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Ground penetrating radar investigation of the fissuring of the A690 in Houghton-le-Spring

Urban Geoscience & Geological Hazards Programme

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Ground penetrating radar investigation of the fissuring of the A690 in Houghton-le-Spring

R J Cuss & G Thompson

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Front cover

The ground penetrating radar unit passing over one of the surface visible fissures in the A690.

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Foreword

This report outlines the geophysical survey conducted at Houghton-le-Spring, City of Sunderland, on Sunday 16th November 2003 and gives a full interpretation of the acquired data. This survey was a follow-up to a previous survey conducted by the lead author on Sunday 26th May 2002. The first survey and report was produced as part of a series produced for the SE Northumberland project, which is a core project of the Urban Geoscience & Geological Hazards Programme of the British Geological Survey (BGS). The current survey was conducted as a commission for Sunderland City Council.

Acknowledgements

The authors conducted the geophysical survey with the assistance of Bryan Young (BGS) and Dave Usher (Sunderland City Council). The authors would also like to thank Sunderland City Council for closing the A690 and allowing the survey to be conducted in safety. This report utilises data collected at the Transport Research Laboratory (TRL) by David Beamish.

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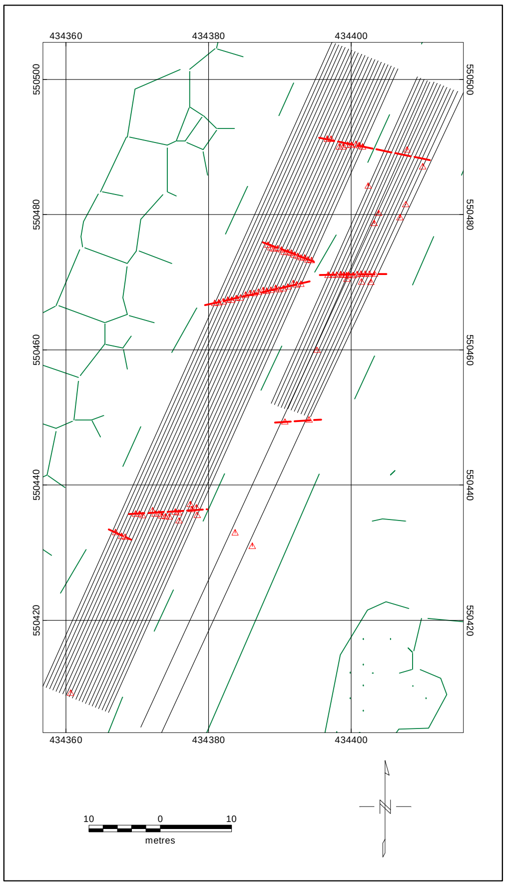
Executive Summary

This report introduces the results of a geophysical survey using ground-penetrating radar (GPR) to investigate the nature of fissuring observed in Houghton Cut, City of Sunderland. The survey was conducted on Sunday 16th November and was a repeat of a survey conducted on Sunday 26th May 2002, allowing temporal changes in the fissuring to be identified.

The collection of data in a 3D manner and the careful application of the automatic gain control filter yielded useful data for the southbound carriageway. Over the area of road re-surfacing, a clear dropout of GPR data was observed. This has not been observed during any of our previous surveys and is not reported in the literature. The origin of this phenomenon remains unknown. The character of the GPR response caused by the major fissure changes across the southbound carriageway. The data in some areas suggests a closed feature while in other areas the data indicate an open fissure.

A 103 m long 3D survey was conducted over the northbound carriageway. The major fissure shows as a clear reflector at approximately 65 m along line and 1 m depth. The November 2003 survey shows that this feature is much more pronounced than in May 2002. This may be because of the remedial works undertaken during 2003. A second fissure is seen at approximately 30 m along line and 1 m depth, this feature has a clear surface expression. This clear reflector is heterogeneous across the carriageway, indicating a complex fissure. The nature of this GPR anomaly has changed over the 18 months between the two surveys, this suggests that this feature is active. A few smaller features were identified in both the north and southbound carriageways.

All features (see map below) identified require careful follow-up investigation to ascertain the degree of opening of the fissures. This can be done by hand augering, window sampling, or standard shallow drilling. All identified features should be monitored in the road surface and ideally they should be resurveyed using the GPR at regular intervals to monitor their behaviour.



1 Scope and limitations of work

The scope of the work presented in this report is to provide an assessment of the fissuring within Houghton Cut on the A690. This assessment is made using data collected using a ground penetrating radar unit (GPR).

The GPR method involves investigating the subsurface with radio energy at micro wave frequencies. A radar signal of fixed frequency is transmitted into the ground. A return reflection is created at an interface where electrical properties vary. Whether a reflection is detected is determined by the variation in electrical properties across the interface, the orientation of the interface and the size in relation to the depth of the interface. GPR has been shown to be an effective method of detecting flat reflectors, but the detection of vertical features is known to be a limitation of the method. The survey of May 2002 (Cuss and Beamish, 2002) demonstrated that the fissuring below the A690 was detectable, and that a 3D GPR survey would yield far more information that a series of spaced 2D profiles.

The question of whether any detected fissure is open or closed, and the degree of opening, can only be qualitatively assessed from the GPR results. Without considerable modelling of the results, it can be difficult to quantitatively assess the amount a fissure is open. With this limitation in mind, we can advise where follow-up investigation should take place.

The primary aim of this investigation was to access the southbound carriageway of the A690 to determine whether the remedial works undertaken on the northbound carriageway should be extended to this area.

2 Introduction

Serious cracking to the wearing surface of the A690 Sunderland-Durham road at Houghton Cut was reported in the Sunderland Echo (April 14, 2000, p1). This led to a field investigation by the British Geological Survey, as published in BGS Technical Reports (Young and Culshaw, 2001 and Young and Lawrence, 2002).

Preliminary field visits suggested that the carriageway damage may be associated with active fissuring in the Magnesian Limestone, and that the movements associated with this fissuring may be traceable well beyond the site of the damaged road. A field survey of approximately 5 km^2 of country around the damaged road revealed numerous examples of fissuring with associated surface collapse on the outcrop of the Magnesian Limestone. Study of the existing geological mapping, together with an examination of the abandonment plans of coal workings beneath the area, indicated a close spatial relationship between the occurrence of surface collapse and structural damage, and the position of faults, both in the Magnesian Limestone and underlying Coal Measures. Processes such as landsliding, cambering and limestone dissolution did not appear to play a significant role in the phenomena observed. The field and other evidence gathered were consistent with ground movement resulting from reactivation of pre-existing faults that cut areas of extensive abandoned underground coal workings.

A geophysical survey was conducted along the A690 and adjacent escarpment in May 2002 (Cuss and Beamish, 2002). The application of the ground penetrating radar (GPR) and ground conductivity methods offered a non-invasive way of investigating the subsurface. This information could be used to answer specific questions about the fissuring immediately below the surface of the A690. This survey showed that the main fissure running across the road had a very strong radar signature, and to a certain degree must be 'open'. The signature of the radar reflection from the fissure altered across the road suggesting that it is open at the edges of the road and closed in the middle. A 100-metre survey line suggested that four other smaller fissures may also have been present along the A690. A significant difference was noted between the radar signal response of the north and southbound carriageways. The southbound carriageway did not yield useful data. This was attributed to the south carriageway being constructed over the older A690, while the northbound carriageway is a newer construction.

Since the geophysical survey of 2002, maintenance work on the northbound carriageway discovered that the major fissure was open on the scale of tens of centimetres across the carriageway (Young, 2003). Evidence from the road and other features in the Houghton-le-Spring area suggest that fissure movement occurred in April or May 2003. The fissure was filled with crushed limestone and resurfaced. No work was conducted on the southbound carriageway. The primary aim of the current survey was to assess the nature of the fissure across the southbound carriageway.

3 Survey location and specification

Two 3D radar surveys were conducted along the northbound and southbound carriageways of the A690 within Houghton Cut, on the edge of Houghton-le-Spring, City of Sunderland. The A690 is a major dual carriageway running from Durham to Sunderland and is one of the main routes from the A1 into Sunderland. The survey has an approximate location of 434500E 550500N (BNG). Figure 1 shows the location of the survey sites on the edge of Houghton-le-Spring, and Figure 2 shows the survey areas in more detail. The primary survey was conducted along the southbound carriageway, with any other surveying being conducted if time was available. The current survey was conducted with ground penetrating radar and not with GPS or ground conductivity (as in 2002), enabled a larger area to be covered in the same time. The current survey needed to cover the same area as the 2002 survey as a minimum. The 2002 survey demonstrated that 3D radar data meant that the features of interest (fissures) did not have to be surveyed perpendicular to their strike, as is usual in geophysical surveying. Thus, the surveys could be conducted along the direction of the road (approximately NNE).

3.1 SITE A – SOUTHBOUND CARRIAGEWAY

The southbound carriageway is dual lane, but is not as wide as the northbound carriageway. The survey was set-up as a series of lines parallel to the direction of the road. In order that the Council could easily locate any of the findings, the survey was set-up by limits defined by the street light posts. Lights L397/L398 delimit the northern edge of the survey, the south by L401/L402. The orientation of the top and bottom lines was decided by the line made between the lights on the east and west side of the dual carriageway. The distance between the lights meant that the survey lines were approximately 52.5 metres long, with the target fissure at approximately 20m along line (from the south). A network of 15 parallel lines was set out separated by 0.5 metres. The SW corner of the survey was chosen as the survey origin, with x and y distances increasing in an easterly and northerly direction respectively. The limits of the survey are shown in Table 1.

As shown in Figure 2, two survey lines were extended to approximately 103 metres length to the south to light posts L405/L406. This would allow features identified in the northbound carriageway to be traced across the southbound carriageway. These two lines were coincident with the eighth and fourteenth lines.

3.2 SITE B – NORTHBOUND CARRIAGEWAY

As progress on the southbound carriageway survey was good, the decision to conduct a 103-metre survey along the northbound carriageway was taken. This would allow the major fissure to be examined and for another fissure to the south to be investigated. A network of 21 lines of 103-metre length was set out, separated by 0.5m parallel to the direction of the road (approximately NNE). The northern edge of the survey was delimited by light L397/L398, the south by L405/L406. This meant that the two target fissures were located at approximately 28 (as shown in Figure 4) and 64 metres along line (y-direction). The SW corner of the survey was chosen as the survey origin, with x and y distances increasing in an easterly and northerly direction respectively. Figure 2 shows the location of the survey area, which had limits as shown in Table 2.

4 Survey Method

The ground penetrating radar (GPR) apparatus consisted of a Noggin Smart Cart System. The Smart Cart is an integrated ground penetrating radar acquisition platform. The complete system comprises the cart, a Noggin antenna, an odometer wheel, a digital video logger (DVL), and a battery. Figure 3 shows the Noggin Smart Cart at the Houghton site. The DVL gives the operator an instant display of GPR signal, allowing the survey to be modified if necessary.

GPR is the general term applied to techniques that employ radio waves, typically in the 1 to 1000 MHz frequency range, to map structures and features buried in the ground. The Noggin uses a 250 MHz fixed-frequency system, operated in reflection mode. The principles of GPR are similar to those of seismic surveying.

The most important step in a GPR survey is to clearly define the problem. There are five fundamental questions to be answered before deciding if a radar survey is going to be effective:

- What is the target depth?
- What is the target geometry?
- What are the target electrical properties?
- What is the host material?
- What is the survey environment like?

Taking these points into consideration, the Houghton-le-Spring site should yield good results. However, as with many of the geophysical techniques there are no guarantees of finding the target. Many factors can influence the survey, such as interference from metallic objects and “ringing” in tarmac structure.

The significant electrical differences between the host limestone material and the open fissure should yield a strong GRP signature. The Noggin system used is limited in the fact that the survey can only be conducted at 250 MHz, in reflection mode, with the antenna in one orientation.

Survey sites A and B were recorded with closely spaced lines so that 3D-GPR could be attempted. Experience has shown that 3D surveys yield significantly more detail than 2D survey lines.

5 Ground Penetrating Radar Results

GPR data were processed using the REFLEXW program (v2.5), used for processing and interpretation of reflection and transmission data. This package allows all the required processing to be conducted on GPR data in 2D (vertical cross-sections) and 3D (volume).

The processing of GPR consists of a number of stages. These include:

Import of data: Data are first imported into REFLEXW from the Noggin format.

Flip: This simply flips the line so that all line data are represented south to north.

Dewow: This is a simple mean subtraction along the line and is used to remove the low-frequency part of the signal.

Static correction: The static correction removes the “dead” signal from the first few nano-seconds of recording. This time is related to the separation of the Noggin and the ground. There are numerous valid reasons why this separation will change slightly during the survey. REFLEXW is used to pick the first radar arrival, and this time is tripped from the start of all records.

Background Removal: This removes the average of all traces along line and is used to remove any systematic noise reflections produced by the Noggin.

Automatic Gain Control: AGC is applied to account for the decay in power of reflections as depth increases.

Migration: It is possible to migrate the data to remove the effect of off-line features. However, the characteristic hyperbolae seen along lines, which the migration process removes, are indicative of the fissure feature of interest. Thus migration was not applied.

Desampling: It is necessary to de-sample along long lines, as there are restrictions on the amount of data along 2D lines when creating 3D data volumes.

These simple processing steps produce clear results that can be interpreted for geological structure in bedrock, man-made artefacts, and open or closed fissures.

5.1 VELOCITY STRUCTURE OF THE ROAD

Radar data, like seismic reflection data, can show hyperbolae reflections from solid singular points, such as boulders within bedrock. This effect is created by non-vertical reflections; all recorded data are assumed to be reflected from directly below the data recorder. This data is in effect “noise”, but can be used to determine wave propagation values (radar velocity). REFLEXW allows the processor to identify two points along the hyperbola and outputs a corresponding velocity at that point.

Examination of the radar data from the current survey showed similar velocity structure to the data acquired in 2002 (Cuss and Beamish, 2002). Obvious hyperbolae were recorded from all lines along the northbound carriageway. Figure 5 shows the velocity structure of the northbound carriageway of the A690. As shown, radar velocity ranged from 0.0563 – 0.0871 m/ns, with an average of 0.0679 m/ns. No obvious trend of velocity variation with depth is observed, thus the velocity structure is assumed to be:

0.0679 m/ns

Data were not depth converted due to the expected difference in radar velocity and thickness between the tarmac, hardcore and Magnesian Limestone bedrock. All data have been presented in terms of time sections with estimates of depth assuming a velocity of 0.1 m/ns, this being the default display of REFLEXW.

5.2 TARGET FEATURE

The experience of the survey of May 2002 (Cuss and Beamish, 2002) gives an idea of what a fissure feature would look like in the ground penetrating radar (GPR) results. This survey showed that an open fissure is identified as a series of hyperbolae features extending to depth. The stronger the reflection, the more the contrast in electrical properties at depth, and can be viewed as the more open the fissure. One problem that GPR data suffers from is the identification of vertical features, such as a fissure. Thus it is expected that any identified fissure feature will have some degree of opening.

Since the survey of May 2002, the British Geological Survey has had the opportunity to test some of its geophysical equipment at the Transport Research Laboratory (TRL). Our work at TRL allowed a GPR survey to be conducted over known synthetically createdvoids of defined location. Figure 6 shows that voids within a road structure are identified by hyperbolae diffraction centred on either the roof or floor of the void. This data shows that smaller voids, 200 mm, did not show any GPR response. Thus any detected hyperbolae will have been formed by fissures open more than this amount. However, fissures are extensive features that continue for several metres or more. This lateral extent will mean that fissures with less opening than 200 mm will be detected.

5.3 SOUTHBOUND CARRIAGEWAY 50M 3D SURVEY AREA

Close examination of the 3D GPR data from the southbound carriageway initially did not show any obvious fissure features within the road structure (Figure 7). However, at the location of the road re-surfacing (approximately 20m along line), it was noted that a distinct dropout in GPR signal occurred. This had also been noted in the survey of May 2002. This is not a feature of GPR surveying on tarmac observed during any of our previous surveys, and a trawl of the literature could not identify what such a feature could be attributed to. A loss in GPR signal can be caused by steel work used during the treatment of the road, but this was not known to be the case. It can also be caused by large void features, as has been seen over tunnels. However, large void features are almost always accompanied by diffraction hyperbolae on either side of the opening. We therefore cannot identify the source of this GPR feature, but note it’s occurrence.

Within the 3D survey area, few features were identified that could be associated with fissuring. Several cultural features derived from sideswipe of the GPR signal and infrastructure (such as the metal crash-barrier in the central reservation and drainage system on the edge of the road). Figure 9 shows the location of features identified on the southern carriageway.

The application of the filter automatic gain control (AGC) can be used to enhance GPR data in areas where data dropout occurs. This algorithm simply enhances the signal to a common amplitude, but can create rather noisy looking displays. The data near to the road re-surfacing has been treated with AGC in order to observe the GPR signal in the zone of "drop-out." These results are shown in Figure 8 for all survey lines. As can be seen, the application of AGC allows structure to be identified.

There is a distinct change in response across the carriageway. Towards the central reservation (L0 - L4) a fissure may be seen, especially on L0-L2. The dimensions of this open fissure are just on the limit of resolution of the GPR apparatus. Lines L5 - L7 show little disturbance to a well-constructed road structure. Lines L8 to L11 display characteristics of fissuring, while the remaining lines (L12 - L14) appear intact. This data suggests that the fissure may be open along part of the southbound carriageway, but that this feature (Feature A, Figure 9) is towards the limit of resolution of the GPR unit, suggesting that there is not a significantly open fissure below this carriageway across the whole of the carriageway.

5.4 SOUTHBOUND CARRIAGEWAY 100M SURVEY LINES

The two survey lines that were extended to 103 m length showed no significant fissure features, as shown in Figure 10. Subtle features have been identified (Features A-E, Figure 9), some of which may align with the features identified on the northbound carriageway (Features A-D, Figure 9).

5.5 NORTHBOUND CARRIAGEWAY

The 3D data from the northbound carriageway shows that the two fissures with a surface expression can be traced across the road, as seen in Figure 11. In addition to these fissures, 3 other features are noted, as shown in Figure 9. Each feature has been labelled by a letter in Figure 9 to aid identification.

5.5.1 Treated fissure (65 m along line) – Feature F

The treated fissure at approximately 65 metres along line (Figure 11) shows a very clear GPR reflection across the entire northbound carriageway. On the western side of the carriageway, this fissure shows as a bright reflection at approximately 1 metre depth. This feature continues across the road and changes in character, becoming much less pronounced. Towards the central reservation, the fissure feature becomes more difficult to identify as the character of the road changes. Identification is also complicated by a feature of different orientation (Feature G, Figure 9), which was interpreted as a utility running across the road in the previous survey (Cuss and Beamish, 2002).

Even though this fissure (Feature F, Figure 9) has been treated and filled with crushed limestone, it is still obvious in the GPR results.

5.5.2 Southern fissure (30 m along line) – Feature H

The southern fissure (Feature H, Figure 9), which also has a surface expression as shown in Figure 4, is identified across the entire carriageway, although the character of the GPR results changes across the road. This bright feature is smaller in extent than the major fissure, but gives very strong reflections from about 1 metre depth and below. This suggests that this fissure is extensive and could be open. As the character of this fissure changes across the road, it is suggested that the fissure may be open by a differing amount across the carriageway.

5.5.3 Other features

Several other continuous fissure features are observed on the northern carriageway, as shown in Figure 9 Features I & J. The two known fissures are evident (Features F & H, Figure 9), along with the utility seen adjacent to the main fissure (Feature G, Figure 9). However, a feature is seen at about 90m along line near to the central reservation (Feature J, Figure 9), and another feature is seen at about 25 m along line on the pavement side (Feature I, Figure 9). Both of these features do not have significant GPR reflections, but could form potential areas of fissuring.

5.5.4 Comparing the surveys of May 2002 and November 2003

The two surveys over the northbound carriageway separated by 18 months allow any changes in fissuring to be assessed. The identified utility has been used to align the data, clearly seen as bright reflector at 57 m along line in the May 2002 data (Figure 12).

5.5.4.1 THE MAJOR FISSURE – FEATURE F

The 100m long survey conducted in May 2002 did not show a significant GPR reflection from the area of the known fissure, although a weak reflector was identified. The November 2003 survey shows a very clear reflection. This has been created either through movement along the fissure or by the remedial works undertaken in 2003. Generally, the November 2003 data has a much more pronounced reflection than in May 2002.

5.5.4.2 The crack in the road – Feature H

The fissure that is identified as a clear crack in the road surface (Figure 4) was identified in the GPR results of May 2002. Comparing the data of 2002 and 2003 clearly shows that the latter survey has a significant reflection from this fissure, whereas only a moderately weak reflection was seen in 2002. This indicates that this fissure has become a more substantial feature in the intervening time. However, the character of the fissure feature identified in the 2003 data does change in character across the road and any differences in radar response may derive from any slight misalignment of the survey lines.

5.5.4.3 Environmental considerations

The differences seen between the surveys of May 2002 and November 2003 may also be accounted for by changes in environmental conditions. The water content of the road and underlying limestone bedrock may create variations in GPR signal reflectance. The survey of 2002 was conducted during bad weather, after a lengthy period of rain. The survey of 2003 was conducted at the end of a dry summer period, with the week preceding the survey being wet. Variations in moisture content could also account for the differences observed.

6 Conclusions

The following conclusions emerge from the current study:

General comments

- The surveying of both the south and northbound carriageways of the A690 gave good results.
- The survey areas were chosen to be delimited by the light posts along each side of the A690, this should allow the council to locate any features we identify.
- Our survey at the Transport Research Laboratory has given a clear indication of the size of void (or open fissure) that will give good GPR response. We have found that a 250 MHz GPR unit does not detect voids with dimensions of 200mm and less. This data has allowed our interpretation to be more precise. The lateral extent of the fissures may mean that fissures opened only small amounts will be detected.
- The repeat surveying of the site in May 2002 and November 2003 allows temporal variations to be investigated.

Southbound carriageway

- The collection of data in a 3D manner and the careful application of the automatic gain control filter yielded useful data for the southbound carriageway.
- Over the area of road re-surfacing, a clear dropout of GPR data was observed. This has not been observed during any of our previous surveys and is not reported in the literature. The origin of this phenomenon remains unknown.
- The character of the GPR response across the southbound carriageway changes. Nearest to the central reservation, the fissure is seen in the GPR data and is probably open. This feature then appears to disappear and an intact road structure is seen. Towards the centre of this

carriageway the fissure is observed once again, and towards the path side is not evident in the GPR data. This shows that the fissure is heterogeneous along its length.

- A few other features were identified in the southbound carriageway data, but only along single profiles (i.e. implying isolated features).

Northbound carriageway

- Good data were collected for a 103 metre long 3D area of the northbound carriageway.
- The major fissure (Feature F, Figure 9) shows as a clear reflector at approximately 65 metres along line and 1 metre depth.
- A second fissure (Feature H, Figure 9) is identified at approximately 30 m along line and below 1 m depth. This clear reflector is heterogeneous across the carriageway, indicating a complex fissure. We believe that this fissure is open and should be further investigated.
- Comparing the May 2002 survey data with that of November 2003 shows that the major fissure (Feature F, Figure 9) across the A690 is much more pronounced in the latter survey. This may be because of the remedial works undertaken during 2003.
- The November 2003 survey also shows a much more pronounced southern fissure (Feature H, Figure 9), as seen as a crack in the road surface. We believe that this feature has opened in the time between the two surveys.
- The nature of the hardcore varies across the northbound carriageway.
- A new fissure is noted to the north of the major fissure (Feature J, Figure 9).

7 Recommendations

The current survey has indicated that the southbound fissure (Feature A, Figure 9) could be open along part of its length. This should be investigated. This information can then be used to ascertain the degree of opening across the southbound carriageway.

The fissure identified on the northbound carriageway by the crack in the road surface (Feature H, Figure 9) requires further investigation. This feature gives a clear GPR reflection at 1 metre depth and deeper. The degree of opening along this heterogeneous fissure needs to be established. The southbound carriageway also needs to be monitored to make sure the fissure does not propagate onto this carriageway; a continuation feature (Feature D, Figure 9) may have already been identified by the GPR.

The identification of other features (Features B, C, D, E, I, and J, Figure 9) should be monitored in the road surfacing and ideally should be resurveyed using the GPR at regular intervals to ensure that fissures do not open.

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Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

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Figures

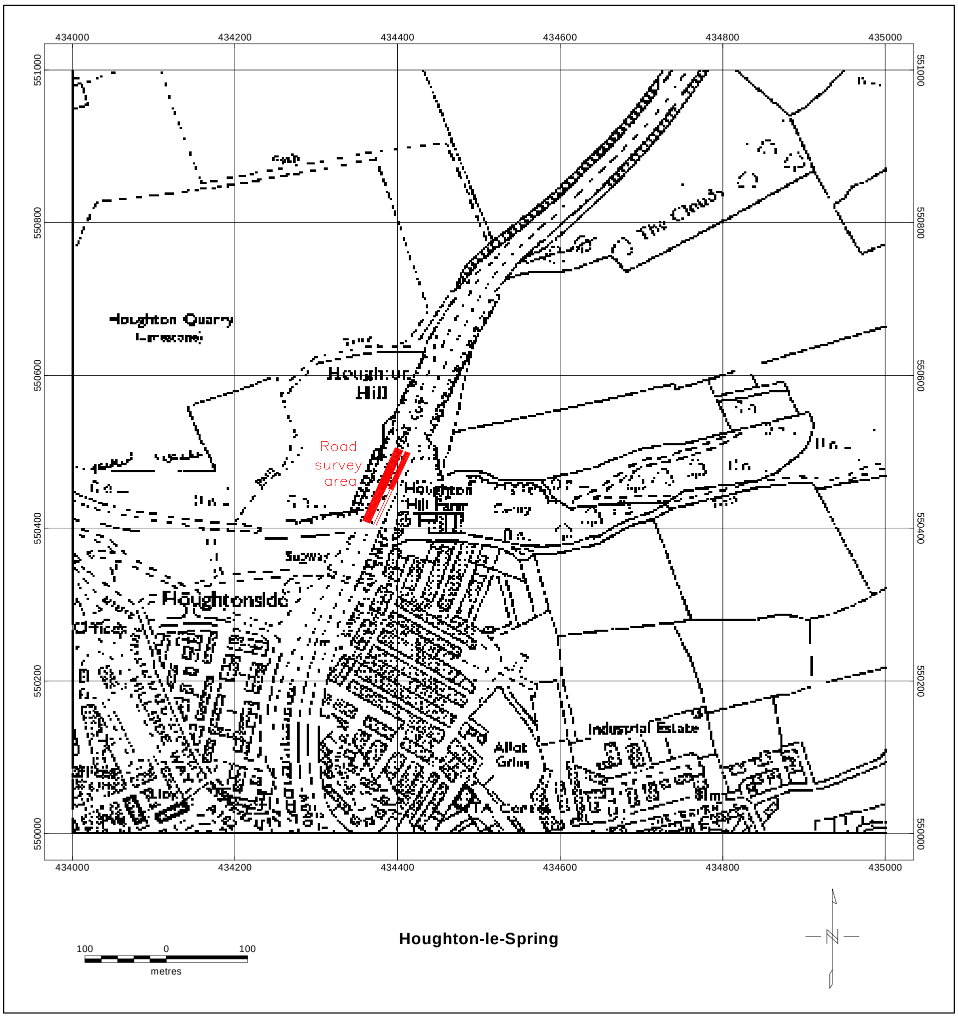


Figure 1 Location of the survey sites in reference to the Houghton-le-Spring.

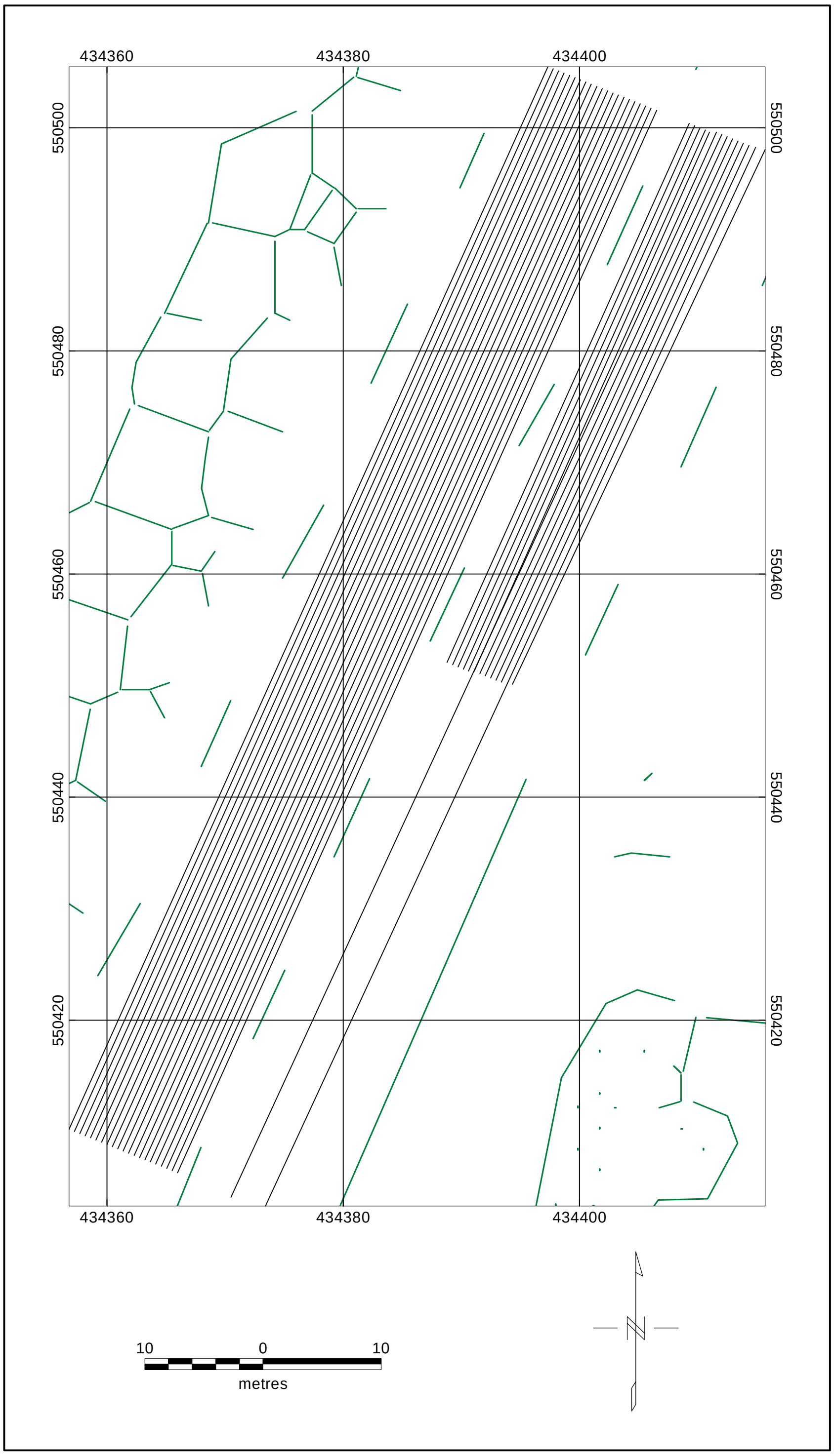


Figure 2 Location of the surveys sites on the A690 in Houghton Cut. Topography traced from OS image displayed in Figure 1.

Figure 3 The geophysical equipment used in the survey. The ground penetrating radar unit is the black and yellow box seen between the wheels of the cart. This is connected to the yellow digital video logger.

Figure 4 Fissure seen in the surface of the northbound carriageway of the A690, note that the fissure is not a perfectly linear feature. This is feature H shown in Figure 9.

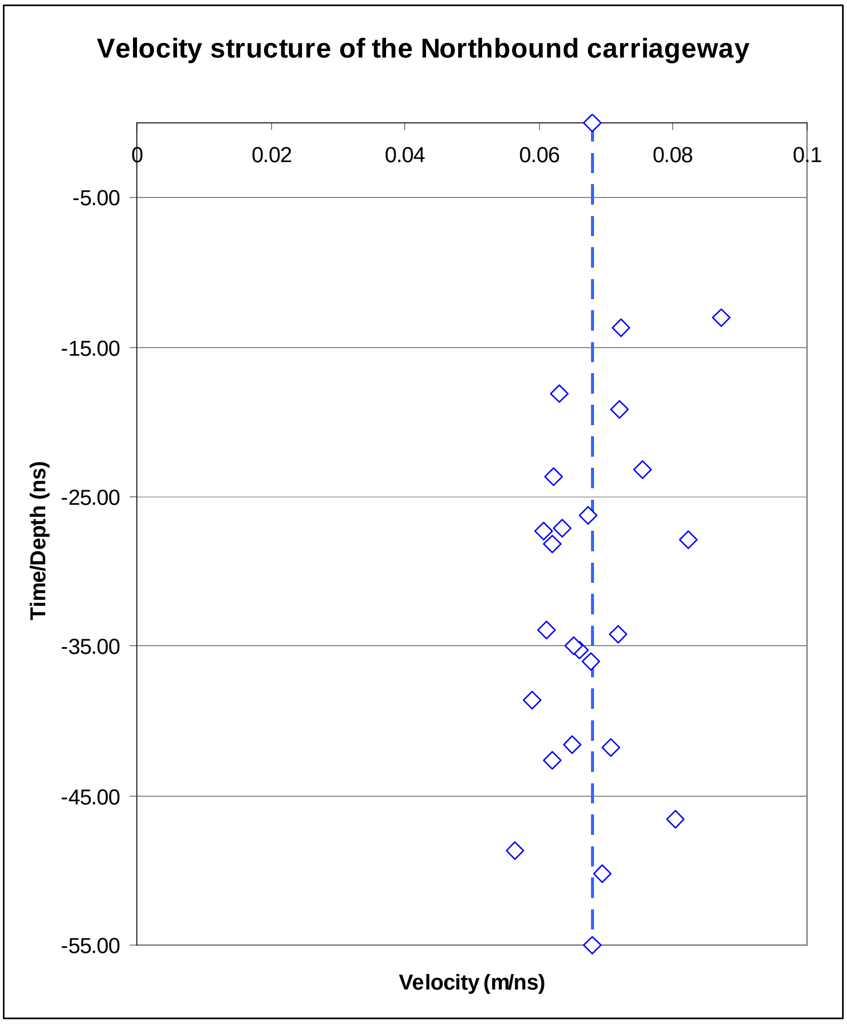
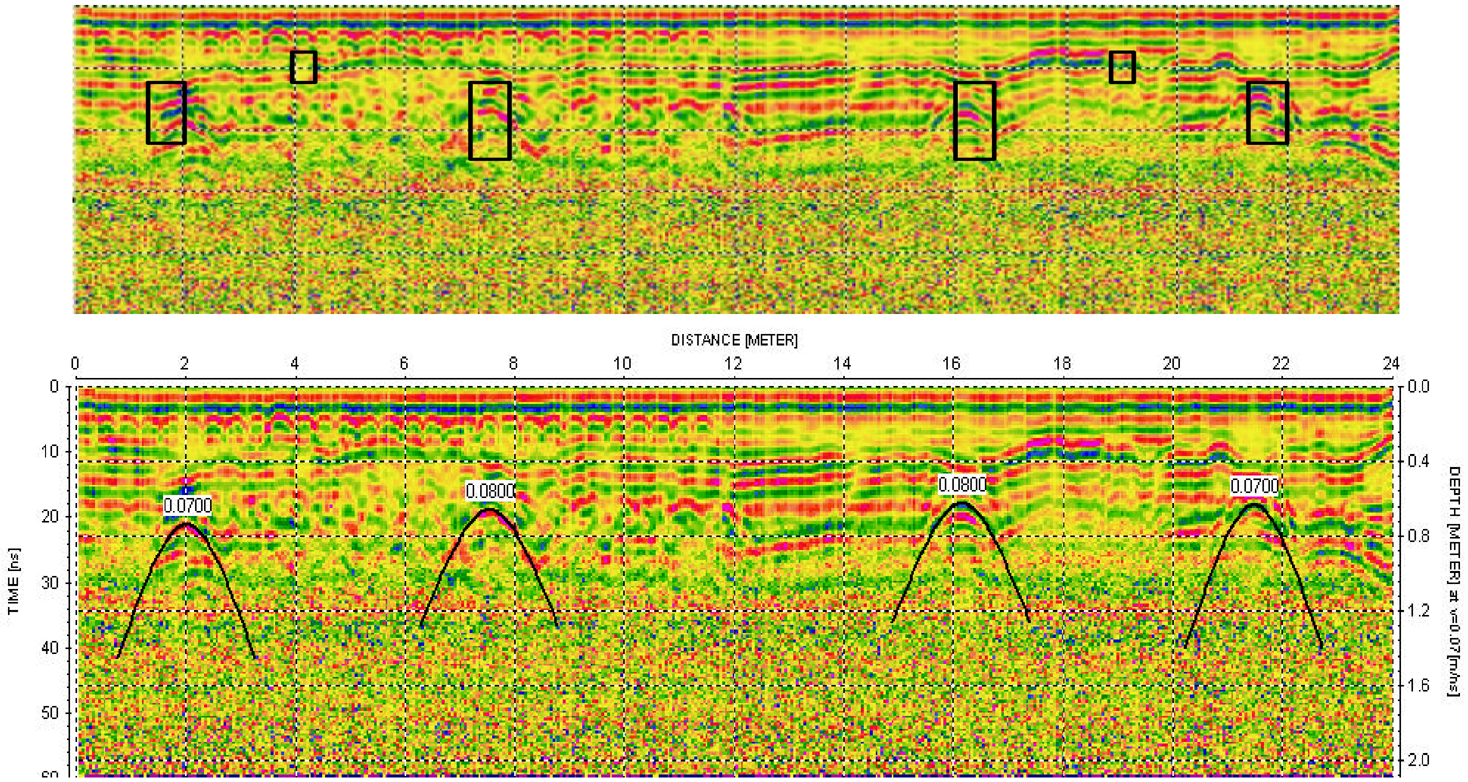


Figure 5 Velocity structure of the northbound carriageway. Average velocity is 0.0679 m/ns, with velocity ranging from 0.0563 to 0.0871 m/ns.

Void detection with Noggin 250 Mhz along TRL test track

Concrete surface (0-240mm), Sub-base (limestone aggregate, 200-250 mm) on London Clay. Rebar in concrete from 0 to 12 m.



Smaller voids (thickness of 200 mm) not detected

Figure 6 Results from the TRL survey showing the response of voids within a road structure. Note that the GPR unit does not detect smaller voids.

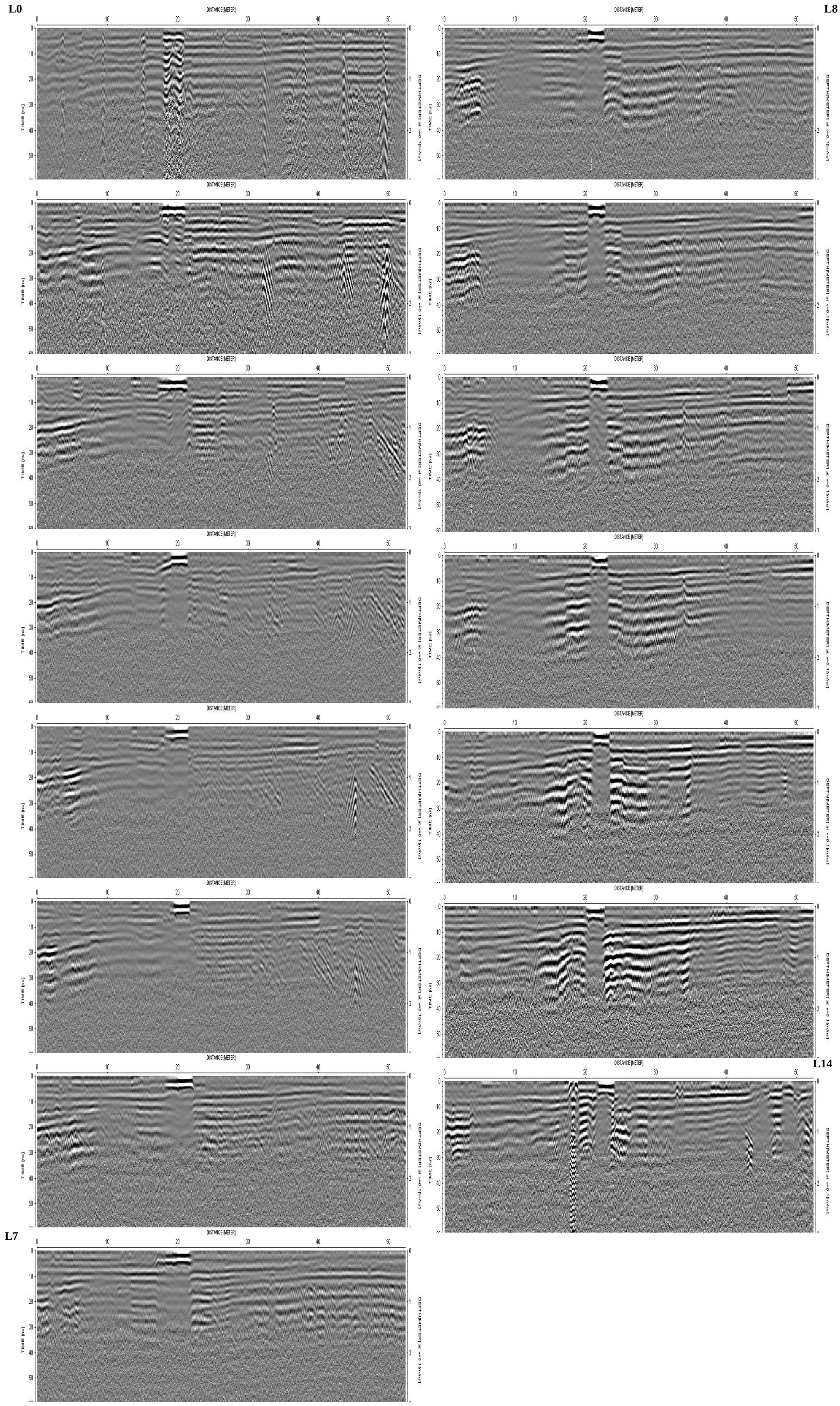


Figure 7 GPR results for the southbound carriageway. Note that the area of resurfacing (approximately 20m along line) can be seen as a dropout in data.

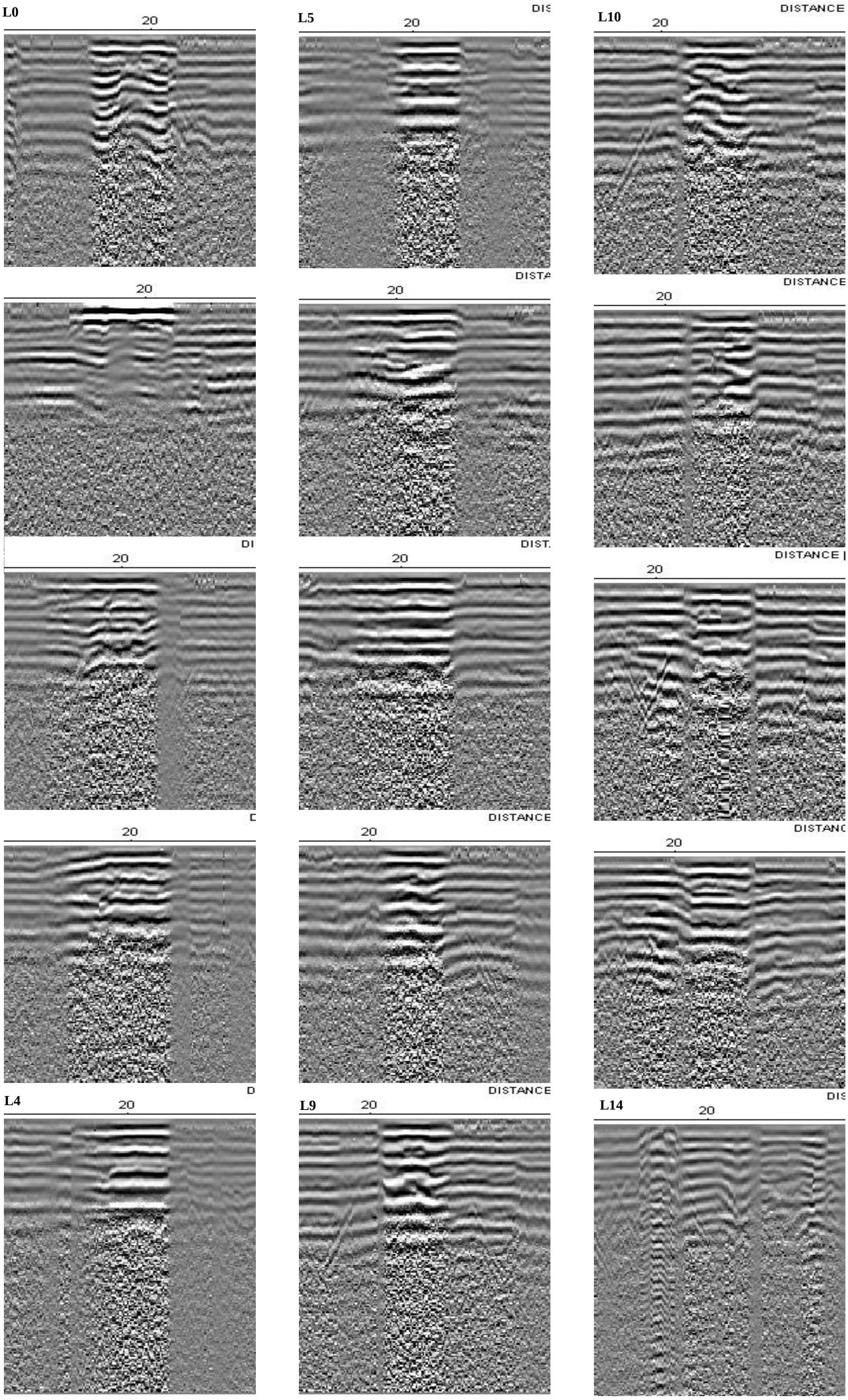


Figure 8 Detailed GPR results from the southbound carriageway of the fissure zone after AGC has been applied to the results.

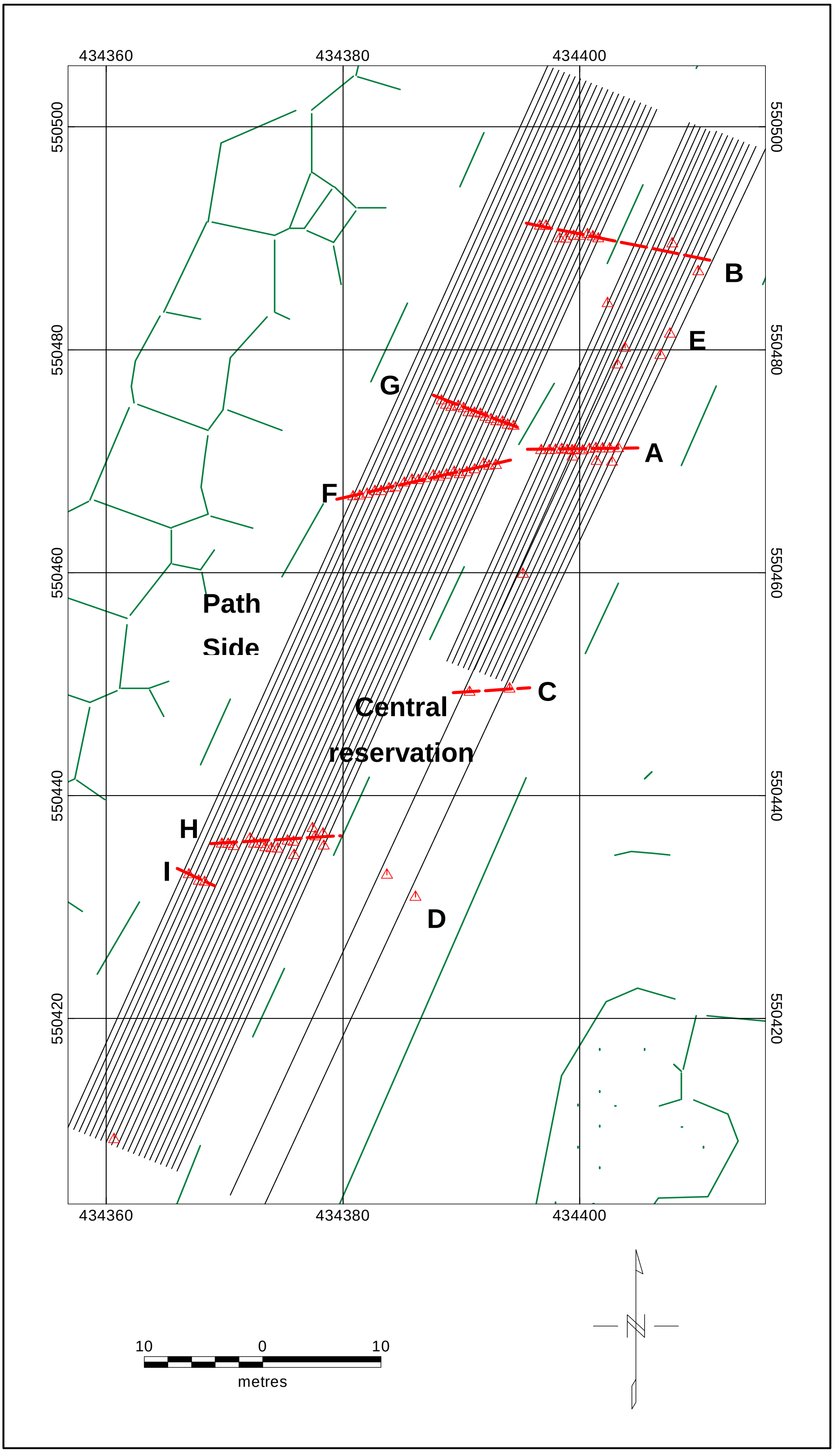


Figure 9 Summary results from both carriageways of the A690 showing continuous GPR features detected by the surveys.

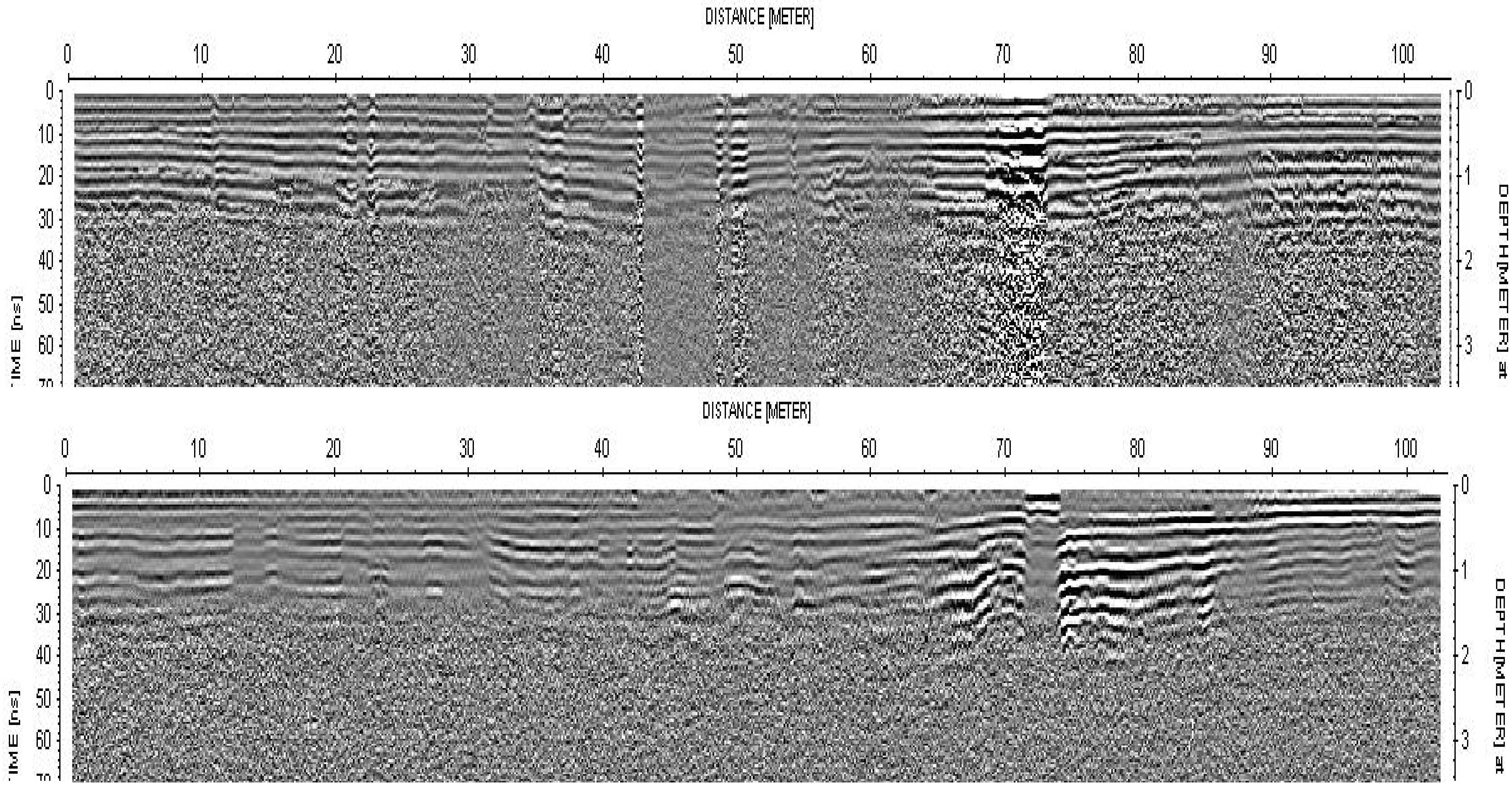


Figure 10 GPR results from the two 103 metre long survey lines of the southern carriageway.

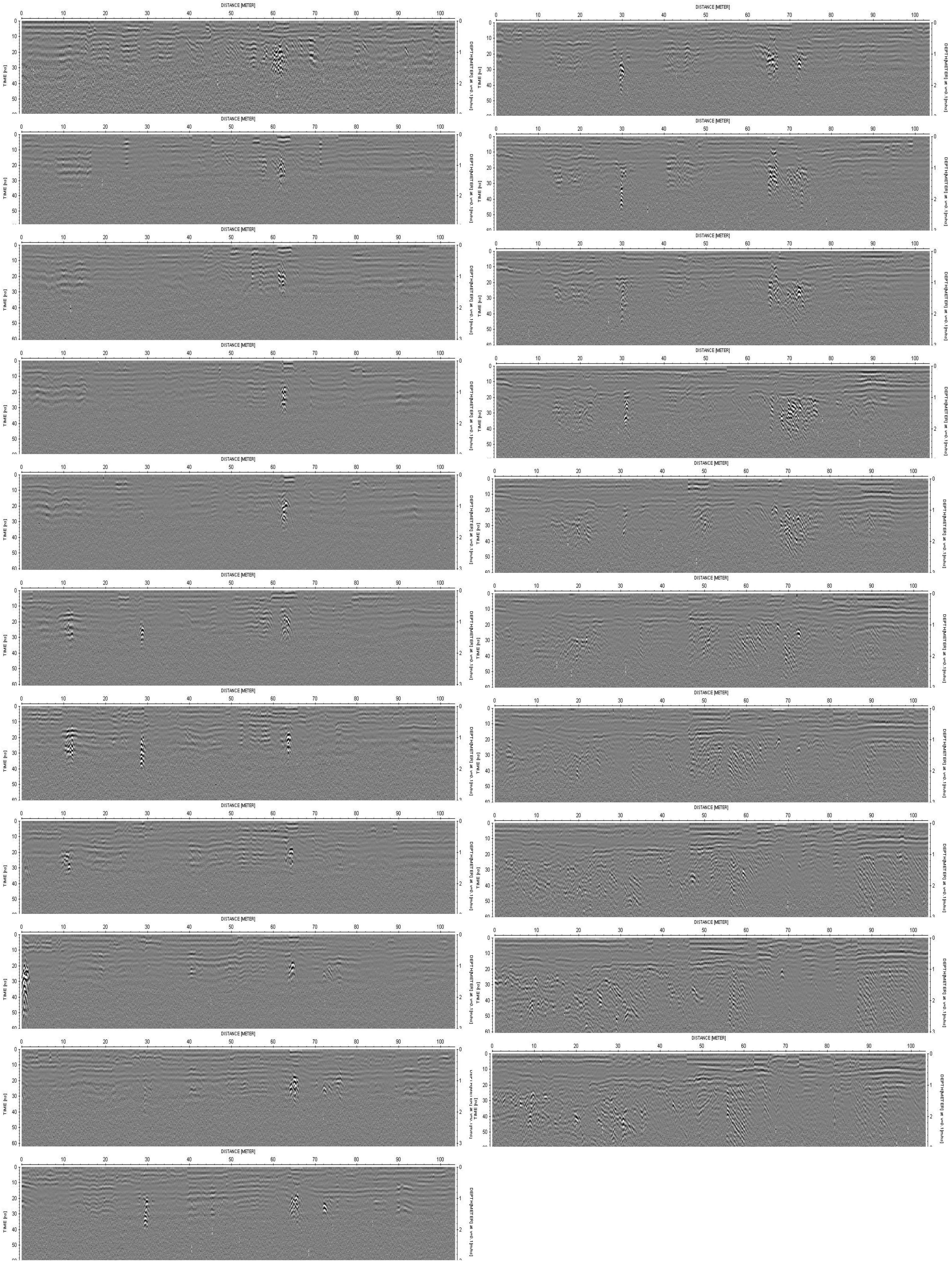


Figure 11 GPR results from the northbound carriageway. This image clearly shows the two known fissures, as well as a few features that should be monitored in future.

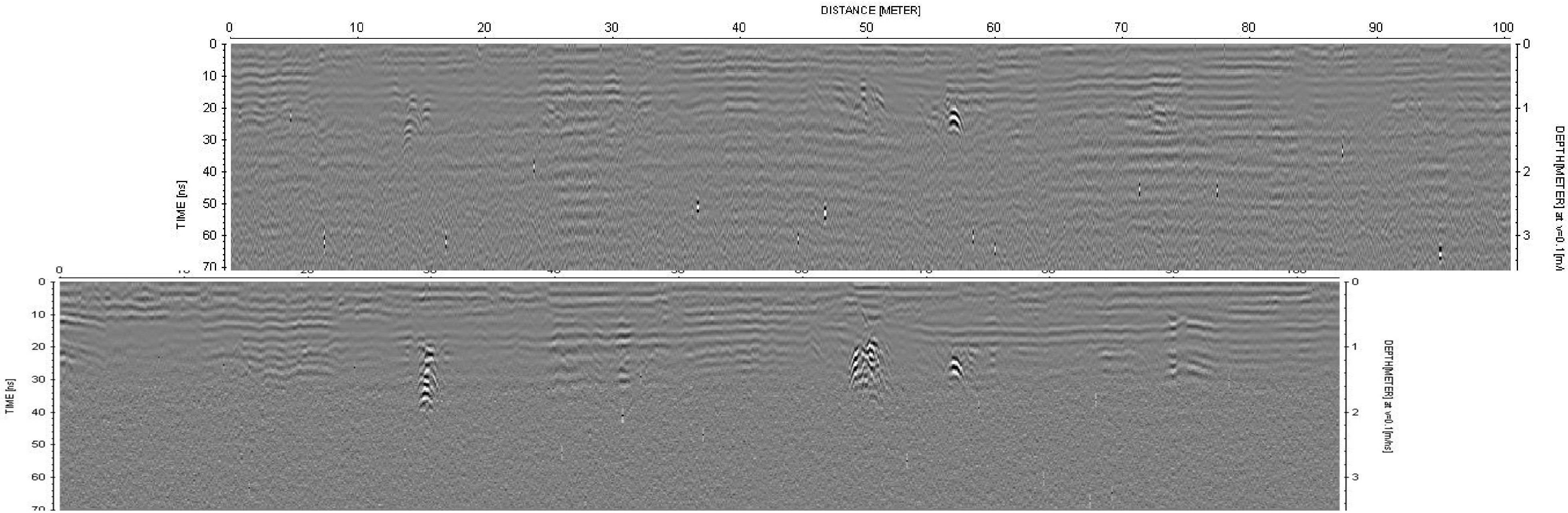


Figure 12 Comparison between the GPR surveys on the northbound carriageway of May 2002 (upper image) and November 2003 (lower image). The 2D lines have been adjusted to align geographically. The reflection from both known fissures is much more pronounced in the latter survey. The major fissure can be seen at 50m along line (top profile), while the crack in the road is seen at 15 m along line. The bright reflector at 57 m was interpreted as a utility (pipe or cable) due to the pronounced electromagnetic anomaly observed in 2002. Without further conformation of the presence of a utility, this feature could also be due to fissuring.

Tables

	Easting (BNG)	Northing (BNG)	Lightpost
NE corner	434415.7	550498.0	L397/L398
SE corner	434394.3	550450.1	L401/L402
SW corner	434388.8	550452.3	L401/L402
NW corner	434409.3	550500.4	L397/L398

Table 1 Limits of the southbound carriageway survey

	Easting (BNG)	Northing (BNG)	Lightpost
NE corner	434396.8	550478.7	L397/L398
SE corner	434385.1	550451.3	L405/L406
SW corner	434375.9	550455.2	L405/L406
NW corner	434387.6	550482.6	L397/L398

Table 2 Limits of the northbound carriageway survey