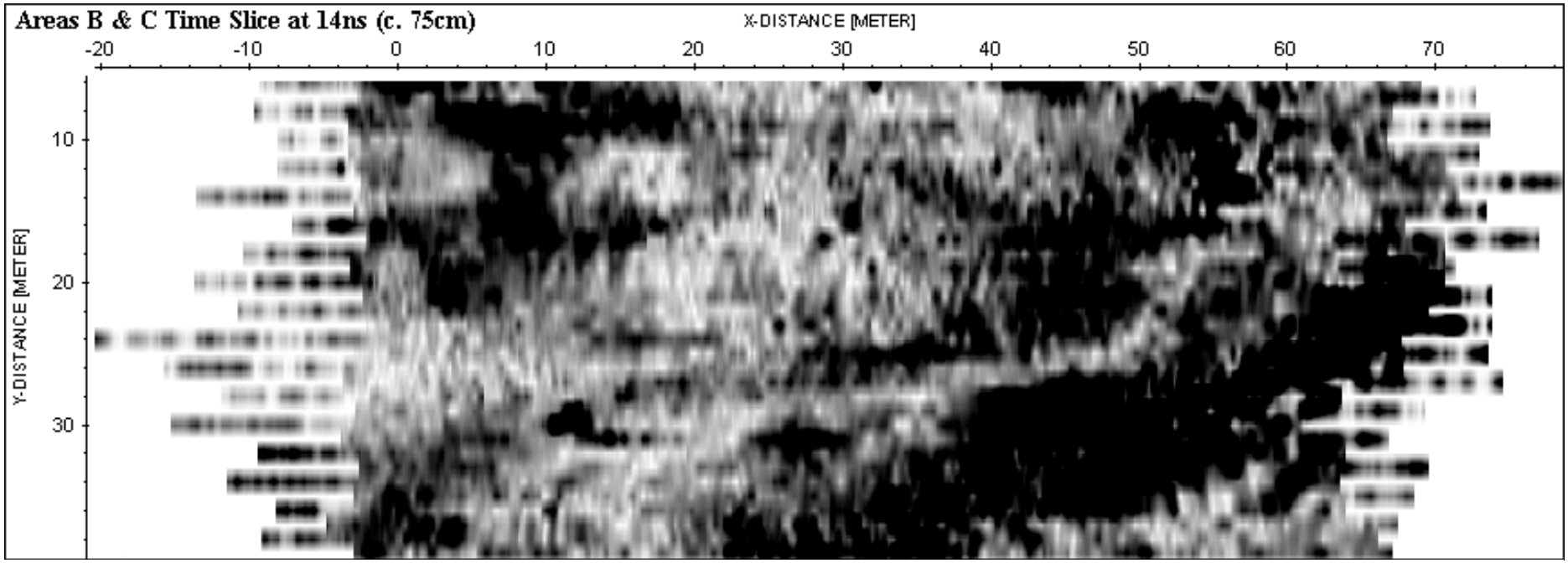

Figure 16: Areas B & C Time Slice at 14ns showing possible Fort outline

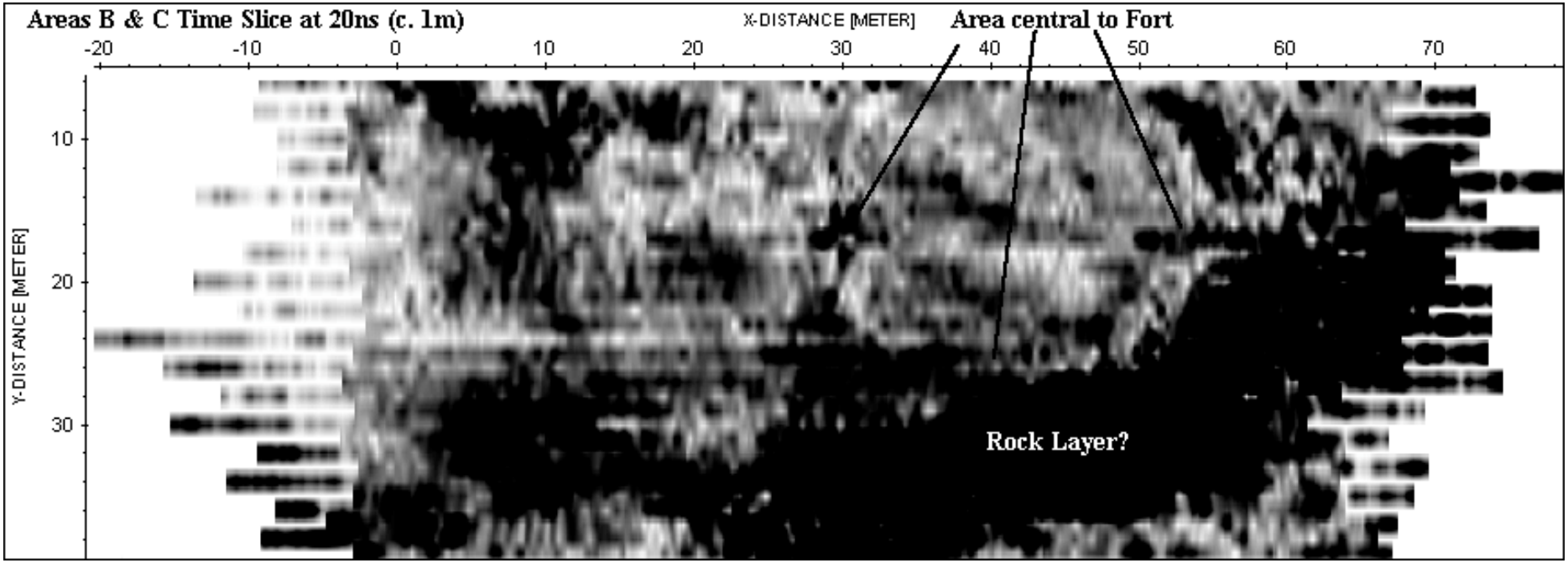

Figure 17: Areas B & C Time Slice at 20ns showing central area of Fort

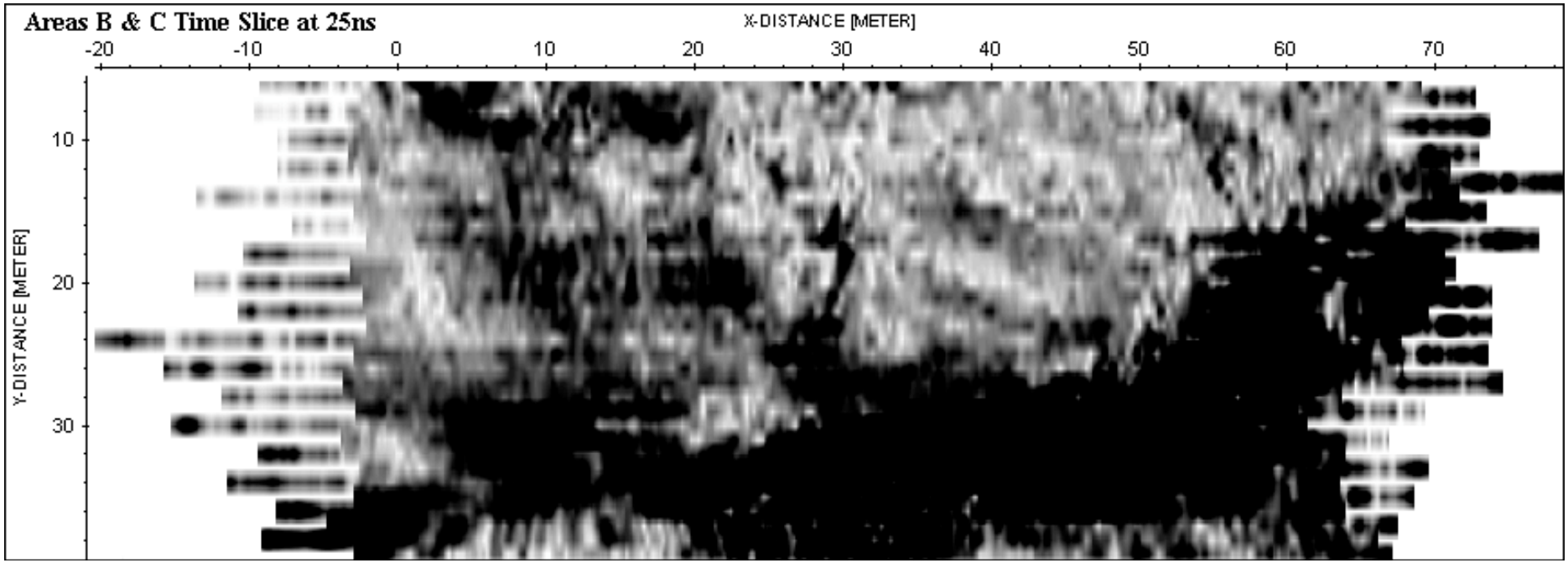

Figure 18: Areas B & C Time Slice at 25ns showing Central Area of Fort

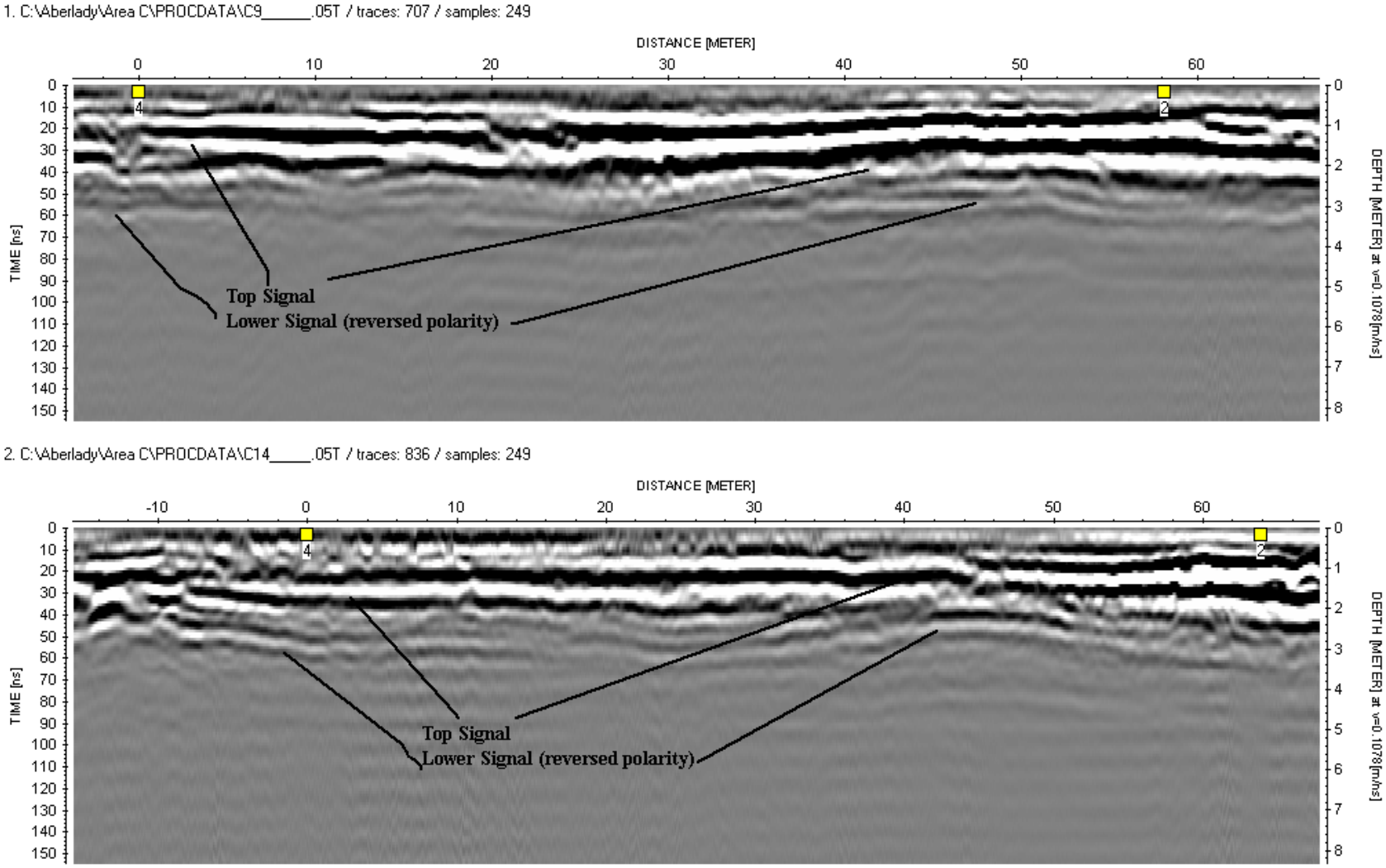

Figure 19: Area C Profiles C9 & C15 showing layering which may be voids within the rock

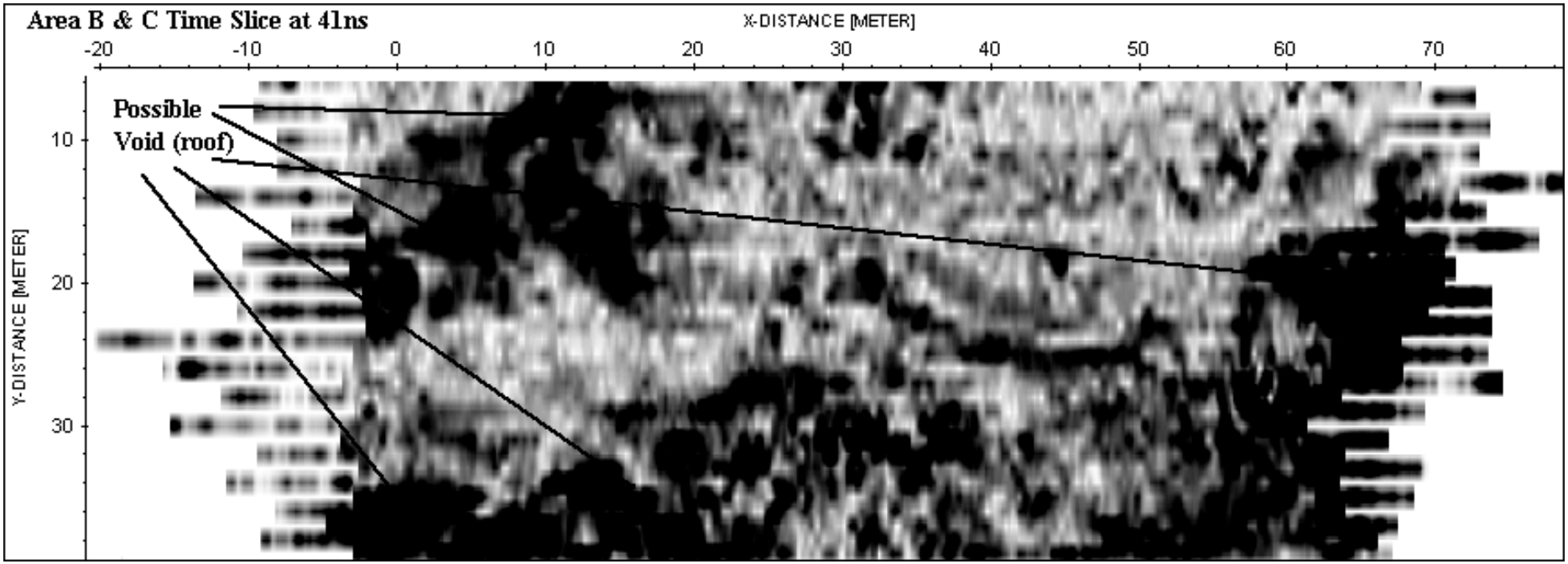

Figure 20: Areas B & C Time Slice at 41ns showing major stratigraphic change at c. 2.22m depth

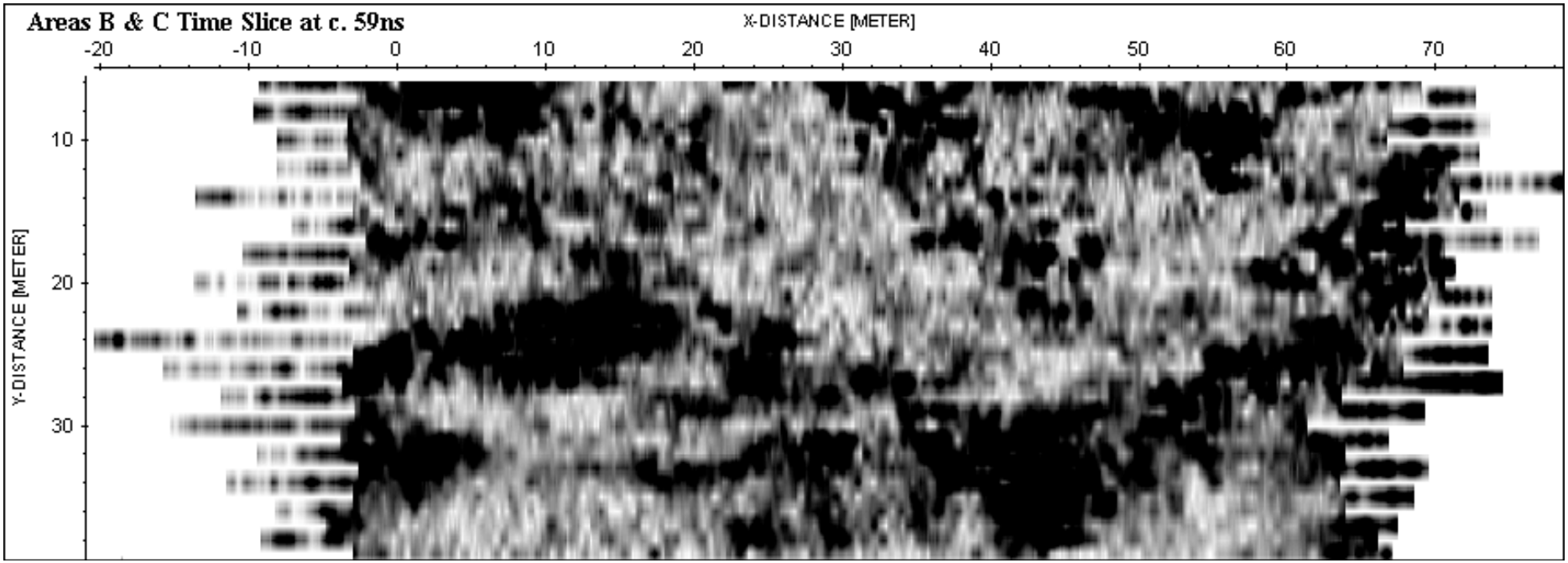

Figure 21: Areas B & C Time Slice at c. 59ns: Possible floor of voids

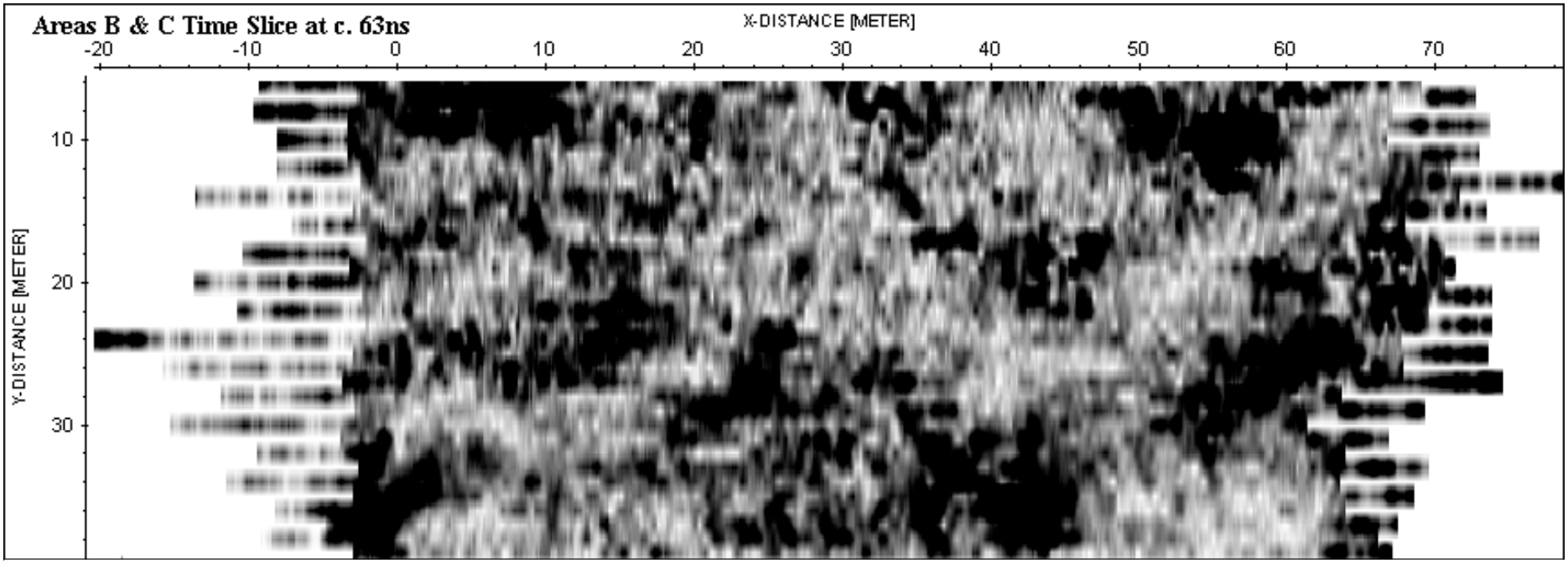

Figure 22: Areas B & C Time Slice at c. 63ns: Possible Void Floors