British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL

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

Urban Geoscience & Geological Hazards Programme

Internal Report IR/02/142

BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT IR/02/142

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

R J Cuss & D Beamish

Key words

Ground penetrating radar; EM31; Ground investigation; ground conductivity; Houghton-le-Spring; multi-sensor platform; geophysic.

Front cover

The ground penetrating radar and EM31 set-up during surveying, the patch of resurfaced material behind the surveyors is the location of the major fissure.

Bibliographical reference

CUSS, R.J. & BEAMISH, D.. 2002. Ground penetrating radar and ground conductivity investigation of the fissuring of the A690 in Houghton-le-Spring. *British Geological Survey Internal Report*, IR/02/142. 36pp.

Keyworth, Nottingham British Geological Survey 2002

BRITISH GEOLOGICAL SURVEY

The full range of Survey publications is available from the BGS Sales Desks at Nottingham and Edinburgh; see contact details below or shop online at www.thebgs.co.uk

The London Information Office maintains a reference collection of BGS publications including maps for consultation.

The Survey publishes an annual catalogue of its maps and other publications; this catalogue is available from any of the BGS Sales Desks.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as its basic research projects. It also undertakes programmes of British technical aid in geology in developing countries as arranged by the Department for International Development and other agencies.

The British Geological Survey is a component body of the Natural Environment Research Council.

Keyworth, Nottingham NG12 5GG

☎ 0115-936 3241 Fax 0115-936 3488
e-mail: sales@bgs.ac.uk
www.bgs.ac.uk
Shop online at: www.thebgs.co.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA

☎ 0131-667 1000 Fax 0131-668 2683
e-mail: scotsales@bgs.ac.uk

London Information Office at the Natural History Museum (Earth Galleries), Exhibition Road, South Kensington, London SW7 2DE

☎ 020-7589 4090 Fax 020-7584 8270
☎ 020-7942 5344/45 email: bgslondon@bgs.ac.uk

Forde House, Park Five Business Centre, Harrier Way, Sowton, Exeter, Devon EX2 7HU

☎ 01392-445271 Fax 01392-445371

Geological Survey of Northern Ireland, 20 College Gardens, Belfast BT9 6BS

☎ 028-9066 6595 Fax 028-9066 2835

Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB

☎ 01491-838800 Fax 01491-692345

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU

☎ 01793-411500 Fax 01793-411501
www.nerc.ac.uk

Foreword

This report is one 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). This report outlines the geophysical survey conducted at Houghton-le-Spring, Tyne-and-Wear, on Sunday 26th May 2002 and gives a full interpretation of the acquired data.

Acknowledgements

The authors conducted the geophysical survey. The survey utilised the GPS unit owned by the Department of Geomatics, University of Newcastle. The authors thank Richard Eyers, Martin Robertson, and Jamal Gledan for their assistance during the survey. The authors would also like to thank Sunderland City Council for closing the A690 and allowing the survey to be conducted in safety. This work was partly funded by Sunderland City Council. We would also like to thank Brian Young and David Lawrence (BGS Edinburgh) for their assistance and input.

Contents

Foreword i

Acknowledgements i

Contents i

Summary iii

1 Introduction 4

2 Survey location and specification 5
- 2.1 Site A – Northbound carriageway 5
- 2.2 Site B – Southbound carriageway 6
- 2.3 Site C – Escarpment adjacent to the A690 6

3 Survey Methods 10
- 3.1 Ground penetrating radar (GPR) 10
- 3.2 Ground conductivity 10
- 3.3 Real-time kinematic Global Positioning System (RTK-GPS) 11

4 Ground Conductivity Results 13
- 4.1 Horizontal coil apparent conductivity 13
- 4.2 Horizontal coil metallic response 13
- 4.3 Vertical coil apparent conductivity 13

5 Ground Penetrating Radar Results 17
- 5.1 Site A – Northbound carriageway 17
- 5.2 Site B – Southbound carriageway 25

5.3 Site C – Escarpment adjacent to the A690 ... 28

6 Conclusions ... 32

References ... 32

FIGURES

Figure 1 Location of the survey sites in reference to the Houghton-le-Spring ... 5

Figure 2 Location of the surveys sites on and adjacent to the A690 ... 7

Figure 3 Location of the survey lines along the A690 ... 8

Figure 4 Location of the survey lines on Houghton Hill, adjacent to the A690 ... 9

Figure 5 The multi-sensor platform used in the survey ... 12

Figure 6 Apparent conductivity results for the northbound carriageway with horizontal coils ... 14

Figure 7 The in-phase coupling ratios for the northbound carriageway with horizontal coils ... 15

Figure 8 Apparent conductivity results for the northbound carriageway with vertical coils ... 16

Figure 9 Velocity structure of the northbound carriageway ... 18

Figure 10 Data from Ground Penetrating Radar for 12 of the lines conducted along the northbound carriageway of the A690 ... 19

Figure 11 Map of radar data as produced from 3D radar data ... 21

Figure 12 Interpretation of the radar data on the northbound carriageway ... 22

Figure 13 GPR data from the 100m long survey line ... 24

Figure 14 Interpretation of the northbound carriageway ... 25

Figure 15 Radar data for the southbound carriageway ... 27

Figure 16 Velocity structure of the limestone beneath Houghton Hill ... 28

Figure 17 Summary of general features seen at Houghton Hill farm ... 30

Figure 18 Interpretation of the Houghton Hill site, confirming the location of the known features and the location of some new features ... 31

Summary

This report introduces the results of a geophysical survey using ground-penetrating radar (GPR) and ground conductivity methods to investigate the nature of fissuring observed in Houghton Cut, Tyne & Wear. The survey on the northbound carriageway of the A690 mapped the location of a known fissure and described the nature of this feature to a depth of 3m. A suspected manmade feature (pipeline or other utility) was noted close to the known feature, as identified by ground conductivity measurements. Data interpretation was aided by the use of 3D radar data. The southbound carriageway was found to yield no useful data. A full investigation of Houghton Hill highlighted two major fissures that had surface expressions. These features were imaged to a depth of 7m and were mapped laterally up to 50m further than their surface expression. Three other smaller fissures were observed. A final linear feature was identified, but is suspected to be manmade (either a utility or drainage pipe). This work was partly funded by Sunderland City Council.

1 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). The major crack beneath the road forms the main target of the investigation described in this report.

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 land sliding, 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.

The application of the ground penetrating radar (GPR) and ground conductivity methods offers a non-invasive way of investigating the subsurface. This information can be used to answer specific questions about the fissuring immediately below the surface of the A690. This report introduces and summarizes the results of the field investigation conducted on Sunday 26th May 2002. This survey was conducted in poor weather; it drizzled during most of the morning, with a severe thunderstorm in the afternoon whilst on Houghton Hill. This was not ideal weather for conducting a geophysical survey, but should have not severely affected the survey results.

2 Survey location and specification

Three survey areas were selected on the edge of Houghton-le-Spring, Tyne & Wear, in the proximity of the A690 Durham to Sunderland road. 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.

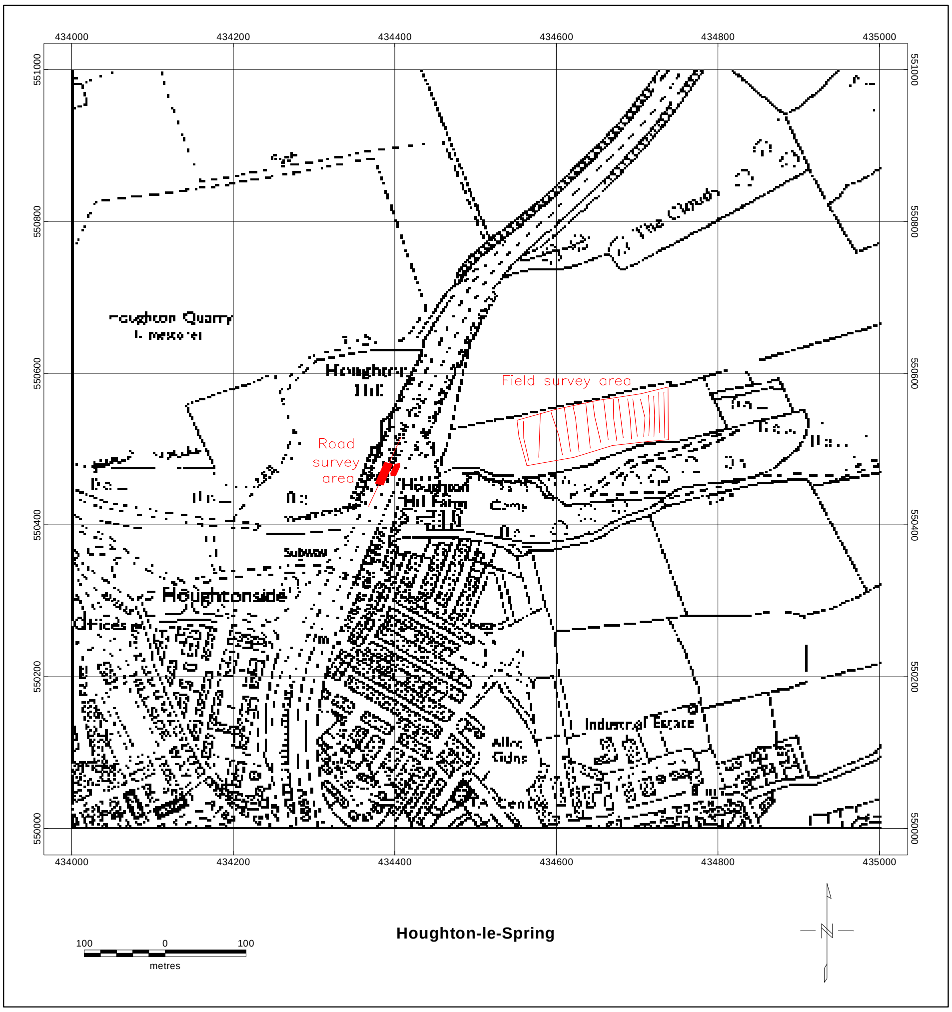

Figure 1 Location of the survey sites in reference to the Houghton-le-Spring.

2.1 SITE A – NORTHBOUND CARRIAGEWAY

The most detailed survey was conducted on the northbound carriageway of the A690. A network of parallel lines 30m long and separated by 0.5m was set out parallel to the direction of the road (approximately NNE). Data were thus not recorded perpendicular to the target fissure. This section of road is dual carriageway and allowed 19 parallel lines of radar data. In addition, nine lines were repeated with the EM and radar, and two 100m long lines were recorded of EM and radar data. The 100m survey line was coincident with the 10th survey line (centre of the 19 survey lines), and the nine EM and radar survey lines were also centred on the 19 line survey area. Successive lines were surveyed in alternate directions. Figure 3 shows the location of the survey area, which had limits of:

	Easting (BNG)	Northing (BNG)
NE corner	434397	550480
SE corner	434385	550453
SW corner	434376	550455
NW corner	434388	550483

2.2 SITE B – SOUTHBOUND CARRIAGEWAY

The southbound carriageway was also dual carriageway, but was not as wide as the northbound carriageway. Here the survey was set up slightly differently, with 23 lines conducted perpendicular to the target fissure feature. This meant that some lines were very short, while the centre line was only 12m long. For the northern portion of this survey area, lines were recorded north to south, while the southern part of the survey was recorded south to north. Figure 3 shows the location of the survey area, which had limits of:

	Easting (BNG)	Northing (BNG)
NE corner	434407.5	550481.0
SE corner	434401.0	550465.0
SW corner	434393.5	550464.5
NW corner	434400.0	550480.0

2.3 SITE C – ESCARPMENT ADJACENT TO THE A690

A final GPR dataset was recorded in Houghton Hill Farm fields adjacent to the A690 and on the top of the limestone escarpment. Here 16 lines of 50-60m lengths were recorded in alternate directions.

Figure 4 shows the location of the survey area (including additional points that locate the fissure feature), which had limits of:

	Easting (BNG)	Northing (BNG)
NE corner	434740	550585
SE corner	434740	550510
SW corner	434555	550480
NW corner	434555	550545

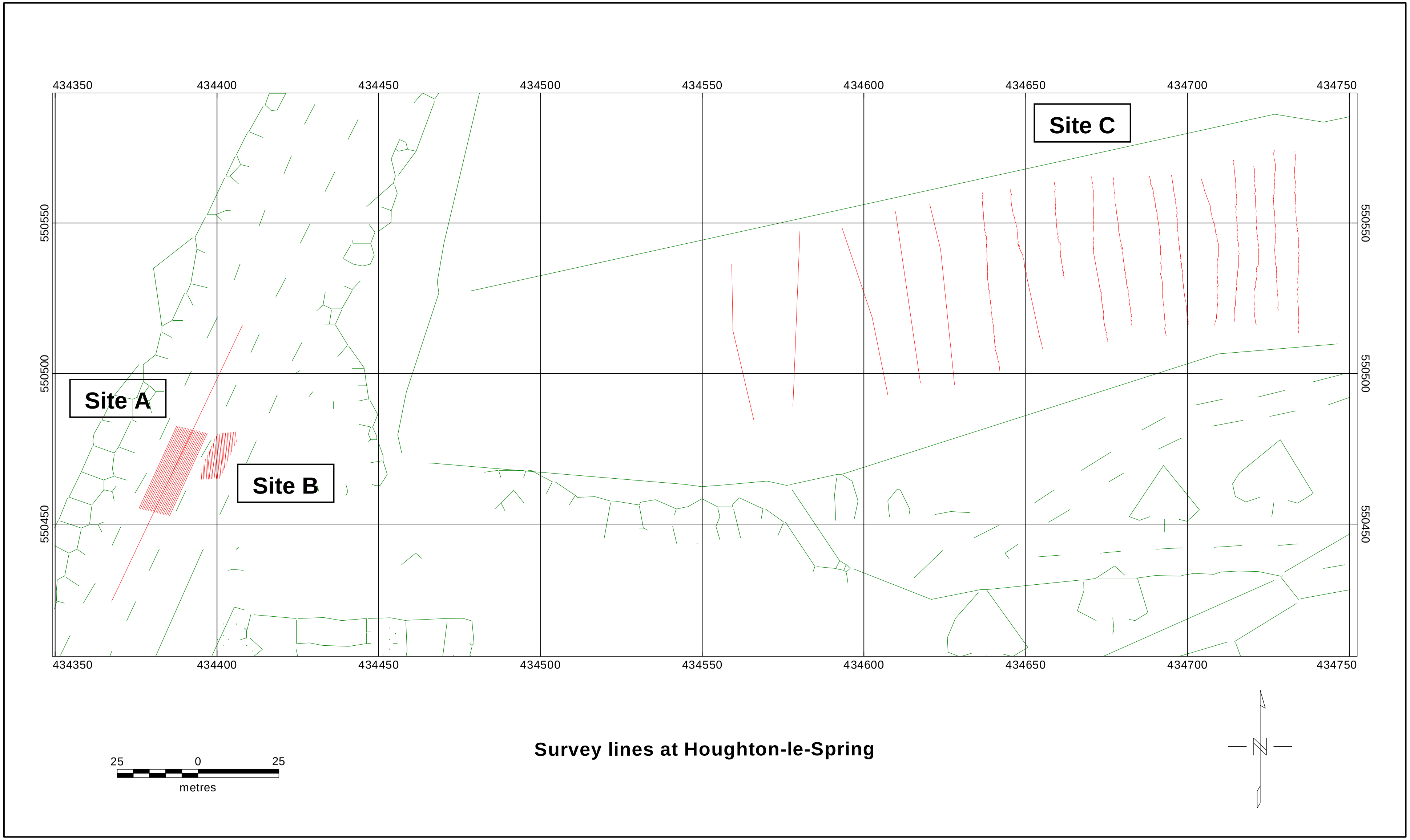

Figure 2 Location of the surveys sites on and adjacent to the A690. Topography traced from OS image displayed in Figure 1.

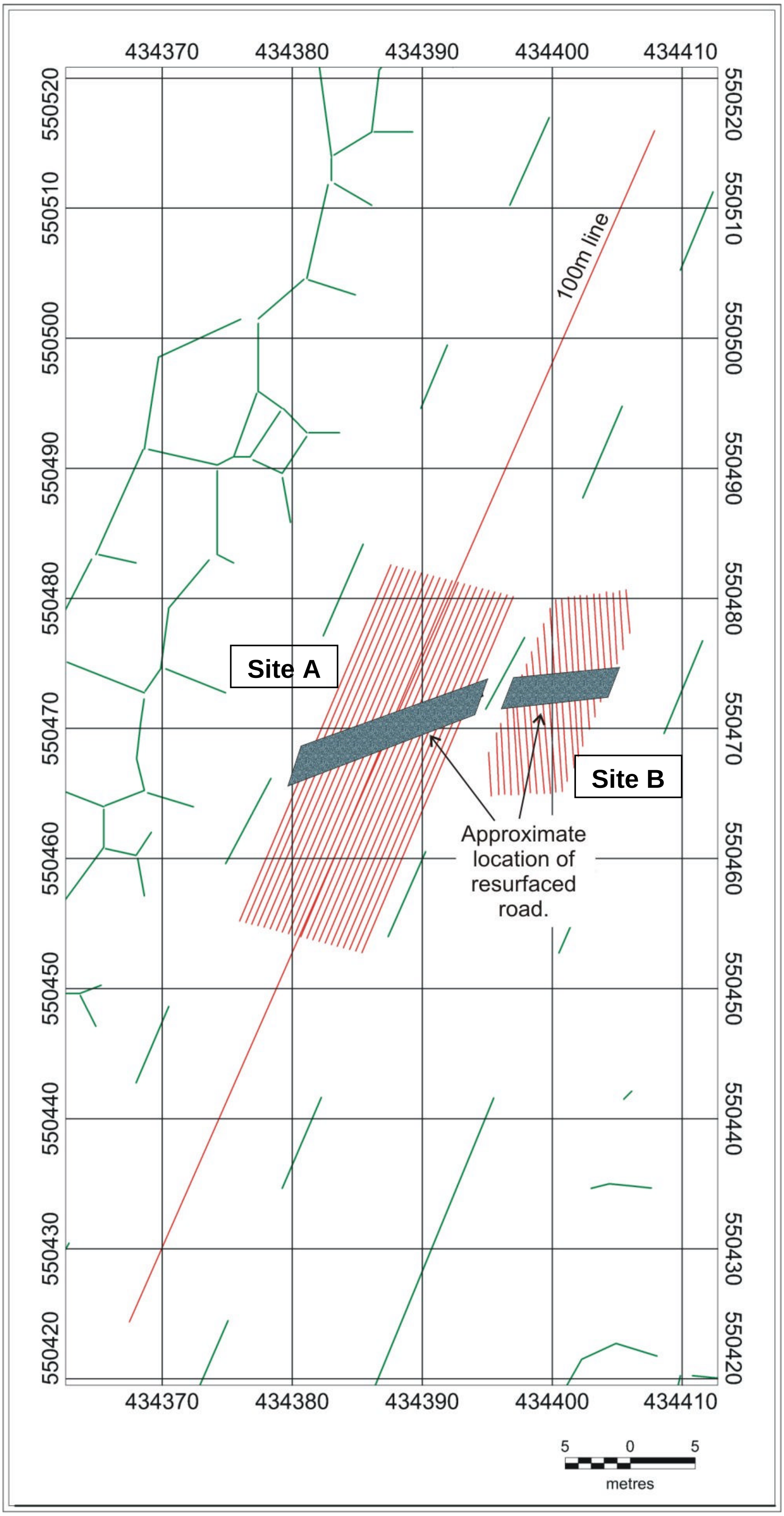

Figure 3 Location of the survey lines along the A690. Topography traced from OS image displayed in Figure 1.

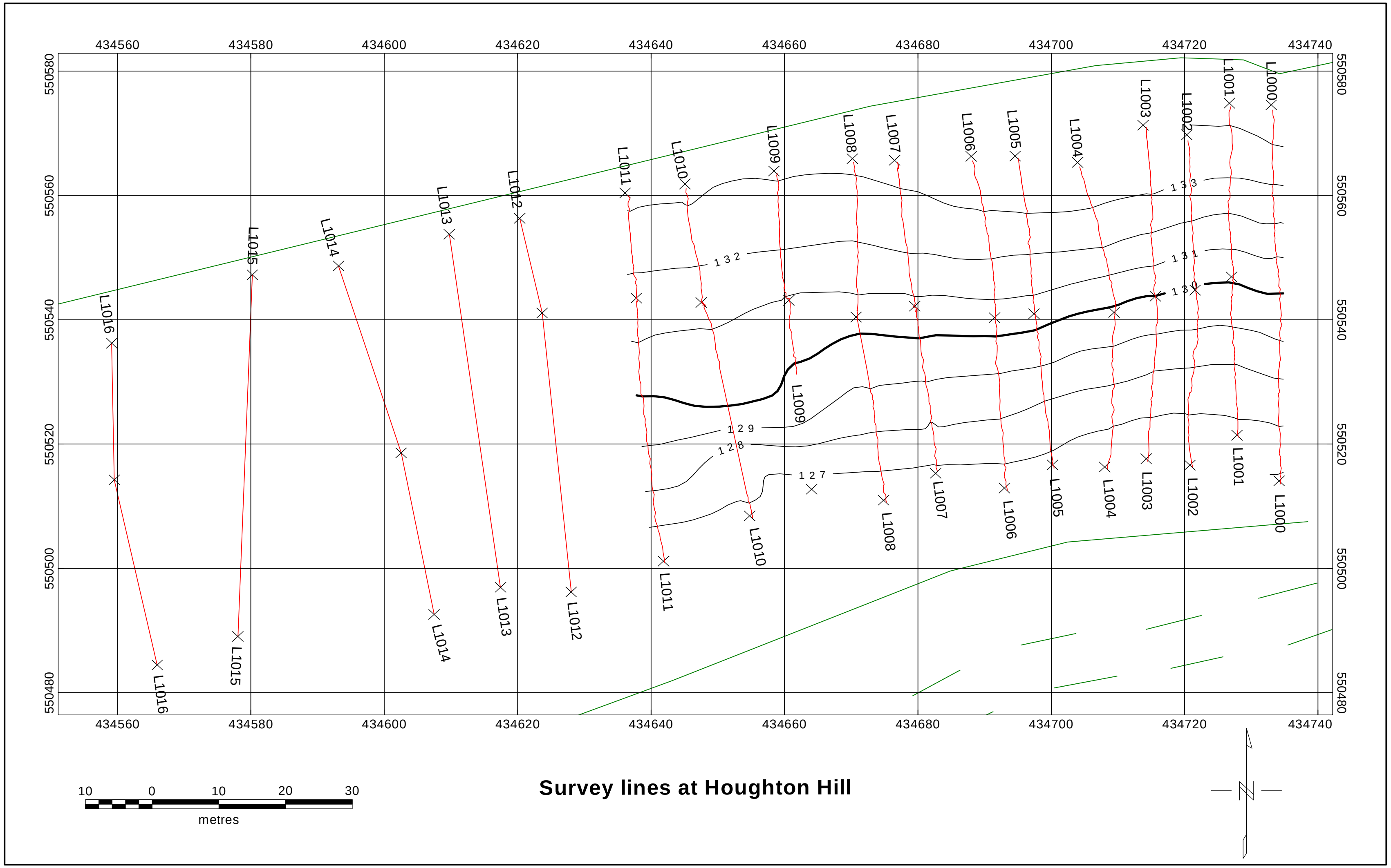

Figure 4 Location of the survey lines on Houghton Hill, adjacent to the A690. The central crosses along some lines indicate the location of the observed fissure. The profile deviations illustrate the difficulty in obtaining straight survey lines on sloping rough pastureland. Contours show the terrain recovered from the GPS (not corrected for the height of the antenna), significant errors will be associated with these values, but illustrate the sloping nature of the site.

3 Survey Methods

Two geophysical methods were employed on the three sites. These were; Ground penetrating radar (GPR) and ground conductivity (EM). In addition to these geophysical apparatus, a GPS unit was attached to the GPR cart. The availability of all three units allowed a trial to be conducted on this survey into the operation of the apparatus on one convenient multi-sensor platform (the GPR cart), as shown in Figure 5.

3.1 GROUND PENETRATING RADAR (GPR)

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 5 shows the Noggin Smart Cart at the Houghton site, with the EM, it's data logger, and the RTK-GPS unit attached. 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, which 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. Site C was surveyed in a coarse manner as a series of 2D profiles.

3.2 GROUND CONDUCTIVITY

Ground conductivity measurements were made with the Geonics EM-31 instrument along the northbound carriageway of the A690. The origin of the survey grid was 434397E, 550480N at the kerbstone step of the central reservation, the grid was coincident with the GPR survey area. A 30 m survey profile length was used. Distances along the profiles increase to the south. The survey baseline (approximately E-W and about 10 m in width) was perpendicular to the strike of the road with distances increasing to the west. Services and drains were apparent running along the western edge of the carriageway.

The EM31 was mounted on the Noggin cart with its axis perpendicular to the survey profiles (Figure 5). Two sets of measurements were made corresponding to two different depths of investigation:

- Horizontal coils: depth of investigation is about 5 m
- Vertical coils: depth of investigation is about 2 m with maximum sensitivity in the first 1.5 m

During the surveys it became apparent that road-edge effects (the central crash barrier in the east and the services to the west) influenced the measurements. The more extensive horizontal coil survey was carried out across baseline distances from 2.5 to 10 m at an interval of 0.5 m. Measurements were made, discretely, every 0.5 m along each profile. In discrete mode, the instrument returns both apparent conductivity value (in mS/m) and an in-phase coupling ratio (in ppt = parts per thousand). The in-phase coupling ratio responds primarily to metallic objects.

The vertical coil survey proved to be more sensitive to the road-edge effects and was carried out across baseline distances from 4 to 8 m at an interval of 0.5 m. Measurements were made in the walk-along mode (fixed time interval recording); in this mode the instrument returns only apparent conductivity values.

3.3 REAL-TIME KINEMATIC GLOBAL POSITIONING SYSTEM (RTK-GPS)

Positional data was supplied by a Leica Geosystems 500 real-time kinematic GPS (GTK-GPS) unit. This was owned and operated by the Geodectics Department of the University of Newcastle. Data were stored within the GPS unit as a series of way-points located at the ends of the survey lines and also at points of interest.

Data were also directly transferred to the radar unit as a standard serial string. Due to technical difficulties in establishing this link, GPS data at each survey point is only available for lines 1-11 on Houghton Hill. These data were converted to British National Grid co-ordinates using Grid InQuest, a free utility supplied by the Ordnance Survey. All way point data were processed by Richard Eyers at the University of Newcastle and were adjusted by BGS to account for the offset between the GPS antenna and the radar unit.

Figure 5 The multi-sensor platform 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. (DVL) Also shown is the EM-31 (wide boom), it's associated logger (small red logger next to the DVL) and the RTK-GPS unit (in a rucksack attached below the DVL).

4 Ground Conductivity Results

The three sets of results obtained across the northern carriageway are shown in a similar form (a perspective view) looking from north to south. The main results are shown as a colour-contoured surface since this allows more subtle (small amplitude) effects to be resolved. A subsidiary colour-contoured plan view of the same data is also shown.

4.1 HORIZONTAL COIL APPARENT CONDUCTIVITY.

The deeper penetrating horizontal coil apparent conductivities are shown in Figure 6. The values extend from several mS/m to over 100 mS/m. A ‘U’ perturbation to the values is caused by the road-edge effects (values increase as the road-edge is approached). Only values obtained in the centre of the carriageway (e.g. 40 to 50 mS/m) are ‘correct’. Within this overall distortion a main anomaly (decreasing values) is seen to strike across the road between profile distances of about 5 to 8 m. The source of the continuous feature is not known but it is likely to be man-made rather than geological. In the vicinity of the target crack location (profile distances of about 15 m) only a very slight perturbation is seen in the data. Any deep ground conductivity features that may be associated with the target fissure appear to be largely beyond the limits of detection using the EM-31 instrument.

4.2 HORIZONTAL COIL METALLIC RESPONSE

The in-phase coupling ratios, shown in Figure 7, again display a ‘U’ shaped distortion across the road. A strong anomaly (towards the road edge) is observed in association with the corresponding conductivity anomaly and indicates a localised metallic component of the same (unknown) feature. Elsewhere a series of localised ‘bulls-eyes’ can be observed relating to isolated metallic objects beneath the road.

4.3 VERTICAL COIL APPARENT CONDUCTIVITY

The vertical coil apparent conductivity results, shown in Figure 8, relate to the very shallow subsurface. Baseline values are here restricted to between 4 and 8 m. The results probably relate to the construction fabric of the road itself. Apparent conductivity values vary between 10 and 40 mS/m (lower than the deeper penetrating data).

The main anomaly observed, in this case an increase to high values, is clearly associated with the same feature detected in the deeper penetrating data. Peak values occur slightly to the south of the deeper results indicating a possible dip of the feature to the north. In the vicinity of the crack location (profile distances of about 15 m) no significant perturbation is observed. Any shallow conductivity features that may be associated with the target fissure appear to be largely beyond the limits of detection using the EM-31 instrument.

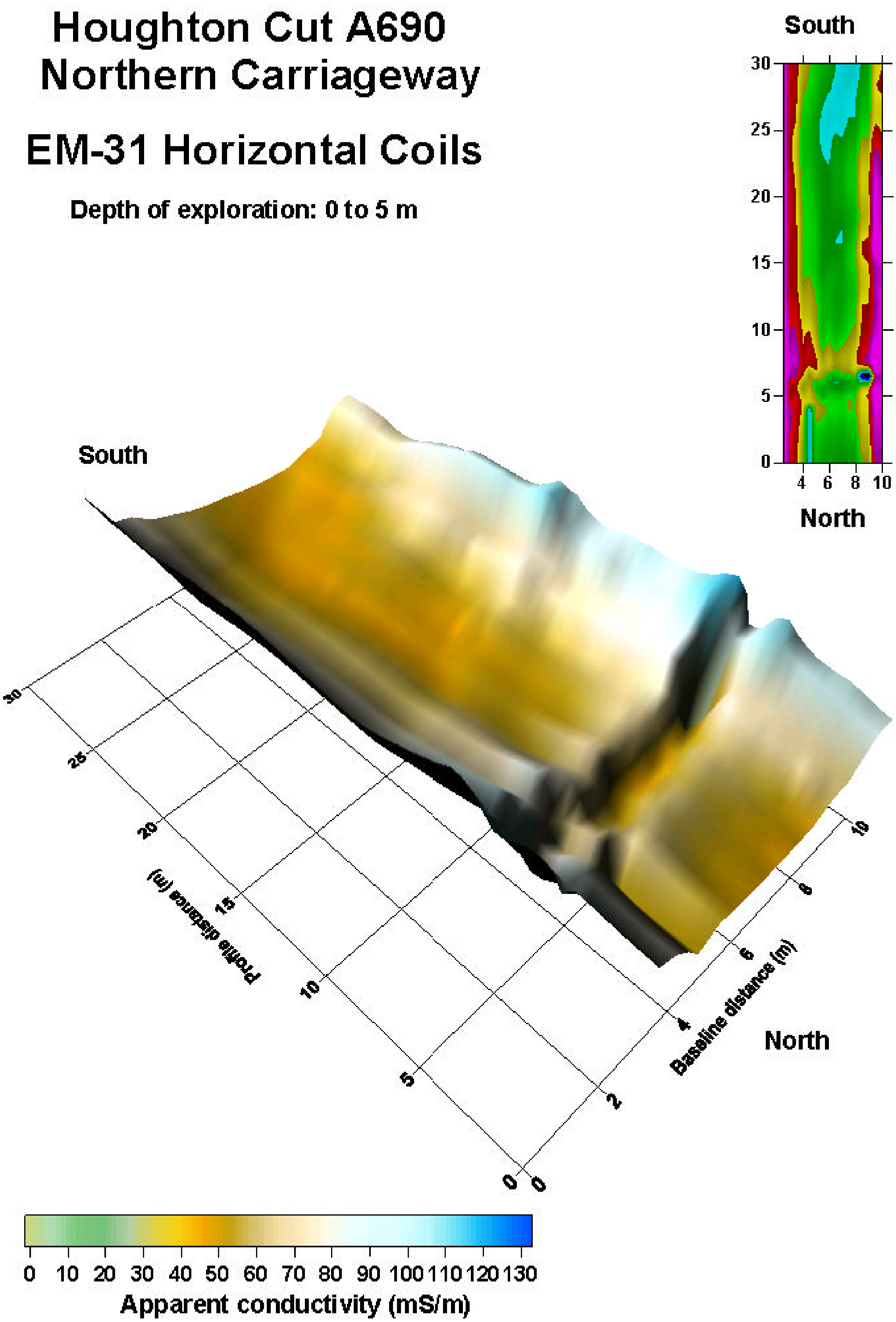

Figure 6 Apparent conductivity results for the northbound carriageway with horizontal coils. Local grid origin is 434397E, 550480N.

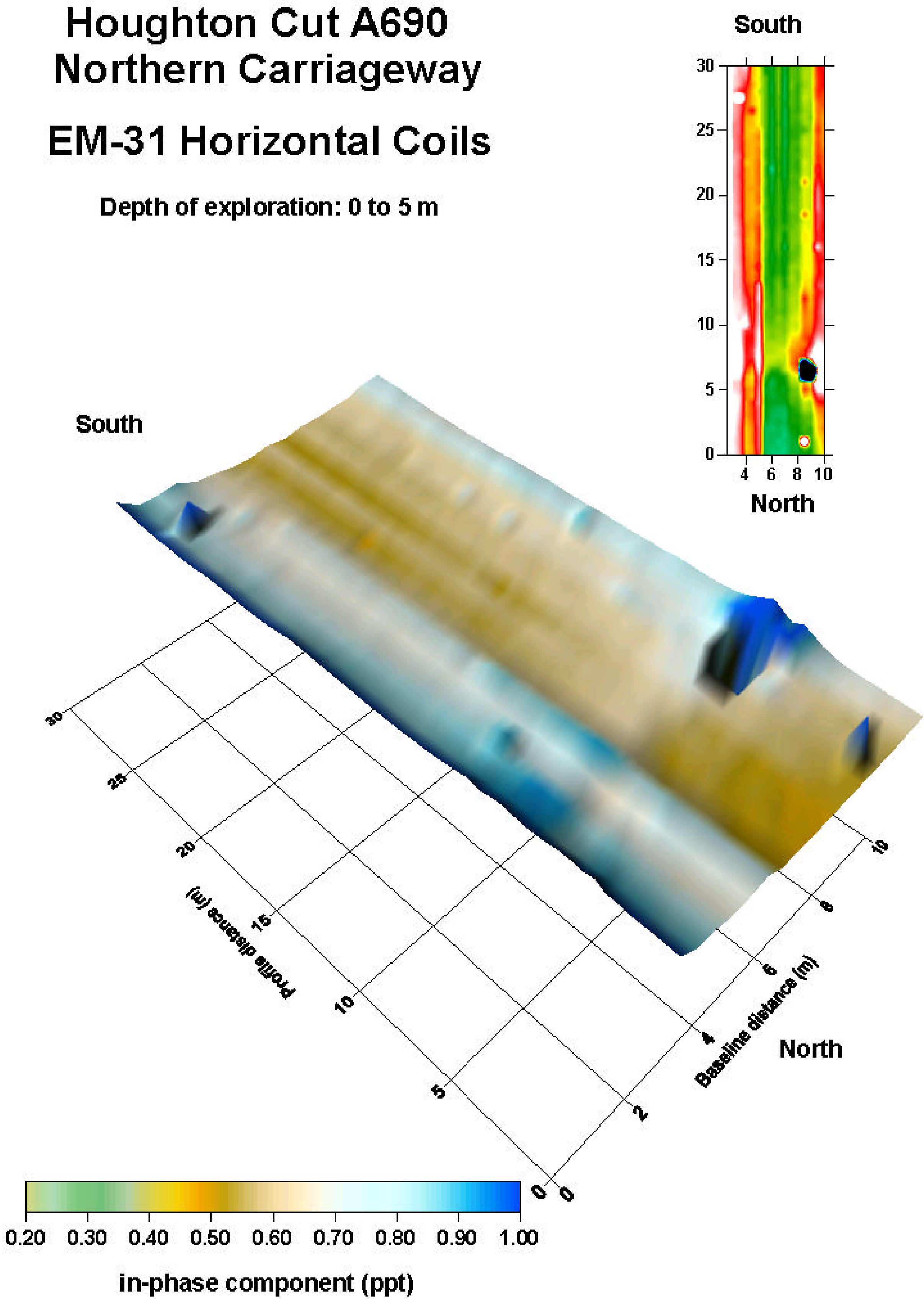

Figure 7 The in-phase coupling ratios for the northbound carriageway with horizontal coils. Local grid origin is 434397E, 550480N.

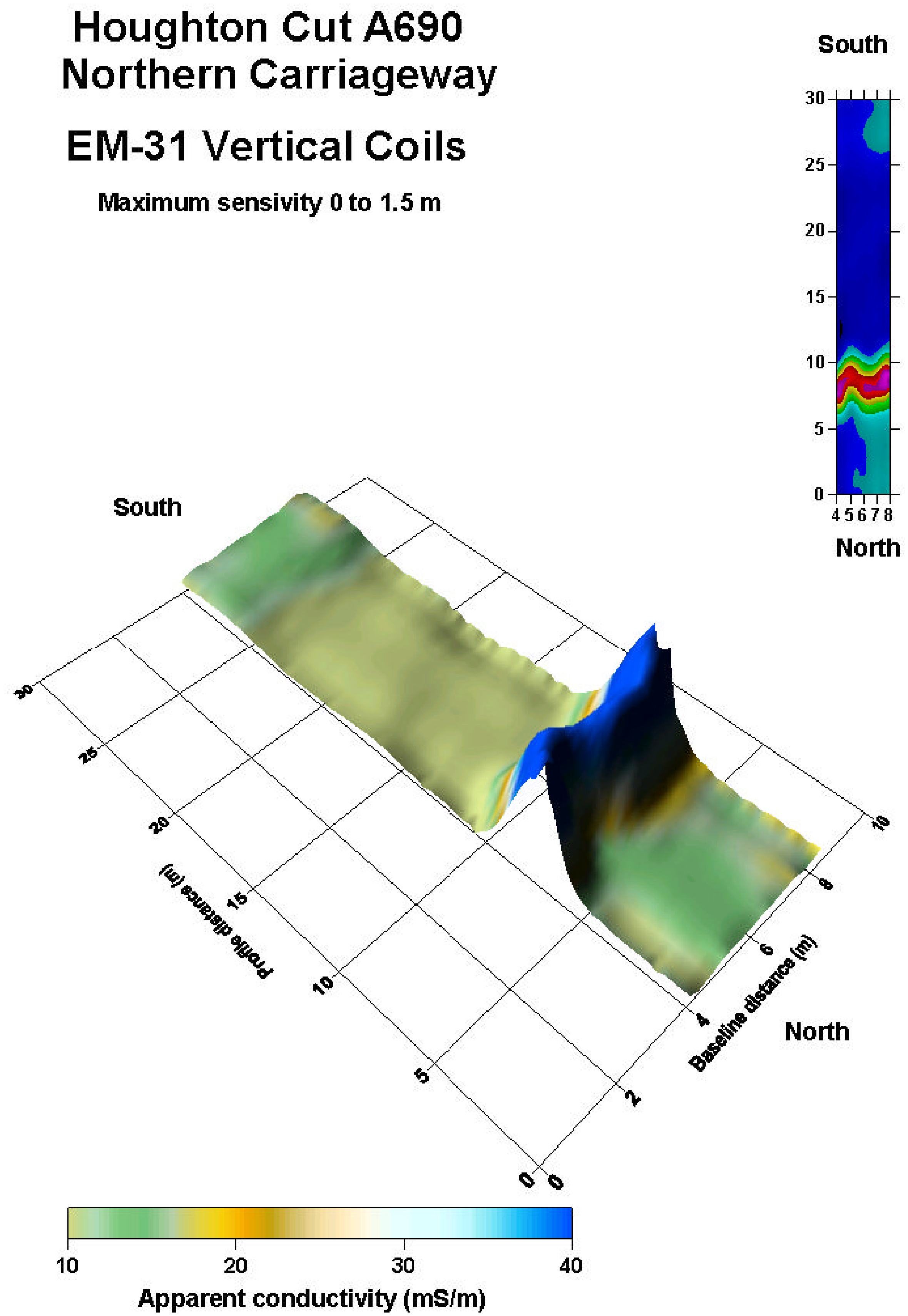

Figure 8 Apparent conductivity results for the northbound carriageway with vertical coils. Local grid origin is 434397E, 550480N.

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.

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.

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

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

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

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 SITE A – NORTHBOUND CARRIAGEWAY

Data were incorporated into a 3D volume of radar information so that cross-line correlations could be investigated. Data were initially viewed as 2D cross-sections to identify the location of the known fissure.

5.1.1 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.

Obvious hyperbolae were recorded from all lines along the northbound carriageway. Figure 9 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.

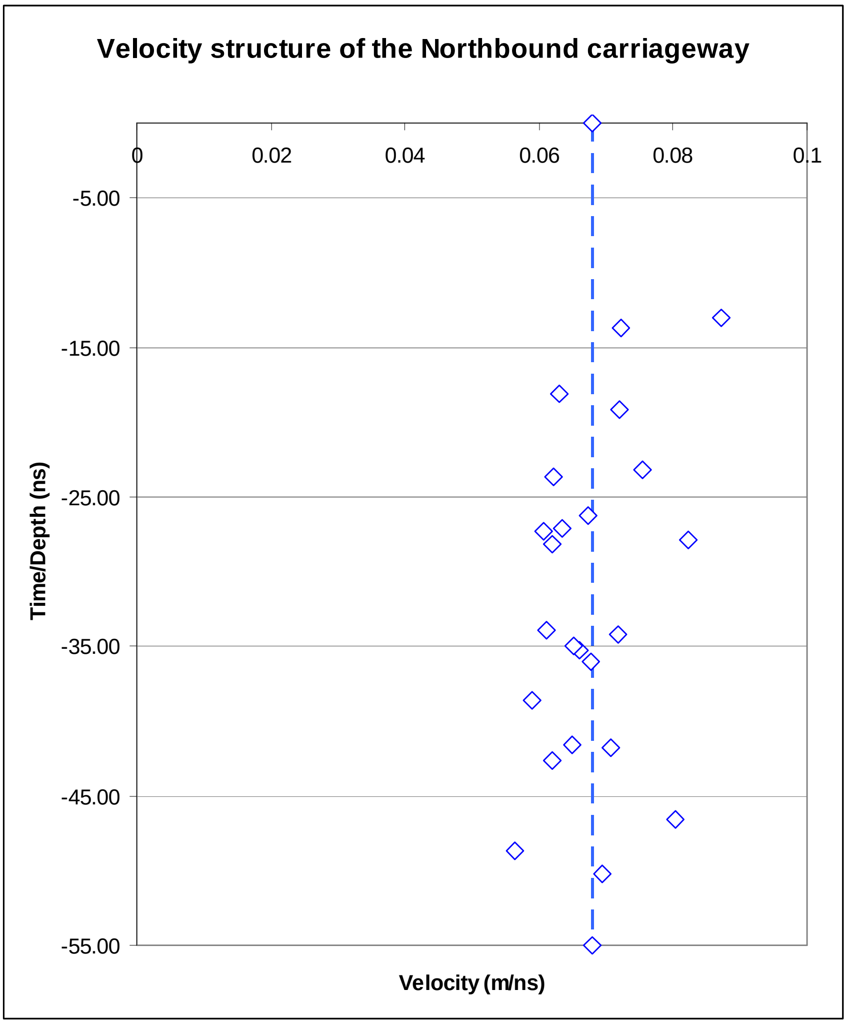

Figure 9 Velocity structure of the northbound carriageway. Average velocity is 0.0679 m/ns, with velocity ranging from 0.0563 to 0.0871 m/ns.

5.1.2 2D data interpretation

Figure 10 shows 12 of the 19 GPR profiles recorded on the northbound carriageway. These are all oriented south to north, and in series 1-12 progress from west to east. As can be seen, the section of road that has been resurfaced can be identified, this is most obvious in Figure 10.3 and Figure 10.4, identified as a series of ‘flat’ lines. This effect can be attributed to “ringing”, which is explained in more detail in section 5.1.6.

The fissure is clearly identifiable on almost all of the survey lines. It is most clear in Figure 10.2 and Figure 10.3. Using these clear markers, it is then possible to identify the fissure on the remainder of the profiles.

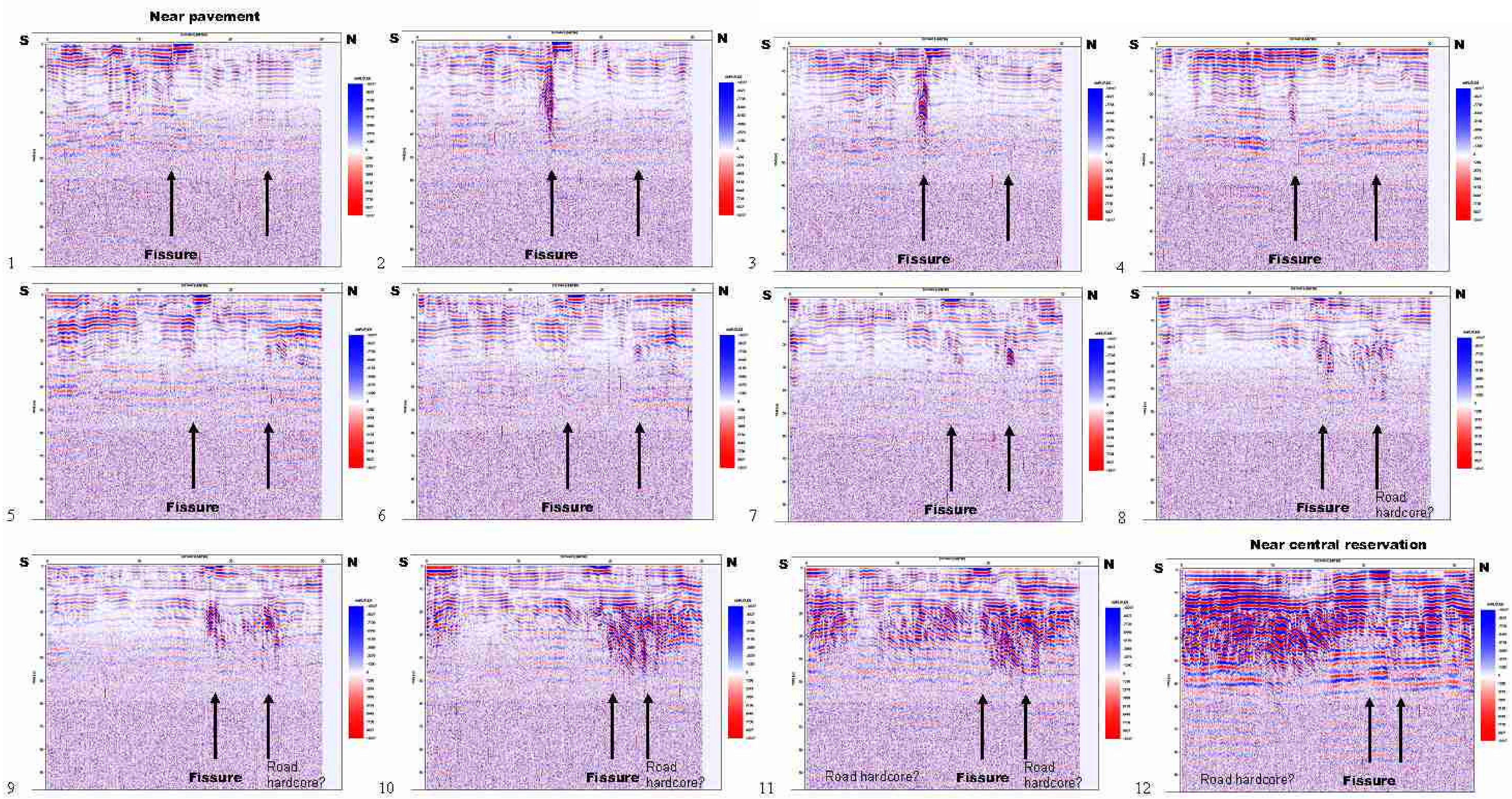

Figure 1 Data from Ground Penetrating Radar for 12 of the lines conducted along the northbound carriageway of the A690. As highlighted, the fissure can be seen on almost all of the cross-sections. Note: Assuming a radar velocity of 0.0679 m/ns, each section has a full depth extent of <u>6.65 m</u>, with useful penetration not exceeding <u>3 m</u>.

Figure 10 clearly shows that the character of the fissure changes across the road. On some lines it is only just visible, whereas on others it has created a clear radar reflection. This may indicate sections of the fissure that are open (good reflection) or closed (poor reflection). Radar reflections are created where a discontinuity of electrical properties occurs. The difference between limestone and air is significantly greater than the difference between intact Magnesian limestone in the bedrock and deformed limestone within a closed fissure.

A feature that is seen at approximately 23m along line complicates the interpretation of the northbound carriageway site. Towards the central reservation there can be seen to be some form of structure below the road. There are a number of possible causes of this feature:

- Some form of utility crossing the road
- A broad disturbed section of bedrock relating to a major fissure.
- Geological structure within the limestone being imaged.
- Variations in depth of road hardcore.

As this feature is approximately coincident with the ground conductivity feature, it is expected to be disturbed ground around a man-made feature.

5.1.3 3D data interpretation

Data were also interpreted from the 3D radar data; this allows maps to be produced at successively increasing time slices (to a depth of approximately 1m). Figure 11 shows a number of the time slices. As can be seen, the fissure is very obvious, seen at an angle across the survey site. In the top few layers, this strong signal is related to the resurfaced section of the road, but from time-slice 8 onwards, is related to the fissure itself. This clearly shows that the fissure is a continuous linear feature.

With increased time (~depth) the fissure feature is seen to gradually move to the south. This shows that the fissure dips towards the south, as observed in the exposures surrounding the A690.

Figure 11 also suggests that there are no other continuous major fissures within the 30m length of survey.

5.1.4 Interpretation of the northbound carriageway

Figure 12 shows the interpretation of the radar data for the northbound carriageway. All 2D sections were examined to identify significant features; including drop-outs (reduced strength sections), strong reflections and hyperbolae crests. These features are marked on Figure 12 as open circles. Two strong continuous features are observed.

The existing fissure is observed oriented at 068°. This feature is continuous but varies in characteristics across the road. It gives a strong reflection on both sides of the carriageway, but appears as a weaker signal in the centre of the road.

To the north of the existing fissure is a lineation oriented at 100°. This is close to the location of the EM feature and is possibly man made.

It is possible to identify other linear features, but these are probably created by material within the hardcore structure of the road.

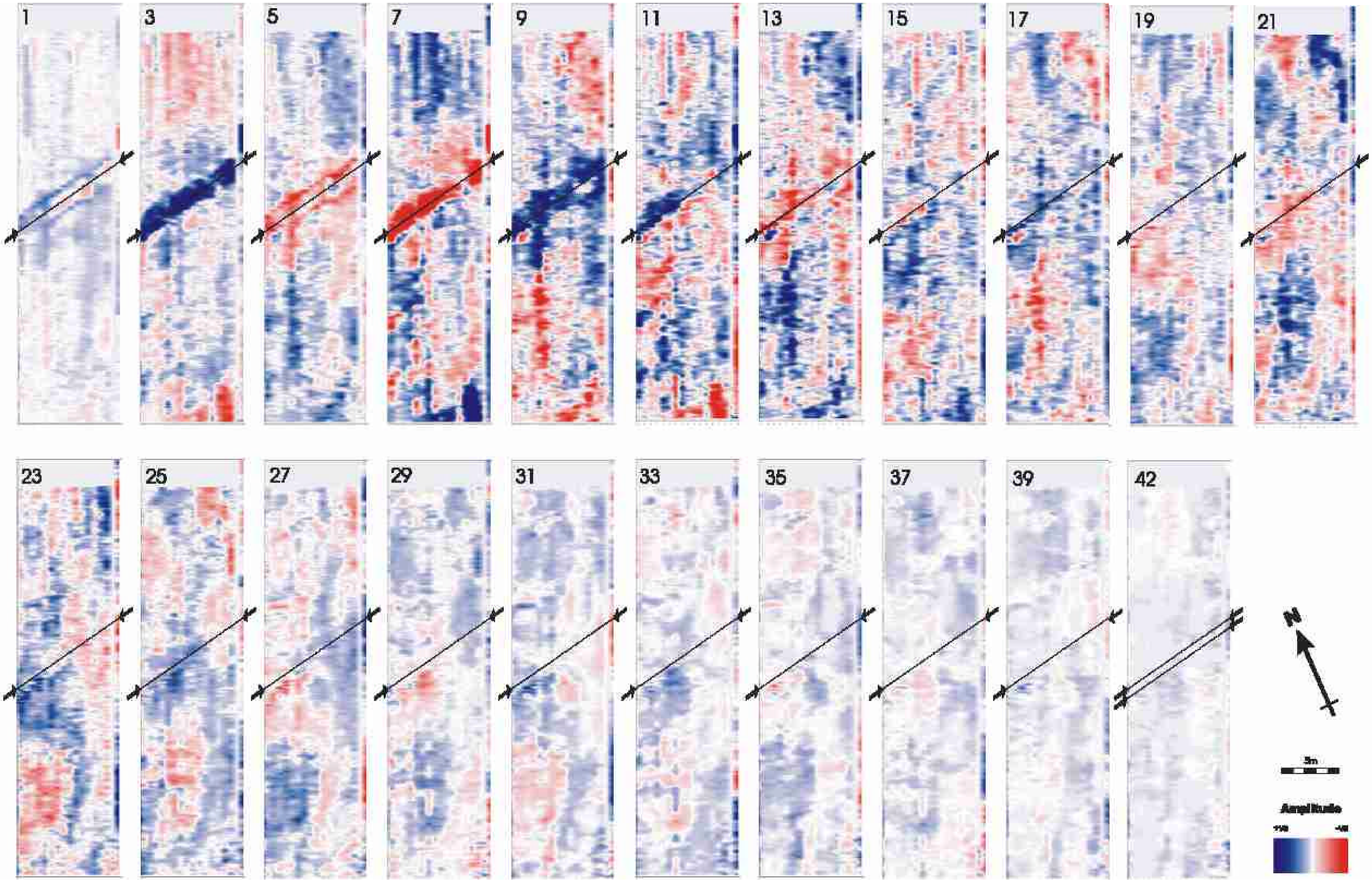

Figure 11 Map of radar data as produced from 3D radar data. Each successive map represents increasing depth. The location of the known fissure is highlighted.

Note: Depth slices from 1-42 represent the surface level down to a depth of approximately <u>1m</u>, assuming a radar velocity of 0.0679 m/ns.

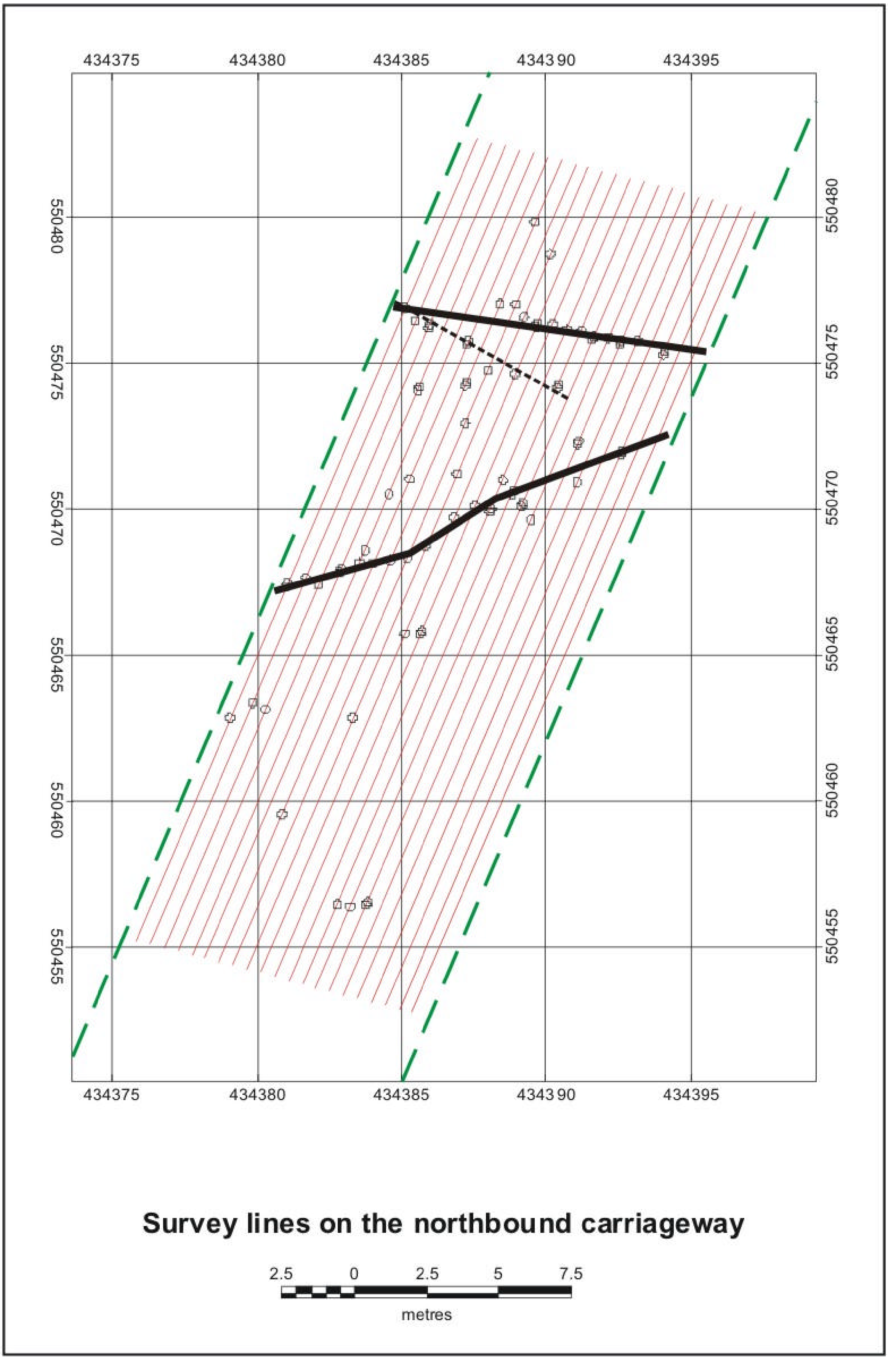

Figure 12 Interpretation of the radar data on the northbound carriageway. The open circles represent features noted in the radar data. The solid black lines show continuous features. The main feature centred within the survey is the known fissure. The other feature is coincident with the EM feature.

5.1.5 The 100m line

Figure 13 shows the GPR data for the 100m line taken along the northbound carriageway of the A690. As shown, the central portion of this line (between 35 and 65m) overlapped the main survey area. Within this region, the fissure is observed, as is the man-made feature.

These data suggest that there is another fissure (or possibly another man-made feature) at approximately 14-15m along line. Cracking in the road surface was observed in this general locality.

There are also a number of smaller features at approximately 25m, 30m, 75m, and 85m along line. These are less clear, but potentially could signify further fissures.

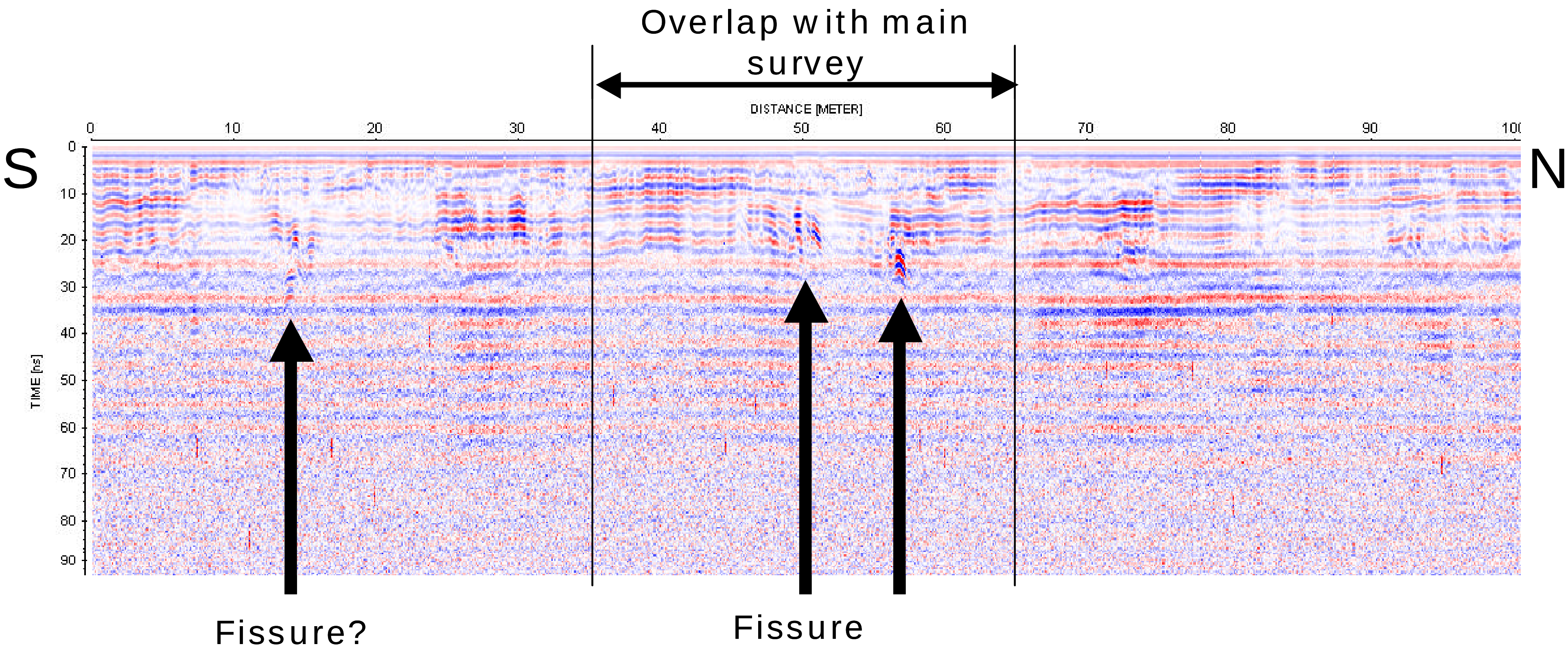

Figure 13 GPR data from the 100m long survey line. As highlighted, two features, similar to those identified on the 30m long survey lines, can be seen. It is likely that the feature seen at 14-15m along line is another fissure feature.

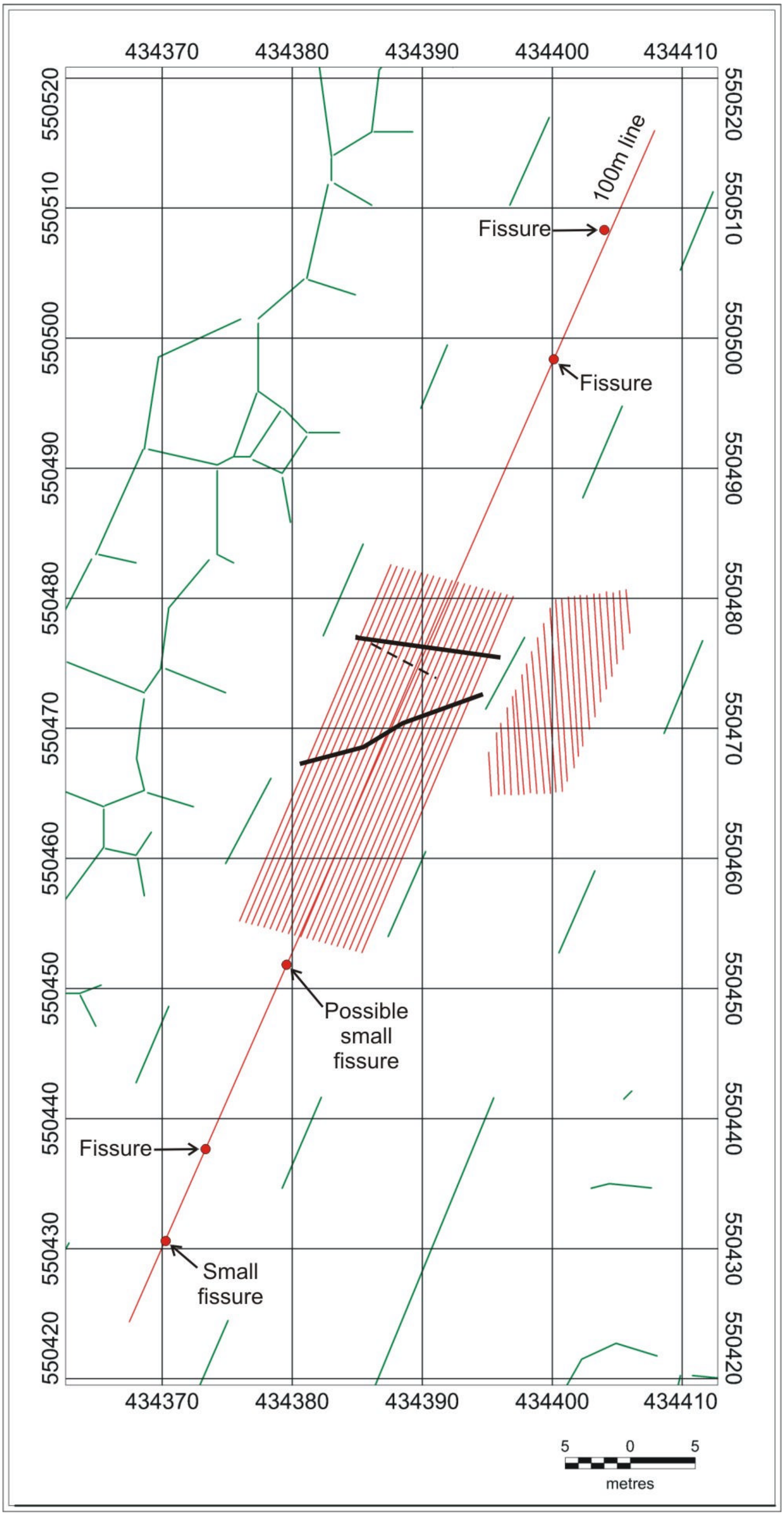

Figure 14 Interpretation of the northbound carriageway.

Site B – Southbound carriageway

The results from the southbound carriageway were disappointing and are summarised in Figure 15. The resurfaced section of the road can be easily distinguished between 6.2 and 8.5m along line. Diffraction hyperbolae are also observed, probably centred where the new section of Tarmac has been laid. Fresh Tarmac in contact with older material may give a good reflection. However, no evidence of the fissure is seen below this section, this being the case for all of the survey lines in this area.

5.1.6 "Ringing"

Radar surveys on tarmac ground often suffer from the problems of ringing. Close inspection of Figure 15A shows a repetitive series of reflection down to 75ns. It is unlikely that the layer construction of the road will extend to this depth and what is actually occurring is ringing. The crest of the diffraction hyperbola is seen at 8ns, suggesting that the strong signal seen on the right of this figure is also ringing.

Figure 15B attempts to illustrate the phenomena of "ringing". This cartoon shows the layer makeup of a typical road. In the ideal case, radar energy is both transmitted through and reflected back at each margin of the individual road materials. As depicted, some of this reflected material is then re-reflected at the tops of some of these layers. Thus, instead of a simple path of:

> A reflected at C and back to A

we see:

> A reflected (upwards) at C, reflected (downwards) at B, reflected (upwards) at C for a second time and back to A.

The journey C-D-C is additional to the A-C-A time, giving a later reflection signal. When systems are highly layered with strong reflection coefficients (the proportion of energy reflected compared with the energy passed over an interface), as in a road, the number of multiple reflections can be great.

On the southbound carriageway ringing may be stopping energy from passing from the road and into the bedrock. This may explain why the fissure is not imaged. However, the nature of the fissure may also explain the lack of a clear reflection. If the fissure is closed, there may be insufficient radar energy reflected.

5.1.7 Interpretation of the southbound carriageway

Little can be concluded about the fissure below the southbound carriageway, as it has not been imaged. However, the fact that one carriageway gave good results while the other gave poor results raises questions. It had been hypothesised that the southbound carriageway had been constructed in a slightly different manner than the northbound. It was suggested that the southbound carriageway is the route of the original road and the northbound carriageway was added at a later date. This has been confirmed. Thus each carriageway has a different hardcore base, one of which results in severe ringing.

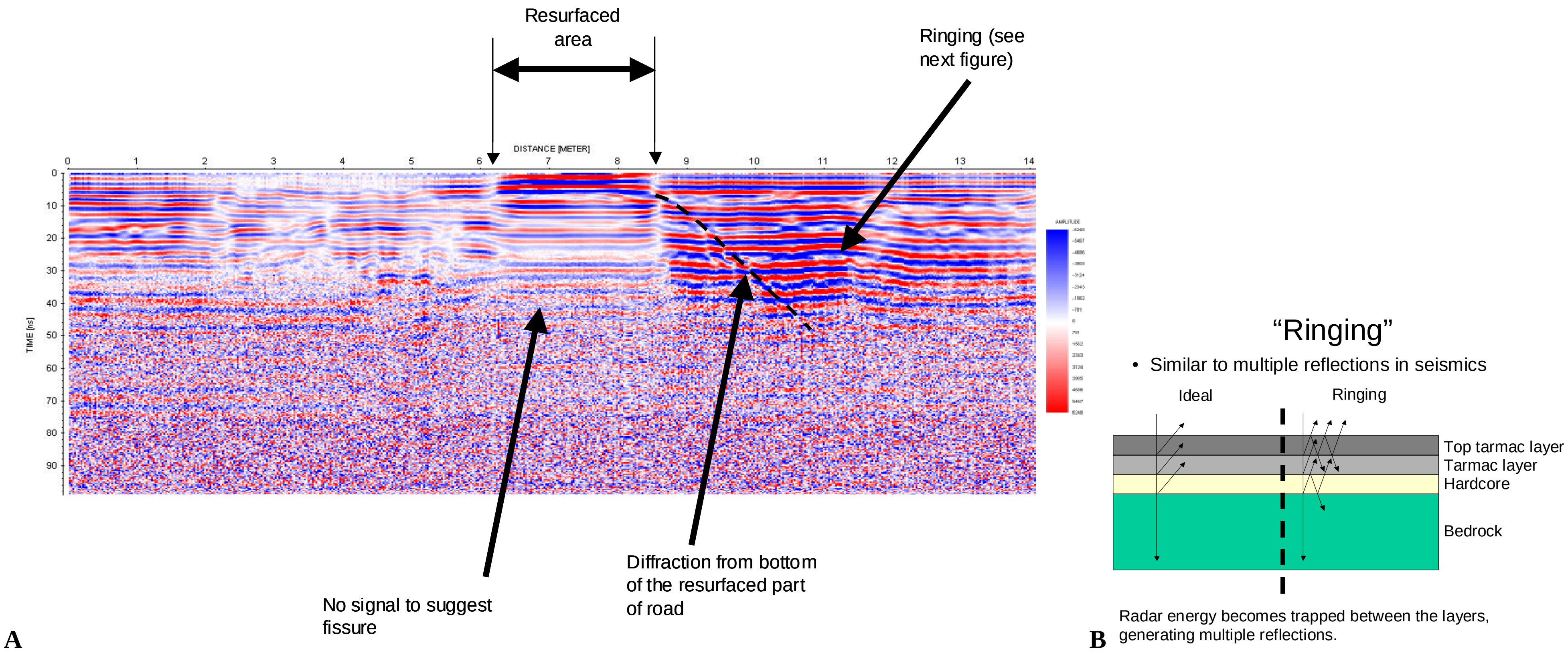

Figure 15 Radar data for the southbound carriageway. As shown, in A there is no apparent sign of any fissure feature, this is due to the "ringing" observed. B explains the phenomena of ringing.

5.2 SITE C – ESCARPMENT ADJACENT TO THE A690

Data recorded at Houghton Hill farm showed increased depth penetration, compared with the surveys conducted on the A690. This was due to the lack of a layered road cover. Depth penetration of the radar was in excess of 7m (assuming a velocity of 0.0715 m/ns). The GPR unit could have been reconfigured to log for longer than 100ns. It was decided not to increase the logging time, as this would have slowed the survey. Field conditions were not favourable, with a thunderstorm approaching the site. The decision was made to cover as much ground as possible in the limited time as opposed to observe deeper features.

5.2.1 Velocity structure

Figure 16 shows the velocity structure at Houghton Hill. The radar velocity ranges from 0.0512 to 0.112 m/ns, with an average velocity of 0.0715 m/ns. This figure shows that the overburden may have a considerably higher radar velocity than the solid Magnesian limestone bedrock. As no clear relationship of velocity with depth is evident, the radar velocity at Houghton Hill has been assumed to be:

0.0715 m/ns

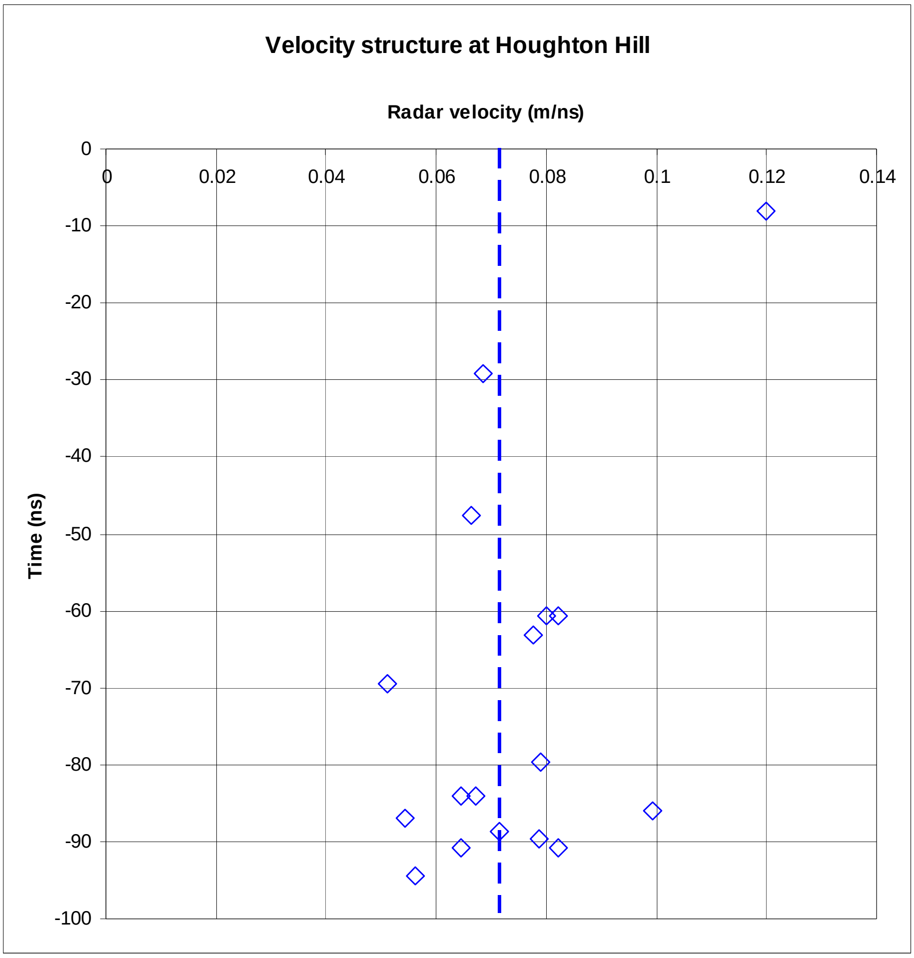

Figure 16 Velocity structure of the limestone beneath Houghton Hill. The dashed blue represents the average velocity of 0.0715 m/ns

5.2.2 Interpretation of the Houghton Hill site

Figure 17 summarises the general features observed on the escarpment. Most lines showed similar features and may be used to answer specific questions about the geology on the escarpment. As shown, the fissure is a very obvious feature, central along the line. Due to the open nature of the fissure at this point, it is seen as a 'shadow' zone as the radar data is not transmitted to depth at this point. Other shadow zones may be indicative of smaller fissures.

The radar data shows considerable structure within the Magnesian limestone, as seen by the continuous reflections that generally dip to the north on the northern side of the field site. Further investigation may yield insight into the nature of the Magnesian limestone at depth.

A comprehensive study was conducted of the 2D sections within the Houghton Hill survey site. The position of shallow reflections, dropouts and strong reflections at depth were noted for each survey line. These were plotted onto a map and features were identified. Figure 18 shows the results of this study.

The surface expression of the major fissure within the Houghton Hill site is marked as a red-dashed line on Figure 18. The corresponding feature identified from the radar data shows a similar alignment to this feature, but suggests that the feature extends further to the east (5m) and west (30m). The position of the surface expression was found to be consistently within 0-2m of a radar feature.

The second fissure to the west was not as well recorded by the GPS positioning system and was only seen to cut the three furthest west survey lines. However, the radar data suggests that this feature extends much further east by approximately 50m. This may require further investigation.

Four smaller features are shown in Figure 18 in dark blue. Three of these are 35, 45, and 70m long and display the characteristic curvilinear geometry of the fissures within this region. These are probably smaller sized fissures.

The final feature is linear in geometry and cuts the field at 107°. This is a similar orientation to the feature across the A690 that was hypothesised as a man-made feature. Young and Culshaw, 2001, did not identify any features in this or a similar orientation. The majority of this feature was identified as a shallow strong reflection and thus this may be a form of drainage ditch or utility supply.

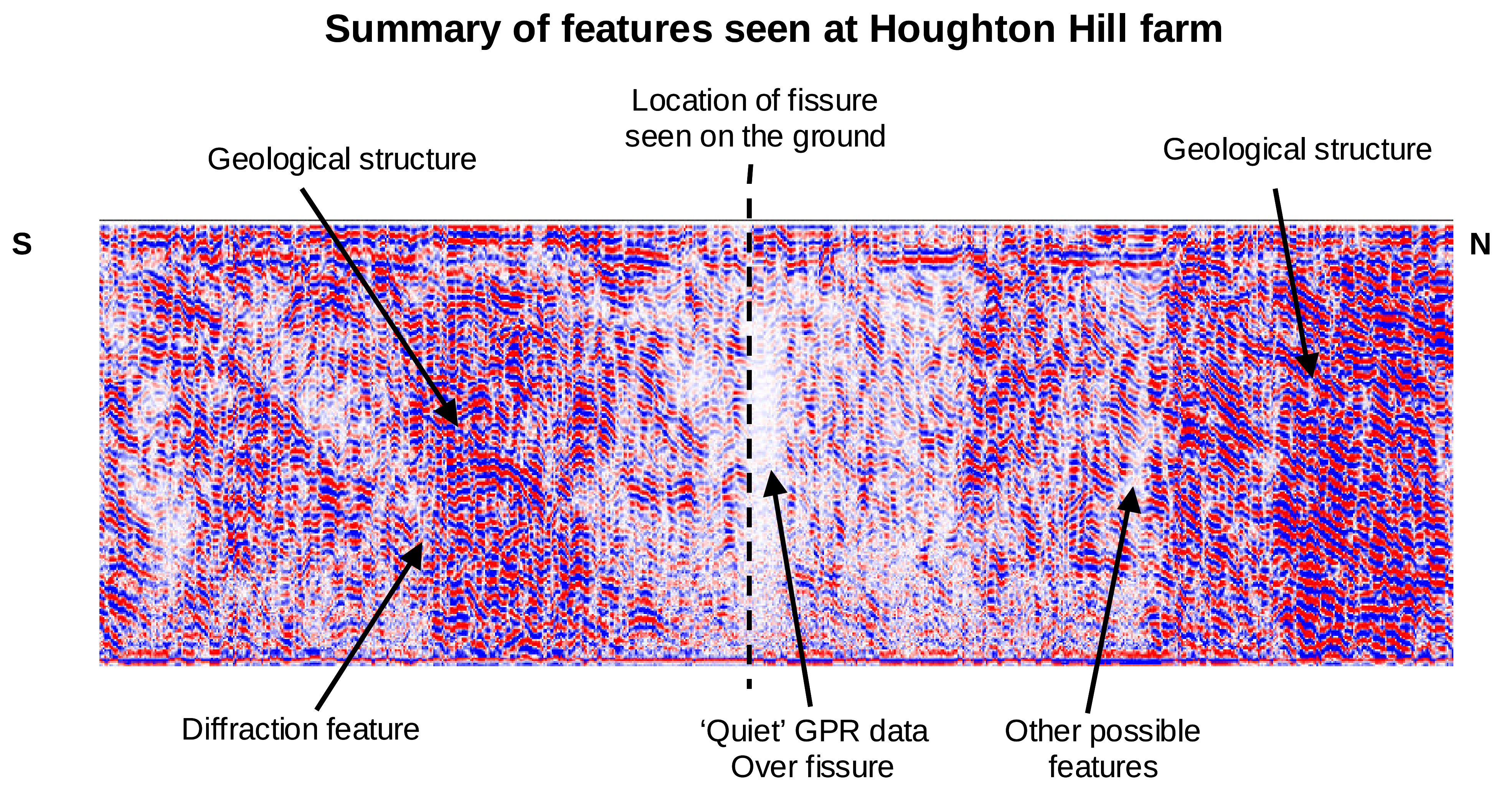

Figure 17 Summary of general features seen at Houghton Hill farm. The fissure is obvious, as seen by a shadow feature. Considerable geological structure is observed. Other shadow zones may suggest smaller scale fissures. A diffraction feature is also seen at depth, this could also be a fissure. Note: Assuming a radar velocity of 0.0715 m/ns, this section has a full depth extent of 7m

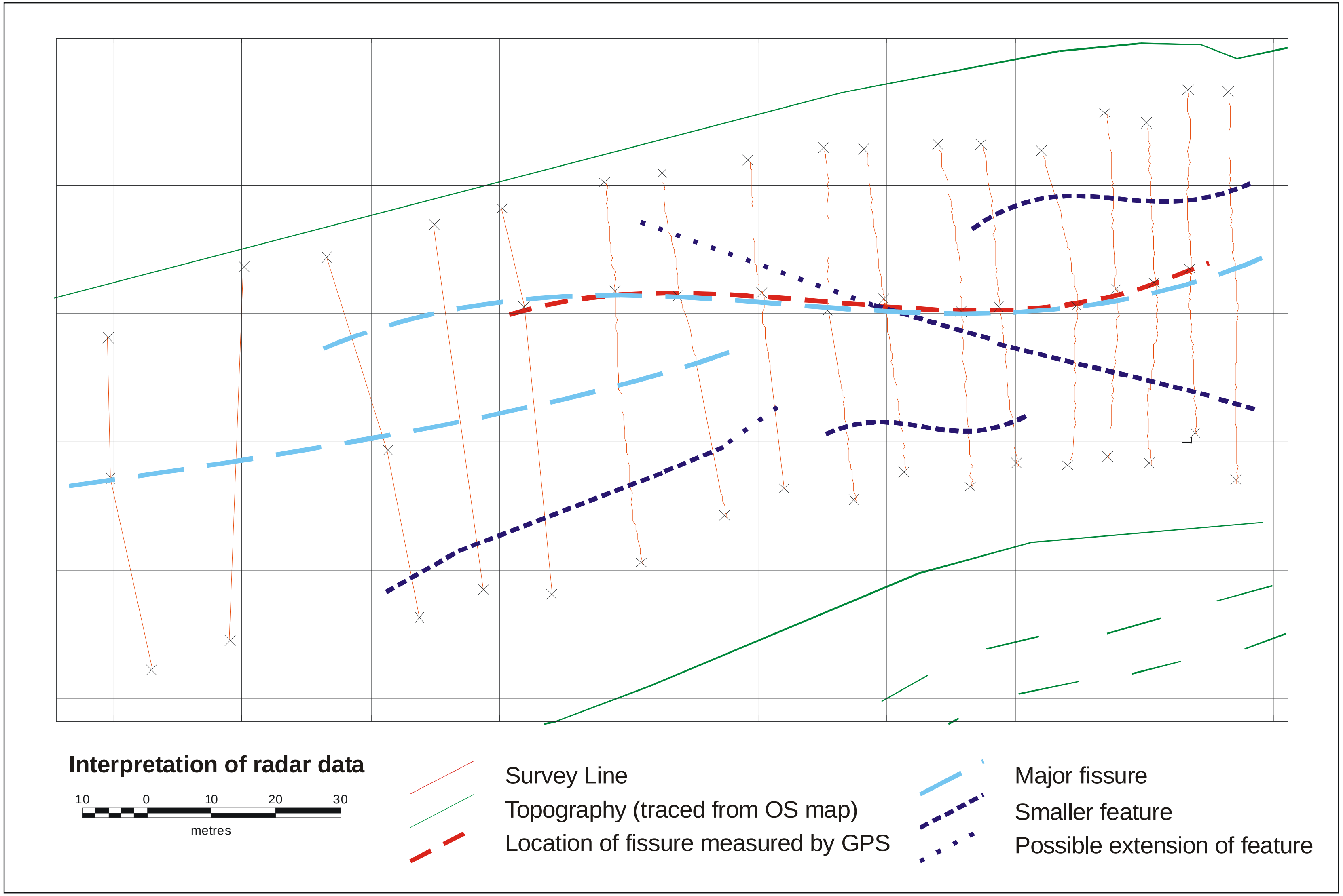

Figure 18 Interpretation of the Houghton Hill site, confirming the location of the known features and the location of some new features.

6 Conclusions

The following conclusions emerge from the current study:

Northbound carriageway

- Radar penetration was 6.5m on the northbound carriageway, with only the top 3m providing useful reflective data.
- The known fissure shows up as a strong GPR feature on the northbound carriageway.
- The application of 3D GPR aided in the identification of the structure beneath the A690 showing it to be a continuous linear feature that dips towards the south.
- A 100m survey line suggested that four other smaller fissures may also be present along the A690.
- 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 strong electromagnetic feature was observed at approximately 5m from the northern edge of the northbound carriageway survey area. A corresponding GPR signal was also seen. This is probably a manmade feature.
- The nature of the hardcore varies across the northbound carriageway.

Southbound carriageway

- The southbound carriageway did not yield useful data

Houghton Hill

- Radar penetration was in excess of 7m and clearly identifies complex structure within the Magnesian limestone.
- Two large fissures were imaged on Houghton Hill; these were both longer in extent than seen on the ground.
- Three smaller fissures (35-70m long) were also observed on Houghton Hill.
- A linear feature was observed cutting the field at 107°, this is possibly related to a service utility (drain or pipe).

References

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.

Young, B., and Culshaw, M.G. (2001). Fissuring and related ground movements in the Magnesian Limestone and Coal Measures of the Houghton-le-Spring area, City of Sunderland: *British Geological Survey Technical Report WA/01/04*.

Young, B., and Lawrence, D.J.D. (2002). Recent fissuring in the Magnesian Limestone at Houghton-le-Spring, City of Sunderland. *British Geological Survey Research Report RR/02/03*