Geophysical Survey Report

Legs Cross, Bolam

County Durham

For

DigVentures

Magnitude Surveys Ref: MSNZ847

OASIS Number: Digventu1-398440

February 2021

Unit 17, Commerce Court

Challenge Way

Bradford

BD4 8NW

01274 926020

info@magnitudesurveys.co.uk

Report By:

Edward Burton BA PCIfA

Report Approved By:

Finnegan Pope-Carter BSc (Hons) MSc FGS

Issue Date:

09 February 2021

Abstract

A fluxgate magnetometer survey was carried out across c. 2.2ha of land at Legs Cross, Bolam, County Durham, to identify potential archaeological features relating to the stone cross, the Roman road (Dere Street) and reported cropmarks within the survey area. Targeted ground-penetrating radar and aerial photogrammetry surveys were also undertaken within the survey area to investigate known earthworks around the cross. The magnetic and GPR data have identified a junction of probable early-medieval land boundaries, three discrete features that could be pits or possibly sunken-featured buildings, and a complex of possible archaeological anomalies possibly relating to archaeological features of unknown date. A number of 'Undetermined' anomalies may also be archaeological in origin. The aerial photogrammetry data has aided the interpretation of the geophysical data, while characterising the morphology of earthworks within the survey area in detail. The data also reflect medieval and post-medieval agricultural activity, including ridge and furrow ploughing systems and drainage features. A probable unmapped post-medieval land boundary has been identified, as well as a series of natural deposits.

Contents

List of Figures

1. Introduction

1.1. Magnitude Surveys Ltd (MS) was commissioned by DigVentures to undertake a geophysical survey over a c. 2.2ha area of land near Legs Cross, Bolam, County Durham (NZ 2071 2244).

1.2. The magnetic survey comprised hand-carried, GNSS-positioned fluxgate gradiometer survey. Magnetic survey is the standard primary geophysical method for archaeological applications in the UK due to its ability to detect a range of different features. The technique is particularly suited for detecting fired or magnetically enhanced features, such as ditches, pits, kilns, sunken featured buildings (SFBs) and industrial activity (David *et al*., 2008).

1.3. The ground penetrating radar survey comprised hand pushed, cart-mounted ground penetrating radar (GPR) survey. MS' Ofcom Ground Probing Radar licence number is 1200059/1.

1.4. The aerial photogrammetric survey comprised UAV-mounted photogrammetry survey and was conducted in line with: CAP393 The Air Navigation Order 2016 and Regulations (CAA 2019); CAP722 Unmanned Aircraft System Operations in UK Airspace – Guidance (CAA 2020); and the conditions of the Permission for Commercial Operation granted to MS by the CA. MS' CAA Operator ID is OP-5QLPK6Q.

1.5. The survey was conducted in line with the current best practice guidelines produced by Historic England (David *et al*., 2008), the Chartered Institute for Archaeologists (CIfA, 2020) and the European Archaeological Council (Schmidt *et al.,* 2015).

1.6. The survey commenced on 20/01/2021. Magnetic and ground penetrating radar surveys were completed on the same day. An aerial photogrammetry survey was completed on 23/01/2021.

2. Quality Assurance

2.1. Magnitude Surveys is a Registered Organisation of the Chartered Institute for Archaeologists (CIfA), the chartered UK body for archaeologists, and a corporate member of ISAP (International Society for Archaeological Prospection).

2.2. The directors of MS are involved in cutting edge research and the development of guidance/policy. Specifically, Dr Chrys Harris has a PhD in archaeological geophysics from the University of Bradford, is a Member of CIfA and is the Vice-Chair of the International Society for Archaeological Prospection (ISAP); Finnegan Pope-Carter has an MSc in archaeological geophysics and is a Fellow of the London Geological Society, as well as a member of GeoSIG (CIfA Geophysics Special Interest Group); Dr Kayt Armstrong has a PhD in archaeological geophysics from Bournemouth University, is a Member of CIfA, the Editor of ISAP News, and is the UK Management Committee representative for the COST Action SAGA; Dr Paul Johnson has a PhD in archaeology from the University of Southampton, has been a member of the ISAP Management Committee since 2015, and is currently the nominated representative for the EAA Archaeological Prospection Community to the board of the European Archaeological Association.

2.3. All MS managers, field and office staff have degree qualifications relevant to archaeology or geophysics and/or field experience.

3. Objectives

3.1. The objective of the survey was "to identify potential archaeological features associated with Legs Cross or the Roman road, or which may relate to other archaeological periods" in order to "inform research aims and objectives for a second stage of archaeological fieldwork, which would ground truth anomalies through a phase of archaeological excavation" (Noon, 2020).

3.2. Specific research questions relating to the geophysical survey (Noon, 2020) included:

3.2.1. Q1: Can any sub-surface archaeology be identified by remote survey associated with the Roman milestone and early medieval cross?

3.2.2. Q2: Can we identify any phasing in the remote sensing anomalies indicative of an extended period of use?

3.2.3. Q4: Can we make any links to the relationship between the cross and early medieval land boundaries?

4. Geographic Background

4.1. The survey area was located c. 750m east of the village of Bolam (Figure 1). Gradiometer survey was undertaken across three targeted survey areas spanning two fields under pasture. The survey area was bounded by Brownside Lane and Bolam Road to the north, and was bisected from north to south by the B6275 (Figure 2).

4.2. Survey considerations:

Survey Area	Ground Conditions	Further Notes
1	Pasture in use for sheep grazing. Flat in the north, gently sloping in the south.	The survey area was bounded by hedgerows with wire fencing to the north and east. The pasture field continued beyond the western and southern boundaries of the survey area. Legs Cross was present on the eastern boundary of the survey area. Ridge-and-furrow earthworks were present on an east-west alignment. An additional banked earthwork was present, aligned parallel and adjacent to the eastern boundary of the field.
2	Pasture in use for sheep grazing. Flat in the west, gently sloping in the east.	The survey area was bounded by hedgerows with wire and sheet metal fencing to the west, and wire fencing to the south. The pasture field continued beyond the northern and eastern boundaries of the survey area. Overhead cables on telegraph poles crossed eastern end of the survey area on a north-south alignment. A line of wire fencing extended eastwards from a sheep pen at the western boundary of the survey area.

3	Pasture in use for sheep grazing. Flat in the north, gently sloping in the south.	The survey area was bounded by hedgerows containing wire fencing to the north and west, with the exception of a short section in the north-west corner, which was bounded by a mortared stone wall. The pasture field continued beyond the southern and eastern boundaries of the survey area.

4.3. The underlying geology comprises sandstone of the Stainmore Foundation. This is overlain by Devensian glacial till deposits. The Armathwaite-Cleveland Dyke, which comprises basaltic andesite, runs on a northwest-southeast alignment c. 120m north of the survey area.

4.4. The soils consist of slowly permeable, seasonally wet, acid loamy and clayey soils (Soilscapes, 2021).

5. Archaeological Background

5.1. The following is a summary of a written scheme of investigation produced and provided by DigVentures (Noon, 2020).

5.1.1. In the centre of the survey area is Legs Cross, an early medieval boundary cross which re-used the site of a Roman milestone, though the Roman foundation stone which originally stood next to the cross is no longer present. The cross is situated on a mound adjacent to and east of a linear earthwork, possibly the extant remains of the Roman Road Dere Street, which may be associated with the boundary of the Anglo-Saxon estate of Gainford.

5.1.2. Linear features identified in the south-west of the survey area on Google Earth satellite imagery, also visible in LiDAR data, have been interpreted as a possible Roman ladder settlement.

5.1.3. Cropmarks identified in the east of the survey area have been interpreted as a possible field system related to an Iron Age settlement.

5.2. The following is a summary of information from available historical mapping.

5.2.1. A pair of small land parcels, containing a building, was recorded on the 1859 Ordnance Survey map immediately northeast of Area 1, within the angle created by the crossroads. By 1970 this building had been removed and the pair of small fields combined. At the time of survey this area comprised a lay-by. A building was also recorded in the north-western corner of Area 3 on 1859 map and had been removed by 1970.

5.2.2. A boundary dividing the field containing Areas 1 and 2 was recorded on the 1857 Ordnance Survey map. On the 1989 Ordnance Survey map this boundary's symbol changed from a solid line to a dashed line, suggesting that a change to the boundary had occurred, or that it had been partially removed. At the time of survey, the boundary could be identified as a banked earthwork.

5.2.3. A trackway was recorded on a west-east alignment running through the centre of Area 1 on the 1857 Ordnance Survey Map. By 1895 this had been revised to a footpath. The route of the track was still a recognised footpath at the time of survey, but no physical remains of a trackway were visible at the surface.

5.2.4. A series of quarries are visible c. 120m northeast of the survey area on the 2nd Edition Ordnance Survey map positioned over the Armathwaite-Cleveland Dyke, (see Section 4.3).

6. Methodology

6.1. Data Collection

6.1.1. Magnetometer surveys are generally the most cost effective and suitable geophysical technique for the detection of archaeology in England. Therefore, a magnetometer survey should be the preferred geophysical technique unless its use is precluded by any specific survey objectives or the site environment. For this site, no factors precluded the recommendation of a standard magnetometer survey. Geophysical survey therefore comprised the magnetic method as described in the following section.

6.1.2. Targeted ground-penetrating radar was also undertaken to characterise and obtain depth information across known earthworks within the survey area. A series of ground penetrating radar profiles, spaced approximately 2m apart, were planned over a c. 40m length of the linear earthwork in the eastern end of Area 1.

6.1.3. Aerial photogrammetric survey was undertaken to create a more detailed surface model of known earthworks within the survey area.

6.1.4. The survey methodology comprised the methods described in the following table.

6.1.5. Table of survey strategies:

Method	Instrument	Traverse Interval	Sample Interval
Magnetic	Bartington Instruments Grad-13 Digital Three-Axis Gradiometer	1m	200Hz reprojected to 0.125m
Ground Penetrating Radar	MALÅ GX HDR with a 450MHz Antenna	2m	0.05m
Aerial Photogrammetry	Zenmuse X7 and 24mm lens kit	Overlap: 70% sideways 80% frontal	1cm/pixel at 60m AGL

The magnetic data were collected using MS' bespoke hand-carried GNSS-positioned system.

6.1.5.1. MS' hand-carried system was comprised of Bartington Instruments Grad 13 Digital Three-Axis Gradiometers. Positional referencing was through a multi-channel, multi-constellation GNSS Smart Antenna RTK GPS outputting in NMEA mode to ensure high positional accuracy of collected measurements. The RTK GPS is accurate to 0.008m + 1ppm in the horizontal and 0.015m + 1ppm in the vertical.

6.1.5.2. Magnetic and GNSS data were stored on an SD card within MS' bespoke datalogger. The datalogger was continuously synced, via an in-field Wi-Fi unit, to servers within MS' offices. This allowed for data collection, processing and visualisation to be monitored in real-time as fieldwork was ongoing.

6.1.5.3. A navigation system was integrated with the RTK GPS, which was used to guide the surveyor. Data were collected by traversing the survey area along the longest possible lines, ensuring efficient collection and processing.

6.1.6. The radar data were collected using a Mala MALÅ GX HDR with a 450MHz Antenna.

6.1.6.1. The radar equipment was set to sample every 0.05m along each line, controlled by the odometer wheel attached to the system. The odometer was distance calibrated at the start of the survey.

6.1.6.2. Traverse lines were separated by approximately 2m. A navigation system was integrated with a Carlson BRx6 RTK GPS, which was used to guide the surveyor. The Carlson BRx6 GNSS Smart Antenna RTK GPS is accurate to 0.008 m + 1 ppm in the horizontal and 0.015 m + 1 ppm in the vertical.

6.1.7. The oblique aerial photographic data were collected using a Zenmuse X7 camera and 24mm lens.

6.1.7.1. The Zenmuse X7 camera was mounted on a gimbal attached to a DJI Matrice M200 GNSS-controlled UAV. The gimbal was tilted downward 70 degrees from the horizon and the platform flown in four directions at 60m above ground level (AGL) to provide a pixel size of 1cm/px.

6.1.7.2. Photographs were collected at timed intervals to provide 80% frontal overlap and 70% side overlap.

6.2. Data Processing

6.2.1. Magnetic data were processed in bespoke in-house software produced by MS. Processing steps conform to the EAC and Historic England guidelines for 'minimally enhanced data' (see Section 3.8 in Schmidt *et al.*, 2015: 33 and Section IV.2 in David *et al.,* 2008: 11).

Sensor Calibration – The sensors were calibrated using a bespoke in-house algorithm, which conforms to Olsen *et al*. (2003).

Zero Median Traverse – The median of each sensor traverse is calculated within a specified range and subtracted from the collected data. This removes striping effects caused by small variations in sensor electronics.

Projection to a Regular Grid – Data collected using RTK GPS positioning requires a uniform grid projection to visualise data. Data are rotated to best fit an orthogonal grid projection and are resampled onto the grid using an inverse distance-weighting algorithm.

Interpolation to Square Pixels – Data are interpolated using a bicubic algorithm to increase the pixel density between sensor traverses. This produces images with square pixels for ease of visualisation.

6.2.2. GPR data were processed in the commercial software package ReflexW. GPR Processing steps were limited to:

DC Shift – The waveform response for each traverse was centred to correct for striping effects caused by small variations in sensor electronics and orientation.

Background Removal – Background 'noise' was filtered out of the data to improve clarity and aid in the detection of weak anomalies.

Gain Adjust – A gain curve was manually calculated to account for signal attenuation with depth. The gain adjust allows features at depth with a weaker signal to be resolved at the same plotting scale as near surface features.

Hyperbola fitting – Manual fitting of hyperbola curves was conducted to calculate the velocity of the wave. This allows the calculation of response depth from response time.

6.2.3. Aerial photographic data were processed in Pix4D Cloud software to produce a digital surface model (DSM). The following additional steps were included:

Noise Filtering – Noise filtering corrects the altitude of erroneous points with the median altitude of the neighbouring points.

Surface Smoothing – Surface smoothing corrects outlying geometry resulting from erroneous points that remain after noise filtering.

6.3. Data Visualisation and Interpretation

6.3.1. This report presents the gradient of the sensors' total field data as greyscale images, as well as the total field data from the lower sensors. The gradient of the sensors minimises external interferences and reduces the blown-out responses from ferrous and other high contrast material. However, the contrast of weak or ephemeral anomalies can be reduced through the process of calculating the gradient. Consequently, some features can be clearer in the respective gradient or total field datasets. Multiple greyscale images of the gradient and total field at different plotting ranges have been used for data interpretation. Greyscale images should be viewed alongside the XY trace plot (Figure 8). XY trace plots visualise the magnitude and form of the geophysical response, aiding anomaly interpretation.

6.3.2. The individual GPR radargrams were visualised in ReflexW. The profile spacing of the survey was too coarse to produce time-slice images, so an indicative radargram is presented in this report.

6.3.3. Geophysical results have been interpreted using greyscale images and XY traces in a layered environment, overlaid against open street maps, satellite imagery, historical maps, LiDAR data, and soil and geology maps. Google Earth (2021) was also consulted, to compare the results with recent land use.

6.3.4. The photogrammetric DSM was visualised in a layered GIS environment as a hillshade using a range of values for light source angle and altitude to identify topographic features. The Z factor was also altered to exaggerate their appearance. Identical parameters were used to visualise Environment Agency LiDAR DTM data to compare the two datasets.

6.3.5. Geodetic position of results – All vector and raster data have been projected into OSGB36 (ESPG27700) and can be provided upon request in ESRI Shapefile (.SHP) and Geotiff (.TIF) respectively. Figures are provided with raster and vector data projected against OS Open Data.

7. Results

7.1. Qualification

7.1.1. Geophysical results are not a map of the ground and are instead a direct measurement of subsurface properties. Detecting and mapping features requires that said features have properties that can be measured by the chosen technique(s) and that these properties have sufficient contrast with the background to be identifiable. The interpretation of any identified anomalies is inherently subjective. While the scrutiny of the results is undertaken by qualified, experienced individuals and rigorously checked for quality and consistency, it is often not possible to classify all anomaly sources. Where possible, an anomaly source will be identified along with the certainty of the interpretation. The only way to improve the interpretation of results is through a process of comparing excavated results with the geophysical reports. MS actively seek feedback on their reports, as well as reports from further work, in order to constantly improve our knowledge and service.

7.2. Discussion

7.2.1. The geophysical and photogrammetric results are presented in combination with satellite imagery and historical maps (Figure 6) and Environment Agency LiDAR Data (Figure 7).

7.2.2. The fluxgate magnetometer survey was successfully undertaken across 2.2ha of land at Legs Cross, Bolam, County Durham. The survey has identified a number of potential archaeological features in the vicinity of Legs Cross, some of which are associated with earthworks within the survey area. The survey area's varied magnetic background included some spreads of discrete anomalies which are likely the result of superficial deposits. However, it was possible to identify weak linear anomalies within these spreads, so the impact of this background disturbance on interpretation confidence was only slight. Magnetic interference from modern sources was limited to 'haloes' of strong magnetic signal caused by extant fencing material at the edges of the survey areas.

7.2.3. A series of ground penetrating radar profiles, spaced approximately 2m apart, were successfully collected over a c. 40m length of the linear earthwork in the eastern end of Area 1 in order to support the magnetic interpretation. The GPR survey has responded well to the environment of the survey area, with evidence of good signal penetration to around 2m below ground level.

7.2.4. An aerial photogrammetric survey was successfully undertaken over Areas 1 and 3. The data has been used to characterise earthworks within the survey area in greater detail than would be possible with available Environment Agency LiDAR data. The photogrammetric data has been used to aid the interpretation of the geophysical results.

7.2.5. Anomalies of probable and possible archaeological origin have been identified in the survey results. Magnetic anomalies have been identified following a known linear earthwork running through the centre of the site. Possible subsurface extensions of this feature to the east and west of the cross have been identified in the magnetic data, but these were not identified as earthwork features in the photogrammetric data. The photogrammetric data has generated a more detailed surface model of the earthworks than available LiDAR data, although no 'new' features have been identified that were not already visible. The radar data has not identified any specific structural features within the earthwork, but rather fill material within the bank itself. The earthwork feature does appear to continue towards the northwest beyond the survey area, as a curving field boundary that extends some distance beyond the survey area to the northwest. That boundary was recorded as an administrative boundary in the Second Edition Ordnance Survey Map (Figure 6), while the current route of the B6275 continues north on a straight orientation, which is traditionally associated with Roman roads. Therefore, an explanation of the earthwork and associated geophysical anomalies as boundary features is considered more likely than as an intact section of Dere Street as has been suggested (see Section 5.1.1).

7.2.6. In the east of Area 3, a group of possible archaeological magnetic anomalies which may represent ditched features has been identified, which may extend beyond the survey area to the north and/or east. It is uncertain whether these are associated with cropmarks in the vicinity of Area 3 (see section 5.1.3). Additionally, three large discrete magnetic anomalies have been identified within Area 3, which are indicative of cut features filled with magnetically-enhanced material, such as pit features or possibly sunken-featured buildings.

7.2.7. Elsewhere, the magnetic data reflects the site's agricultural use, including ridge and furrow ploughing trends and drainage features. Many of these correspond with features visible on the Environment Agency LiDAR data and the photogrammetric survey data. Anomalies relating to a probable land boundary not recorded in historical mapping have been identified in the east of the survey area, enclosing a small parcel of land around a building in the angle between the B6275 and Bolam Road.

7.2.8. A number of 'Undetermined' anomalies have been identified within the survey area, where a specific interpretation cannot be made based on the anomaly's shape, location or magnetic signal, or where there is a possibility the anomaly reflects a natural feature. An archaeological origin for these cannot be entirely ruled out, especially where they are close in proximity to anomalies which have been classified as probable or possible archaeological features.

7.2.9. In relation to the research questions outlined in Section 3.2:

7.2.9.1. Q1: "Can any sub-surface archaeology be identified by remote survey associated with the Roman milestone and early medieval cross?". Potential sub-surface archaeological features have been detected in the vicinity of the cross, including a possible junction of boundary features in Area 1, but no association with the Roman milestone or early-medieval cross has been identified within the geophysical data.

7.2.9.2. Q2: "Can we identify any phasing in the remote sensing anomalies indicative of an extended period of use?". The magnetic anomalies which have been identified do not overlap, which would typically indicate multiple phases of activity in the same position, though multiple phases of activity are also possible without these cross-cutting relationships. The cross is located on a series of earthworks which share similar sub-surface geophysical characteristics, as is illustrated in the radar data (Figure 13). The data do not indicate any re-working of the linear earthwork and the mound on which the cross is positioned.

7.2.9.3. "Q4: Can we make any links to the relationship between the cross and early medieval land boundaries?". While potential sub-surface archaeological features have been identified and interpreted as possible boundaries, no direct relationship to the cross itself has been identified from the geophysical data.

7.3. Interpretation

7.3.1. General Statements

7.3.1.1. Geophysical anomalies will be discussed broadly as classification types across the survey area. Only anomalies that are distinctive or unusual will be discussed individually.

7.3.1.2. **Ferrous (Spike)** – Discrete dipolar anomalies are likely to be the result of isolated pieces of modern ferrous debris on or near the ground surface.

7.3.1.3. **Magnetic Disturbance** – The strong anomalies produced by extant metallic structures, typically including fencing, pylons, vehicles and service pipes, have been classified as 'Magnetic Disturbance'. These magnetic 'haloes' will obscure weaker anomalies relating to nearby features, should they be present, often over a greater footprint than the structure causing them.

7.3.1.4. **Undetermined** – Anomalies are classified as Undetermined when the origin of the geophysical anomaly is ambiguous and there is no supporting contextual evidence to justify a more certain classification. These anomalies are likely to be the result of geological, pedological or agricultural processes, although an archaeological origin cannot be entirely ruled out. Undetermined anomalies are generally distinct from those caused by ferrous sources.

7.3.2. Magnetic Results - Specific Anomalies

7.3.2.1. **Archaeology Probable and Possible (Linear Earthwork) –** At the eastern end of Area 1, a linear group of strong discrete anomalies [**1a**] has been identified, which follows the course of a raised linear earthwork. This earthwork is visible in both Environment Agency LiDAR data and in the aerial photogrammetry data (Figures 4, 5, 7, 12). The magnetic anomalies are likely caused by deposits of material within the earthwork itself. The magnetic signal of these anomalies is not consistent with ceramic building material, which is typically stronger and dipolar (Figure 8). Additional curving alignments of magnetically similar anomalies [**1b**] and [**3a**] extend northwest and northeast of [**1a**], but with no associated surface earthworks. [**3a**] has been classified as 'possible' archaeology as it is not directly connected to [**1a**].

7.3.2.2. **Archaeology Possible (Linear and Discrete Anomalies) –** In the north-eastern corner of Area 3 are a group of linear and discrete anomalies covering an area c. 35m x 35m (Figures 4 and 5). It is possible that these anomalies extend to the north and west of Area 3. Their shape and magnetic signal are more consistent with anthropogenic features than natural ones (Figure 8) and are typical of anomalies relating to cut features such as ditches and pits that are backfilled with more magnetically enhanced material. Therefore, these have been interpreted more broadly as possibly archaeological in origin.

7.3.2.3. **Archaeology Possible (Discrete Anomalies) –** Within Area 3 are three discrete anomalies, [**3c**], [**3d**] and [**3e**], which are high in magnetic field strength, with a broad signal peak shape which is not consistent with the natural magnetic background in this area (Figures 4, 5, 8). Such a magnetic signal is more likely to relate to a cut feature containing magnetically-enhanced fill material, which could be anthropogenic in origin. Anomaly [**3c**] is sub-rectangular in shape measuring c. 6m x 3m; this shape and size would be consistent with an early-medieval sunken featured building, though as it is an isolated example, this is quite a tentative interpretation. Anomaly [**3d**] shares similar morphological and geophysical characteristics with [**3c**], though its full extent appears to be masked by the limit of the survey area. Anomaly [**3e**] is also similar to [**3c**] in shape, size and magnetic signal shape, though its field strength is lower than that of [**3c**] and [**3d**].

7.3.2.4. **Undetermined (Strong, Weak) –** In the west of Area 3, a dispersed grouping of strong amorphous anomalies [**3g**] has been identified which broadly follows a break of slope parallel to the B6275 (Figures 4, 5 and 10). Many of the anomalies [**3g**] are different from [**1a**], [**1b**], and [**1c**] in that their edges are more diffuse, and they do not exhibit a weak negative 'halo' around them. The diffuse edges are generally more indicative of variation in superficial deposits than cut features, but an anthropogenic origin cannot be ruled out.

7.3.2.5. **Agricultural (Strong) –** A linear alignment of strong anomalies has been identified in the north-western corner of Area 3 [**3f**] (Figure 4 and 5). Its alignment and size suggests an extension of the boundary demarcating a land parcel recorded on historical maps west of B6275 (Figure 6). Additionally, [**3f**] extends from either end of a right-angled section of extant stone wall at the north-western boundary of Area 3, which was recorded in the photogrammetric data (Figures 10, 11, and 12). Together they could have formed a triangular land parcel around the building mapped at the north-western corner of Area 3, so [**3f**] has been interpreted as an unrecorded land boundary. The ferrous anomalies northwest of [**3f**] are probably associated with the construction or demolition of the building recorded on historical mapping in the north-western corner of Area 3 (Figure 6), or more general alteration of the land between the building and boundary [**3f**].

7.3.2.6. **Ridge and Furrow (Trend) –** Weak curvilinear trends have been identified in Areas 1 and 2 which are indicative of ridge and furrow cultivation. The alignment and position of these correspond with earthworks visible in LiDAR data, and the aerial photogrammetric data (Figures 4, 5, 7, 9, and 10).

7.3.2.7. **Agricultural (Strong, Weak) –** Linear anomalies [**1c**] and [**2a**] follow the alignment of adjacent ridge and furrow ploughing trends but are broader. They may represent contemporary plough furrows that were re-used as agricultural boundaries or drainage feature (Figures 4 and 5).

7.3.2.8. **Drainage Features –** In Areas 1 and 2, a number of linear anomalies and trends have been identified and interpreted as drainage features. For some anomalies this was based on their straight shape, regular distribution, or their collocation with linear negative topographic features visible in LiDAR data (Figures 4, 5 and 7). For others it was based on their magnetic signal, which was either negative (suggesting a less-magnetic construction such as stone or plastic), or an alignment of dipoles (indicating a buried fired clay drain).

7.3.2.9. **Natural (Strong, Weak, Zone)** – In the centre of Area 2 is a fan-shaped group of broad anomalies of varying field strength. They are located across an area of gently sloping terrain, including a shallow depression which was covered in surface water at the time of survey (see section 4.2). The anomalies lie downslope of a number of gully-like topographic features visible in LiDAR data to the northwest (Figure 7). This anomaly group may therefore represent deposits of material from fluvial events. Across the survey area, several spreads of small discrete anomalies have been identified which are characteristic of variation in the type of superficial geology here.

7.3.2.10. **Undetermined (Weak) –** In the south-western corner of Area 1 are two weak curvilinear anomalies suggestive of buried ditch features [**1d**] (Figures 4 and 5). They have been interpreted as 'Undetermined' in origin as they are located within a natural 'zone' of magnetic . Anomalies [**1d**] may be coincidental, but an archaeological origin cannot be ruled out.

7.3.2.11. **Undetermined (Strong, Weak) –** In the northern end of Area 1 is a large, dipolar discrete anomaly [**1e**] (Figures 4, 5 and 8). It may represent a buried magnetic object or a concentrated deposit of magnetically-enhanced, ferrous, or burnt-fired material. Without further contextual information, it has been classified as 'Undetermined' in origin.

7.3.3. GPR Results – General Statements

7.3.3.1. Ground penetrating radar data profiles were collected perpendicular to the earthwork in Area 1. No structural features within the earthwork were identified, but subsurface reflections generally following the surface topography across the earthworks were identified at a depth ranging from 10cm to 75cm; these are likely the interface between two layers of the earthwork's construction. While traverse spacing was too coarse to create time slices, the radargrams were relatively uniform along the length of the earthwork, so an indicative radargram has been included in this report (Figure 13).

8. Conclusions

8.1. A fluxgate magnetometer survey was successfully carried out across the c. 2.2ha survey area. A series of ground penetrating radar profiles were successfully collected over the earthwork in the centre of the survey area, and an aerial photogrammetry survey was successfully carried out over Areas 1 and 2.

8.2. Magnetic interference from modern infrastructure was minimal. The site's varied natural background slightly impacted confidence in the interpretation of some magnetic anomalies, where weak or small discrete anomalies were located within or near superficial deposits, leading to the classification of some anomalies as 'undetermined' in origin, though an archaeological cause of these cannot be ruled out.

8.3. Magnetic anomalies relating to construction of the known banked earthwork have been identified, along with two possible extensions to the west and east. These anomalies have been interpreted as a junction of early-medieval land boundaries in the vicinity of the cross. The photogrammetry survey has aided the magnetic interpretation and provided a more detailed surface model of the earthworks. The interface between two layers of material within the earthwork has been identified in the radar data.

8.4. In the northeast of the survey area a group of possibly archaeological anomalies of unknown date has been identified, as well as three larger discrete anomalies which may represent pits or sunken-feature buildings.

8.5. A probable unmapped post-medieval land boundary has been identified enclosing a small area of debris at the junction between Bolam Road and the B6275. Elsewhere, the magnetic survey results have identified ridge and furrow ploughing, drainage features, and natural deposits.

9. Archiving

9.1. MS maintains an in-house digital archive, which is based on Schmidt and Ernenwein (2013). This stores the collected measurements, minimally processed data, georeferenced and un-georeferenced images, XY traces and a copy of the final report.

9.2. MS contributes reports to the ADS Grey Literature Library upon permission from the client, subject to any dictated time embargoes.

10. Copyright

11. References

British Geological Survey, 2021. Geology of Britain. Bolam, County Durham. [http://mapapps.bgs.ac.uk/geologyofbritain/home.html/]. Accessed 21/01/2021.

CAA, 2019. The Air Navigation Order 2016 and Regulations. CAP 393: 5th Edition, amended 13th March 2019.

CAA, 2020. Unmanned Aircraft System Operations in UK Airspace – Guidance. CAP 722: Eighth Edition, 5 November 2020.

Chartered Institute for Archaeologists, 2020. Standards and guidance for archaeological geophysical survey. CIfA.

David, A., Linford, N., Linford, P. and Martin, L., 2008. Geophysical survey in archaeological field evaluation: research and professional services guidelines (2nd edition). Historic England.

Google Earth, 2021. Google Earth Pro V 7.1.7.2606.

Noon, S. 2020. Legs Cross, Bolam: Written scheme of investigation for geophysical and photogrammetric survey. DigVentures.

Olsen, N., Toffner-Clausen, L., Sabaka, T.J., Brauer, P., Merayo, J.M.G., Jorgensen, J.L., Leger, J.M., Nielsen, O.V., Primdahl, F., and Risbo, T., 2003. Calibration of the Orsted vector magnetometer. Earth Planets Space 55: 11-18.

Schmidt, A. and Ernenwein, E., 2013. Guide to good practice: geophysical data in archaeology (2nd edition). Oxbow Books: Oxford.

Schmidt, A., Linford, P., Linford, N., David, A., Gaffney, C., Sarris, A. and Fassbinder, J., 2015. Guidelines for the use of geophysics in archaeology: questions to ask and points to consider. EAC Guidelines 2. European Archaeological Council: Belgium.

Soilscapes, 2021. Bolam, County Durham. Cranfield University, National Soil Resources Institute. [http://landis.org.uk]. Accessed 21/01/2021.

12. Project Metadata

MS Job Code	MSNZ847
Project Name	Geophysical Survey Report of Legs Cross, Bolam, County Durham
Client	DigVentures
Grid Reference	NZ 2071 2244
Survey Techniques	Magnetometry, Ground Penetrating Radar, Aerial Photogrammetry
Survey Size (ha)	2.2ha (Magnetometry), 1.7ha (Aerial Photogrammetry), 0.1ha (Ground Penetrating Radar)
Survey Dates	2021-01-20; 2021-01-23
Project Lead	Stephen Twist BSc MSc
Project Officer	Stephen Twist BSc MSc
HER Event No	N/A
OASIS No	Digventu1-398440
S42 Licence No	N/A
Report Version	1.0

13. Document History

Version	Comments	Author	Checked By	Date
0.1	Initial draft for Project Lead to review	EB	HB	01 February 2021
0.2	Incorporate feedback from HB. Feedback was significant enough to produce 0.2 for Project Lead to review	EB	ST	03 February 2021
0.3	Director Approval with minor corrections	EB	FPC	04 February 2021
1.0	No changes from 0.3. Issued as final	EB	FPC	09 February 2021