NAA

GEOPHYSICAL SURVEY

LAND TO THE NORTH OF TENDLEY QUARRY

CUMBRIA

prepared for

Tendley Quarries Ltd

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Archaeological
Associates

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GEOPHYSICAL SURVEY REPORT

TABLE OF CONTENTS

Disclaimer

The results of geophysical survey may not reveal all potential archaeology and do not provide a comprehensive map of the sub-surface, but only responses relative to the environment. Geological, agricultural and modern responses may mask archaeological features. Short-lived features may not give strong responses. Only clear features have been interpreted and discussed in this report.

LAND TO THE NORTH OF TENDLEY QUARRY
GEOPHYSICAL SURVEY REPORT

Summary

Northern Archaeological Associates (NAA) was commissioned by Tendley Quarries Ltd to undertake a geophysical survey of land to the north of the existing workings at Tendley Quarry, Brigham, Cumbria, in advance of a proposed quarry extension and access road (NGR: NY 08645 29302). The work was required to assess the archaeological potential of the site and help inform subsequent archaeological mitigation, if required. The geophysical survey targeted approximately 4.8ha of agricultural land and was carried out on 17th October 2019.

The survey area has been in an agricultural landscape since at least the medieval period, and historic maps record mineral exploitation with an abundance of lime kilns to the east and west of Hotchberry Brow. Generally, the archaeological record in the direct vicinity of Tendley Quarry is fairly sparse. On Tendley Hill, a mound was recorded as a possible round barrow, and medieval burials were discovered on Tendley Hill during early 19th-century quarrying. Although several archaeological investigations were undertaken as part of former extensions to west and south of Tendley Quarry, very few notable archaeological features have been revealed.

Area 1 comprised a small area along the eastern edge of a field located to the north-west of the current quarry workings. No anomalies were identified that were considered to relate to buried archaeological features; instead, results were considered either to be agricultural or modern in nature.

The results in Area 2 demonstrated a higher potential for buried archaeological features. A field boundary present on the 1867 OS map appeared well defined, and it is possible that two further linear anomalies, not recorded on historic OS maps, also relate to former field boundaries. There is potential evidence of quarrying in the east of the field. A near-perfect circular anomaly occurs in the north-west of the site that is considered likely to denote a prehistoric feature, and is possibly suggestive of a round barrow. Further curvilinear anomalies were identified across Area 2, but incomplete patterning and/or poor increases in magnetic value has meant interpretation is tentative and it is uncertain if they also relate to prehistoric activity, or are modern, agricultural or geological in origin.

Other linear, curvilinear and amorphous anomalies, as well as trends, were identified across the survey area, but were composed of weak increases in magnetic response or poor patterning.

Consequently, their origin is unknown, and it is uncertain if they are archaeological, agricultural or geological in nature.

Two clear alignments of regularly spaced linear anomalies were identified that are indicative of ridge and furrow. Several weak regularly spaced linear anomalies were also identified and, although they are likely to be caused by cultivation-related activity, it is not certain if they are medieval, post-medieval or modern in origin.

Other anomalies were largely considered to be modern or geological in origin. A bipolar linear anomaly runs through the centre of the field in a south-west to north-east orientation that is possibly indicative of a buried utility, and there are several areas containing an increased level of magnetic disturbance. A broad increase in magnetic values corresponds with a natural depression running on an east-west orientation through the centre of the field, and is likely to relate to a palaeochannel, possibly suggesting an earlier tributary stream of the Eller Beck.

1.0 INTRODUCTION

1.1 Northern Archaeological Associates Ltd (NAA) was commissioned by Tendley Quarries Ltd to undertake a geophysical survey of land to the north of the existing Tendley Quarry, Brigham, Cumbria, in advance of a proposed quarry extension (NGR: NY 08645 29302). The work was required to assess the archaeological potential of the site and help inform subsequent archaeological mitigation, if required. The geophysical survey was carried out on 17th October 2019.

1.2 This report details the setting (location, topography, geology) and archaeological background of the scheme and sets out the methodology used for the geophysical survey. The interpretation of the geophysical survey is achieved through the analysis of identified anomalies and is aided by a rapid examination of supporting information. The results of the geophysical survey are discussed below, and the interpretations are supported by appropriate illustrations. Where feasible, a detailed synopsis of anomalies is provided and, if possible, the features that the anomalies are likely to relate to are suggested.

2.0 LOCATION, TOPOGRAPHY AND GEOLOGY

Location

2.1 The survey areas lay directly to the north of Tendley Quarry, which is approximately 1km to the south of Brigham village and 0.75km to the north-east of Eaglesfield. In total, 4.8ha of pasture to the north of the quarry was targeted by geophysical survey (Fig. 2). Area 1 consisted of a narrow corridor along the eastern edge of a field located directly to the north-west of the existing quarry. Area 2 comprised a field to the north-east of the quarry and was bounded to the south by an unnamed road and area of scrubland (probably a former quarry), to the east by a lane called Hotchberry Brow and to the west and north by fields.

Geology and soils

2.2 The solid geology of the evaluation area consists of Carboniferous Limestone overlain by Devensian diamicton till (BGS 2019). The soils are mapped as being of the Malham 1 Association, consisting primarily of well-drained soils in silty aeolian drift, intermixed in places with bare limestone pavement or crags (Soil Survey of England and Wales 1983; Jarvis *et al*. 1984, 234-5).

Topography

2.3 The natural topography in Area 1 slopes upwards to the south, so that the north of the field lies at 100m above Ordnance Datum (aOD) and the south of the field is 101m aOD.

2.4 The topography of Area 2 slopes up slightly to either side of a shallow dry gully crossing the area from south-west to north-east and it can be seen to continue beyond the area to the north-east. This may represent the course of a former tributary stream of the Eller Beck. Beyond the boundaries of Area 2, the ground continues to rise to the north-west; formerly, it also rose to the south-east towards Tendley Hill, although this area has been quarried. The highest point in Area 2 lies at 99m (aOD and the lowest point is 93m aOD.

3.0 ARCHAEOLOGICAL AND HISTORICAL BACKGROUND

Early prehistoric

3.1 No early prehistoric finds or sites are recorded in the immediate vicinity of the quarry.

3.2 A number of prehistoric sites are extant in the wider area, the nearest of which is a mound on Tendley Hill of unknown date (Cumbria County Council HER list number: 6852) that has been recorded as a possible Bronze Age barrow. Elva Plain stone circle (Heritage List No. 1013385) lies 8.5km to the east, and further evidence for widespread Neolithic activity comes from numerous finds of stone axes across the Solway Plain (Bewley 1994, 54). The Early Bronze Age is represented by the find of a Collared Urn at Papcastle, c.3km to the north-east of Tendley Quarry (*op. cit*. 61).

Iron Age and Roman

3.3 No Iron Age evidence has been found within the immediate vicinity of the site. A site of this period may exist at Fitz Wood, c.2.5km to the north-east, where a possible fortified enclosure has been identified (Bradbury 1996, 11).

3.4 The route of a Roman road running between Ravenglass and Papcastle is reputed to pass close to Tendley Hill (Margary 1973, 389-95). Historic accounts suggest parts of this road were uncovered during quarrying activity, though no other finds or sites dating to this period have been revealed in the vicinity.

Medieval

3.5 A cist burial of probable early medieval date was found at Eaglesfield, possibly associated with a further six burials in the region (Wilson 1978).

3.6 Closer to the current site, a number of burials are reported to have been found during quarrying on Tendley Hill, and one discovered in 1814 was accompanied by a 10th-century sword, a 'pike' (possibly a spear) and a brooch (Wilson 1978, 48; Edwards 1992, 48). The 1867 Ordnance Survey (OS) map notes "Human remains have been found here" on Tendley Hill at the eastern side of Hotchberry Brow. There is believed to be some correlation between early medieval burials and historic boundaries, and the presence of the boundary between Dean and Brigham parishes, skirting Tendley Hill, may suggest that it was an early cemetery.

3.7 Little is known about medieval activity at Brigham and Eaglesfield (Wilson 1978, 48), and while Brigham was the centre of a vast parish, Cockermouth is likely to have been the most important settlement in the area.

3.8 The light soils overlying the limestone in this area are suitable for arable cultivation (Jarvis *et al*. 1984, 235) and many of the nearby fields are used in this way today. Previous geophysical surveys of other parts of Tendley Quarry (e.g. Gidman and Webb 2007; NAA 2017) have produced evidence for widespread former ridge and furrow cultivation in the area, of either medieval or early post-medieval date. The 1867 map shows that much of the area within the main quarry was still laid out in strip-fields at that date.

Post-medieval to modern

3.9 During the post-medieval period, limestone quarrying became a major industry in the vicinity of the site. References to antiquarian finds being made during quarrying on Tendley Hill show that this activity was already in full swing by the beginning of the 19th century. The OS map of 1867 shows a considerable number of quarries and lime kilns in the areas immediately to the south and east of Area 2, although not within it. By 1898 the quarries were larger, becoming combined and linked by an extensive network of trackways. The plot immediately to the south of Area B was a large quarry.

3.10 Around the quarries, there was an active agricultural landscape, with large-scale arable cultivation indicated by the presence of a water-powered corn mill at Ellerbeck recorded on the 1867 OS map. The 1867 OS map shows that the northern and

western parts of Area 2 were previously a separate field, which has since been amalgamated with the larger field to the south-east. Also of note is a historic boundary, which in 1867 was marked as a parliamentary boundary, that runs along the south-eastern edge of Area 2.

Previous archaeological investigations

3.11 A number of archaeological works have been carried out prior to quarry extensions at Tendley Quarry:

- Headland Archaeology: a rapid archaeological desk-based assessment (Conolly and Carter 2001) and trial trenching (Dutton 2003);
- ASWYAS: geophysical surveys (Webb 2003; Gidman and Webb 2007; Watson 2008);
- Oxford Archaeology North: trial trenching (Lee and Vannan 2008);
- North Pennines Archaeology: trial trenching (Jackson 2009; Haigh 2011);
- GSB Prospection: geophysical survey (GSB 2014);
- Northern Archaeological Associates: trial trenching (NAA 2014);
- Northern Archaeological Associates: geophysical survey (NAA 2017);
- Northern Archaeological Associates: trial trenching (NAA 2018a); and
- Northern Archaeological Associates: excavation (NAA 2018b).

3.12 No significant archaeological remains were revealed during the surveys undertaken between 2001 and 2014. The geophysical survey undertaken in 2017 in an area at the north-western side of the quarry, c.100m south of the current Area 1 and c.300m south-west of Area 2, identified several linear anomalies that could have been indicative of archaeological features. Trial trenching and a subsequent small excavation carried out by NAA in 2018 recorded small linear gullies and pits containing charcoal, burnt stones and fired clay (NAA 2018b). Artefacts were limited to a whetstone and a probable hammerstone, neither of which were diagnostic. Although these features were undated, the pits were of a character suggestive of prehistoric settlement in the vicinity.

4.0 AIMS AND OBJECTIVES

4.1 The aim of the geophysical survey was to map and record potential buried features located within the proposed development area (PDA). Through detailed analysis of the results of the geophysical survey, NAA aimed to provide a detailed interpretation that

assessed the archaeological potential of the site and will inform future archaeological mitigation strategies.

4.2 The objectives of the survey were to:

- undertake a geophysical survey across areas deemed suitable for data collection;
- attempt to identify and record any sub-surface remains within the survey boundary;
- characterise the nature of identified anomalies, and where possible suggest the nature of feature to which they potentially relate;
- assess the archaeological significance of identified anomalies;
- identify possible concentrations of past activity in order to inform the requirement for any further archaeological investigation at the site; and
- produce a detailed report that includes illustrated results of the geophysical survey.

5.0 METHODOLOGY

5.1 The geophysical survey was undertaken as a gradiometer survey using the Bartington Grad601-2 dual magnetic gradiometer system with data logger. The readings were recorded at a resolution of 0.01nT and data was collected with a traverse interval of 1m and a sample interval of 0.25m. All recorded survey data was collected with reference to a site survey grid comprising individual 30m x 30m squares. The grid was established using Real Time Kinematic (RTK) differential GPS equipment and marked out using non-metallic survey markers. All grid nodes were set out with a positional accuracy of at least 0.1m as per existing guidelines (CIfA 2014; Schmidt *et al*. 2015) and could be relocated on the ground by a third party. The base lines used to create the survey grids are shown on Figure 2 and further details are available in Appendix A.

5.2 The processing was undertaken using Geoplot 3.0 software and consisted of standard processing procedures. Details of processing steps applied to collected data are given in Appendix B.

5.3 On the greyscale plot (Fig. 3 and Fig. 4), positive readings are shown as increasingly darker areas and negative readings are shown as increasingly lighter areas.

5.4 Interpretation of identified anomalies is generally achieved through analysis of anomaly patterning and increases in magnetic response, and is often aided through examining supporting information (including but not limited to historic maps, LiDAR

survey data, aerial photographs, as well as geophysical survey data and excavation results in the direct hinterland of the scheme). The interpreted data uses colour coding to highlight specific readings in the survey area (see Fig. 5).

Surface conditions and other mitigating factors

5.5 There were no major issues with the surface conditions at the time of survey that impeded the collection of data. Field boundaries comprised hedgerows and metal fencing, and there were occasional areas of high vegetation along field edges.

5.6 Attempts were made to avoid areas affected by above-ground features that were likely to have a high magnetic susceptibility, such as metal fencing, to minimise the potential for their magnetic responses to impinge on the survey results and mask potential buried features.

6.0 GEOPHYSICAL SURVEY RESULTS

Area 1

6.1 The survey result in Area 1 are relatively 'quiet'. Two parallel trends were identified that are likely to continue beyond the limits of the survey area. Although speculative, because their full extent is not known, it is plausible that these trends denote agricultural activity.

6.2 Bipolar responses along the northern and eastern edges of the survey area were likely to be caused by metal fencing that bounded the site.

Area 2

6.3 A field boundary that is present on the first edition 1867 OS map appears in the geophysical survey results as a bipolar linear anomaly (**A**). The bipolar response is suggestive that a material with a high magnetic susceptibility was used to fill the former field boundary **A**, and although speculative it is plausible that the ditch belonging to the former field boundary was repurposed with a land drain or utility.

6.4 A linear anomaly (**B1)** continues to the north of the field boundary recorded on the 1867 OS map (**A**) and joins a linear anomaly running perpendicular on a west-southwest to east-northeast orientation (**B2**). Although tentative it is plausible that **B** denotes former field boundaries that were removed prior to the 1867 OS map.

6.5 In the north of the field there is an oval-shaped anomaly that is likely to relate to former quarrying (**C**).

6.6 A second similar sub-circular anomaly (**D**) appears in the south of the survey area, and corresponds with a raised mound that was noted in the field during data collection. Consequently, it is uncertain if the patterning of **D** demonstrates it denotes quarrying or, given the earthwork, there is a potential for **D** to be caused by a prehistoric archaeological feature. As a result, detailed interpretation is speculative and further analysis is required to understand fully the nature of this anomaly.

6.7 In the north of the survey area there is a curvilinear anomaly composed of good patterning and increases in magnetic value (**E**). Given the shape of **E** it is considered likely to denote a buried prehistoric feature. **E** has a diameter of c.18m, which is suggestive of a relatively substantial feature such as a round barrow.

6.8 Several further curvilinear anomalies have been identified that potentially also denote infilled features (**F-L**). Generally, these anomalies have clear circular forms, but lack the necessary increases in magnetic value for conclusive interpretation. **F** is located directly to the south of **E** and although it has a coherent patterning, fails to have the same increases in magnetic value. Consequently, it is uncertain if **F** also denotes a buried archaeological feature that was either relatively short-lived or has been disturbed by subsequent human interaction, or is instead of an agricultural or pedological nature. Both **G** and **H** are located near to areas of potential quarrying. Therefore, it is uncertain if they also relate to mineral exploitation, or their curvilinear form is instead suggestive of buried archaeological features. **I** to **L** are located within an area containing a higher level of magnetic disturbance to the west of the former field boundary **A** and possible field boundary **B**. Consequently, detailed interpretation is difficult, and it is uncertain if they denote buried archaeological features, or relate to magnetic 'noise' (see section 6.16).

6.9 Several linear anomalies were identified in the south of the survey area (**M**) that possibly relate to buried ditches. Conversely, the lack of definitive patterning coupled with variation in magnetic values and shape of anomalies of **M1 – M5** is suggestive that they relate to different phases of human activity, or are instead caused by agricultural activity, or geological or pedological changes within the substrata.

6.10 There are several broader linear and amorphous anomalies in the south-west of the survey of an unknown origin (**N**). For both **K** and **N,** it is difficult to ascertain if they denote buried features or belong to the magnetic disturbance that occurs in the area they are located. If they do relate to buried features, it is uncertain if **N** is of an archaeological or geological nature, or is instead indicative of former quarrying activity.

6.11 There are numerous weak isolated anomalies with an amorphous form across the survey area. Those with a coherent patterning or broader form have been identified within the interpretation; however, given the high level of background disturbance, a very tentative interpretation applies, and their origin is unknown.

6.12 There are several weak and diffuse linear trends. Generally, trends lack the necessary patterning of increase in magnetic value to be fully interpreted and as a consequence their origin is unknown. Those with a more coherent form may be indicative of buried infilled features

6.13 There are two clear phases of ridge and furrow. The first has a distinct west-facing curve and runs on a broad south-southwest to north-northeast orientation, while the second has a straighter line running on a west-southwest to east-northeast alignment. There are also several curved linear anomalies running along the eastern edge of the survey area. It is not clear if these anomalies indicate a turning point at the end of plough-strip or a third phase of medieval farming. Several regularly spaced linear anomalies composed of weak increases in magnetic response and narrow spacing have been identified (agriculture?), but it is uncertain if they also belong to ridge and furrow cultivation, or modern ploughing.

6.14 Dipolar anomalies are generally likely to relate to ferrous or modern objects buried in the topsoil. Consequently, these anomalies are largely considered to be of a modern nature and so have not been depicted on interpretation plots.

6.15 Several bipolar responses have been identified. Isolated bipolar anomalies are likely to be caused by highly magnetic material, such as ferrous objects in the topsoil of the site. A linear dipolar anomaly runs on a south-west to north-east alignment through the centre of the field (**O**). Usually, linear bipolar anomalies relate to buried utilities; however, the inconsistent increases in magnetic value has meant interpretation of **O** is tentative and it is possible it instead denotes an infilled feature.

6.16 Areas of increased magnetic response have been used to highlight concentrations of dipolar anomalies. Generally, these are considered likely to be caused by modern magnetic debris in the topsoil or near the surface of the site. An area of magnetic disturbance is present to the west of the former field boundary **A** and the possible former field boundary **B**. It is uncertain if this variation in magnetic response is caused by a concentration of ferrous material in the topsoil, nearby natural geological or pedological formations or, given the clarity of ridge and furrow and nearby quarry activity including limestone kilns, caused by human activity. Where anomalies have a coherent shape, they have been identified in the interpretation. It should be noted that interpretation of these anomalies is generally very tentative, and that further features may be present but their responses have been masked.

6.17 Strong responses caused by above-ground features external to the survey area, such as metal fencing and gates, have been characterised as external interference.

6.18 It is plausible that variations in magnetic values relate to geological and pedological changes in the substrata. Anomalies of a geological origin often have either broad or amorphous forms, and relate to topographic changes or geographic features within the landscape. There is a band of broad responses running through the centre of the field that is likely to be caused by a paleochannel (**P**). A tributary stream of the Eller Beck is shown to finish at a spring c.0.15km to the north-east of the survey area. Although very speculative, it is plausible that **P** relates to the former course of the stream.

7.0 CONCLUSIONS

7.1 NAA was commissioned to undertake a geophysical (gradiometer survey) to the north of Tendley Quarry to assess the archaeological potential of two areas in advance of a proposed new access road (Area 1) and extension of quarrying (Area 2).

7.2 Area 1 comprised a small area located to the north-west of the present quarry operations. No substantial buried features were identified through the survey, with anomalies being either of a modern or agricultural nature.

7.3 Area 2 was located to the north-east of the present operations and is proposed to form a quarry extension to the north. Lime kilns are recorded in the area surrounding the field on the 19th-century maps. In the east of the survey area there is evidence of quarrying. It is possible that anomalies relate to post-medieval lime extraction but,

given that quarrying occurred during the medieval and Roman period, an earlier origin cannot be dismissed.

7.4 During the medieval and post-medieval periods, Area 2 is likely to have belonged to an agricultural landscape. This is demonstrated in the results of the survey with linear anomalies being identified that relate to ridge and furrow and former field boundaries.

7.5 The results of the geophysical survey in Area 2 demonstrated a potential for prehistoric activity to be extant with a well-defined circular feature appearing in the north-west of the survey area. If of a prehistoric origin, the size of the anomaly is suggestive of a fairly substantial feature and plausibly indicative of a round barrow. Further curvilinear anomalies were identified across the survey site that may also belong to prehistoric occupation, but weak increases in magnetic value coupled with incomplete patterning has meant interpretation was tentative and further investigation is required to confirm an archaeological interpretation. Numerous linear and amorphous anomalies and trends were identified but generally lacked the necessary shape and increases in magnetic value for detailed interpretation. Consequently, it is unknown if they relate to archaeological features, belong to quarrying-related activity, or are agricultural, modern or geological in origin.

7.6 Other anomalies were considered to relate to modern or geological activity including a broad increase in magnetic values that is likely to relate to a paleochannel and a bipolar linear anomaly that is possibly indicative of a buried utility. There are also several areas of magnetic disturbance in Area 2. It should be noted that in areas where magnetic disturbance occurs, identified anomalies generally have a tentative interpretation and that the responses of buried archaeological features, if present, may have been masked.

8.0 STORAGE AND CURATION

8.1 The records of the geophysical survey are currently held by NAA. All material will be appropriately packaged for long-term storage in accordance with national guidelines (CIfA 2014; Schmidt *et al*. 2015). An online OASIS form will be completed within three months of the completion of the project. This will include submission of a .pdf version of the final report to the Archaeology Data Service via the OASIS form.

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Ordnance Survey (1867) Six-inch Cumberland Sheet LIV (Surveyed 1864).

Ordnance Survey (1900) Six-inch Cumberland Sheet LIV.NE (Revised 1898).

APPENDIX A

TECHNICAL INFORMATION

GRADIOMETER SURVEY

Magnetic surveys measure distortions in the earth's magnetic field caused by small magnetic fields associated with buried features (Gaffney and Gater 2003, 36) that have either remnant or induced magnetic properties (Aspinal *et al*. 2008, 21–26). Human activity and inhabitation often alter the magnetic properties of materials (Aspinal *et al*. 2008, 21) resulting in the ability for numerous archaeological features to be detected through magnetic surveys. Intensive burning or heating can result in materials attaining a thermoremanent magnetisation; examples of which include kilns, ovens, hearths and brick structures (Aspinal *et al*. 2008, 27; Gaffney and Gater 2003, 37). When topsoil that is rich with iron oxides fills a man-made depression in the subsoil, it creates an infilled feature, such as a pit or ditch, with a higher magnetic susceptibility compared to the surrounding soil (Aspinal *et al*. 2008, 37–41; Gaffney and Gater 2003, 22–26). Magnetic surveys can also detect features with a lower magnetically susceptibility than the surrounding soil, an example of which is a stone wall.

LIMITATIONS

Poor results can be due to several factors including short-lived archaeological occupation/use or sites with minimal cut or built features. Results can also be limited in areas with soils that are naturally deficient in iron compounds or in areas with soils overlying naturally magnetic geology, which will produce strong responses masking archaeological features.

Overlying layers, such as demolition rubble or layers of made ground, can hide any earlier archaeological features. The presence of above-ground structures and underground services containing ferrous material can distort or mask nearby features.

Particularly uneven or steep ground can increase the processing required, or distort results beyond the capabilities of processing. It is also possible in areas containing dramatic topographical changes that natural weathering, such as hillwash, often in combination with intensive modern ploughing, will reduced the topsoil on slopes and towards the peaks of hills, and possibly destroy or truncate potential archaeological features. Conversely, features at the bottom of slopes may be covered by a greater layer of topsoil and so if buried features are present, they appear faint within the results, if at all.

Over processing of data can also obscure or remove features, especially if they are on the same orientation as the direction of data collection. Consequently, where possible, attempts are made to ensure data is not collected on the same orientation as known potential features and that data quality is sufficient to minimise the required data processing.

INSTRUMENTATION

The data was collected using handheld Bartington Grad 601-2 fluxgate gradiometers. The Bartington 601-2 is a singleaxis, vertical component fluxgate gradiometer comprising a data logger battery cassette and two sensors. The sensors are Grad-01-1000L cylindrical gradiometer sensors mounted on a rigid carrying frame; each sensor contains two fluxgate magnetometers with 1m vertical separation.

The difference in the magnetic field between the two fluxgates in each sensor is measured in nanoTesla (nT). NAA gradiometer data is recorded with a range of ±100nT, which equates to a resolution of 0.01nT. It should be noted that the actual resolution is limited to 0.03nT as a consequence of internal instrumental noise (Bartington Instruments Ltd, 23).

The gradiometer records two lines of data on each traverse, the grids are walked in a zig-zag pattern amounting to 15 traverses. The gradiometers are calibrated at the start of every day and recalibrated whenever necessary.

SURVEY DETAILS

Table A1: survey summary.

Item	**Survey**
Grid size	30m x 30m
Traverse interval	1m
Reading interval	0.25m
Direction of 1st traverse	N
Number of grids	73
Area covered	4.8ha

Table A2: baseline coordinates.

Item	**Survey**
gpA	308323.3995 529135.6478
gpB	308353.3228 529136.4026
gpC	308643.8612 529206.1169
gpD	308673.8612 529206.1169

Table A3: site information and conditions.

Item	**Detail**
Geology	Carboniferous Limestone
Superficial deposits	Devensian Till
Soils	Malham 1 Association
Topography	Highest: 101m aOD Lowest: 93m aOD
Land use	Agricultural - pasture
Weather conditions prior to and during survey	Overcast

APPENDIX B

DATA PROCESSING INFORMATION

Gradiometer survey data is downloaded using the Bartington Grad 601 software and the processing was undertaken using Geoplot 3.0 software.

Table B1: commonly applied techniques.

Process	Effect
Zero mean traverse	Removes stripping that can occur as a consequence of using multi-sensor arrays or a 'zig-zag' data collection method by setting the mean reading for each traverse to zero.
Destagger	Removes stagger in the data introduced through inconsistent data collection pace and often exacerbated through the 'zig-zag' methodology.
Clip	Clips data above or below a set value to enhance potential weaker anomalies.
Despike	Removes random spikes or high readings to reduce the appearance of dominant readings, often created by modern ferrous objects that can distort the results.
Low pass filter	Removes low-frequency waves or broad anomalies such as those caused by strong or large gradual variations in the soil's magnetic susceptibility often caused by geological or natural changes in the substrata.
Interpolation	Used to smooth or reduce the blocky appearance of data by improving the spatial density and increase the quantity of data points in the Y direction.

Table B2: processing steps.

Minimal Processing	Increased Processing
• Zero mean traverse +5/-5 • Destagger: *Area 1* - All grids: 2 *Area 2* - Grids 15, 21, 35 and 36: -2 - Grids 5, 6, 28, 41, 55, 60 and 64: -1 - Grids 19, 20, 26, 27, 38, 39, 40, 42, 52, 54, 80 and 81: 1 - Grids 4, 16, 17, 18, 46, 47, 49, and 58: 2 - Grids 32, 53, 59, 61 and 72: 3 - Grid 71: 4 - Grids 31, 43 and 65: 5 - Grids 51 and 60: 6	• Low Pass Filter • Interpolate Y, Expand - Linear, x2

APPENDIX C

DATA VISUALISATION INFORMATION

FIGURES

The data was used to produce a series of images to demonstrate the results of surveys, which are detailed below:

- Greyscale/Colourscale Plot – This visualised the results as a shaded drawing with highest readings showing as black, running through different shades to lowest showing as white.
- XY-trace Plot – This creates a line drawing showing the peaks and troughs of the readings as vertical offset from a centreline.
- Interpreted Plot – Through detailed analysis, anomalies have been interpreted and possible features identified. Interpretation drawings are used to show potential features and in particular to reinforce and clarify the written interpretation of the data. Anomalies have been characterised using the terminology detailed in the following section, and have been assigned colour coding outlined in keys found on the relevant figures associated with this report.

MAGNETIC ANOMALIES AND TERMINOLOGY

Table C1: lexicon of terminology.

Terminology	Detail
Anomaly	Any outstanding high or low readings forming a particular shape or covering a specific area within the survey results.
Feature	A man-made or naturally created object or material that has been detected through investigation works and has sufficient characteristics or supporting evidence for positive identification.
Magnetic susceptibility	The ability of a buried feature to be magnetically induced when a magnetic field is applied.
Magnetic response	The strength of the changes in magnetic values caused by a buried feature with either a greater or lesser ability to be magnetised compared with the soil around it. Anomalies are considered to have either strong/weak or positive/negative responses. The strength of magnetic response (along with patterning) can be essential in determining the nature of an anomaly, but it should be noted that the size or strength of the magnetic response does not correlate with the size of the buried feature.
Patterning of an anomaly	The shape or form of an individual anomaly.
Thermoremanence	The affect caused when a material has been magnetically altered through a process of heating. Thermoremanent magnetisation occurs when an object or material is heated passed the Curie Point and acquires a permanent magnetisation that is associated with the magnetic field that they cooled within (Gaffney and Gater 2003:37)

Different anomalies can represent different features created by human, agricultural or modern activity, or natural pedological or geological changes in the substrata.

Anomalies interpreted with a 'greater' categorisation are considered more likely to be of the interpreted characterisation; whereas a more tentative interpretation is applied to those with a 'lesser' categorisation as a consequence of weaker increases in magnetic response or the anomaly's incomplete patterning or irregular form.

The strength and size of anomalies can vary depending on the magnetic properties of the feature, the magnetic susceptibility of the soil, the depth to which the feature is buried, and the state of preservation.

Table C2: characterisation of anomalies.

Characterisation	**Detail**
Archaeology	
Bipolar anomaly (quarrying)	Anomalies often composed of a bipolar response that is indicative of quarrying.
Linear anomaly (archaeology)	Linear anomalies with a positive or negative magnetic response, and composed of a patterning or shape that is suggestive of a buried archaeological feature. These are often indicative of structural remains or infilled features such as ditches. The strength of anomaly signal can be suggestive of the properties of the feature. Negative linear anomalies represent upstanding or infilled features that are less magnetically susceptible than background readings; for example, structures or ditches composed of a non-igneous stone material. Bipolar linear anomalies considered to be of an archaeological nature are indicative of material with a high magnetic susceptibility, such as a brick wall.
Isolated anomaly (archaeology)	Isolated anomalies or anomalies with a more amorphous form possibly represent infilled features or thermomagnetic features such as areas of heating/burning of an archaeological origin. Unless associated with conclusively identified archaeological remains, such as linear anomalies, absolute identification of positive responses can be problematic as it is often not possible to decipher if they are of an archaeological, modern or agricultural origin. Consequently, isolated positive responses are not shown within the interpretation unless composed of a broad form or belonging to a series of isolated positive responses. Bipolar responses considered likely to be of an archaeological origin/feature are also interpreted as isolated anomaly (archaeology). These are considered to relate to material with a very strong magnetic susceptibility or thermoremanent magnetisation.
Trends	Weak and diffuse anomalies with an uncertain origin are denoted by trends. It is possible that these belong to archaeological features, but given their weak signatures or incomplete patterning it is equally plausible that they relate to agricultural features or natural soil formations.
Agriculture	
Field boundary	Isolated linear anomalies that are likely to be indicative of former land divisions. A more conclusive interpretation is given to linear anomalies that

Characterisation	**Detail**
	correspond with the location of field boundaries recorded on historic maps, aerial photos or LiDAR coverage of the site.
Ridge and furrow	Broadly spaced linear anomalies that are likely to be indicative of earlier forms of agriculture, such as ridge and furrow. These often correspond with the location of earthworks visible on the ground or identified on aerial photos or LiDAR survey coverage.
Agriculture?	Weak, irregularly spaced or isolated linear anomalies that relate to agricultural activity, but the agricultural process they are caused by is unknown.
Modern	
Bipolar response (modern)	Positive anomalies with associated negative 'halo' (bipolar) denote features with a strong magnetic response that are likely to be of a modern origin. Isolated bipolar responses of a modern nature are likely to relate to buried ferrous material or objects, such as metallic agricultural debris. If a trend is noted in the alignment or spacing of isolated bipolar responses, it is possible that they are indicative of ferrous fittings or connectors used on non-magnetic buried utilities. Linear bipolar anomalies are likely to be indicative of modern services.
Dipolar response	Dipolar anomalies relate to individual spikes within the data and tend to be caused by ferrous objects. These responses have been shown only when located near to archaeological features. When the site is located in a mining landscape it is possible that identified dipolar anomalies relate to mining activity and are indicative of further pits or mine shafts.
Area of increased magnetic response	Areas of increased magnetic response denote areas of disturbance containing a high concentration of dipolar and/or bipolar responses. These are generally considered to be caused by modern debris in the topsoil, although it is possible that the disturbance is in part also caused by isolated archaeological material or geological or pedological changes in the substrata.
External interference	Areas of magnetic disturbance, often along the edges of survey areas, are caused by standing metal structures such as fencing and buildings.

APPENDIX D

OASIS FORM

OASIS DATA COLLECTION FORM: England

OASIS ID: northern1-372819

Project details

Project name	Land to the north of Tendley Quarry
Short description of the project	Geophysical Survey
Project dates	Start: 17-10-2019 End: 17-10-2019
Previous/future work	No / Not known
Type of project	Field evaluation
Site status	None
Current Land use	Grassland Heathland 4 - Regularly improved
Monument type	NONE None
Significant Finds	NONE None
Methods & techniques	"Geophysical Survey"
Development type	Mineral extraction (e.g. sand, gravel, stone, coal, ore, etc.)
Prompt	Planning condition
Position in the planning process	Pre-application
Solid geology (other)	Carboniferous Limestone
Drift geology (other)	Devensian Till
Techniques	Magnetometry

Project location

Country	England
Site location	CUMBRIA ALLERDALE BRIGHAM Tendley Quarry
Postcode	CA13 0SE
Study area	4.8 Hectares
Site coordinates	NY 08645 29302 54.65041390379 -3.416025582152 54 39 01 N 003 24 57 W Point
Height OD / Depth	Min: 93m Max: 101m

Project creators

Name of Organisation	Northern Archaeological Associates
Project brief originator	Tendley Quarries Ltd
Project design originator	Northern Archaeological Associates Ltd
Project director/manager	Alice James
Project supervisor	Oskar Sveinbjarnarson
Type of sponsor/funding body	Developer

Project archives

Physical Archive Exists?	No
Digital Archive recipient	Northern Archaeological Associates
Digital Contents	"none"
Digital Media available	"Geophysics"
Paper Archive Exists?	No

Project bibliography 1

Publication type	Grey literature (unpublished document/manuscript)
Title	Land to the North of Tendley Quarry: Geophysical Survey Report, NAA unpublished report 19/107
Author(s)/Editor(s)	James, A and Speed, G
Other bibliographic details	19/107
Date	2019
Issuer or publisher	NAA
Place of issue or publication	Barnard Castle
Description	blue spine

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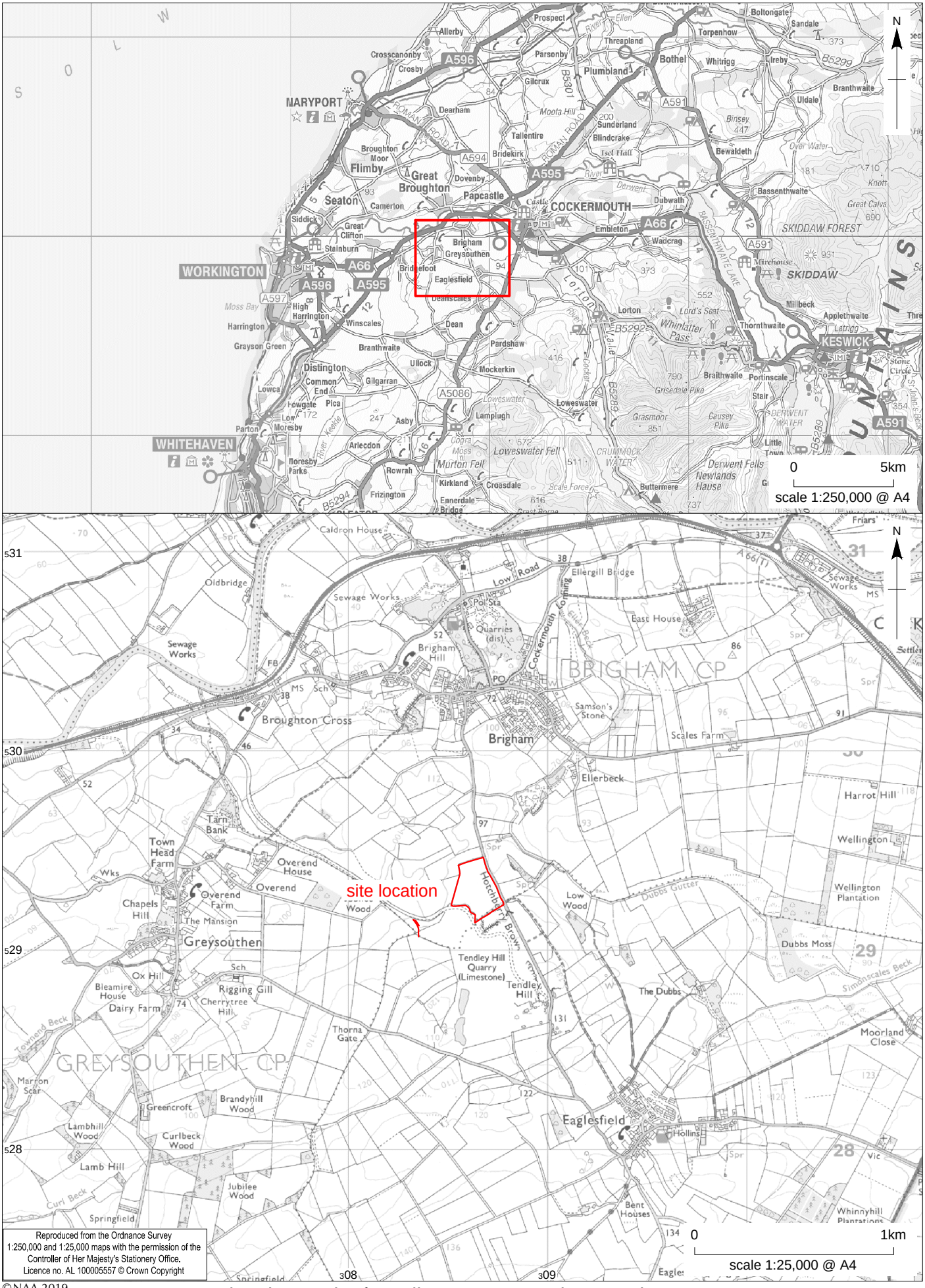
Entered on	5 November 2019



Land to the North of Tendley Quarry, Cumbria: site location *Figure 1*

NAA
Heritage Consultants

KEY
geophysical survey baseline
geophysical survey grid
geophysical survey area
Proposed development area

N

0 100 m
scale 1:2000 @ A3

Area 1
Area 2
gpA
gpB
gpC
gpD
94.2m
90.9m
94.2m
112.2m
120.3m
BM 122.38m
Spring
Lime Kiln (Dis)
Tendley Hill Quarry
Path (um)
HAYCHERRY BROW

Land to the North of Tendley Quarry, Cumbria: location of geophysical survey

Figure 2

NAA
Heritage Consultants

KEY

Proposed development area

0 100 m

scale 1:2000 @ A3

N

5nT

-4nT

Pallette:grey55.ptt

Area 2

Area 1

94.2m

90.9m

94.2m

Spring

Lime Kiln
(Dis)

112.2m

HIGHCHERRY BREW

120.3m

BM 122.38m

Path (um)

Tendley Hill Quarry

Land to the north of Tendley Quarry, Cumbria: unprocessed greyscale plot of gradiometer survey results

Figure 3

NAA
Heritage Consultants

KEY

Proposed development area

0 100 m

scale 1:2000 @ A3

N

4nT

-3nT

Pallette:grey55.ptt

Area 2

Area 1

94.2m

90.9m

94.2m

Spring

112.2m

Path (um)

Lime Kiln
(Dis)

HIGHBERRY BREW

120.3m

BM 122.38m

Tendley Hill Quarry

Land to the north of Tendley Quarry, Cumbria: processed greyscale plot of gradiometer survey results

Figure 4

NAA
Heritage Consultants

Area 2

Area 1

B2
H
E
C
O
F
B1
I
A
P
A
J
L
O
M2
M1
G
N
D
K
M4
M5
M3
M6

94.2m
90.9m
94.2m
BM 102.70m
Spring
Path (um)
112.2m
Lime Kiln
(Dis)
Tendley Hill Quarry

KEY

- bipolar response (quarrying) (greater / lesser)
- positive linear response (archaeology) (greater / lesser)
- positive response (archaeology) (greater / lesser)
- field boundary
- field boundary?
- trends
- ridge and furrow
- agriculture?
- bipolar response (modern?)
- area of increased magnetic response
- external interference (e.g. fencing)
- edge of geophysical survey
- Proposed development area

N

0 100 m

scale 1:2000 @ A3

Land to the north of Tendley Quarry, Cumbria: interpretation of gradiometer survey results

Figure 5