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Elsecar, Barnsley
Report on Geophysical Surveys, May 2017

Neil Linford, Paul Linford and Andrew Payne

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REPORT ON GEOPHYSICAL SURVEY,
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SUMMARY

Caesium magnetometer, Ground Penetrating Radar (GPR) and Earth Resistance Tomography (ERT) surveys were conducted at Elsecar, Barnsley, as part of the Historic England Heritage Action Zone project at the site. Despite considerable interference from land reclamation and landscaping, magnetic (5.4ha) and GPR (3.3ha) survey of the Forge Playing Field area revealed evidence for the former foundry and ancillary works, including possible structural remains associated with a furnace wall. Attempts to determine the location of former beehive coke ovens from ERT sections collected over the Furnace Field proved inconclusive, although a high resistance response suggests the presence of a buried structure with a possible air filled core. Due to the surface conditions only GPR survey (0.5ha) was attempted over the Greenway to investigate the original extent of the canal basin; the New Colliery to determine the presence of subsurface structures associated with the boiler house of the *in situ* Newcomen Engine; and the accessible areas of the Ironworks to either side of the railway lines. Results from these areas were mixed, particularly over the highly attenuating deposits within the former canal basin, but some evidence for structures associated with the Newcomen Engine have been suggested.

CONTRIBUTORS

The geophysical fieldwork was conducted by Neil Linford, Paul Linford and Andrew Payne.

ACKNOWLEDGEMENTS

The authors are grateful to John Tanner, of the Barnsley Museum Service, and colleagues from the Elsecar Heritage Centre for assistance with gaining access to the sites to allow the surveys to take place, and for arranging clearance of vegetation from the Furnace Field. John, together with many local residents, provided invaluable information regarding the former works that has greatly assisted our interpretation of the data which has also benefitted from discussion with our colleague Dave Went, Manager, Historic Places Investigation (North).

ARCHIVE LOCATION

Fort Cumberland, Portsmouth.

DATE OF SURVEY

The fieldwork was conducted between 22nd to 26th May 2017 and the report completed on 5th October 2017. The cover image shows the hand operated ground penetrating radar survey in progress at the New Colliery site with the Newcomen engine house in the background.

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INTRODUCTION

Geophysical surveys were conducted in Elsecar and Hoyland, Barnsley Metropolitan Borough, in support of the Historic Area Assessment of the Heritage Action Zone (HAZ) centred on the Elsecar Heritage Centre (RASMIS project number 7601; Went 2017). The Elsecar HAZ is rich in the remains of C19th industrial activity related to coal mining and iron production, including well preserved standing building remains of the Fitzwilliam estate workshops and mine-workings at the Elsecar Heritage Centre, with less clearly surviving elements of the associated wider industrial complex present in the surrounding landscape.

Geophysical survey was targeted over elements of the former industrial landscape of the Elsecar HAZ, now mainly known only from historical mapping and documentary records, as these areas have been subject to considerable modification as a result of demolition, landscaping and reuse since the peak period of industrial activity. In most cases the sites presented challenging conditions for geophysical investigation in terms of the ground surface, nature of the surviving target features or the subsequent land use. The investigated sites included Ground Penetrating Radar (GPR) survey of the in-filled basin of the Elsecar branch of the Dearne and Dove Canal (The Greenway, NHRE hob uid 1037995), Newcomen engine house (New Colliery, SAM 1004790) and Ironworks (NHRE hob uid 1481464) at the Elsecar Heritage Centre; Earth Resistance Tomography (ERT) survey of the postulated site of a coke oven complex under dense vegetation and uneven terrain above the Elsecar Heritage Centre to the east (Furnace Field, NGR SK 3869 9977); and magnetic and GPR survey of the Milton Iron Works at Hoyland now used as a recreation ground. It was hoped that a combination of geophysical techniques would help identify significant buried remains and complement the existing historic documentary and mapping, aerial photography and lidar evidence.

The sites are all situated on undifferentiated deposits of the Upper Carboniferous Pennine Middle Coal Measures Formation varying between mudstone, siltstone, sandstone, coal, ironstone and ferricrete sedimentary bedrock (Geological Survey of Great Britain 1976). Local soils are largely unclassified due to the predominant urban and industrial land use, but where undisturbed in the Elsecar area consist primarily of slowly permeable seasonally waterlogged clayey, fine loamy over clayey and fine silty soils of the Dale (712a) association (Soil Survey of England and Wales 1983). Weather conditions were warm, dry and sunny throughout the period of the survey fieldwork.

METHOD

Magnetometer survey

Magnetometer measurements were collected along the instrument swaths shown on Figure 1 using an array of six Geometrics G862 caesium vapour sensors mounted on a non-magnetic sledge (Linford *et al.* 2015). The sledge was towed behind a low-impact All-Terrain Vehicle (ATV) which housed the power supply and data logging electronics. Five sensors were mounted 0.5m apart in a linear array transverse to the direction of travel and, vertically, 0.40m above the ground surface. The sixth was fixed 1.0m directly above the centre of this array to act as a gradient sensor. The sensors sampled at a rate of 25Hz resulting in an along-line sample density of ~0.15m given typical ATV travel speeds of 3.5-4.0m/s. As the five non-gradient sensors were 0.5m apart, successive survey swaths were separated by approximately 2.5m to maintain a consistent traverse separation of 0.5m. Navigation and positional control were achieved using a Trimble R8 Global Navigation Satellite System (GNSS) receiver mounted on the sensor platform 1.65m in front of the central sensor and a second R8 base station receiver established using the Ordnance Survey VRS Now correction service. Sensor output and survey location were continuously monitored during acquisition to ensure data quality and minimise the risk of gaps in the coverage.

After data collection the measurements from the five ground-sensing magnetometers were corrected for heading error caused by the towing ATV then interpolated onto a regular grid at 0.25m x 0.25m intervals to create a total field dataset. Measurements from the upper gradient sensor were corrected for heading error but gridded as a separate dataset interpolated to the same resolution. The gradient dataset was then transformed using upward continuation (Blakely 1996, p313-316) to the give the magnetic field values that would have been measured had the gradient sensor been situated 2m rather than 1m above the ground-sensing magnetometers. Measurements from the transformed gradient dataset were then subtracted from the corresponding total field measurements to give the final 2m gradiometer dataset. This processing accentuates the strength of more deeply buried magnetic anomalies likely to be associated with buried industrial archaeology while retaining the ability of gradiometry to filter out strong magnetic gradients when in close proximity to modern surface ferrous objects such as fencing and goal posts. A linear greyscale image of the magnetic data is shown superimposed over the base Ordnance Survey (OS) mapping in Figure 3 and minimally processed versions of the range truncated data (±100nT/m) are shown as a trace plot and a histogram equalised greyscale image in Figures 5 and 6 respectively.

Ground Penetrating Radar survey

A 3d-Radar MkIV GeoScope Continuous Wave Step-Frequency (CWSF) Ground Penetrating Radar (GPR) system was used to conduct the survey collecting data with a multi-element DXG1820 vehicle towed, ground coupled antenna array (Linford *et al.* 2010). For the survey of the New Colliery site the antenna was operated by hand. A roving Trimble R8 Global Navigation Satellite System (GNSS) receiver, together with a second R8 base station receiver established using the Ordnance Survey VRS Now correction service, was mounted on the GPR antenna array to provide continuous positional control for the survey collected along the instrument swaths shown on Figures 2 and 12. Data were acquired at a 0.075m x 0.075m sample interval across a continuous wave stepped frequency range from 40MHz to 2.99GHz in 4MHz increments using a dwell time of 4ms. A single antenna element was monitored continuously to ensure data quality during acquisition together with automated processing software to produce real time amplitude time slice representations of the data as each successive instrument swath was recorded in the field (Linford 2013).

Post-acquisition processing involved conversion of the raw data to time-domain profiles (through a time window of 0 to maximum of 75ns depending on individual site conditions), adjustment of time-zero to coincide with the true ground surface, background and noise removal, and the application of a suitable gain function to enhance late arrivals. Representative profiles from the GPR surveys are shown on Figures 7, 15 and 16. To aid visualisation, amplitude time slices were created from the entire data set by averaging data within successive 2.5ns (two-way travel time) windows (e.g. Linford 2004). Average sub-surface velocities of 0.088m/ns for the Forge Field, 0.0955 m/ns for the New Colliery, 0.08 m/ns for the Greenway and 0.124 m/ns for the Ironworks were assumed following constant velocity tests on the data, and used as the velocity field for the time to estimated depth conversion at the respective sites. Each of the resulting time slices, shown as individual greyscale images, therefore represents the variation of reflection strength through successive ~0.1 to 0.16m intervals from the ground surface in Figures 8, 9, 17(A) and 18. Further details of both the frequency and time domain algorithms developed for processing this data can be found in Sala and Linford (2012).

Due to the size of the resultant data set a semi-automated algorithm has been employed to extract the vector outline of significant anomalies shown on Figures 11 and 19. The algorithm uses edge detection to identify bound regions followed by a morphological classification based on the size and shape of the extracted anomalies. For example, the location of possible pits is made by selecting small, sub circular anomalies from the data set.

Earth Resistance Tomography (ERT)

Plans of Elsecar Works dating from around 1861 (NBC 466/1-4) suggest infrastructure including possibly four rail lines for trolleys to supply coke ovens in Furnace Field above the works to the east. However, as the field is covered with dense undergrowth and, in its western part, woodland it was considered impractical to undertake area surveys here. Instead, six static ERT sections were laid out along strips of ground cleared of undergrowth for the purpose. The length, and hence number of electrodes, in each line varied according to the available clear space between larger patches of scrub but for all sections electrodes were spaced 1m apart and the GNSS system described above was used to accurately locate each electrode and record local topography using the roving antenna in stakeout mode mounted on a staff. The positions of the sections are shown in Figure 20 and their respective lengths are depicted in Figures 21 and 22. Four sections (ERT01, 03, 05 and 06) were aligned parallel to each other as close to the wooded part of the field as possible to provide a broad transect approximately orthogonal to the direction of the rail lines shown in the plans. Two further sections (ERT02 and 04) were positioned to investigate any remains towards the east of the field.

Measurements were made with a Campus Tigre multiplexed earth resistance meter controlled by ImagerPro2006 software running on a field laptop computer. The expanding Wenner electrode configuration was employed owing to its high signal to noise ratio which was considered important in this application due to the degree of disturbance caused by later re-use of the field as a sports pitch and the current dense undergrowth. To guarantee data quality, contact resistance tests were conducted on the electrodes before each section was measured and any electrodes with poor electrical contact were re-seated and moistened to ensure all contact resistances were less than 1000 ohms.

Data from each section were inverted to infer subsurface resistivity models using Geotomo Software’s Res2dinv software (version 3.56.39) with GNSS measurements of the electrode positions incorporated to allow for topographic correction. Error estimation during the inversion used the robust inversion method (absolute errors or the L1 norm) which is more tolerant of discontinuities between adjacent cells and thus tends to resolve boundaries between layers more sharply than the standard least mean squares inversion. The model space was discretised using 0.5m cells (half the base electrode separation) to provide finer resolution of any near-surface anomalies.

Colour images of the output model sections are shown in Figures 21 and 22 and the data from all six sections have been combined using Geosoft OASIS Montaj 8.5 and imaged as depth slices and 3d isosurfaces in Figure 23. The 2m depth slice is superimposed on the base mapping and 1861 historic plan in Figure 24.

RESULTS

Forge Playing Field: Magnetometer and GPR survey

Magnetometer survey

A graphical summary of significant magnetic anomalies [**m1-36**] discussed in the following text superimposed on base OS map data is provided in Figure 10.

The response from the Forge Playing Field reflects the demolition and subsequent landscaping of the Milton Iron Works, producing intense magnetic disturbance (with magnitudes greater than ±200nT/m) across much of the site with the exception of a quieter area to the north of the survey area bordering Millhouses Street. Despite this disturbance a number of significant anomalies have been recognised which correlate with the land use history of the site known from the historical mapping and other sources of evidence.

A partial response [**m1-3**] to the edges of the in-filled Middle Pond is found to the west of the site, together with a more intense anomaly [**m4**] that does not appear to be associated with any buildings visible on the historic mapping (OS Historic County Mapping Series: Yorkshire 1843 - 1893 Epoch 1). The whole of this area has clearly been subject to considerable modification and the near surface deposits probably therefore consist of made ground, producing a highly variable magnetic response.

To the east the ground drops by about 8m in a pronounced scarp towards the main recreation ground area and a line of very strong magnetic anomalies [**m5-9**] runs along the top of this slope (see Figure 6(B)). The intense magnetisation of these anomalies suggests thermoremanently magnetised remains likely to be associated with high temperature industrial processes consistent with intensely heated brick or ferrous materials. The survival of upstanding remains in this approximate location still persist in local memory although historic mapping marks the line of a rail or tramway rather than any structures in this location (OS Historic County Mapping Series: Yorkshire 1843 - 1893 Epoch 1). An isolated structure south of the middle pond shown on historic mapping may be associated with the high magnitude anomaly at [**m10**], possibly suggesting a high temperature industrial process or machine house servicing the indicated water main. The pronounced scarp slope (~8m) immediately to the east down to the recreation ground suggests remains of the iron works buildings still stand buried to an appreciable height. A strong positive linear anomaly at [**m11**] is likely to represent remains of another tramway serving the iron works, joining the incline railway running to the Elsecar canal basin.

Immediately below the scarp slope to the east, the site is dominated by magnetic disturbance [**m12**] together with some very weak linear anomalies which appear most likely to be related to recent land-fill, landscaping or modern drainage, rather than the former iron works. The possible location of the north and eastern extent of the in-filled Lower Pool may relate to a subdued response [**m13**], perhaps suggesting the pond was not entirely used for land-fill and rubbish deposition as initially suspected. The course of a modern sewer or drain [**m14**], perhaps running to an outfall visible in the railway cutting to the east, crosses [**m12**] and may be a culvert for a stream shown on the historic mapping (OS Historic One Inch Mapping Series: 1841-1844). An intermittent linear anomaly [**m15**] may represent a further branch of tramline from the inclined plane running towards the centre of the Milton Iron Works, with a quieter area of more uniform raised response [**m16**] possibly associated with the site of the iron and brass foundry (cf [**gpr11**]) which replaced the iron works around the turn of the 20th century (see for instance Lodge 1974, fig. 6).

A further large building associated with the iron works is visible to the north as a series of rectilinear areas of disturbance [**m17**] and [**m18**], flanked by a quieter response [**m19**], and together suggest either several buildings belonging to the complex or successive phases of buildings may have been detected (cf [**gpr9**]). A further possible tramline may have been detected at [**m20**] running to the west from [**m17**] and [**m18**].

The area to the east beyond the main building complex is more disturbed [**m21**], perhaps due to industrial waste from the iron works, but also contains a series of curvilinear anomalies [**m22-26**] related to geomorphology or later landscaping. One broad curvilinear anomaly [**m27**] could represent an enclosure, boundary or a former track way, possibly associated with evidence shown on the historic mapping (OS Historic County Mapping Series: Yorkshire 1843 - 1893 Epoch 1 and 1891-1921 Epoch 2).

In the less disturbed area of the site adjacent to Millhouses Lane, beyond the extent of the former iron works, a strong linear ditch type response [**m28**] and weaker more intermittent curvilinear anomaly [**m29**] are likely to represent former boundaries or trackways shown on the historic mapping (OS Historic County Mapping Series: Yorkshire 1843 - 1893 Epoch 1). Numerous, very weak, linear anomalies [**m30**] and [**m31**]may be related to former cultivation or drainage, or the row of prefabricated houses shown on aerial mapping to have stood here between 1948 and 1971 (cf [**gpr2**]). A ceramic field drain [**m32**] linked to a herringbone pattern of feeder drains [**m33**] , possibly, relates to the prefabricated houses as might a series of equally spaced ferrous anomalies [**m36**] separate by a distance similar to the width of the house plots. A broader, weakly defined ditch type anomaly [**m34**] possibly correlates with a field boundary shown on the historic mapping and a number of small localised anomalies [**m35**] to the west of the undisturbed area may represent pits or small quarries.

Ground Penetrating Radar survey

A graphical summary of the significant GPR anomalies, [**gpr1-26**] discussed in the following text, superimposed on the base OS map data, is provided in Figure 11.

Significant reflections have been recorded throughout the 50ns two-way travel time window, although later reflections beyond ~40ns become more highly attenuated depending on the level of modern intervention and landscaping over the site. The area of longer vegetation under the central belt of trees is visible due to a slight change of ground coupling [**gpr1**], but this does not appear to have obscured any significant reflections. The near surface data between 0 and 12.5ns (0.0 - 0.66m) provides evidence for the row of prefabricated houses [**gpr2**] built along Millhouses Street (OS Post War Historic mapping: First Edition (National Grid), Epoch a5), and a 'herring bone' drain or soak-away [**gpr3**] possibly associated with these buildings. Other possible services [**gpr4-6**] may be related to the prefabricated houses or, possibly, to the former industrial buildings on the site [**gpr6**]. A broad linear anomaly [**gpr7**] is possibly the course of a canalised stream, drain or modern sewer (cf [**m14**]).

A strong linear reflector [**gpr8**] visible from 10.0ns (0.44m) correlates with the boundary wall shown on the historic mapping (OS Historic County Mapping Series: Yorkshire 1843 - 1893 Epoch 1) and would suggest the complex anomaly at [**gpr9**] is associated with the former large rectangular building immediately to the north of a pond from the same epoch of mapping. Whilst the pond remains unchanged in later historic mapping (OS Historic County Mapping Series: Yorkshire 1904 - 1939 Epoch 3) the building is no longer depicted, perhaps explaining the complex nature of [**gpr9**] associated with a more extensive destruction deposit and subsequent landscaping of the playing field. The central low amplitude response within [**gpr9**] may, perhaps, more closely represent the footprint of the original structure. To the south of [**gpr9**] a dipping anomaly [**gpr10**] most likely represents the northern edge of the in-filled pond.

A group of more structural anomalies at [**gpr11**] to the south most likely represents the former iron and brass foundry that appears to survive on the site until the land is reclaimed for a recreation ground (OS Post War Historic OS: First Revision (National Grid), Epoch b6). Again, [**gpr11**] is a complex anomaly with some rectilinear low amplitude response perhaps indicating the footprint of the buildings. A linear anomaly [**gpr12**] follows the course of a footpath shown on the historic mapping (OS Historic County Mapping Series: Yorkshire

1843 - 1893 Epoch 1), but [**gpr12**] continues further north beyond the brass foundry meeting the line of the sewer [**gpr7**] where it appears to terminate.

Other anomalies found over the recreation ground are more difficult to interpret and include linear drains or ditches [**gpr13**], large pits [**gpr14**] and a curvilinear response [**gpr15**], possibly also a drain, which all correlate with the magnetic data (cf [**m30**] and [**m35**]). Some further evidence for structural remains may be found at [**gpr16-18**], with a linear anomaly [**gpr19**] possibly related to a branch of the tramway.

A high amplitude anomaly [**gpr20**] correlates with the strong magnetic response (cf [**m5-9**]) on the edge of the scarp slope and continues to approximately 40ns (1.75m) where the radar signal becomes increasingly attenuated. Some structural elements are discernible within [**gpr20**], but are difficult to fully interpret as it seems likely that the full depth extent of the furnace wall has not been imaged by the radar and much of the response here will be due to near-surface destruction deposits and subsequent landscaping. The construction and subsequent in-filling with refuse of the Middle Pond has obscured the interpretation of other anomalies in this area. A dipping reflector [**gpr21**] may represent the edge of the pond to the north and a more complex response [**gpr22**] could indicate its extent to the west. Other high amplitude anomalies [**gpr23-26**] between 2.5 and 30.0ns (0.11 – 1.31m) are difficult to interpret, but seem most likely to be associated with the in-filled Middle Pond.

The Greenway, New Colliery and Elsecar Ironworks: GPR survey

A graphical summary of the significant GPR anomalies, [**gpr27-47**] discussed in the following text, superimposed on the base OS map data, is provided in Figure 19.

The Greenway

The survey of the Greenway was conducted over the original extension of the canal basin, which has subsequently been in-filled and used as sidings for the railway goods station. Few significant anomalies have been detected in this area, perhaps due to the made ground used to fill the canal basin or the more recent removal of the railway tracks shown on the historic mapping (OS Historic County Mapping Series: Yorkshire 1843 - 1893 Epoch 1). A linear high amplitude anomaly [**gpr27**] is persistent throughout the data set from the near-surface, but follows the orientation of the former railway sidings. Deeper reflectors at [**gpr28**] and [**gpr29**] are difficult to fully interpret and two tentative linear anomalies [**gpr30**] and [**gpr31**] could, perhaps, be services although a subsequent utilities search failed to detect anything at the location of the latter.

New Colliery

At the New Colliery, adjacent to the Newcomen engine house, a wall type anomaly [**gpr32**] on Figure 19(B) is visible between 2.5 and 60.0ns (0.12 - 0.66m) running E-W following the coping stones and brickwork visible on the surface. There is a gap in [**gpr32**] from 10ns (0.48m) with a less substantial linear anomaly [**gpr33**] running north and a central, discrete high amplitude approximately cylindrical response [**gpr34**] with a diameter of ~0.7m and depth extent from between 20.0 and 45.0ns (0.96 – 2.15m). Figures 17(B), (C) and (D) show the GPR data from the New Colliery rendered as an isovolume model of the high amplitude anomalies [**gpr32-34**] from different viewing angles, although it is difficult to determine how these may relate to any surviving boiler structures. Two parallel linear anomalies [**gpr35**] to the east of the survey suggest an extension to the engine house or structures related to the boiler.

Elsecar Ironworks

Interpretation of the data from the Ironworks, to either side of Elsecar station, is complicated by the response from the jointing of the concrete surface [**gpr36**] on Figure 19(A). A central linear anomaly [**gpr37**] follows the course of the partially visible single railway track shown on the historic mapping (OS Historic County Mapping Series: Yorkshire 1843 - 1893 Epoch 1) and although no other structures are recorded, earlier architectural plans suggest a complex of buildings here pre-dating the construction of the station. To the west of Elsecar station the most likely structural anomalies occur at [**gpr38-40**], and to the east at [**gpr41-43**]. A series of deeper linear anomalies [**gpr44**] and some planar reflectors [**gpr45**] are more difficult to interpret but could be related to either structural elements of the ironworks or the construction of the more recent concrete surfacing. Two discrete circular anomalies [**gpr46**] and [**gpr47**] could, perhaps, related to capped shafts or drains.

Furnace Field: ERT survey

A representative depth slice from 2 metres below the surface has been superimposed on both the modern base OS map data and a portion of the 1861 plan (NBC 466/4) in Figure 24. This figure has been annotated with significant anomalies [**r1-4**] discussed below. The same data is shown as vertical sections in Figures 21 and 22 and as a series of depth slices and 3d isosurface overlaid on a portion of the 1861 map in Figure 23. These figures have also been annotated to indicate the significant anomalies where relevant.

The relatively confined space open enough to survey has limited the degree to which the results can be interpreted and a wider survey would have allowed the background variation in earth resistance to be better assessed resulting in more confident identification of significant anomalies. However, there are no obvious linear anomalies crossing at right angles to the main swath of sections that might correlate with the putative rail lines for trolleys to feed coke ovens or charge the blast furnaces of Elsecar Works which lay to the west. This is unlikely to be due to the ERT sections missing them as from the map the estimated separation of the lines was ~20m and two would certainly be expected to cross the survey area (see Figures 23 and 24). It is therefore likely that any remains have been removed by more recent activity in the field.

There is, however, a very high resistance anomaly [**r1**] located towards the centre of sections ERT03 and 05 and extending into ERT06 around 14m from its southwest end. The core of this anomaly exhibits resistivity values in excess of 500 ohm-m which may suggest rubble or a partly air filled void at its centre. It has a maximum diameter of ~8m and reaches to a depth of ~6-7m beneath the surface. It is tempting to compare these dimensions with those of a typical C19th beehive coke oven and the anomaly does appear to coincide with one of the rail lines marked on the 1861 plan. However, to produce coke in the quantities required for the furnaces a battery of ovens would be required and, while the notation is ambiguous, the plan may be interpreted as suggesting such a battery with ovens arranged in four rows, along each of which adjacent ovens are spaced ~10m apart. Hence, despite the relatively limited area it was possible to cover, further very resistive anomalies caused by adjacent ovens might have been expected within the survey area. So an alternative explanation must also be considered and it is possible that [**r1**] represents the remains of a shaft associated with the coal mines beneath the area. Lidar imagery reveals a concentrated pattern of shafts in Simon Wood nearby to the north so it is possible that further shafts were located here.

To southwest and northeast of [**r1**] are two areas of increased resistivity, [**r2**] and [**r3**], with maximum values in the region of 250 ohm-m; both appear to extend beyond the edges of the survey area. Because they occur at the two ends of the electrical sections, only the near surface has been imaged in these regions. It is possible that these are responses to remains similar to r1 and their lack of highly resistive cores of a similar magnitude is due to the limited depth of investigation or the anomalies centres lying just outside the surveyed area. Alternatively, they might be the result of desiccation of the soil due to nearby tree root activity or ground levelling when the field was repurposed as a sports pitch. However, they may also represent spreads of rubble from other industrial structures contemporary with the iron furnaces at Elsecar Works: [**r2**] appears to coincide with an area where railway lines have been indicated on the 1861 plan (blue ink lines on Figure 24); and the southernmost part of [**r3**] coincides with one of the putative rail lines feeding a row of coke ovens although the larger part of the anomaly is offset to the north.

Southwest of [**r1**] a weaker linear high resistivity anomaly can be discerned running towards it [**r4**]. This has a maximum resistivity ~100 ohm-m and there is some evidence for it at the greatest depth penetrated by the electric current in ERT04. While it might relate to a further industrial response associated with [**r1**] it is perhaps more likely to indicate a variation in underlying geology rather than an anthropogenic feature given its persistence to great depth.

CONCLUSIONS

Despite the complete removal of structural remains and considerable subsequent landscaping, geophysical survey over the Forge Playing Field site of the former Milton iron works has successfully identified a number of anomalies which correlate and enhance evidence from the historic mapping and other sources. Complementary coverage with both magnetic and radar survey has proved particularly helpful in areas of the site where a single technique would have been comprised by adverse site conditions, such as intense ferrous disturbance or presence of highly attenuative made ground. Site conditions proved more challenging over the site of the in-filled canal basin, where the radar signal was highly attenuated by the made ground and cinder track bedding from the former railway sidings. More successful results were obtained from the Elsecar Ironworks site, although a significant number of the original works buildings have been removed during the construction of the later railway station, which has hampered the full interpretation of the data set. The site of the putative bee hive coke ovens on Furnace Field above the Elsecar Ironworks also proved challenging due to the overgrown vegetation and depth of the expected target furnace features. Investigation through the use of earth resistance tomography has identified at least one potential industrial feature, possibly an oven or former mine shaft, but further investigation may be required to fully describe anomalies in this area. Finally, a limited GPR survey over the boiler house adjacent to the Newcomen engine revealed evidence for some subsurface structures, possibly walls, pipes or flues associated with the original apparatus.

LIST OF ENCLOSED FIGURES

Figure 22 Linear colourscale images of (A) ERT03, (B) ERT05 and (C) ERT06 sections from the Furnace Field after inversion (1:200).

Figure 23 Linear colourscale images of 3D model derived from all ERT sections depicted as (A) horizontal depth slices (1:1000) and (B) a 3d isosurface view.

Figure 24 Colourscale image of 2m ERT depth slice from Figure 23 superimposed over base OS mapping and 1861 works plan annotated to show significant anomalies (1:1000).

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Figure 1

ELSECAR, BARNSLEY
Forge Playing Field, location of caesium magnetometer survey, May 2017

Geophysics Team 2017

Historic England

Figure 2

ELSECAR, BARNSLEY
Forge Playing Field, location of GPR instrument swaths, May 2017

0 60m
1:1500

Ground Penetrating Radar survey swaths

2017-05-23-001 Location of selected GPR profiles shown on Figure 7

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Historic England

Figure 3

ELSECAR, BARNSLEY

Forge Playing Field, location of caesium magnetometer survey, May 2017

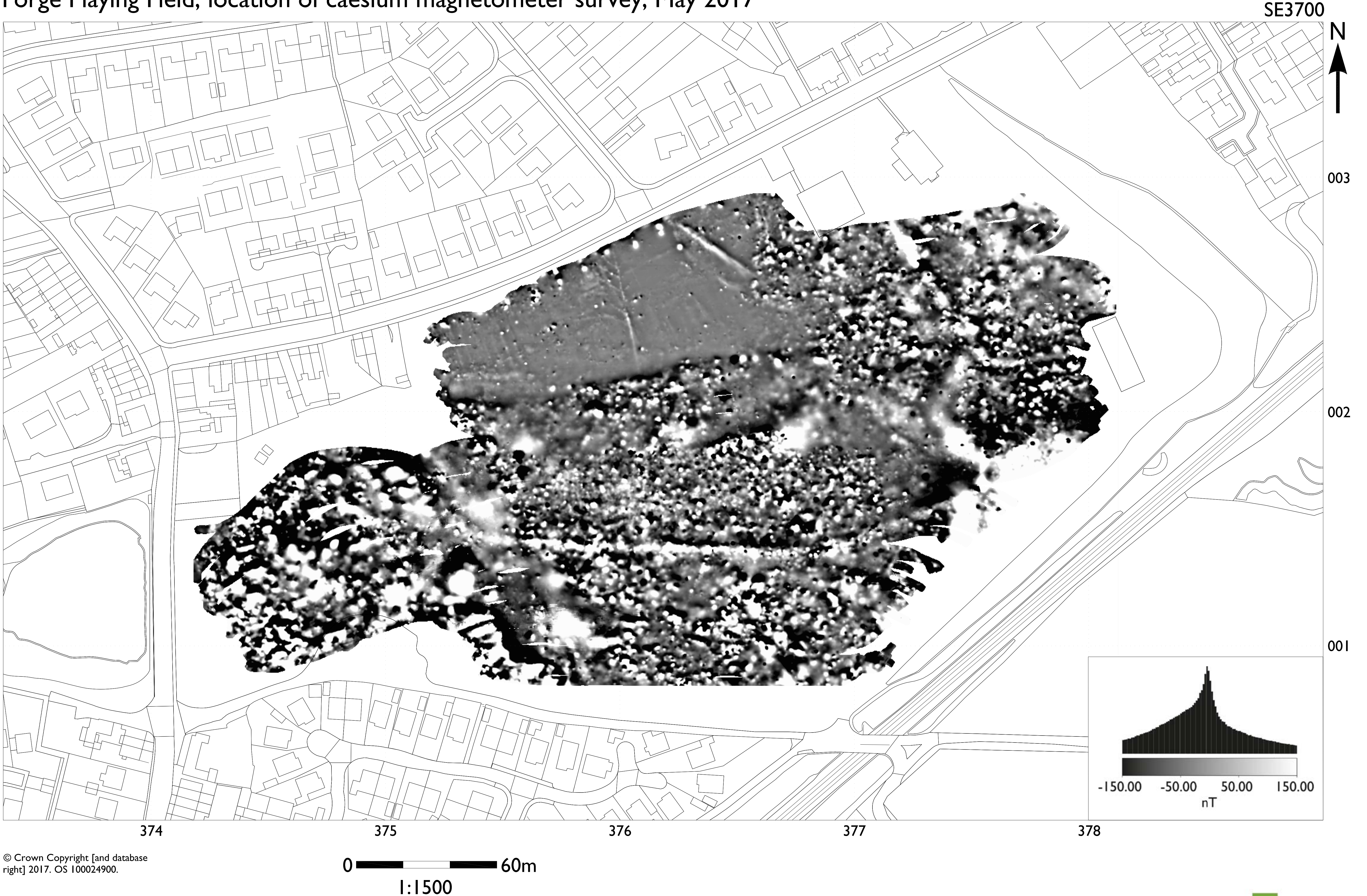

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Figure 4

ELSECAR, BARNSLEY

Forge Playing Field, GPR amplitude time slice between 5.0 and 7.5ns (0.25 - 0.38m), May 2017

0 60m

1:1500

2017-05-23-001 Location of selected GPR profiles shown on Figure 7

Low High relative reflector strength

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Figure 5

ELSECAR, BARNSLEY Forge Playing Field, caesium magnetometer survey, May 2017

Trace plot of minimally processed data

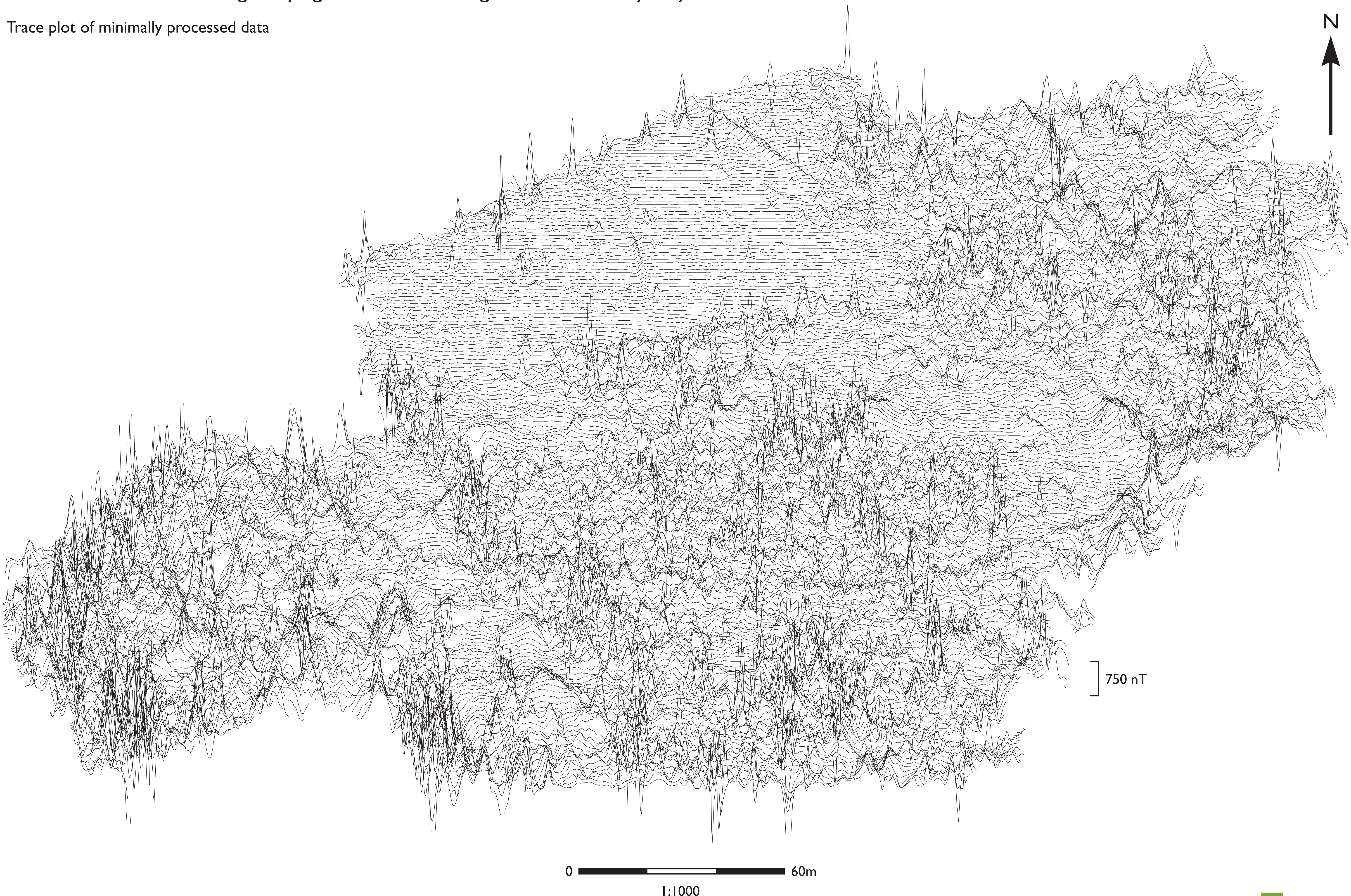

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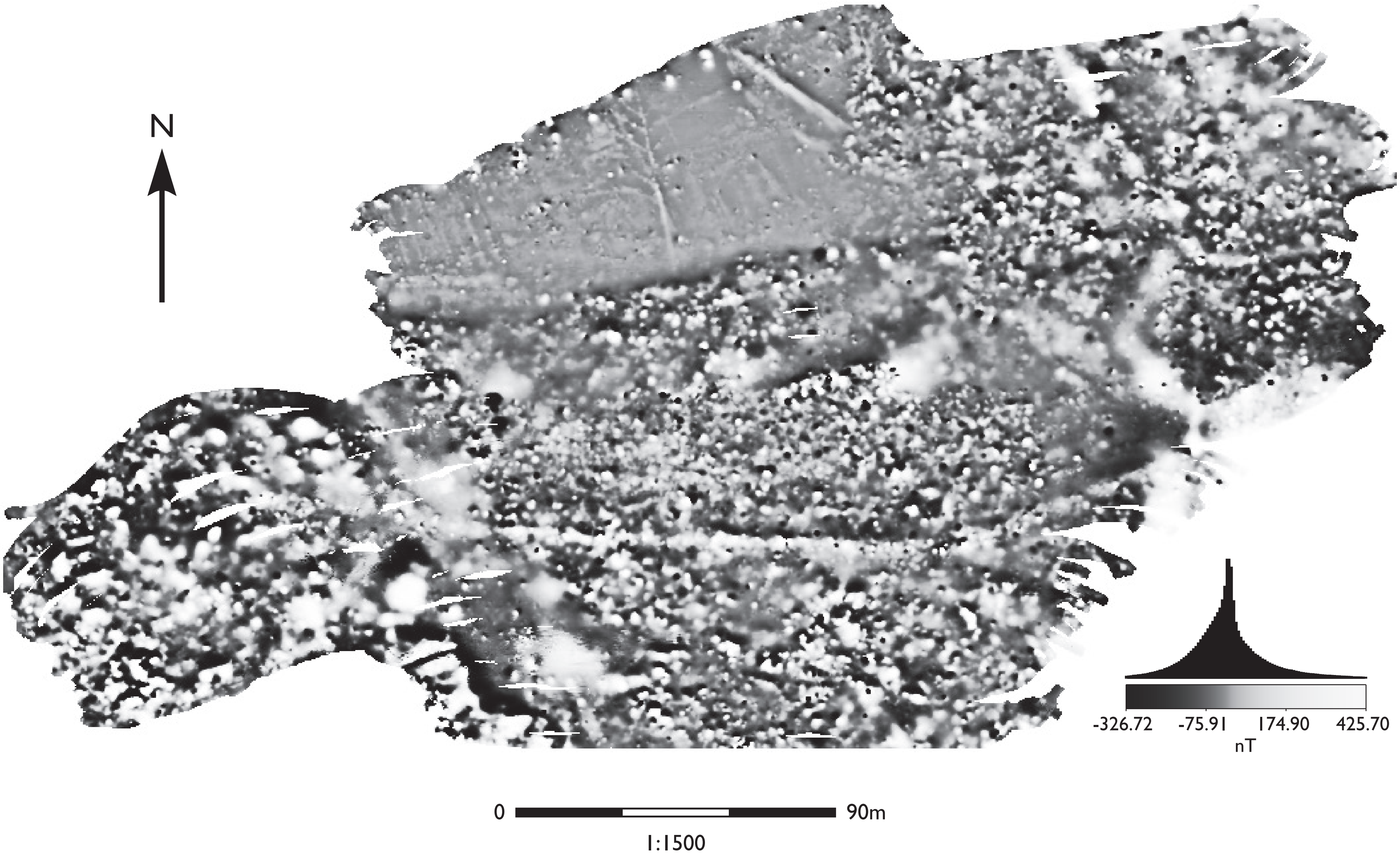
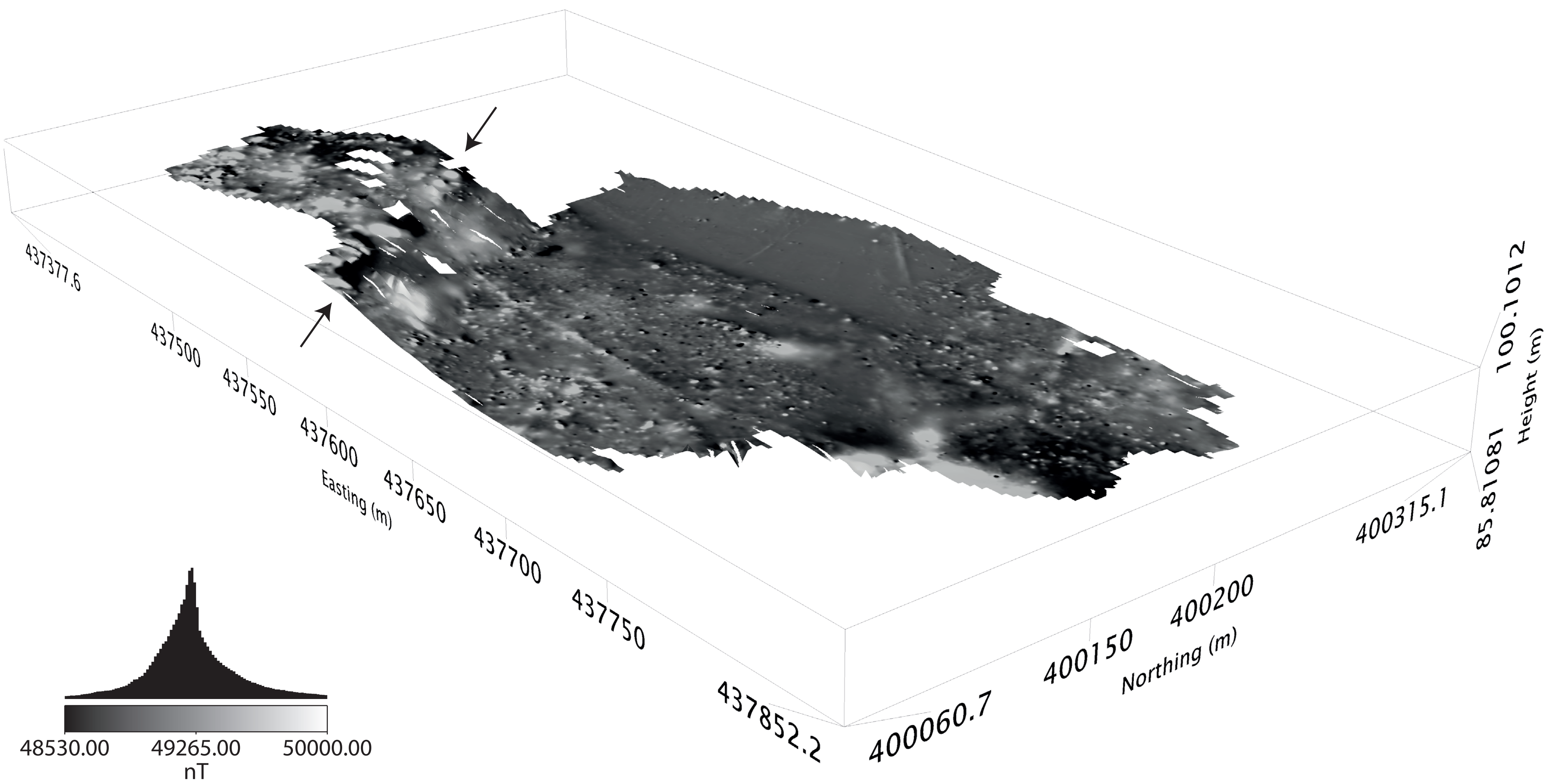
Figure 6

ELSECAR, BARNSLEY
Forge Playing Field, caesium magnetometer survey, May 2017

(A) Equal area greyscale image of minimally processed data



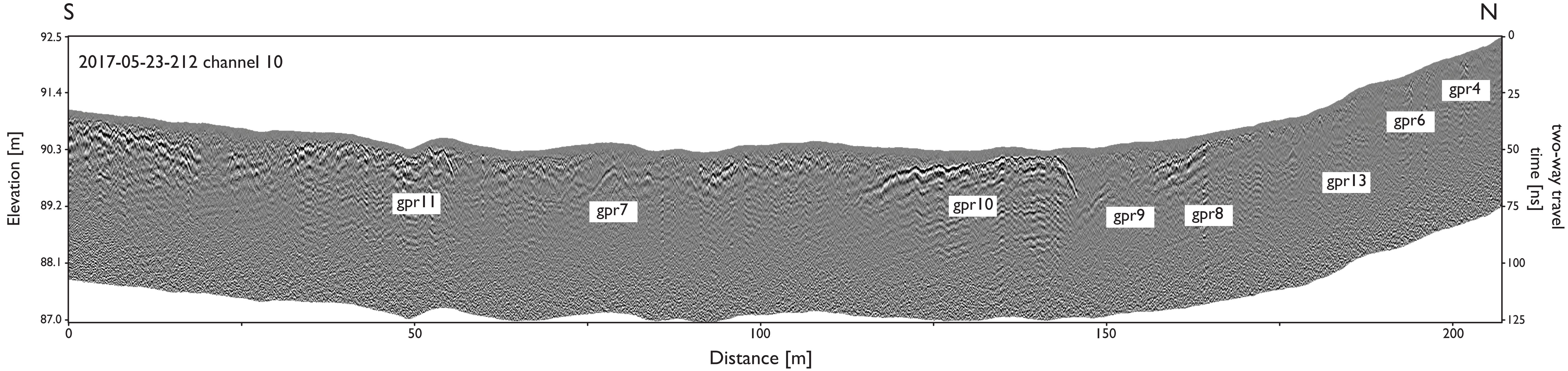
(B) Greyscale image of total field magnetic data draped over a digital terrain model (2x vertical exaggeration) viewed from the SE looking NW. Arrows denote a line of strong magnetic anomalies running along the top of the slope.

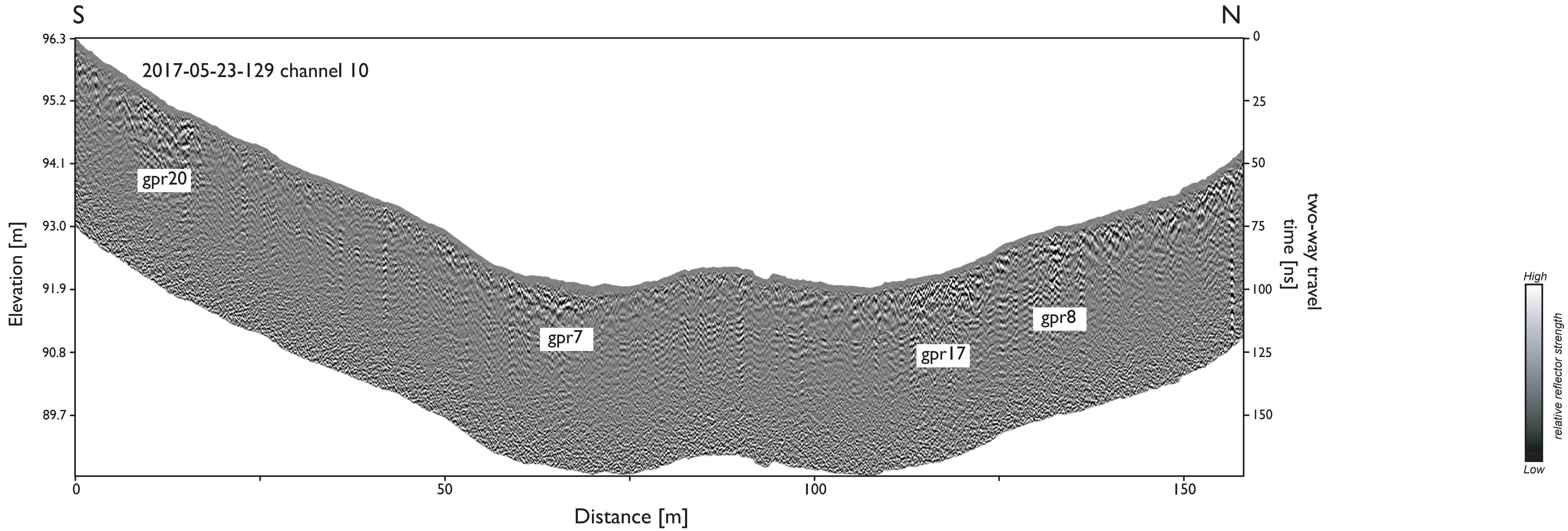


ELSECAR, BARNSLEY

Forge Playing Field, topographically corrected GPR profiles, May 2017

Figure 7

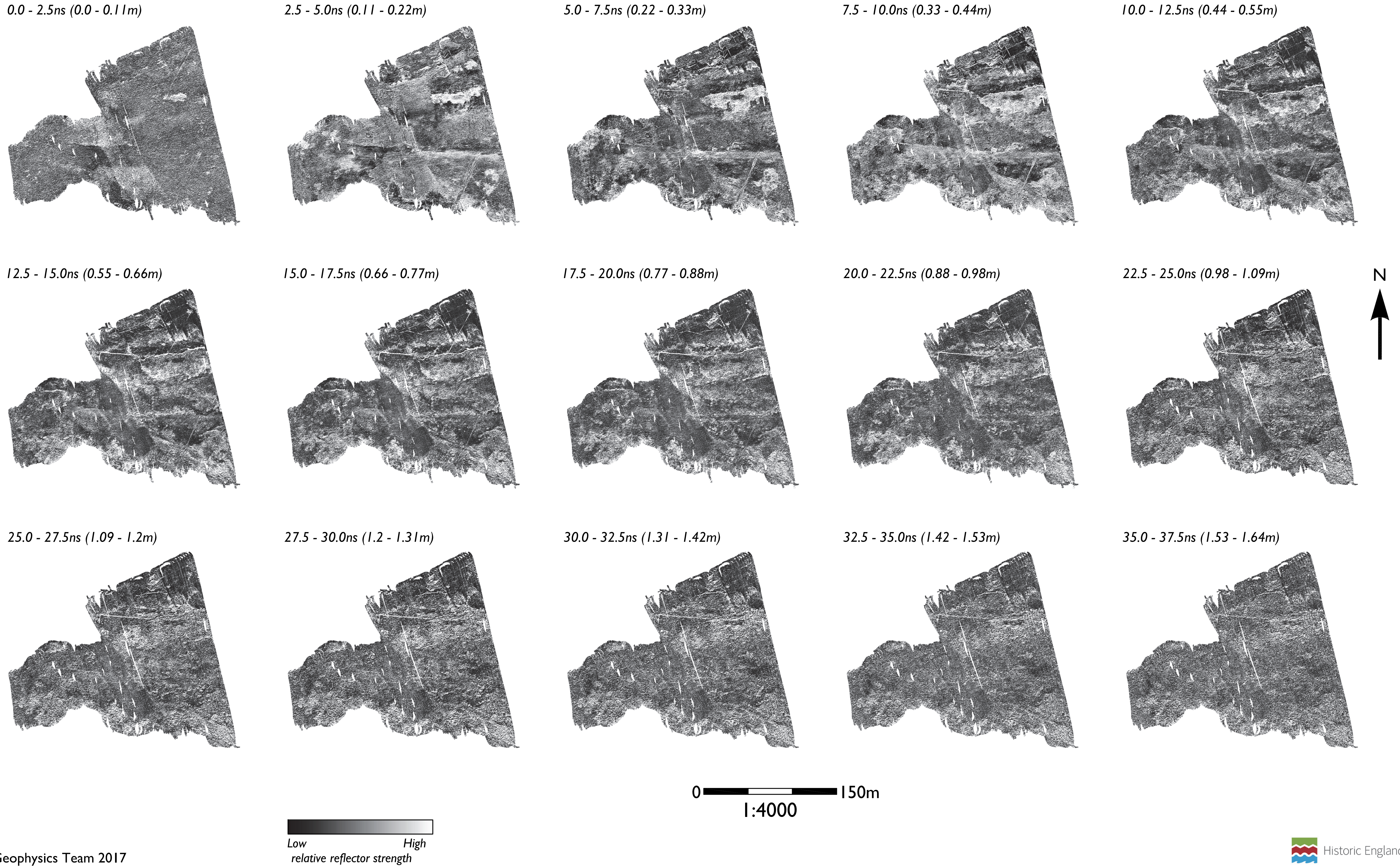




ELSECAR, BARNSLEY

Figure 8

Forge Playing Field, GPR amplitude time slice between 0.0 - 37.5ns (0.0 - 1.64m), May 2017



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Forge Playing Field, GPR amplitude time slice between 37.5 - 75.0ns (1.64 - 3.29m), May 2017

Figure 9

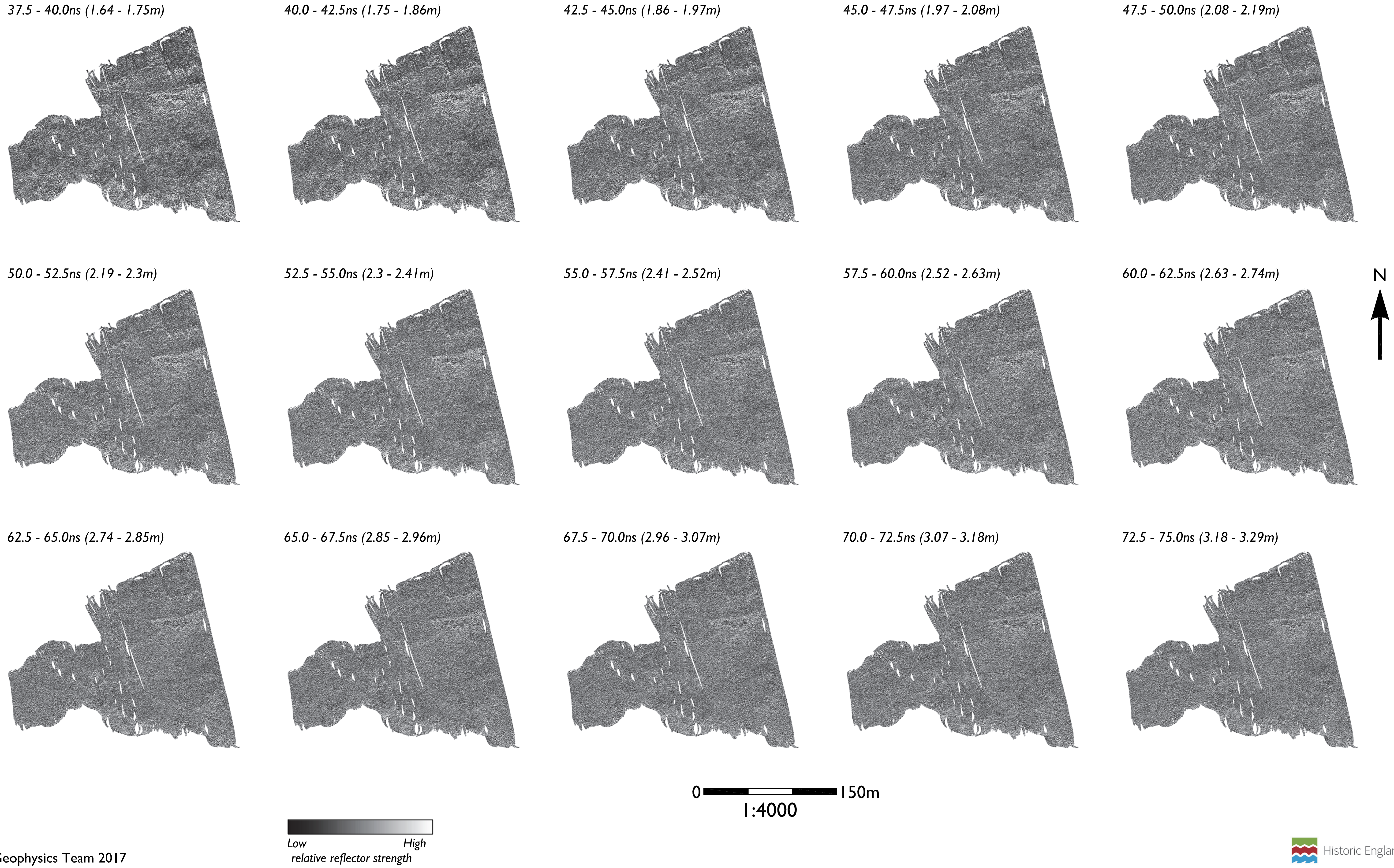

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Figure 10

ELSECAR, BARNSLEY
Forge Playing Field, summary of significant magnetic anomalies, May 2017

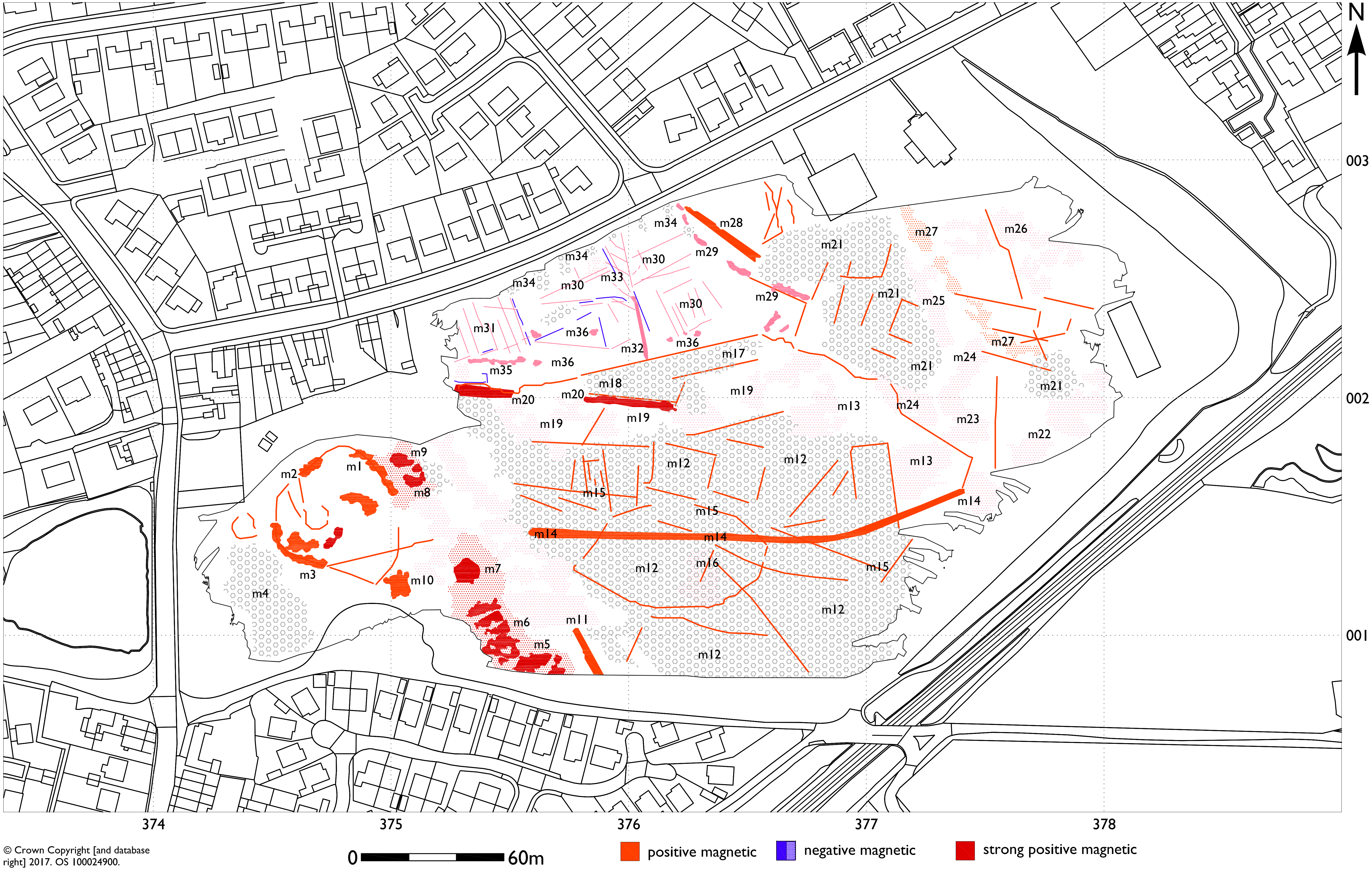

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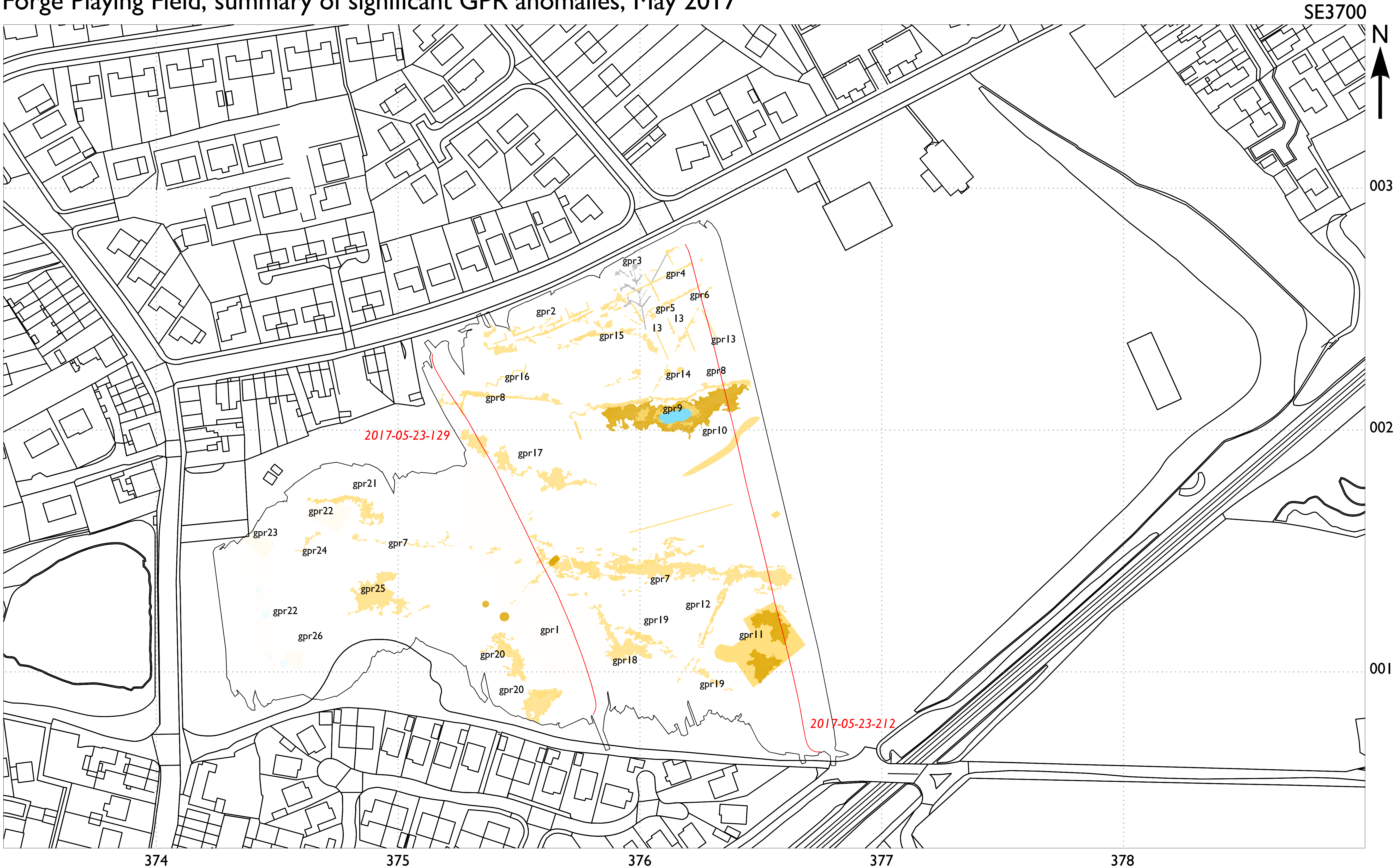
Figure 11

ELSECAR, BARNSLEY
Forge Playing Field, summary of significant GPR anomalies, May 2017



low amplitude reflectors

high amplitude reflectors

anomalies of known or recent origin

Location of selected GPR profiles shown on Figure 7

2017-05-23-129

0 60m

1:1500

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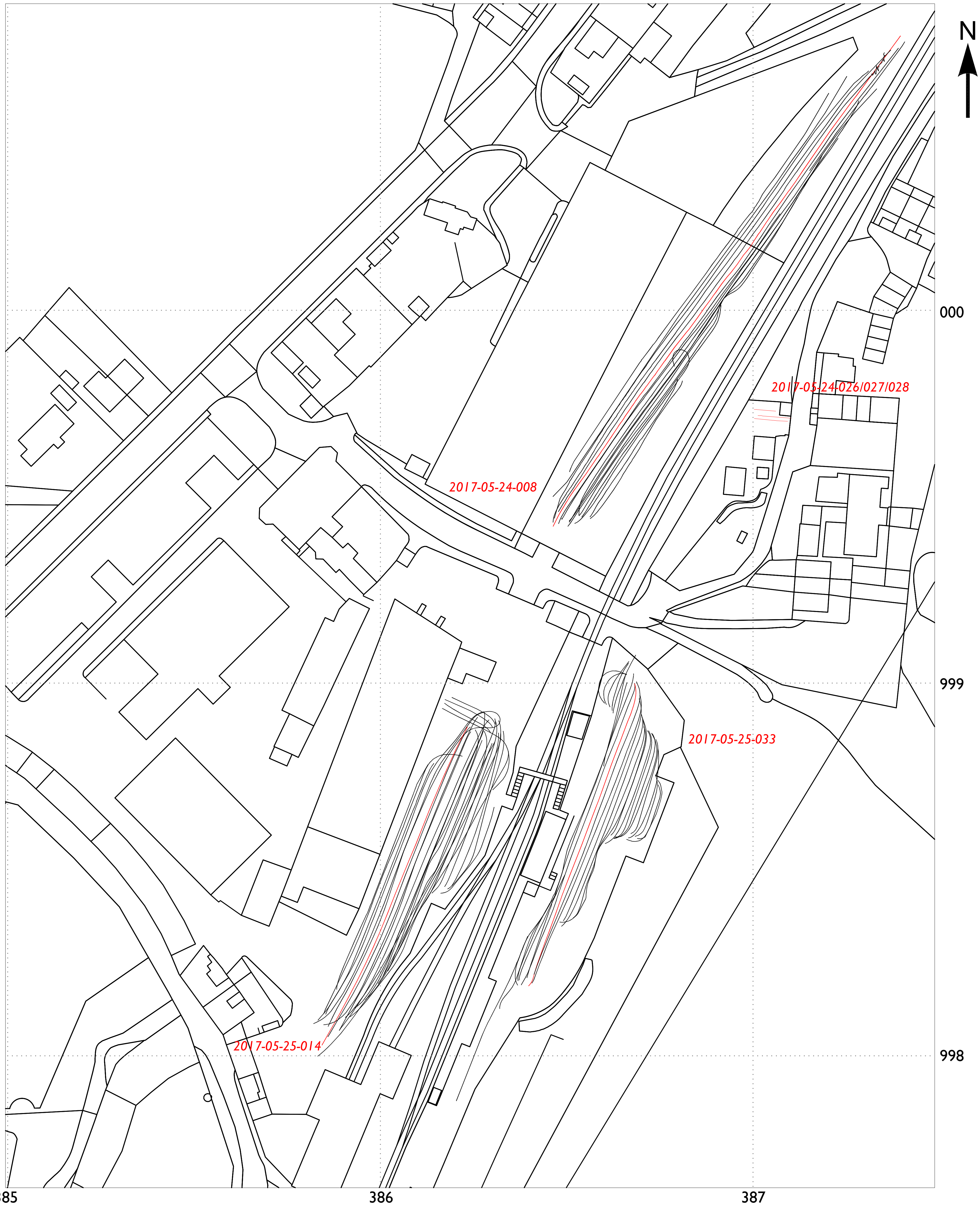
Figure 12

ELSECAR, BARNSLEY
The Greenway, New Colliery and Ironworks,
Location of GPR instrument swaths, May 2017

SE3899



0 60m

1:1000

Ground Penetrating Radar survey swaths

2017-05-24-008 Location of selected GPR profiles shown on Figures 15 and 16

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Figure 13

ELSECAR BARNSLEY
New Colliery GPR amplitude time slice between and 30 and 32.5ns (1.35 - 1.6m), May 2017

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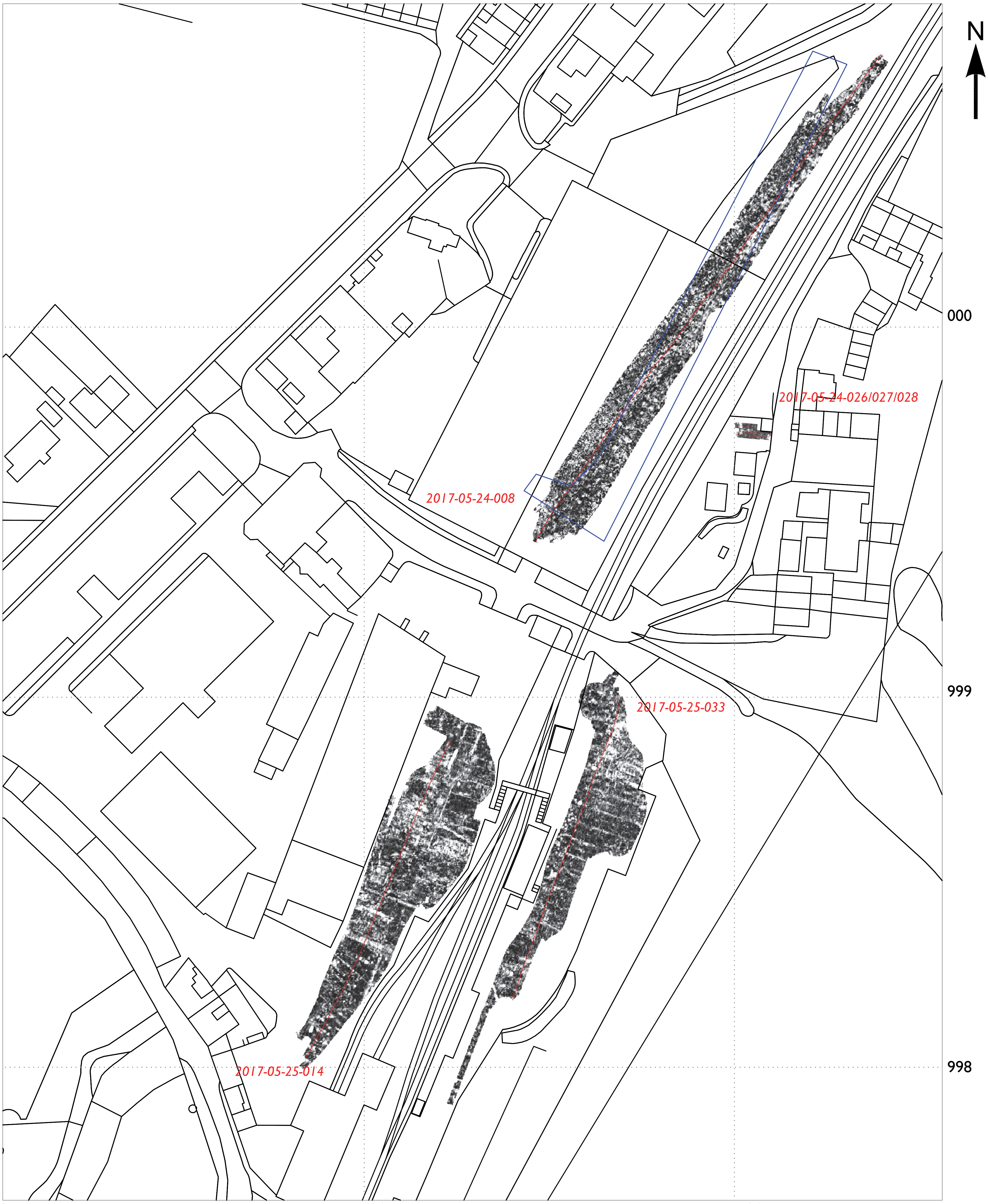
Figure 14

ELSECAR, BARNSLEY
The Greenway, New Colliery and Ironworks
GPR amplitude time slices between 22.5 and 25ns (1.04 - 1.15m), May 2017

SE3899



0 60m

1:1000

Low High
relative reflector strength

approximate location of canal basin

2017-05-24-008 Location of selected GPR profiles shown on Figures 15 and 16

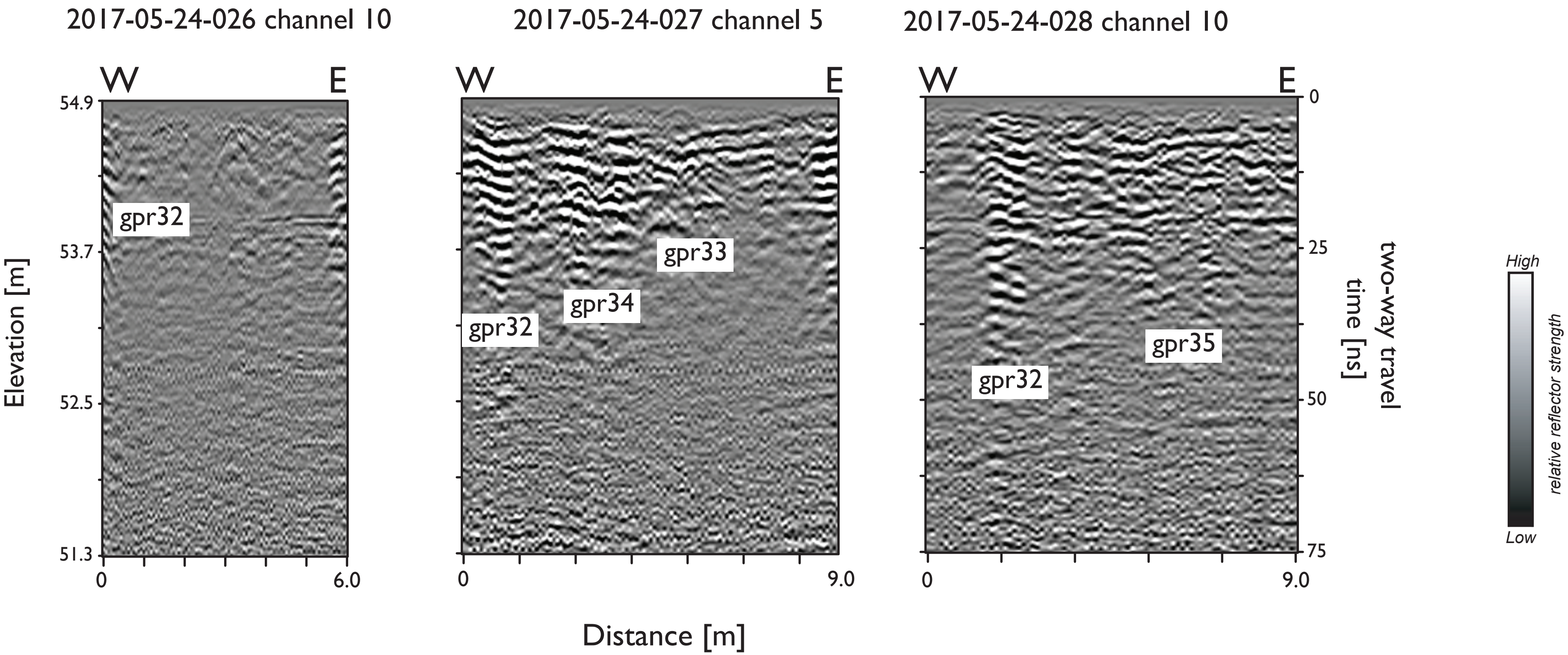
Geophysics Team 2017

Historic England

ELSECAR, BARNSLEY

New Colliery topographically corrected GPR profiles, May 2017

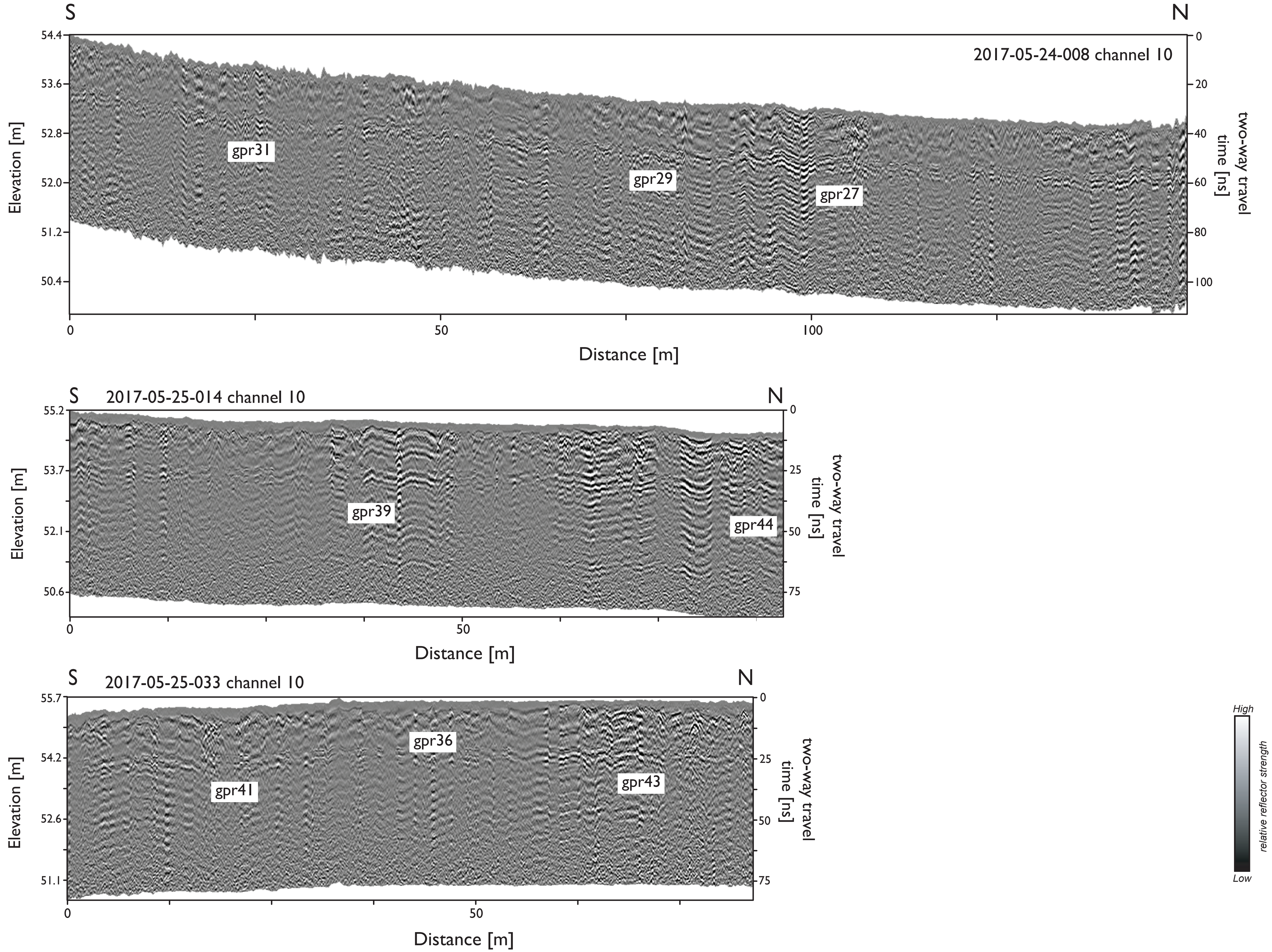
Figure 15



ELSECAR, BARNSLEY

Figure 16

The Greenway and Ironworks topographically corrected GPR profiles, May 2017

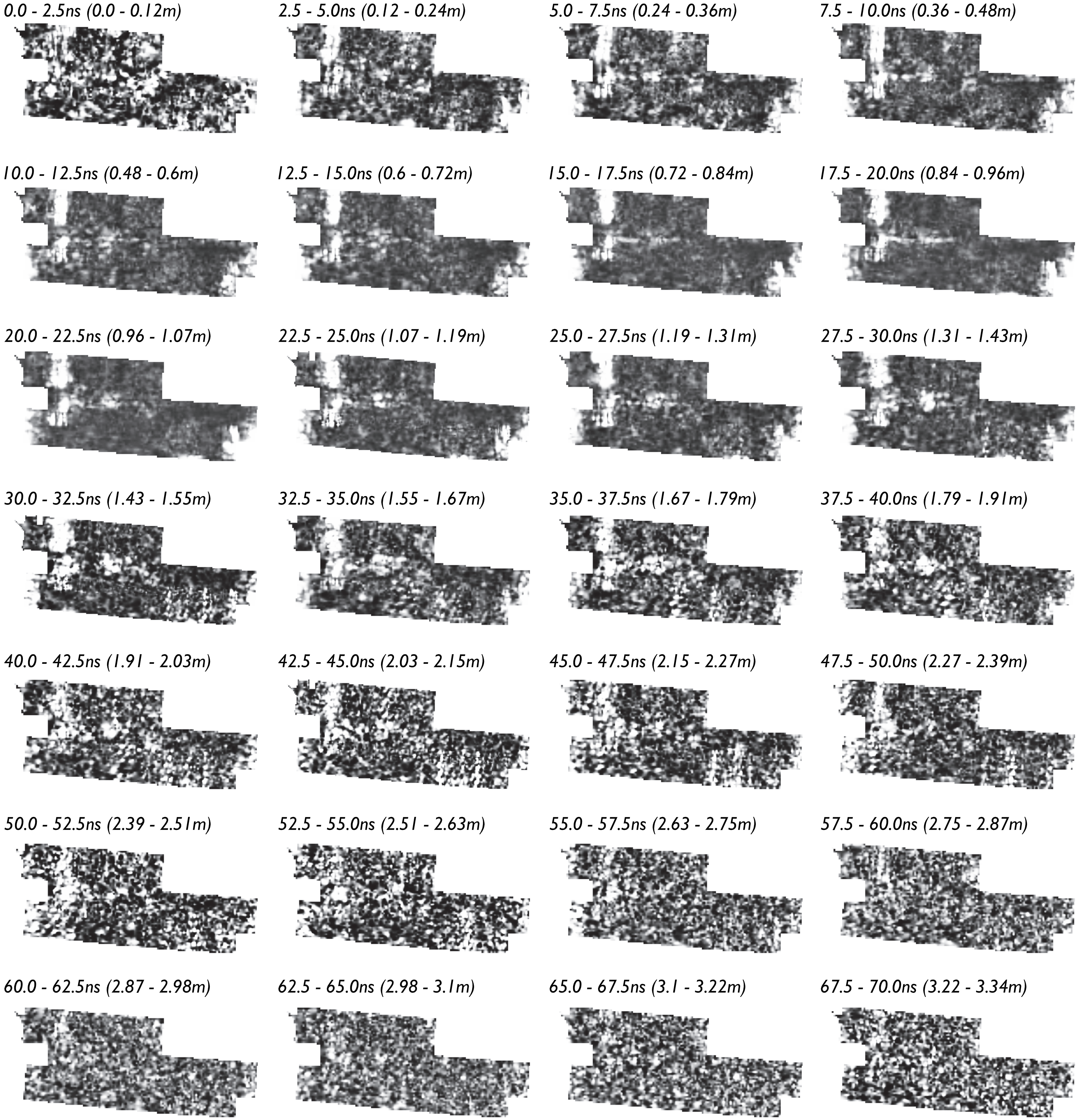


ELSECAR, BARNSLEY

New Colliery GPR data, May 2017

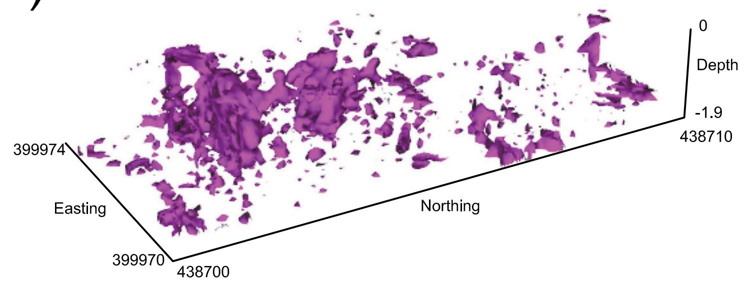
Figure 17

(A)

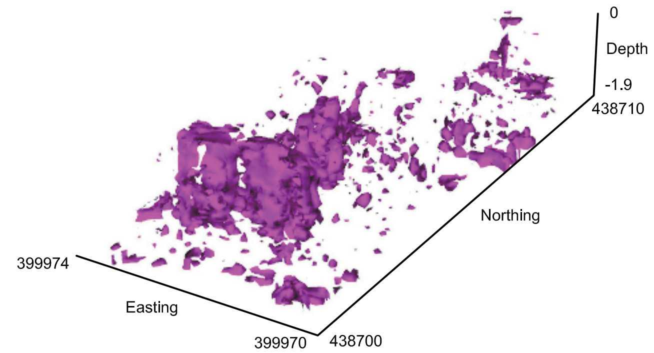


N

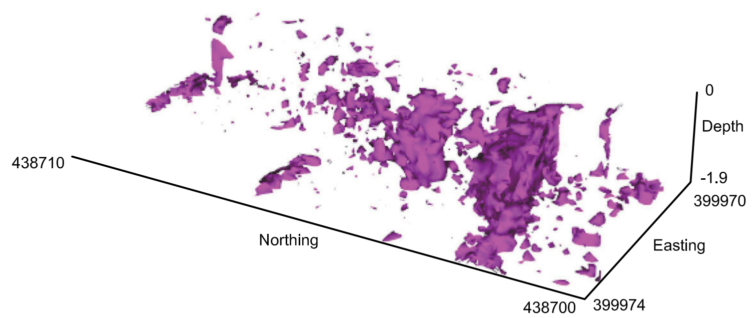
(B)



(C)



(D)



(E)

0 15m

1:200

Low High

relative reflector strength

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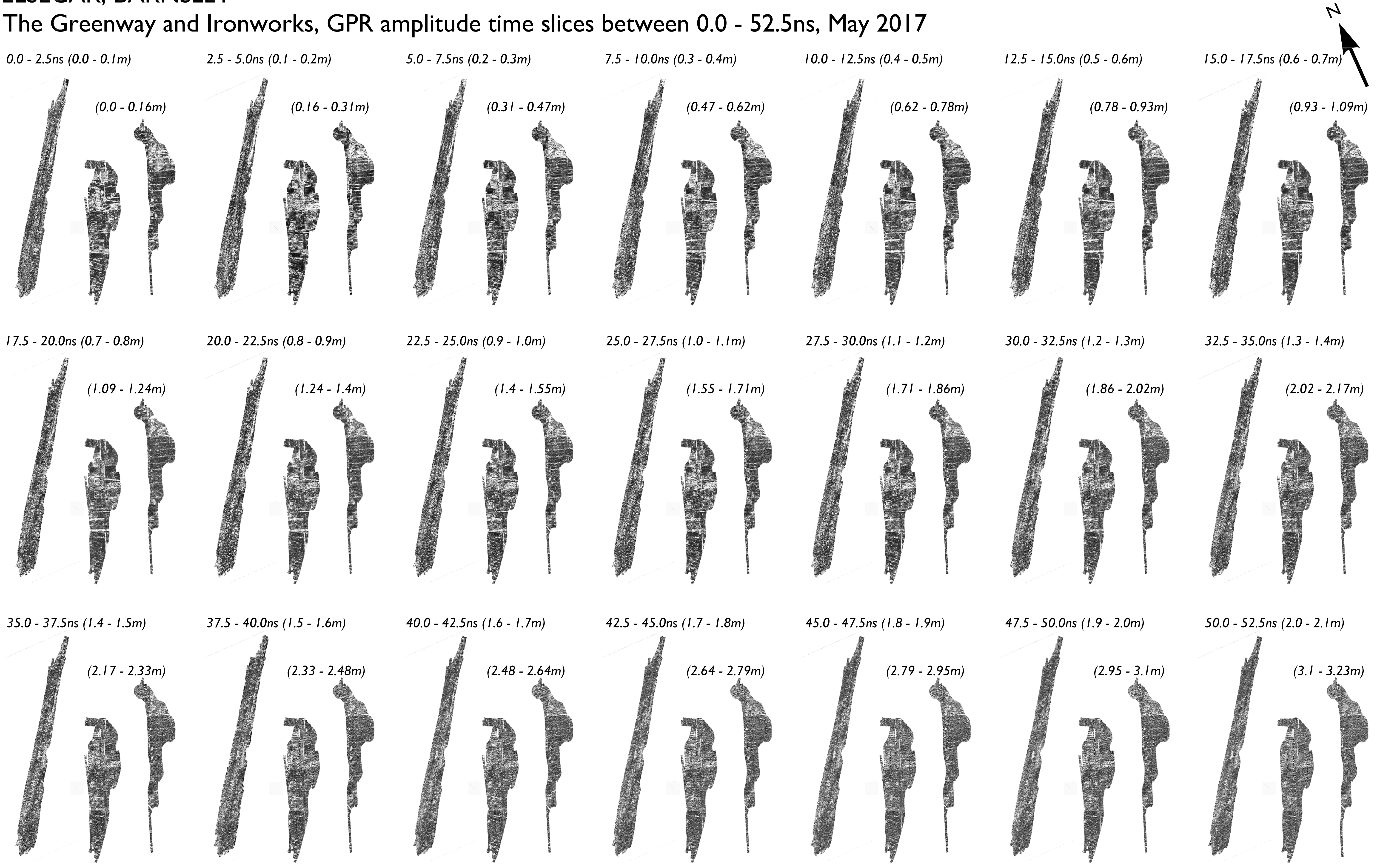
The Greenway and Ironworks, GPR amplitude time slices between 0.0 - 52.5ns, May 2017

Figure 18



Low High
relative reflector strength

0 90m
1:2500

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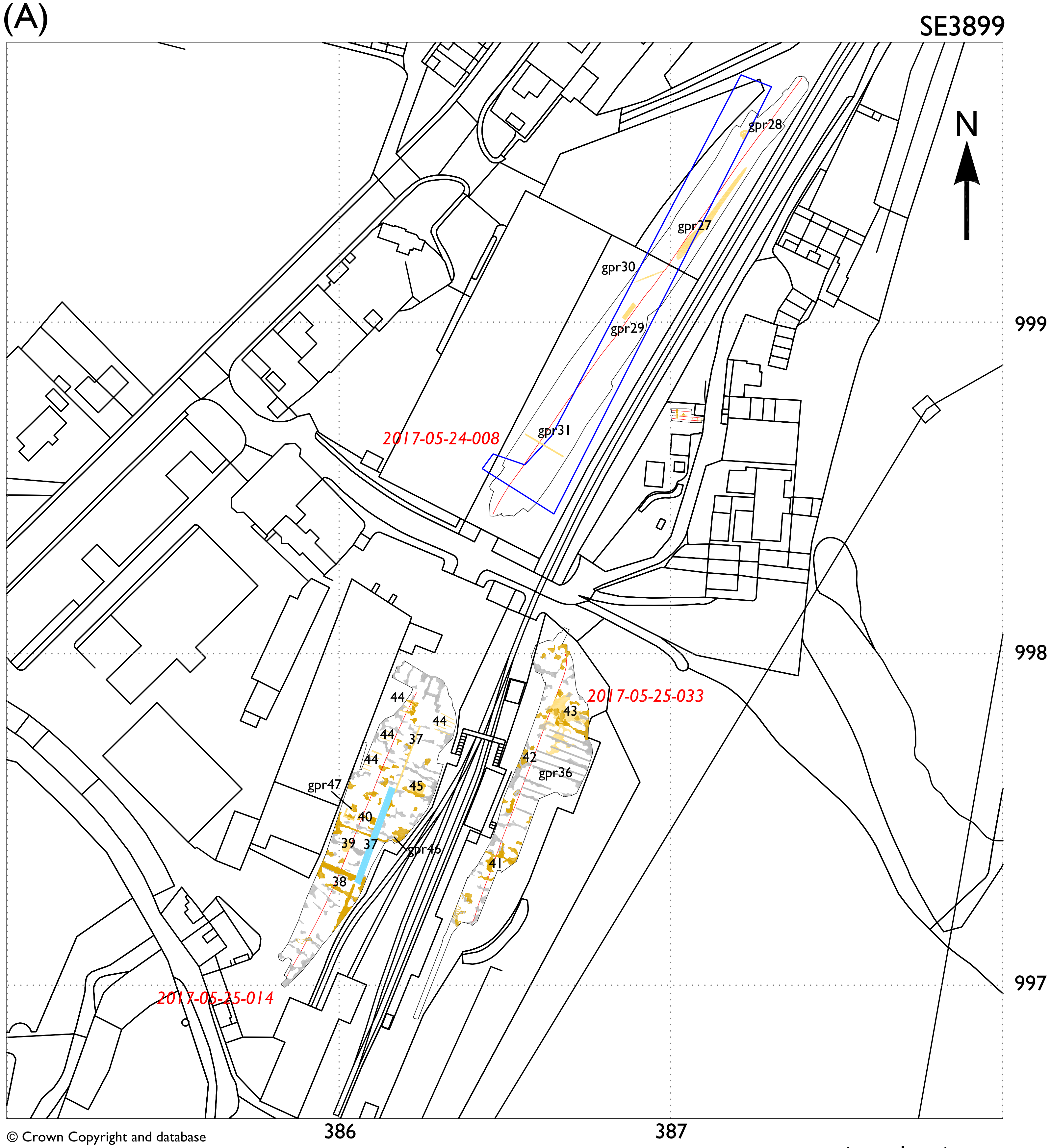
ELSECAR, BARNSLEY

The Greenway, New Colliery and Ironworks, summary of significant GPR anomalies, May 2017

Figure 19

(A)

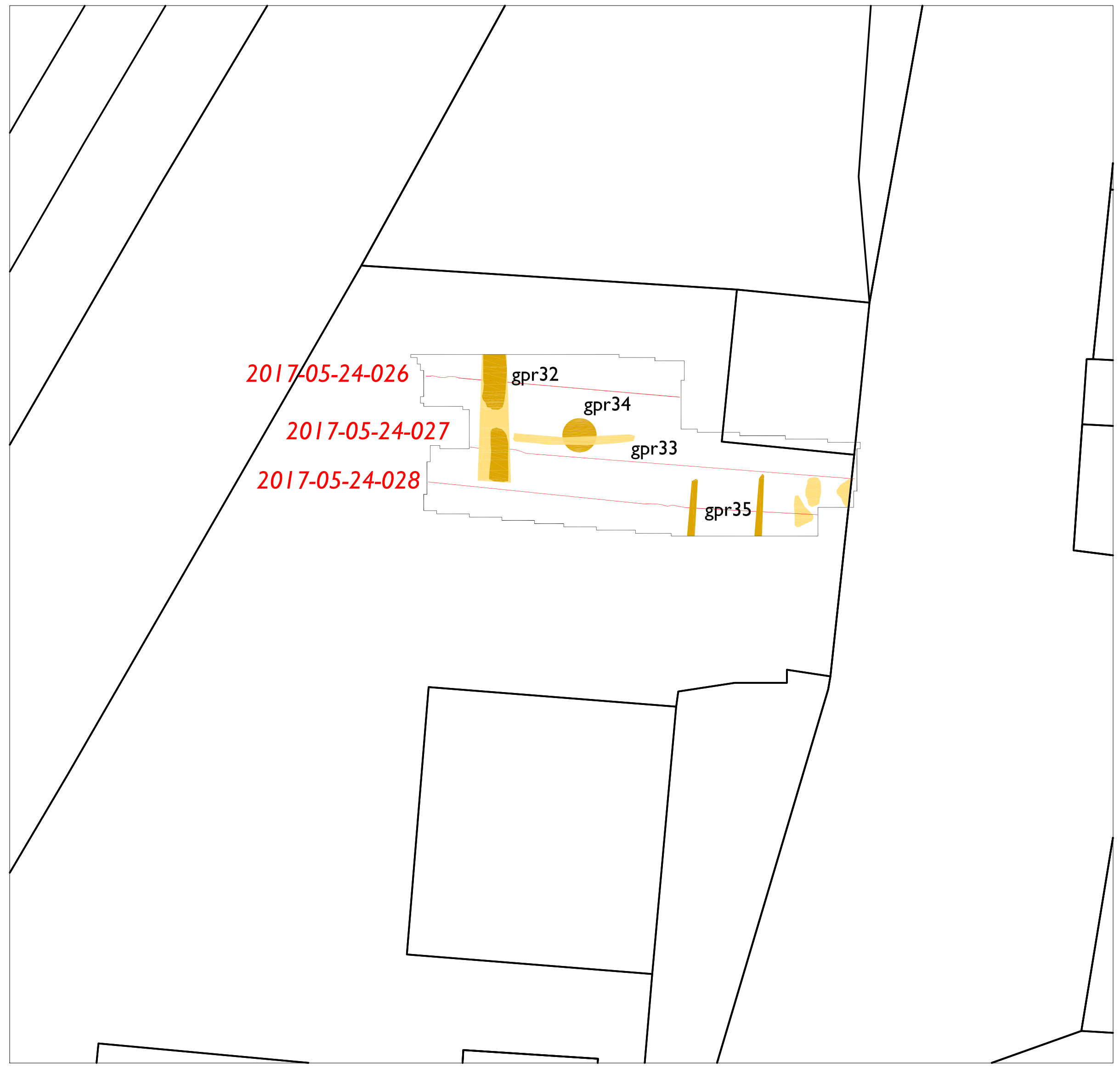


0 60m

1:1500

approximate location of canal basin

(B)



0 6m

1:100

low amplitude reflectors

high amplitude reflectors

anomalies of known or recent origin

2017-05-24-008 Location of selected GPR profiles shown on Figures 15 and 16

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Figure 20

ELSECAR, BARNSLEY
Furnace Field, location of ERT sections, May 2017

0 60m
1:1000

ERT01 - ERT06 Location of ERT sections shown in Figures 21 and 22

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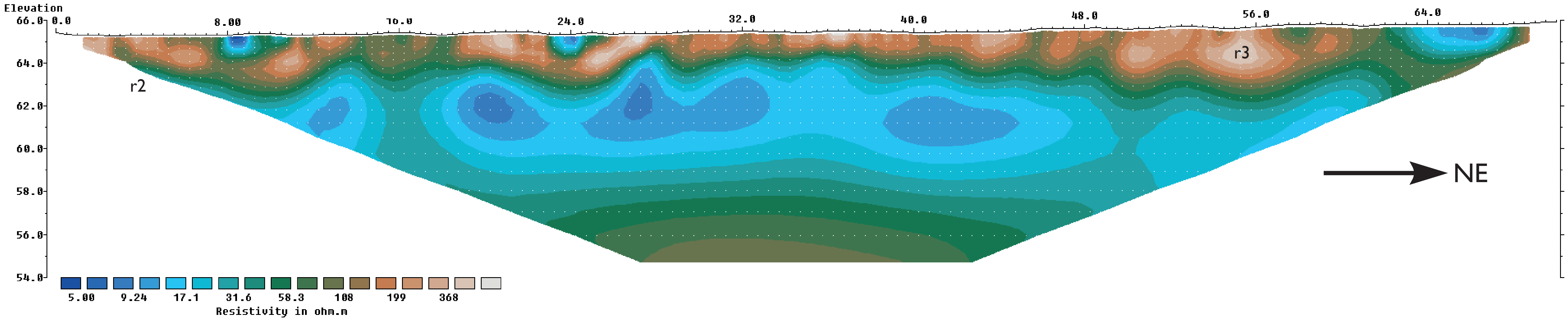
Figure 21

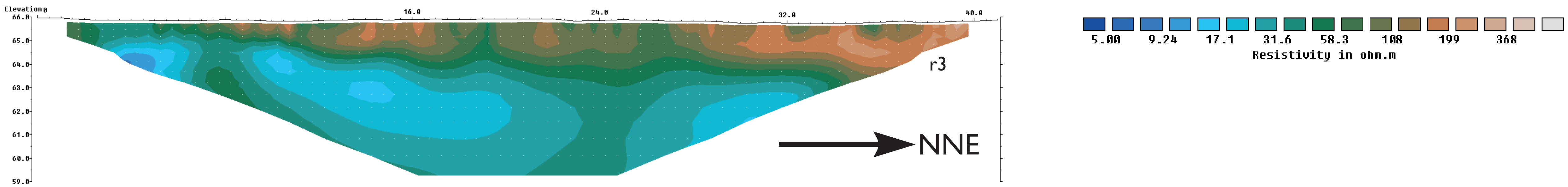
ELSECAR, BARNSLEY

Furnace Field, linear colourscale image of ERT sections 01, 02 and 04 after inversion, May 2017

(A) ERT01: 70m long SW to NE section annotated with significant anomalies r2 and r3 (absolute error between model and field measurements = 7.2%)



(B) ERT02: 41m long SSW to NNE section annotated with significant anomaly r3 (absolute error between model and field measurements = 4.2%)



(C) ERT04: 47m long WSW to ENE section annotated with significant anomalies r2 and r4 (absolute error between model and field measurements = 3.0%)

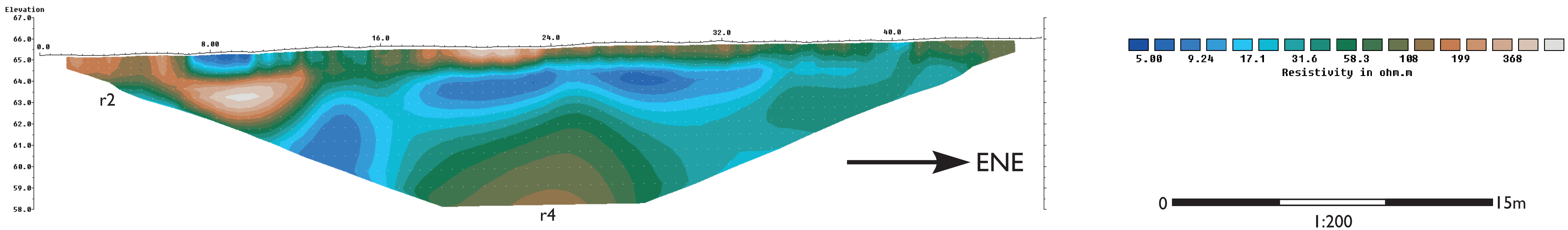


Figure 22

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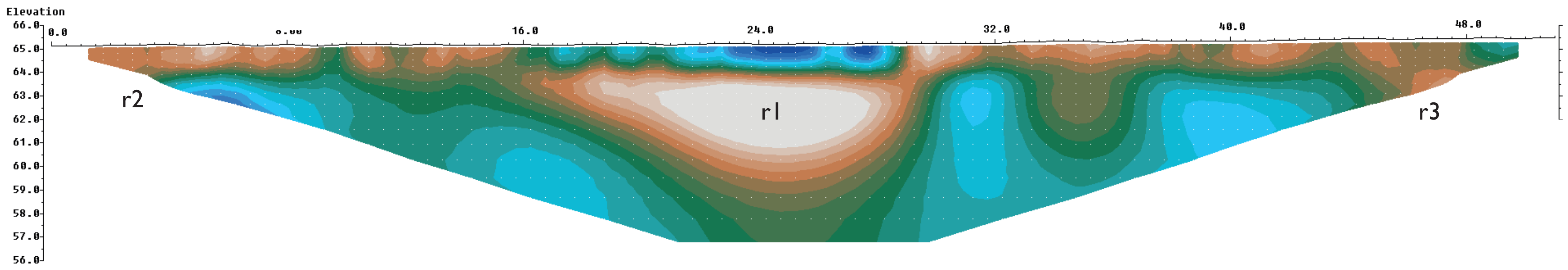
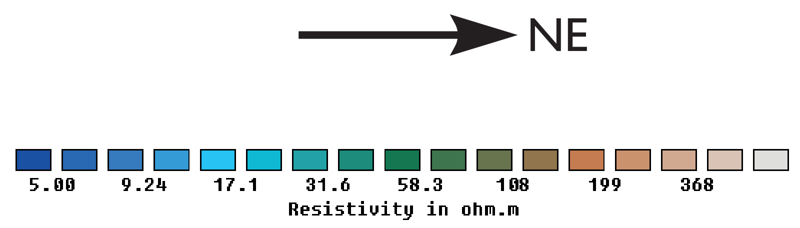
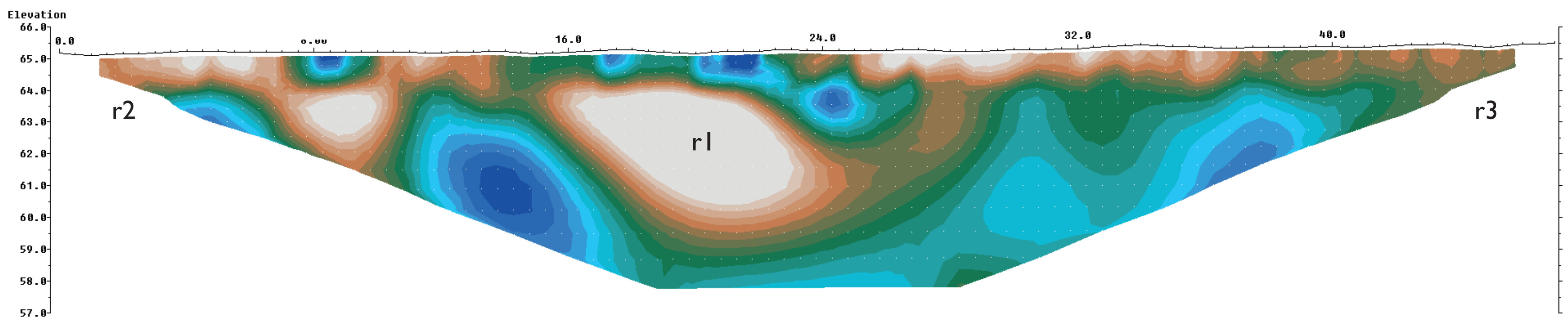
Furnace Field, linear colourscale image of ERT sections 03, 05 and 06 after inversion, May 2017

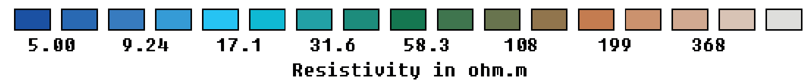
(A) ERT03: 51m long SW to NE section annotated with significant anomalies r1-3 (absolute error between model and field measurements = 8.2%)



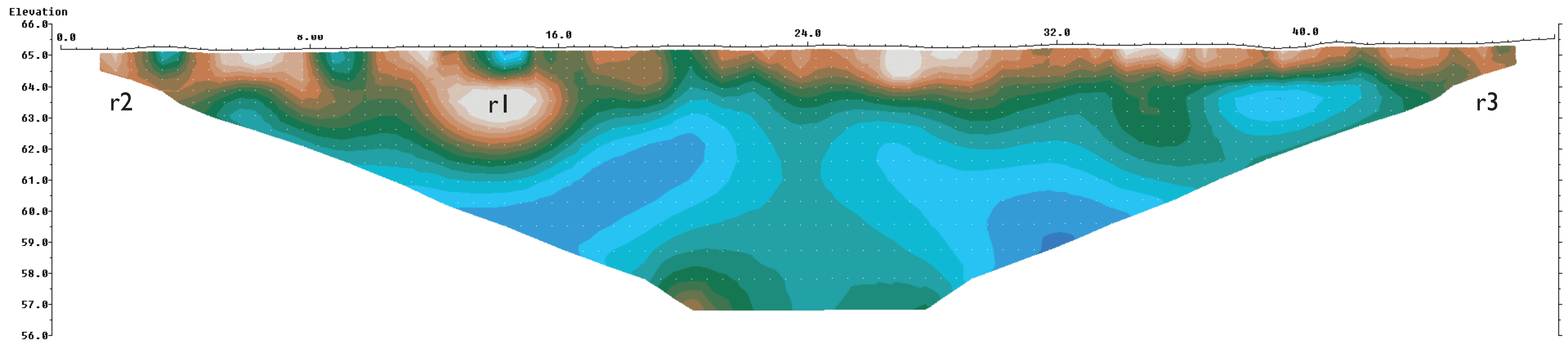


(B) ERT05: 47m long SW to NE section annotated with significant anomalies r1-3 (absolute error between model and field measurements = 6.7%)





(C) ERT06: 48m long SW to NE section annotated with significant anomalies r1-3 (absolute error between model and field measurements = 2.6%)



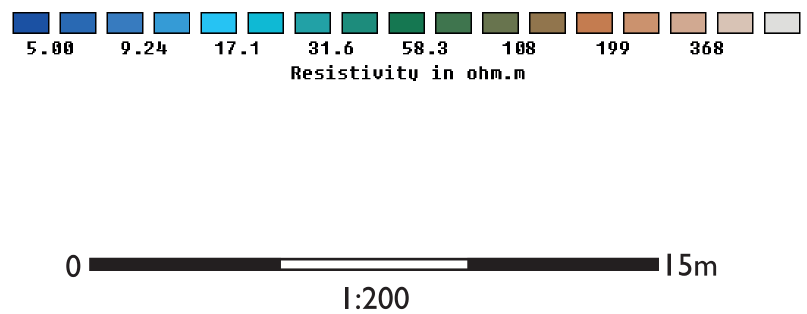


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Figure 23

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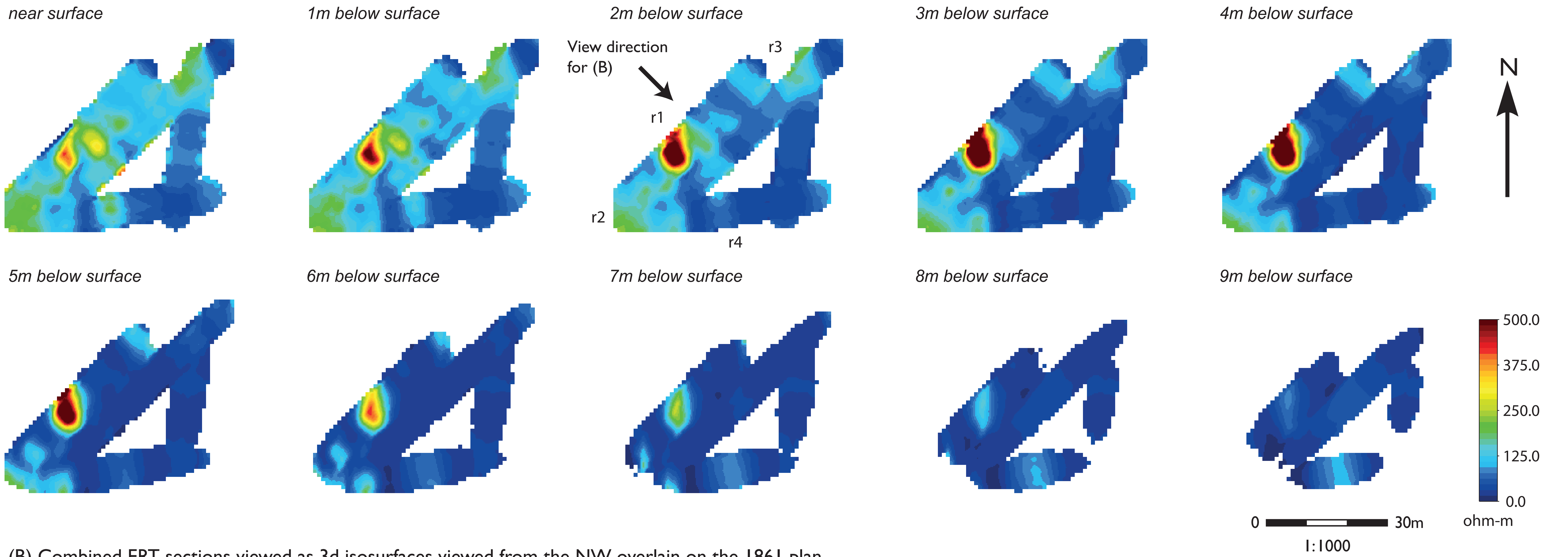
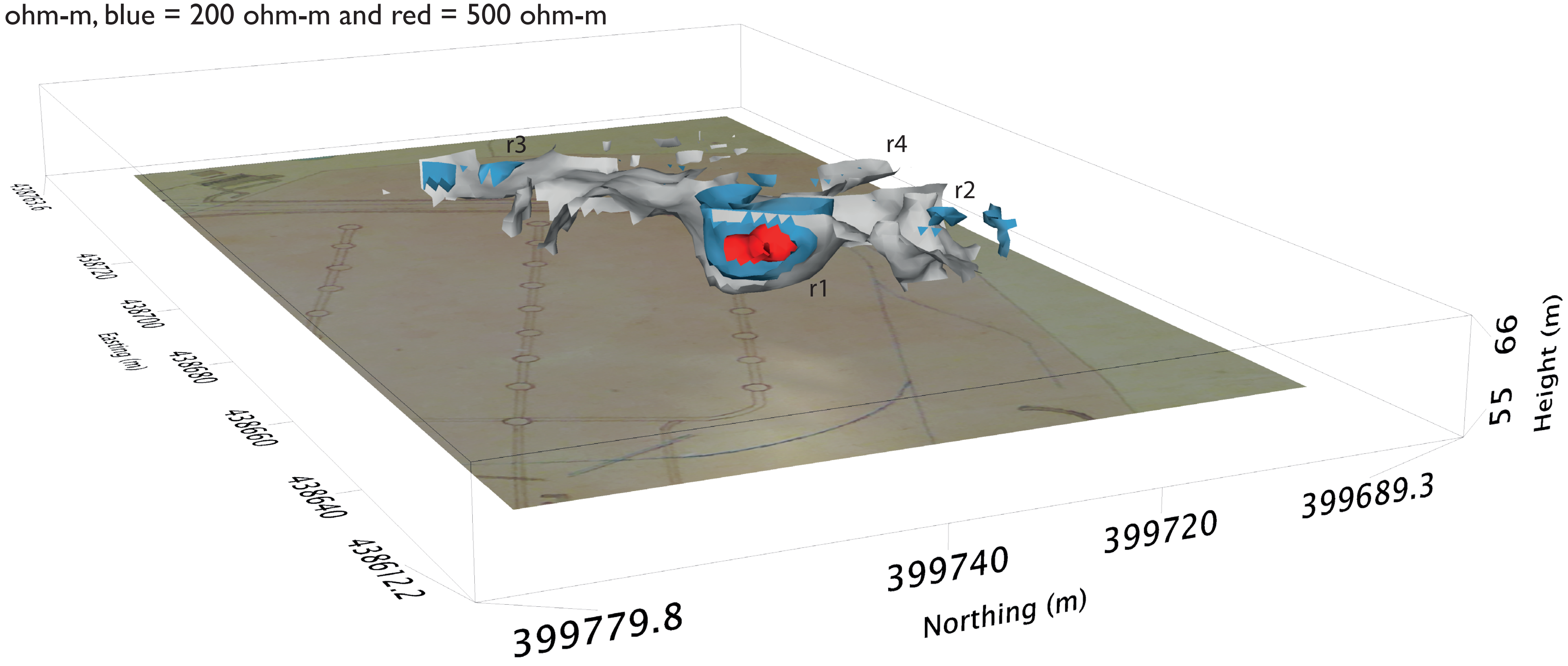
Furnace Field, linear colourscale images of ERT sections after inversion, May 2017

(A) Horizontal depth slices through combined ERT sections



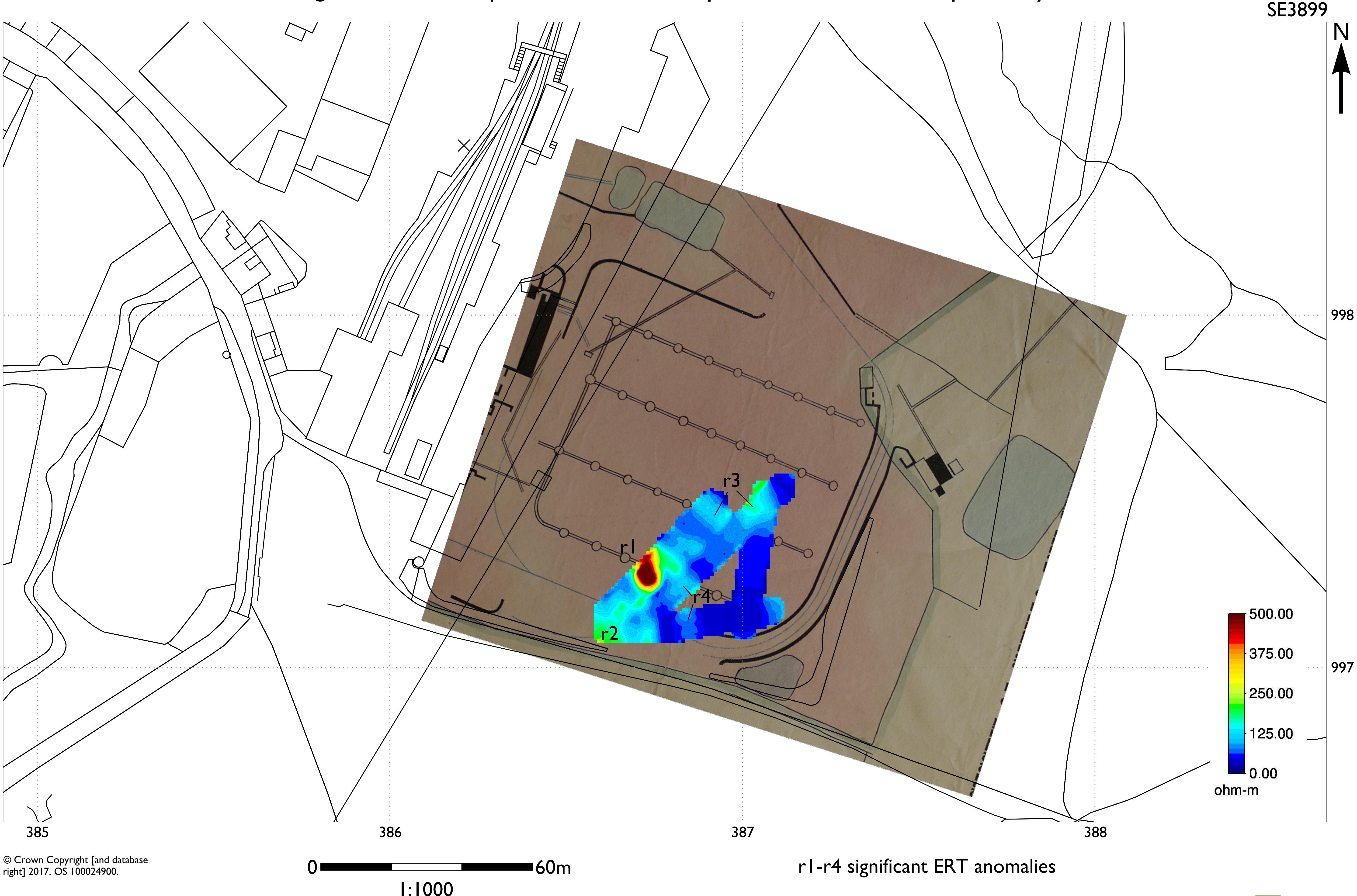
(B) Combined ERT sections viewed as 3d isosurfaces viewed from the NW, overlain on the 1861 plan.
Contours shown as light grey = 100 ohm-m, blue = 200 ohm-m and red = 500 ohm-m



ELSECAR BARNSLEY

Furnace Field, colourscale image of ERT 2m depth slice overlain on portion of 1861 works plan, May 2017

Figure 24



r1-r4 significant ERT anomalies

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