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Survey Event No.	**76**
Survey Name	**N2 Slane Bypass, Co. Meath (2009)**

This Geophysical Report should be Referenced or Acknowledged as:

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Ministerial Directions No.	Not Applicable
NRA Route No.	N2
NRA Scheme Name	Slane Bypass
NRA Scheme ID	MH/02/230

Survey carried out for Meath County Council

Survey funded by the National Roads Authority

Known problems with this report

There are no known archive issues with this report

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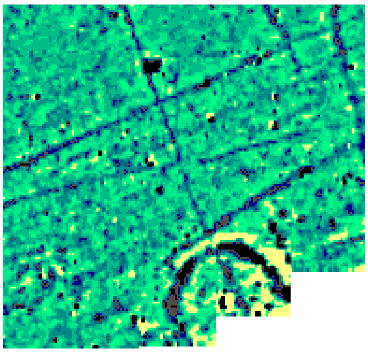
GEOPHYSICAL SURVEY REPORT
2008/73

N2 Slane Bypass

Licence No. 08R322



Client:

Roughan & O'Donovan
NRDA, Meath County Council

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Specialising in Shallow and Archaeological Prospection

GSB Survey No. 2008/73

N2 Slane Bypass, Co. Meath

NGR	Northern Section: 298200, 277000 to 297550, 275250 Southern Section: 297450, 273300 to 296600, 271150
Location	The proposed route leaves the existing N2 road approximately 3.5km north-northeast of Slane, extends southwards, over the river Boyne, rejoining the N2 roughly 3km south of the town.
Study Area	Two sections of corridor (northern and southern) which diverge from the previous proposed route (GSB 2005/2006). Total length c4km; maximum corridor width 100m.
County / Townlands	Meath / Balrenny, Knockmooney, Mooretown, Crewbane, Fennor, Cullen.
Topography	Gently undulating with some steep slopes.
Current land-use	Arable: under stubble, plough or young crop; some boggy rough pasture.
Soils / Geology	Varying depths of clay, sands and gravels overlying limestone (information provided by Roughan & O'Donovan, see previous report GSB 05/87).
Archaeology	No known sites identified in 2005 desk based study. Previous geophysical survey (GSB 05/87 and 06/03) identified a concentration of clear archaeological type anomalies at 297500, 274400 approx. (outside the current study area), but elsewhere only very tentative responses were recorded.
Survey Methods	Magnetic scan; detailed magnetic (fluxgate gradiometer) survey.
Licence No.	08R322

Aims

To locate and characterise any archaeological type responses that may be present within the study area. The work forms part of a wider archaeological assessment being carried out by **Roughan & O'Donovan** on behalf of the **National Roads Design Office (NRDO), Meath County Council**.

Summary of Results*

Definitive archaeological anomalies, comprising a circular feature c. 25m in diameter and a pattern of overlapping field system ditches have been identified towards the southern end of the route (Areas 17 & 18). Although linear ditch type anomalies have been detected in a few other sample blocks (for example Area 12), they are either isolated, ill defined, or form less convincing archaeological patterns, making an archaeological interpretation cautious. "Pit type" anomalies are noted in most of the survey areas, including some strong responses which could indicate burnt/fired material. They are, however, not associated with any clear linear anomalies and, in the absence of corroborative evidence, an archaeological interpretation remains tentative.

Project Information

Project Co-ordinator: C Stephens
Project Assistants: E Collier, R Green, J Tanner & G Taylor
J Leigh (JML Surveys) & D Shiel (Dan Logistics)
Date of Fieldwork: 9th - 18th December 2008
Date of Report: 16th January 2009

***It is essential that this summary is read in conjunction with the detailed results of the survey.**

Survey Specifications

Method

The survey grids were set out using tapes and tied in to the Irish National Grid using a Trimble differential GPS system. A copy of the georeferenced results in AutoCAD format is included on the Archive CD.

Technique	Traverse Separation	Reading Interval	Instrument
Magnetometer - Scanning (Appendix 1)	10m	n/a	Bartington Grad 601-2
Magnetometer – Detailed (Appendix 1)	1m	0.25m	Bartington Grad 601-2
Resistance – Twin Probe (Appendix 1)	-	-	-
Ground Penetrating Radar (GPR) – 250MHz (Appendix 1)	-	-	-

Data Processing

	Magnetic	Resistance	GPR
Tilt Correct	Y	n/a	n/a
De-stagger	Y	n/a	n/a
Interpolate	Y	n/a	n/a
Filter	N	n/a	n/a

Presentation of Results

Report Figures (Printed & Archive CD): Location, data plots and interpretation diagrams on base map (Figures 1-15).

Reference Figures (Archive CD): Data plots at 1:500 for reference and analysis. Some areas have been subdivided for display at this scale. (See List of Figures).

Plot Formats: See Appendix 1: Technical Information, at end of report.

General Considerations

Ground conditions along the route varied considerably. A few fields were completely unsuitable for survey due to densely packed overgrown rushes and weeds, or excessively boggy ground. The fields that were under deep plough presented particular hindrances to survey. In the case of the scan it was difficult to walk safely and observe the display panel simultaneously, reducing the effectiveness of this method. For the detailed survey it was impossible to walk at an even pace and maintain the instrument in an absolutely vertical position; this has resulted in stepping errors (correctable by data processing) and an increase in the potential for spurious instrument noise responses.

The geology along the route should not have had any significant effect on the results and major archaeological features such as field system ditches and settlement sites should be readily detectable. However, localised natural soil variations, such as pockets of magnetic gravels, can produce responses which are comparable in form to archaeological "pit type" anomalies. Interpretation of these "pit type" responses is always cautious, especially when they cannot be associated with other definitive (linear) archaeological features; the potential for natural variations further complicates the identification and analysis of such small scale responses.

Results of Survey

1. Magnetic Survey - Scan

1.1 With gradiometers in scanning mode, the evaluation area was examined along traverses spaced at intervals of approximately 10m. During this operation, fluctuations in magnetic signal were observed on the instruments' display panel. Any significant variations were investigated more closely to determine their likely origin and those anomalies considered to have archaeological potential were marked with canes for detailed recorded survey.

1.2 Isolated scanned targets were identified in many of the fields along the proposed route but confidence in their archaeological potential was generally low. Increased levels of background fluctuation together with a number of noisy responses were encountered midway along the northern section of the route (Areas 7 to 9) and adjacent to the river Boyne (Area 10). Concentrations of potential targets were observed towards southern end of the route (Area 17).

1.3 Detailed survey was carried out to investigate all the scanned anomalies and cover the core area of the evaluation corridor.

2. Magnetic Survey - Detailed Gradiometry

2.1 All of the survey areas contain anomalies of the following categories: *Ferrous/Magnetic Disturbance*, *?Natural* and *Trend*. To avoid repetition, a brief description of each of these is given in the following three paragraphs. Thereafter they are not mentioned unless they have a particular impact on the archaeological assessment of the data.

2.2 The category *Ferrous* is used for discrete, small scale ferrous anomalies, or "iron spikes". These are characteristic of small pieces of ferrous debris scattered in the topsoil and are commonly assigned a modern origin. Only the most prominent of these have been highlighted on the interpretations. *Magnetic Disturbance* refers to bands of ferrous responses and magnetic "shadows" present along the edges of the grid. These have been produced by adjacent wire boundary fences, iron gates or other ferrous material in the adjacent boundaries. The magnitude of the disturbance will have masked any weaker responses, regardless of origin; however, as these bands are narrow, they have had little impact on the wider analysis of the results.

2.3 *?Natural* anomalies can vary in type from small scale "pit type" responses reflecting localised variations in the soil to more substantial, stronger anomalies thought to have been produced by pockets of naturally enhanced material such as magnetic gravels. Also present are broader amorphous or sinuous responses, often weakly negative, caused by soil slippage or water rivulets. The problems differentiating between some natural and archaeological “pit type” anomalies are discussed in the *General Considerations* above.

2.4 Most of the *Trends* in the data are linear or sinuous and weak; some are barely visible above background levels. Most do not form any obvious patterns that would suggest archaeological significance and a combination of agricultural and natural origins seems probable.

Area 1 (Figures 2 & 3)

2.5 "Pit type" anomalies of possible interest are located primarily on higher ground at the northern end of the grid and on the low lying ground to the south. Many of the responses are not particularly well defined and lie within areas of sinuous, weakly negative anomalies. This overall pattern of responses would normally suggest a natural origin (e.g. magnetic gravels) or a modern one (e.g. deeply buried ferrous debris). However, spreads of burnt stones from *fulacht fiadh* could have produced such anomalies and it is largely on this basis that the interpretation

?Archaeology is cautiously offered. The magnitude of discrete anomalies (1) could suggest intact burnt/fired features, but again, natural or modern origins cannot be excluded.

Area 2 (Figures 2 & 3)

2.6 This field slopes steeply down from south to north. The archaeological "pit type" responses are largely confined to the northern half of the grid where the ground becomes increasingly boggy and overgrown. These waterlogged conditions, close to a stream, favour the location of *fulacht fiadh*; however none of the responses are strong enough to indicate burnt material. Moreover, the ground conditions will have hindered walking and contributed to instrument noise; it is equally possible, therefore that any or all of these *?Archaeology* responses are in fact a product of natural and pedological variations.

2.7 Negative anomaly and trend (2) share an alignment parallel with the eastern field boundary ditch. The linear nature of (2) would suggest an anthropogenic origin and it is suggested that they might represent drainage ditches.

Area 3 (Figures 2 & 3)

2.8 Anomaly (3) is a truncated linear, roughly 30m long, containing some strongly magnetic elements. Based on anomaly form, an archaeological interpretation is posited but there is nothing to suggest its precise function. The interpretation of all the other ?*Archaeology* responses is highly tentative.

2.9 A weak negative trend (4) aligns directly with the existing field boundary ditch described in paragraph 2.7 above and could represent a continuation of this feature. Ditches usually produce positive responses; the negative could indicate a lack of magnetic ditch fill. Alternatively (2) could represent a non-magnetic (e.g. plastic) field drain.

Area 4 (Figures 4 & 5)

2.10 Anomalies (5) have a magnitude that indicates strongly magnetic material, possibly burnt/fired deposits; however they could equally reflect deeply buried ferrous objects. Natural or modern (deeply buried ferrous) origins should also be considered for the few other *?Archaeology* responses in this block.

Area 5 (Figures 4 & 5)

2.11 Comparatively low levels of background fluctuation were recorded and very few archaeological type responses have been identified. Anomalies (6) have a magnitude that could suggest burnt material and could represent *fulacht fiadh*; however although the ground was boggy, the absence of any nearby obvious water source makes this interpretation cautious. Four well defined "pit type" anomalies are present; although their form suggests an archaeological origin, the lack of a wider context precludes any firm interpretation. Anomaly (7) is a very weak linear anomaly, petering out to a barely visible trend. It may be of interest, possibly reflecting a former boundary, but could equally represent a more recent drainage feature or have some other agricultural origin.

2.12 A roughly oval area of increased magnetic response (8), some 16m in diameter, is difficult to interpret. The maximum values of the response are around 10nT; these levels are consistent with either archaeological or natural deposits. If the former, it could indicate a very large pit of uncertain function. However, it is also possible that (8) is a magnetic "shadow" produced by a mid-sized ferrous object buried at considerable depth below ground.

Area 6 (Figures 6 & 7)

2.13 Only a very few "pit type" responses of possible interest have been identified in this area; an archaeological interpretation for these is highly cautious.

2.14 Anomaly (9) is comparable in form and size to response (8) discussed in paragraph 2.12 above. It seems likely that (8) and (9) have the same origin, though this remains unclear.

Area 7 (Figures 6 & 7)

2.15 This dataset illustrates well the problems in interpreting archaeological versus natural "pit type" anomalies. A large number of such responses are present throughout much of the area and none form any obvious archaeological patterns. In general, a possible archaeological origin has been assigned to those which are stronger or more coherent in form, but this interpretation is far from conclusive. It is also possible that some of the weaker positive *?Natural* anomalies may represent archaeological pits. At the northern end of the grid, the concentration of "pit type" responses appears to terminate roughly at trend (10); to the south the responses continue into Area 8 (paragraph 2.18 below).

2.16 Linear anomaly (11), roughly 27m long, is magnetically strong, suggesting burnt/fired material. If it is archaeological, its precise function remains unclear. Alternatively, it could represent a short section of brick or clay pipe/drain of more recent origin.

2.17 A magnetically quiet band at the southern edge of the grid is an effect of overhead electricity cables.

Area 8 (Figures 6 & 7)

2.18 The effect of the overhead cables is also present in the northern half of this survey area; it has effectively masked most other magnetic signals emanating from below surface. Beyond the cable effect, the recorded anomalies are comparable to those in Area 7 above, with similar uncertainties surrounding the interpretation.

Area 9 (Figures 6 & 7)

2.19 There is a reduction in background magnetic fluctuation in this block with fewer "pit type" anomalies identified. Those that have been interpreted as *?Archaeology* have a well defined archaeological form, but in the absence of a wider context, the interpretation is tentative.

Area 10 (Figures 8 & 9)

2.20 The northern half of this sample is on steeply sloping ground (conditions unlikely to be suitable for most human activity) and is largely devoid of anomalies of possible interest. The low lying ground to the south contains a band of "pit type" and sinuous responses (12) which vary in strength and definition. The location, close to a major water source, might favour anthropogenic activity; as such, some of the more coherent responses have been interpreted as *?Archaeology*, although their function cannot be determined. However, the location equally supports a natural interpretation for all the responses, which may reflect material deposited during river flooding.

2.21 The distinct linear nature of anomaly (13) suggests an anthropogenic origin, but whether archaeological or modern is unclear.

Area 11 (Figures 8 & 9)

2.22 This area is magnetically very quiet, with no anomalies of possible archaeological interest identified.

Area 12 (Figures 8 & 9)

2.23 In terms of anomaly form and distribution, this area can be roughly divided into two by trend (14). All bar one of the tentative "pit type" *?Archaeology* responses lie north of this line together with a general increase in background variation, *?Natural* responses and short trends. South of (14) the data are generally magnetically quiet, with only a few broad trends suggesting natural variations or agricultural practices and a linear band of responses (15), with a ferrous component, suggestive of a field drain or ploughed out boundary.

Area 13 (Figures 10 & 11)

2.24 Anomaly (16) comprises a linear negative response and trends partially bound by positive linears. Together these could indicate the remains of a former boundary wall and ditch and as such may be of archaeological interest. The possibility that (16) reflects more recent agricultural practices (e.g. drainage) must also be considered.

2.25 There are hints of a circular response, roughly 8m in diameter at (17). Although the pattern suggests an archaeological origin, it must be stressed that the anomaly is barely visible above background levels (thus represented as a dashed line) which makes the interpretation highly cautious.

2.26 Very weak closely spaced parallel linear responses in the data are typical of ploughing trends.

Area 14 (Figures 10 & 11)

2.27 Several broad parallel positive and negative linears (18) are present in this block. This parallel arrangement suggests some form of cultivation activity, but the responses are several orders of magnitude stronger than the weak modern ploughing trends and may therefore be archaeologically significant. Two more sinuous parallel responses (19) and (20) run perpendicular to (18) and appear to at least partially delimit them. Together the anomalies could represent part of a former strip field system, though the poor definition of (19) and (20) in particular, makes this interpretation cautious.

2.28 Another weak linear anomaly (21) may be of interest, possibly indicating a former boundary. It is on a different orientation to the above group and is therefore likely to represent an unrelated feature.

Area 15 (Figures 10 & 11)

2.29 Two indistinct parallel linear anomalies are on a slightly different alignment to the modern ploughing trend. As such they may be of archaeological interest, possibly indicating a trackway, though a modern agricultural origin cannot be dismissed. Of the few "pit type" anomalies tentatively categorised as *?Archaeology*, well defined response (22) has a magnitude that could indicate burnt/fired material; but it could equally be the product of more deeply buried ferrous debris.

Area 16 (Figures 12 & 13)

2.30 Three "pit type" anomalies have been categorised as *?Archaeology*; the interpretation is inconclusive and they could equally have natural or modern origins. Cultivation responses, represented by weak positive and negative trends, are present on two alignments, parallel to the existing boundaries. A more pronounced linear negative response has been identified on the same orientation as one of the ploughing trends. Its precise significance is unclear but an agricultural origin seems most likely.

Area 17 (Figures 12, 13, 14 & 15)

2.31 A number of generally well defined ditch type anomalies of probable archaeological origin have been detected in this area. The majority form overlapping rectilinear patterns suggesting at least two phases of former field systems. A single well defined "pit type" anomaly (23), roughly 5m in diameter, seems to be appended to one of the ditches and as such it has been given a more definitive archaeological interpretation. Weaker "pit type" responses, short linears and faint trends may also be of archaeological interest, given the wider context. However, since these responses are somewhat indistinct and form incomplete patterns, they have been downgraded to the *?Archaeology* category.

2.32 A relatively strong well defined circular ditch type anomaly (24), with a diameter of roughly 25m, is present at the southern grid edge, extending into the boundary. The anomaly becomes markedly weaker on the northern side (indicated by the dashed lines) for a distance of about 2.5m; this could indicate a deliberate break in the ditch, later damage, or simply a reduction in the magnetic fill at this point. One of the field system ditches described above appears to cross the circular response. This could support the middle interpretation (later damage) and certainly indicates another phase of activity in the area. Unfortunately ferrous anomalies and magnetic disturbance associated with the adjacent boundary have hindered a full analysis of the interior of the circle. In areas unaffected by this noise, three "pit type" *?Archaeology* anomalies have been identified, but interpretation is cautious due to their weak nature.

Area 18 (Figures 12, 13 14 & 15)

2.33 No evidence for the circular feature is present at the northern edge of this strip, thus its continuation must lie wholly under the modern road. Well defined linear anomaly (25) is likely to represent an extension of the field systems described above (paragraph 2.31); it continues southwards for roughly 100m to the limit of the survey corridor. No clearly defined ditches extend westwards from (25), while to the east the potential archaeological responses are somewhat weak and/or ill defined.

2.34 The remainder of this survey block contains no definitive archaeological anomalies; a few isolated "pit type" responses have been highlighted, but these could equally be natural or modern in origin.

3. Conclusions

3.1 Although scanned target anomalies were found in many of the fields within the study area, most of these were isolated and in some fields, due to poor ground conditions, the levels of confidence in the scan was low. Increased concentrations of scanned responses were observed in Areas 7 to 10 and 17.

3.2 Of all the areas investigated by detailed gradiometry, only two (Areas 17 and 18 at the southern end of the route) contain definitive archaeological responses. These comprise a circular feature and a pattern of overlapping field systems. Although a possible strip field system may be present in Area 14, this interpretation is far more cautious due to the poor definition of many of the responses.

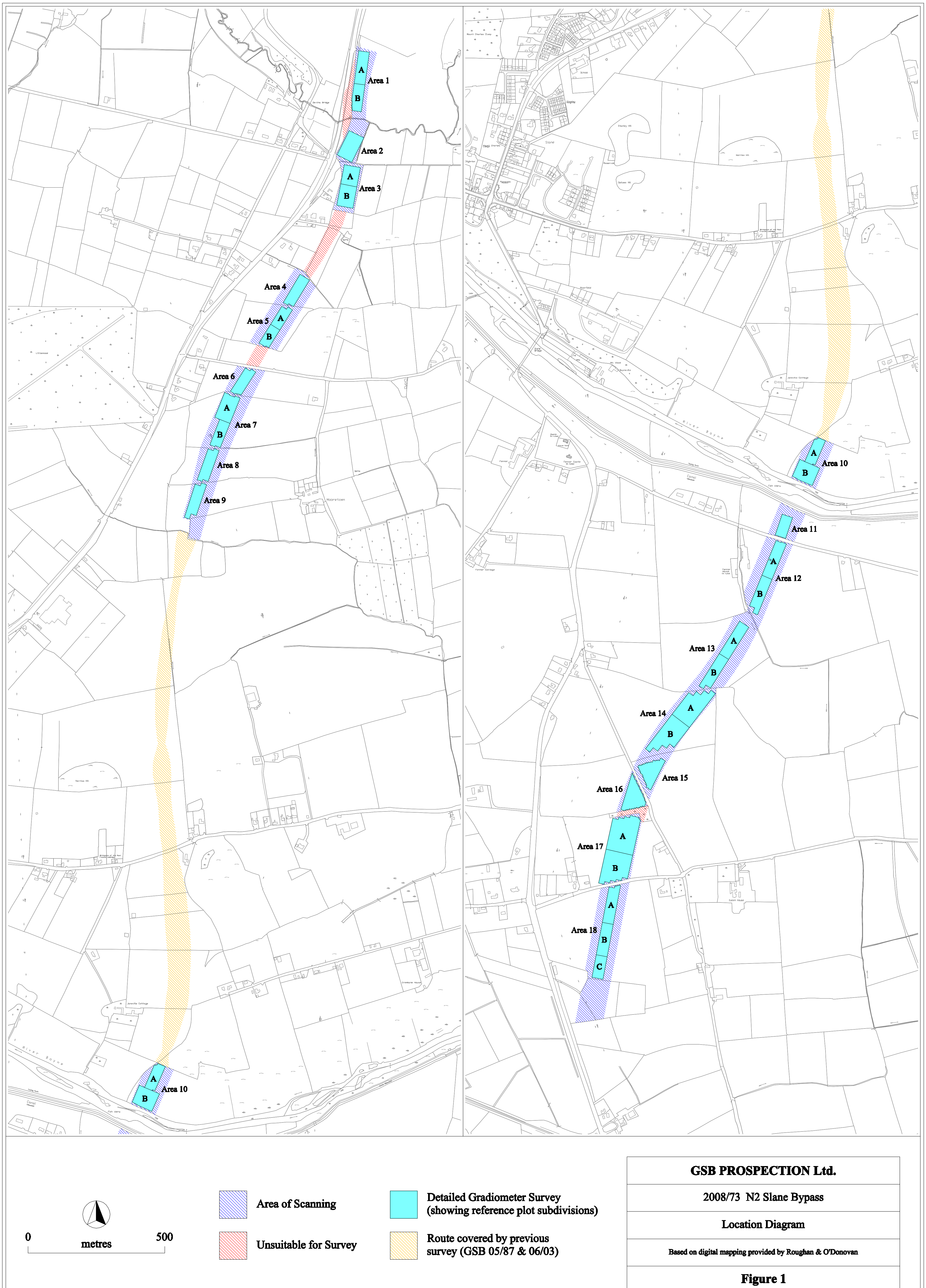
3.3 Some of the other areas contain isolated linear responses which may be of interest but the lack of a wider context for them makes an archaeological interpretation inconclusive. Even more tentative is the archaeological interpretation of the "pit type" responses detected by the survey. Concentrations of these anomalies are present in Areas 7, 8 and 10, but most of the other areas contain several isolated responses of this type. While an archaeological origin cannot be dismissed, in the absence of a wider definitive archaeological context (e.g. enclosure ditches), natural or modern origins are equally tenable.

3.4 Several anomalies are noted which are magnetically strong, suggesting the presence of burnt/fired remains. *Fulacht fiadh* can produce anomalies of such a magnitude; however, although some of the responses are in suitable locations (waterlogged ground close to a water source) none have the ‘kidney’ or ‘horseshoe’ shape commonly associated with these burnt stone features. While they might still represent damaged/denuded remains, they could equally be natural or modern in origin.

List of Figures

Report Figures

Reference Figures on CD



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Location Diagram

Based on digital mapping provided by Roughan & O'Donovan

Figure 1

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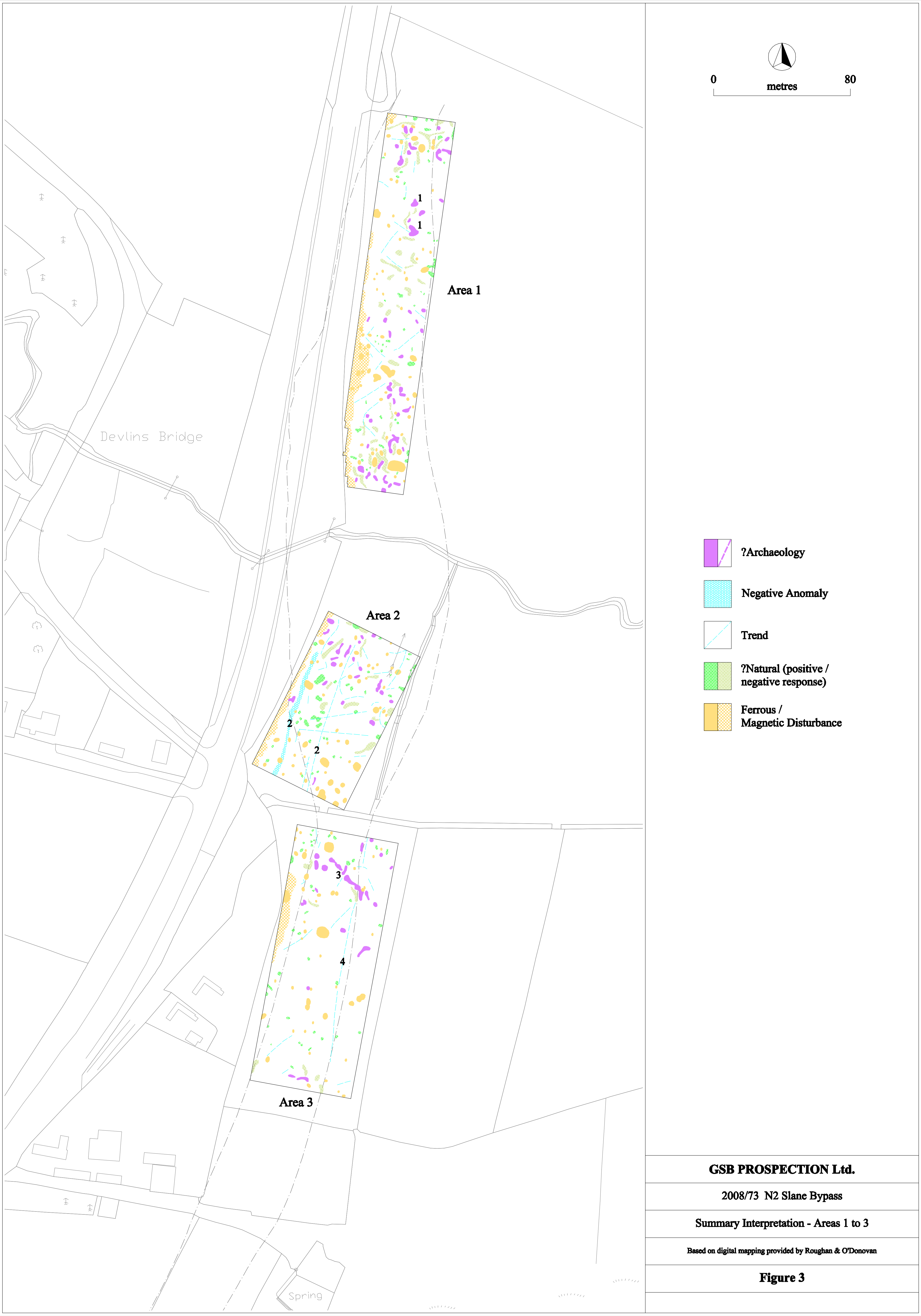
Summary Greyscales - Areas 1 to 3

Based on digital mapping provided by Roughan & O'Donovan

Figure 2



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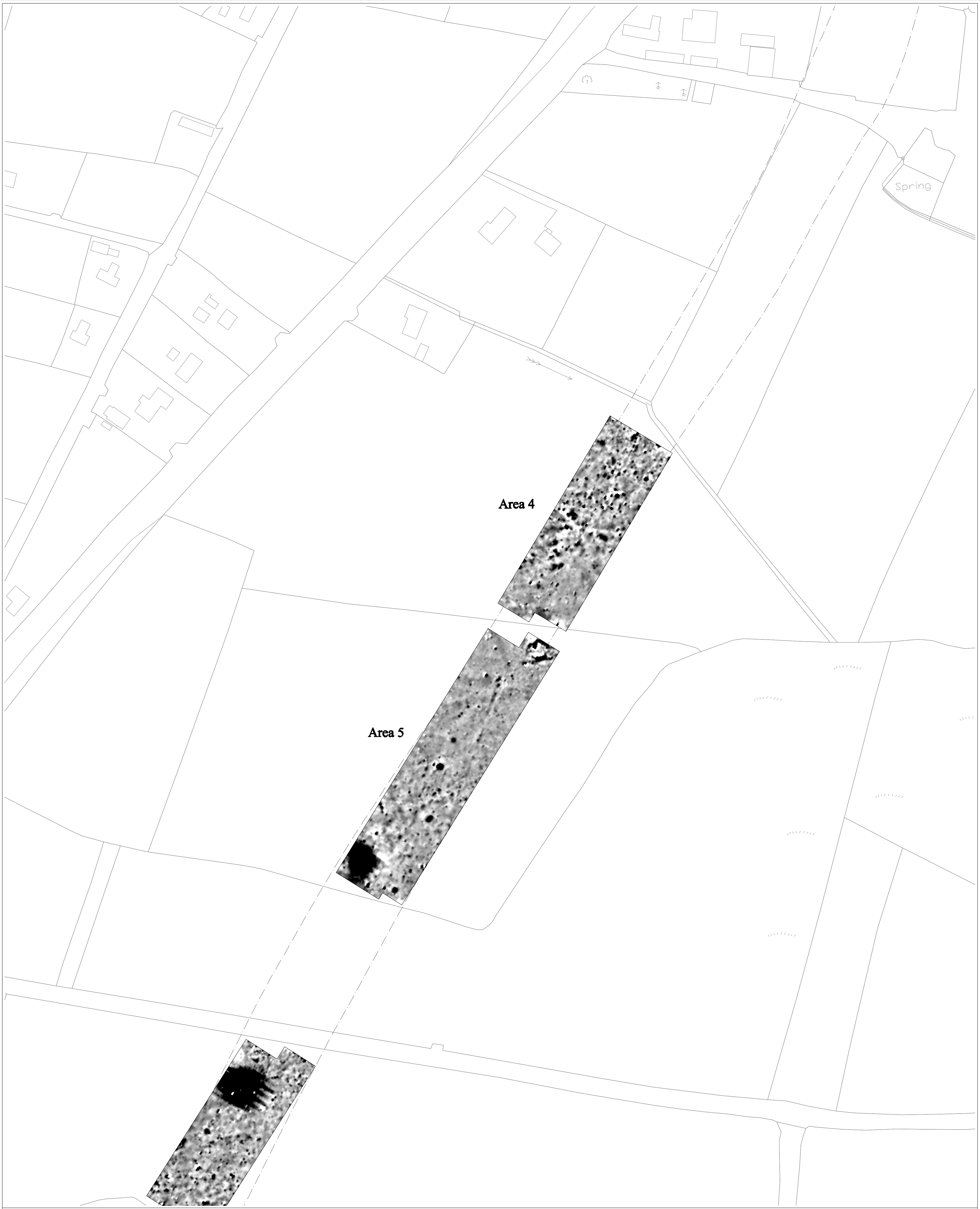
Summary Interpretation - Areas 1 to 3

Based on digital mapping provided by Roughan & O'Donovan

Figure 3



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Summary Greyscales - Areas 4 and 5

Based on digital mapping provided by Roughan & O'Donovan

Figure 4

0 metres 80

?Archaeology

Increased Magnetic Response

Trend

?Natural (positive / negative response)

Ferrous / Magnetic Disturbance

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Summary Interpretation - Areas 4 and 5

Based on digital mapping provided by Roughan & O'Donovan

Figure 5

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Summary Greyscales - Areas 6 to 9

Based on digital mapping provided by Roughan & O'Donovan

Figure 6

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Summary Inerpretation - Areas 6 to 9

Based on digital mapping provided by Roughan & O'Donovan

Figure 7

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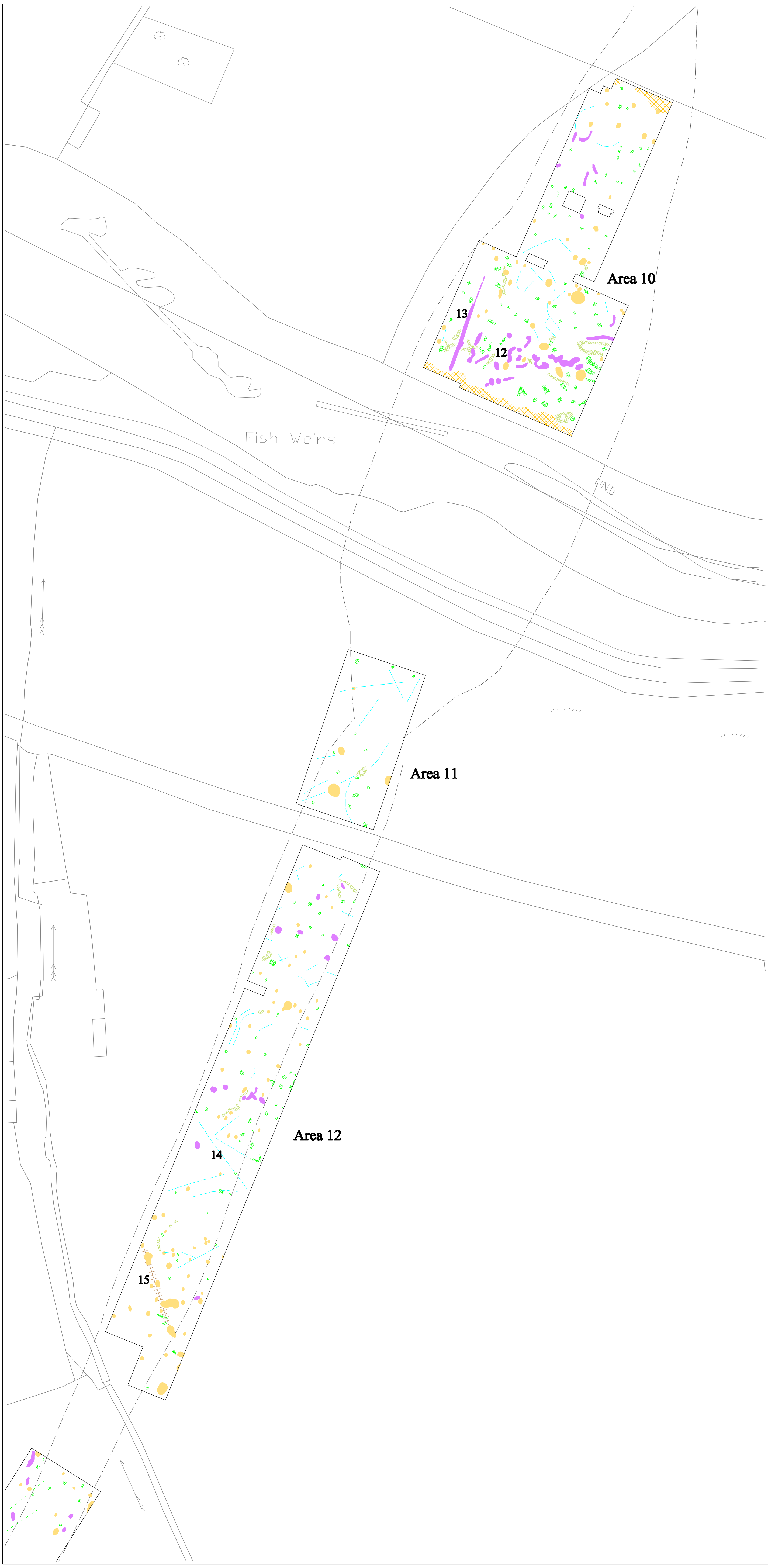
Summary Greyscales - Areas 10 to 12

Based on digital mapping provided by Roughan & O'Donovan

Figure 8



?Archaeology

Trend

?Drain

?Natural (positive / negative response)

Ferrous / Magnetic Disturbance

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Summary Interpretation - Areas 10 to 12

Based on digital mapping provided by Roughan & O'Donovan

Figure 9

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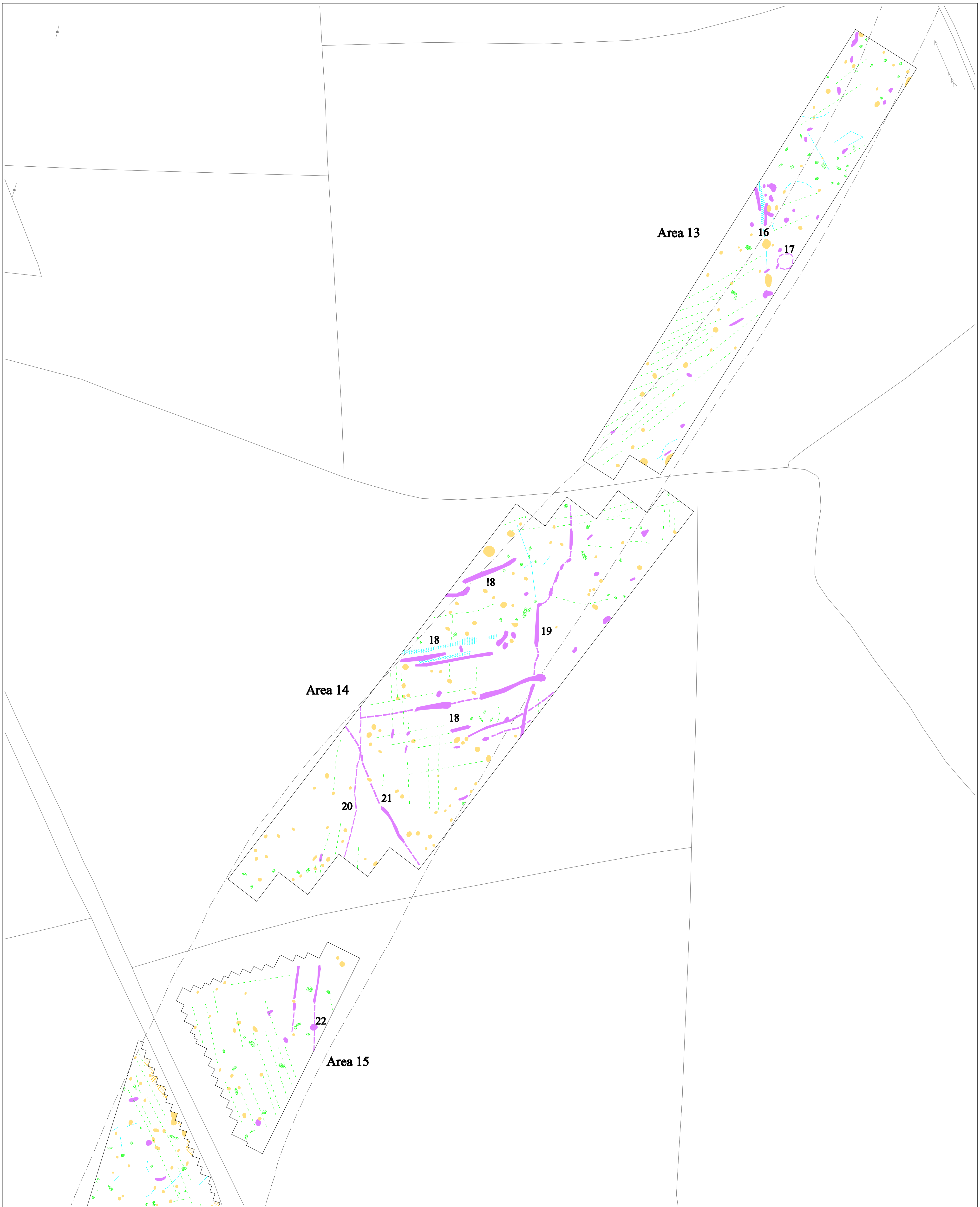
Summary Greyscales - Areas 13 to 15

Based on digital mapping provided by Roughan & O'Donovan

Figure 10



0 metres 80

?Archaeology

Negative Anomaly

Trend

Ploughing

?Natural (positive / negative response)

Ferrous / Magnetic Disturbance

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Summary Interpretation - Areas 13 to 15
Based on digital mapping provided by Roughan & O'Donovan
Figure 11

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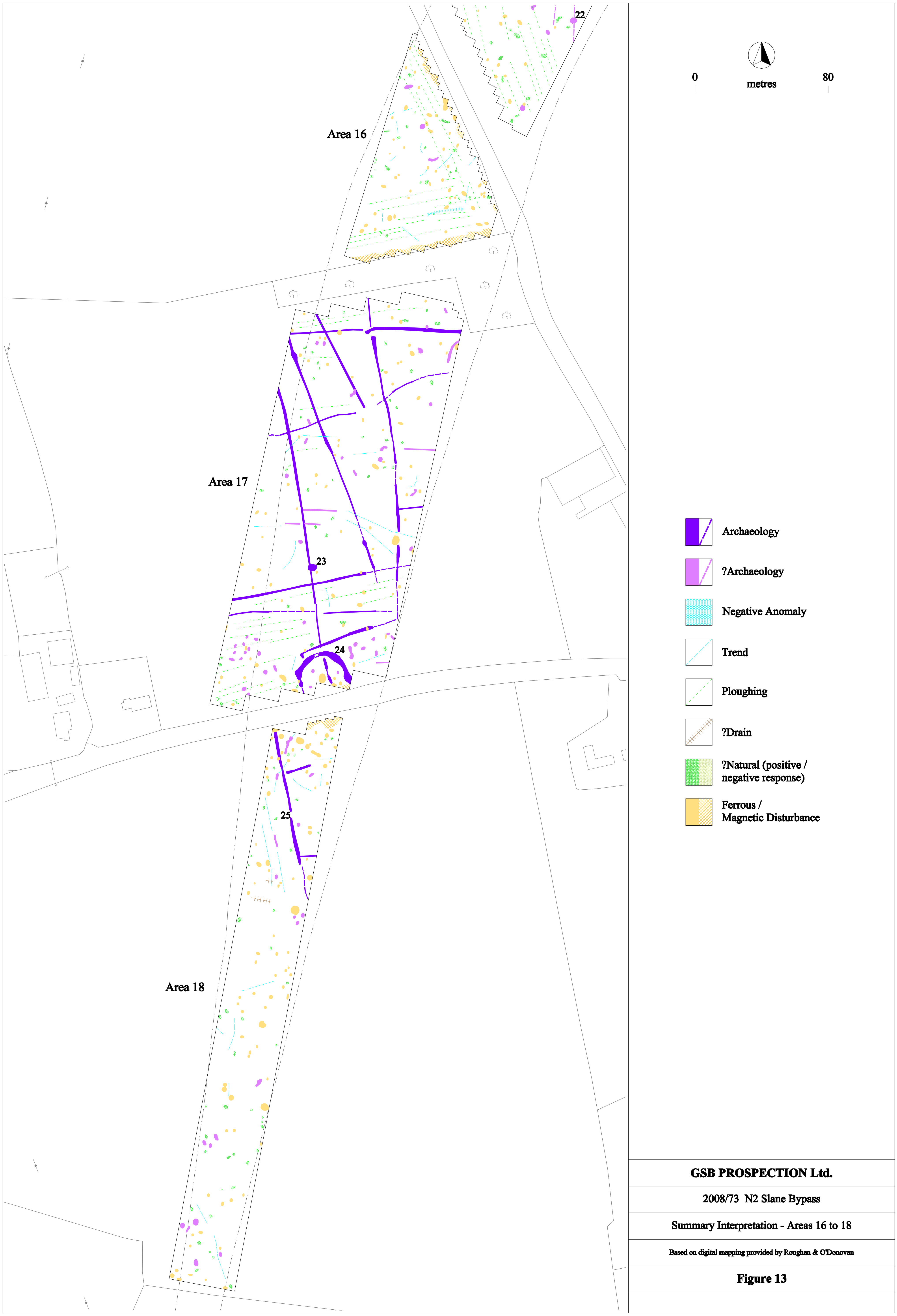
Summary Greyscales - Areas 16 to 18

Based on digital mapping provided by Roughan & O'Donovan

Figure 12



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Summary Interpretation - Areas 16 to 18

Based on digital mapping provided by Roughan & O'Donovan

Figure 13

Point	Easting	Northing
A	296687.94	271891.74
B	296785.65	271870.45
C	296747.32	271694.58
D	296649.61	271715.87
E	296675.45	271644.28
F	296714.76	271636.88
G	296696.26	271538.61
H	296656.95	271546.01

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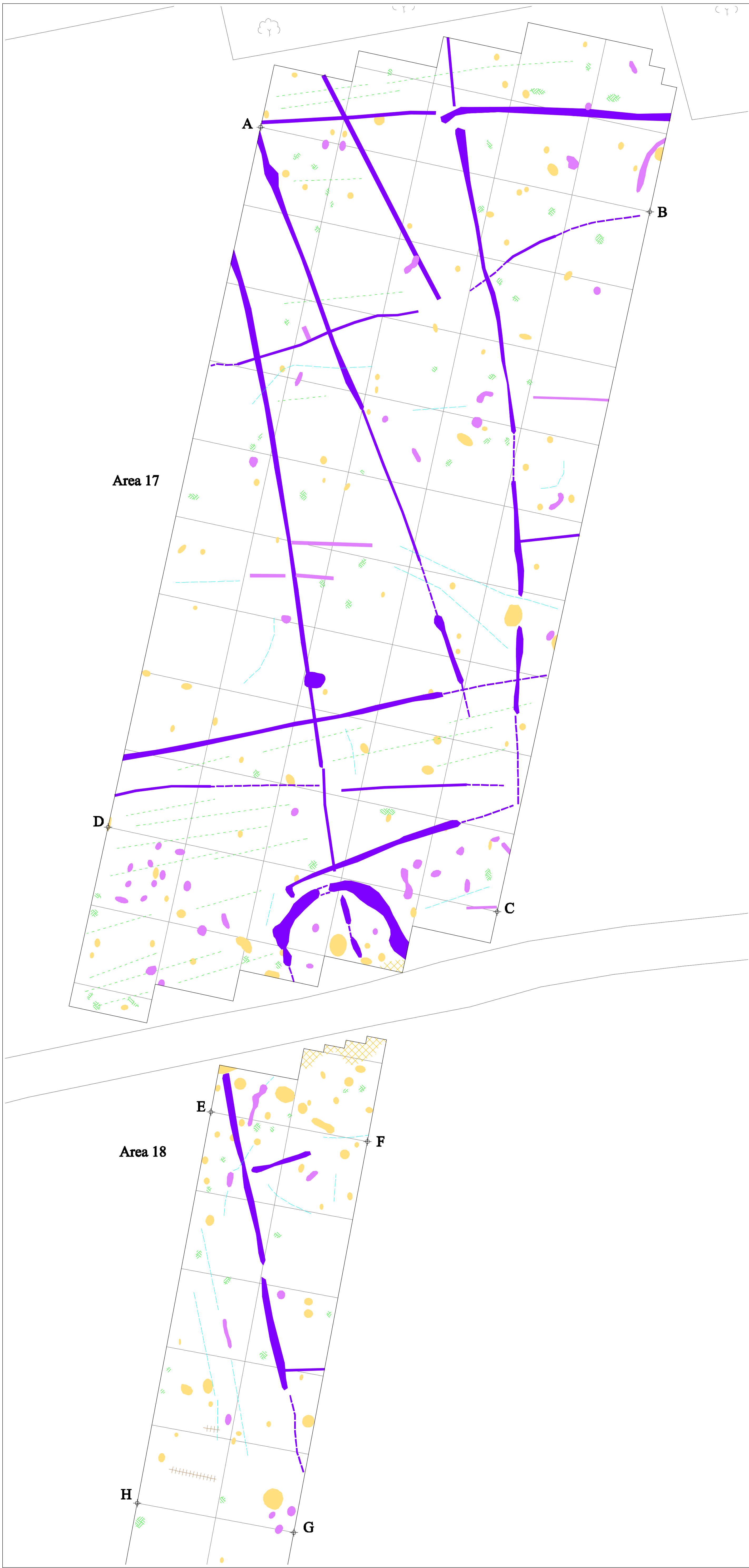
Greyscales at 1:1000 - Areas 17 and 18 (partial)

Based on digital mapping provided by Roughan & O'Donovan

Figure 14



Point	Easting	Northing
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B	296785.65	271870.45
C	296747.32	271694.58
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F	296714.76	271636.88
G	296696.26	271538.61
H	296656.95	271546.01

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2008/73 N2 Slane Bypass

Interpretation at 1:1000 - Areas 17 and 18 (partial)

Based on digital mapping provided by Roughan & O'Donovan

Figure 15

Appendix Archive - Technical Information, all techniques

The following is a description of the equipment and display formats used in ***GSB Prospection Ltd (GSB)*** *reports. It should be emphasised that whilst many display options are regularly used, the diagrams produced in the final reports are the most suitable to illustrate the data from each site. The choice of diagrams results from the experience and knowledge of the staff at* ***GSB.***

All survey reports are prepared and submitted on the understanding that whilst they are based on a thorough survey of the site, no responsibility is accepted for any errors or omissions.

Instrumentation

(a) Fluxgate Gradiometer – Geoscan FM256 and Bartington *Grad*601-2

Both the Geoscan and Bartington instruments comprises two fluxgate sensors mounted vertically apart; the distance between the sensors on the former is 500mm, while the latter maintains a distance of 1000mm. The gradiometers are carried by hand, with the bottom sensor approximately 100-300mm from the ground surface. At each survey station, the difference in the magnetic field between the two fluxgates is measured in nanoTesla (nT). The fluxgate gradiometer suppresses any diurnal or regional effects. Generally features up to one metre deep may be detected by this method. Readings are logged at 0.25m intervals along traverses 1.0m apart, unless stated otherwise in the report. Having two gradiometer units mounted laterally with a separation of 1000mm, the Bartington instrument can collect two lines of data per traverse.

The magnetic data have been pre-processed by removing baseline shifts due to zig-zag data collection. Where appropriate, traverses have been corrected for minor misalignments; these are due to variations in walking speed, which are usually a result of ground conditions or topography. Unless stated in the report it should be assumed that no filtering has been undertaken on the datasets collected in this project. In some greyscale images the data have been interpolated, which reduces pixelation in the visualisation.

(b) Resistance Meter - Geoscan RM15

This technique measures the electrical resistance of the earth, using a system of four electrodes (two current and two potential.) Depending on the arrangement of these electrodes an exact measurement of a specific volume of earth may be acquired; in this project the 'Twin-Probe' was used. The Twin Probe arrangement involves the paring of electrodes (one current and one potential) with one pair remaining in a fixed position, whilst the other measures the resistance variations across a grid. The latter pair is often termed 'mobile', while the fixed are called 'remote' or 'stationary'. The resistance is measured in ohms and, when calculated, resistivity is in ohm-metres. The resistance method as used for standard area survey employs a probe separation of 0.5m, which samples to a depth of approximately 0.75m. The nature of the overburden and underlying geology will cause variations in this generality. In area survey, readings are logged at 1.0m x 1.0m intervals.

Where necessary the resistance data have been pre-processed to correct for grid-mismatch errors resulting from surveying on different days – this is not a correction due to geological or topographical variation between sample areas. De-spiking has been undertaken to reduce minor errors from contact with the ground surface. This is carried out prior to interpolation, which is often employed to reduce pixelation in greyscale visualisation. Filtering is commonly used on resistance data to suppress, for example, a geological background and where used this will be noted on the relevant diagrams.

(c) Ground Penetrating Radar – Sensors & Software Smartcart (250 MHz)

The Ground Penetrating Radar (GPR) method utilises the absorption and reflection of electromagnetic waves at contrasting interfaces. The transmitter induces electromagnetic pulses into the ground and reflection of these pulses occurs when there are abrupt changes in the dielectric properties of the propagating medium. GPR systems record detailed vertical time sections that can provide a wealth of stratigraphic information and clearly define any discontinuities (Conyers and Goodman 1997; Conyers 2004). The primary advantage of GPR is that it can provide an estimation of the depth of a target.

The 'Sensors & Software Noggin Plus Smart Cart' includes an onboard digital video logger (DVL III), an odometer wheel, and battery. It is, therefore, a fully integrated system. The built-in software uses the integrated odometer to provide an accurate distance measurement to the response. The data are recorded in digital format and can be processed to produce depth slice maps, 2D sections or 3D cubes. In this project single traverses were collected and corrected for topographic variation.

The time window of data collection per trace (normally in the order of tens of nanoseconds) is user controlled and is displayed on the time axis of the GPR profiles. The time axis denotes the length of time required for a pulse to be emitted from the transmitter, travel down to a reflector and back up to the receiver. This is called 'two-way-time'. The GPR traces are plotted side by side in their correct relative lateral positions and the records, called *radargrams*, are displayed with their 'two-way-time' axes arranged vertically. The nature of archaeological deposits can present a complicated image when viewed as individual radargrams and it can be difficult to relate associated features from one profile to another.

The complex nature of archaeological deposits can present a complicated image when viewed as individual radargrams and it can be difficult to relate associated features from one profile to another. However, by collecting data along a series of closely spaced parallel traverses, one can combine the data to form a series of *time-slice maps*; horizontal slices through the ground at different time/depth intervals, enabling a 3D image of the survey area to be built up. This type of data collection and processing enables more subtle features, and the relationship between features, to be analysed more easily.

(d) Magnetic Susceptibility

Variations in the magnetic susceptibility of subsoils and topsoils occur naturally, but greater enhanced susceptibility can also be a product of increased human/anthropogenic activity. This phenomenon of susceptibility enhancement can therefore be used to provide information about the "level of archaeological activity" associated with a site. It can also be used in a predictive manner to ascertain the suitability of a site for a magnetic survey. Sampling intervals vary widely but are often within the 5- 20m range. The instrument employed for measuring this phenomenon is either a field coil or a laboratory based susceptibility bridge. The field coil measures the susceptibility of a volume of soil. The laboratory procedure determines the susceptibility of a specific mass of soil. For the latter 50g soil samples are collected in the field. These are then air-dried, ground down and sieved to exclude the coarse earth (>2mm) fraction. Readings are made using an AC-coil and susceptibility bridge, with results being expressed either as SI/kg x 10^{-8} or m^3/kg.

(e) Electrical Imaging - Iris (Syscal)

This resistivity technique is used to provide a vertical section / slice through the ground, particularly to estimate depth to features or to investigate stratigraphic sequences (Aspinall and Crummett 1997). Field procedure involves a straight line of electrodes, 24 in number, spaced at a set interval. The electrodes are connected to a portable computer via a multi-core cable. Software is used to switch between each measurement position and the variation in apparent resistivity in both vertical and horizontal directions is mapped. The data can then be analysed using the RES2DINV inversion program to provide an image that is closer to the real variation in resistivity. This model produces a 'true' depth (Loke and Barker 1995).

For this survey the 'Syscal Junior, IRIS' instrument was used. The electrode spacing was 2m for a total length of 96m (2 strings of 24 electrodes). The system has an internal 100W power source; the output voltage is automatically adjusted. Standard electrode arrays can be selected with the option to customise the array and define the depth, dependent on the length of the string. Resistivity accuracy is given at 0.5% typical; Induced Polarisation is 1% of the measured value for input voltage higher than 10 mV.

For both sites the survey line was based on the previous magnetometer and resistance survey. Once the electrodes were in position each array was selected and the data was collected before the electrodes were moved and the process repeated. For continuity the electrodes were overlapped hence the total line length for Area 3 was 186m (-10m to 176m) and 182 m (0m-182m) for Area 4.

The manufacturer's software (Electre II) was used to pre-define the electrode array. Tests were carried out using standard arrays to establish the best combination. The data were viewed using 'Prosys II' software, and processing was limited to merging files to create a continuous line and filtering out erroneous readings.

(f) Seismic Refraction – Geometrics Geode

The seismic investigation was carried out using a 'Geometrics Geode 24-channel seismic recorder'. High spatial resolution was achieved by using 24 single geophones at 2m spacing with shot spacing at 1 and 11m (i.e. 10m between shot points) from each end of the geophone line. The energy source was a hammer and plate with an automatic trigger system. The plate was struck repeatedly to improve the detection of the arrivals by 'stacking' which increases the signal-to-noise ratio.

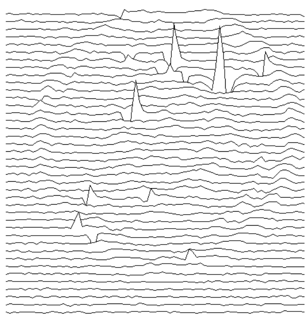
Energy from the source propagates through the ground and is refracted at interfaces, resulting in the ray running along the boundary, whilst sending rays (*headwaves*) back to the surface. Subsurface features manifest themselves as variations in the time difference between source-shot and the arrival of the headwaves, recorded along the line of geophones. The technique is particularly useful when the stratigraphic changes are close to horizontal (Mussett and Khan 2000).

Data collection was conducted via a laptop supporting software provided by the manufacturer. Detailed notes were made of the geophone and shot positions for each profile. Two seismograms were recorded for each shot point to assess the consistency of results, and thus give an indication of the data quality.

Processing initially involves picking headwave *first arrival* times at the geophones which was achieved using 'Interpex IXSeg2SegY' software. Mathematical and graphical analyses (Goulty et al 1990, Milsom 2003) allow for calculation of the seismic wave velocity and thus correction of the obvious time difference induced by an increasing offset between shot point and geophone along the survey line. This allows the depth to a subsurface feature below each geophone to be calculated and plotted against distance, with a topographic correction if necessary. This final analysis can be done in any spreadsheet program, in this case Microsoft Excel.

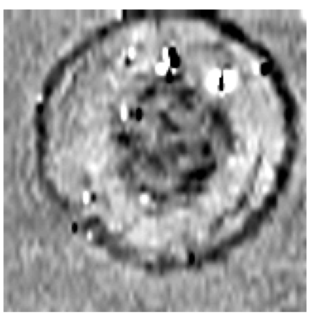
Display Options

The following is a description of the display options used. Unless specifically mentioned in the text, it may be assumed that no filtering or smoothing has been used to enhance the data. For any particular report a limited number of display modes may be used. See Gaffney and Gater 2003 for more details on display options.



(a) XY Plot

This involves a line representation of the data. Each successive row of data is equally incremented in the Y axis, to produce a stacked profile effect. This display may incorporate a hidden-line removal algorithm, which blocks out lines behind the major peaks and can aid interpretation. The advantages of this type of display are that it allows the full range of the data to be viewed and shows the shape of the individual anomalies. The display may also be changed by altering the horizontal viewing angle and the angle above the plane. The output may be either colour or black and white.

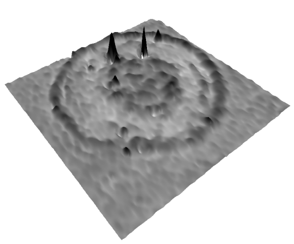


(b) Greyscale

This format divides a given range of readings into a set number of classes. These classes have a predefined arrangement of dots or shade of grey, the intensity increasing with value. This gives an appearance of a toned or grey-scale. Similar plots can be produced in colour, either using a wide range of colours or by selecting two or three colours to represent positive and negative values. While colour plots can look impressive and can be used to highlight certain anomalies, greyscales tend to be more informative.

(c) Relief Plot

Relief Plots / Shaded Relief Maps use colors or greys to map the surface relative to a user-defined light source. The analogy of the sun illuminating a topographic surface is a good way to envisage this form of display. Those parts of the surface that are in the shadow of the light source are darker than those in full view. The display can be varied by changing the height and direction of the light source. In this way, broad changes in the data can be reduced, and subtle changes enhanced.



(d) 3D Surface Plot

All detailed survey data can be used to create 3D plots which involve the creation of a smoothed surface from the original data. The height of the surface corresponds to value of the data and the surface variation can also be enhanced via a colour or greyscale.

Terms commonly used in the graphical interpretation of gradiometer data

Ditch / Pit
This category is used only when other evidence is available that supports a clear archaeological interpretation e.g. cropmarks or excavation.

Archaeology
This term is used when the form, nature and pattern of the response are clearly or very probably archaeological but where no supporting evidence exists. These anomalies, whilst considered anthropogenic, could be of any age. If a more precise archaeological interpretation is possible then it will be indicated in the accompanying text.

? Archaeology
The interpretation of such anomalies is often tentative, with the anomalies exhibiting either weak signal strength or forming incomplete archaeological patterns. They may be the result of variable soil depth, plough damage or even aliasing as a result of data collection orientation.

Areas of Increased Magnetic Response
These responses show no visual indications on the ground surface and are considered to have some archaeological potential.

Industrial
Strong magnetic anomalies, that due to their shape and form or the context in which they are found, suggest the presence of kilns, ovens, corn dryers, metal-working areas or hearths. It should be noted that in many instances modern ferrous material can produce similar magnetic anomalies.

Natural
These responses form clear patterns in geographical zones where natural variations are known to produce significant magnetic distortions e.g. palaeochannels or magnetic gravels.

? Natural
These are anomalies that are likely to be natural in origin i.e geological or pedological.

Ridge and Furrow
These are regular and broad linear anomalies that are presumed to be the result of ancient cultivation. In some cases the response may be the result of modern activity.

Ploughing Trend
These are isolated or grouped linear responses. They are normally narrow and are presumed modern when aligned to current field boundaries or following present ploughing.

Trend
This is usually an ill-defined, weak, isolated or obscured linear anomaly of unknown cause or date.

Areas of Magnetic Disturbance
These responses are commonly found in places where modern ferrous or fired materials are present e.g. brick rubble. They are presumed to be modern.

Ferrous Response
This type of response is associated with ferrous material and may result from small items in the topsoil, larger buried objects such as pipes or above ground features such as fence lines or pylons. Ferrous responses are usually regarded as modern. Individual burnt stones, fired bricks or igneous rocks can produce responses similar to ferrous material.

NB This is by no means an exhaustive list and other categories may be used as necessary.

Terms commonly used in the graphical interpretation of GPR data

HIGH AMPLITUDE ANOMALIES:

Wall / Foundation / Vault / Culvert etc.
This definitive categorisation is used only when other evidence is available that supports a clear archaeological interpretation e.g. aerial photographs, documentary sources or excavation.

Archaeology
This relates to anomalies whose form, nature and pattern are clearly, or very probably, archaeological but where little or no supporting evidence exists. These anomalies, whilst considered anthropogenic, could be of any age. If a more precise archaeological interpretation is possible, for example the responses appear to respect known local archaeology, then this will be indicated in the accompanying text.

? Archaeology
The interpretation of such anomalies is often tentative, with the anomalies exhibiting either little contrast or forming incomplete archaeological patterns. They may be the result of rubble spreads or variations in soil depth.

High Amplitude Response
Discrete high amplitude anomalies that cannot be categorised as archaeological and yet may still hold some importance will fall into this category.

Area of Increased Response
A data set may contain areas in which the response levels are very slightly elevated with respect to the 'background'. Where no obvious surface features or documentary evidence can explain this spread of increased reflectivity it is assumed to denote some kind of disturbance, though the origins could be of any age and either anthropogenic or natural.

LOW AMPLITUDE ANOMALIES:

Archaeology
This term is used when the form, nature and pattern of the response is clearly archaeological (i.e. robbed foundations, wet ditches and pits) and usually some form of supporting evidence exists. These anomalies, whilst considered anthropogenic, could however be of any age. As low amplitude responses are less obvious features, in both time-slices and radargrams, it is unlikely that they would ever have a definitive categorisation but if a more precise archaeological interpretation is possible then it will be indicated in the accompanying text.

? Archaeology
This category is used when the attenuation of the signal could be archaeologically significant, given the discrete nature of the anomaly, but where the distribution of the responses is not clearly archaeological.

Low Amplitude Zone
Responses in this category tend to be anomalous zones of weak response rather than discrete anomalies. They may be the effect of ground water 'ponding' where drainage is impaired, perhaps by archaeological or modern deposits. These zones may also relate to variations in the subsurface composition, when it is unlikely to be natural (for example urban environments).

Terms commonly used in the graphical interpretation of GPR data (cont.)

OTHER CATEGORIES:

Natural
Anomalies in this category can be high and/or low amplitude and will relate to natural sub-surface features as indicated by documentary sources, local knowledge or evidence on the surface.

?Natural
These responses (again high and/or low amplitude) form patterns which may be due to subsoil/geological variations either attenuating or reflecting greater amounts of energy. An archaeological origin such as rubble spreads (high amplitude) or robbed out remains (low amplitude) cannot be dismissed.

Trend
This is usually an ill defined, weak or isolated linear anomaly of unknown cause or date and can be a high or low amplitude response.

Historic
These responses show clear correlation with earlier map evidence and may be high or low amplitude or a combination of both.

?Historic
This category indicates responses that may relate to features not directly recorded on earlier maps but which certainly appear to respect features that are. They may form patterns suggestive of formal gardens, landscaping or footpaths for example.

Modern
This category is used for reflections that indicate features such as services, rebar or modern cellars that correlate with available evidence (maps, communications with the client, alignment of drain covers etc.).

?Modern
This category is used for reflections which appear to indicate buried services but for which there is no supporting evidence. It is also used for responses which form patterns, or are at a depth which suggests a modern origin. However, an archaeological source cannot be dismissed.

Surface
These are responses clearly due to surface discontinuities, the effects of which may be seen to 'ring' down through radargrams and thus also appear in the deeper time-slices.

NB This is by no means an exhaustive list and other categories may be used as necessary.