

# Ground-based and Near-earth Geomatics Surveys - Statement of Capability, 2022

MHR Programme

Open Report OR/22/003





BRITISH GEOLOGICAL SURVEY

MHR PROGRAMME

OPEN REPORT OR/22/003

The National Grid and other  
Ordnance Survey data  
© Crown Copyright and  
database rights 2022.  
Ordnance Survey Licence  
No. 100021290 EUL.

*Keywords*

Geomatics, LiDAR, UAS.

*Front cover*

UAS Thermal Survey at  
Aldbrough, Yorkshire

*Bibliographical reference*

JONES, L.D.2021.  
Ground-based and Near-earth  
Geomatics Surveys -  
Statement of Capability, 2022.  
*British Geological Survey  
Open Report, OR/22/003.*  
44pp.

Copyright in materials derived  
from the British Geological  
Survey's work is owned by  
UK Research and Innovation  
(UKRI) and/or the authority  
that commissioned the work.  
You may not copy or adapt  
this publication without first  
obtaining permission. Contact  
the BGS Intellectual Property  
Rights Section, British  
Geological Survey, Keyworth,  
e-mail [ipr@bgs.ac.uk](mailto:ipr@bgs.ac.uk). You  
may quote extracts of a  
reasonable length without  
prior permission, provided a  
full acknowledgement is given  
of the source of the extract.

Maps and diagrams in this  
book use topography based  
on Ordnance Survey  
mapping.

# Ground-based and Near-earth Geomatics Surveys - Statement of Capability, 2022

L D Jones

*Contributor/editor*

L Bateson

## BRITISH GEOLOGICAL SURVEY

The full range of our publications is available from BGS shops at Nottingham, Edinburgh, London and Cardiff (Welsh publications only) see contact details below or shop online at [www.geologyshop.com](http://www.geologyshop.com)

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

We publish an annual catalogue of our maps and other publications; this catalogue is available online or from any of the BGS shops.

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

*The British Geological Survey is a component body of UK Research and Innovation.*

*British Geological Survey offices*

**Nicker Hill, Keyworth,  
Nottingham NG12 5GG**

Tel 0115 936 3100

**BGS Central Enquiries Desk**

Tel 0115 936 3143

email [enquiries@bgs.ac.uk](mailto:enquiries@bgs.ac.uk)

**BGS Sales**

Tel 0115 936 3241

email [sales@bgs.ac.uk](mailto:sales@bgs.ac.uk)

**The Lyell Centre, Research Avenue South,  
Edinburgh EH14 4AP**

Tel 0131 667 1000

email [scotsales@bgs.ac.uk](mailto:scotsales@bgs.ac.uk)

**Natural History Museum, Cromwell Road,  
London SW7 5BD**

Tel 020 7589 4090

Tel 020 7942 5344/45

email [bgs london@bgs.ac.uk](mailto:bgs london@bgs.ac.uk)

**Cardiff University, Main Building, Park Place,  
Cardiff CF10 3AT**

Tel 029 2167 4280

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

Tel 01491 838800

**Geological Survey of Northern Ireland, Department of  
Enterprise, Trade & Investment, Dundonald House,  
Upper Newtownards Road, Ballymiscaw,  
Belfast, BT4 3SB**

Tel 01232 666595

[www.bgs.ac.uk/gsni/](http://www.bgs.ac.uk/gsni/)

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

Tel 01793 411500

Fax 01793 411501

[www.nerc.ac.uk](http://www.nerc.ac.uk)

**UK Research and Innovation, Polaris House,  
Swindon SN2 1FL**

Tel 01793 444000

[www.ukri.org](http://www.ukri.org)

Website [www.bgs.ac.uk](http://www.bgs.ac.uk)

Shop online at [www.geologyshop.com](http://www.geologyshop.com)

# Forward

***This report is the published product of a study by the British Geological Survey (BGS) and consists of the current (2022) statement of capability for ground-based and near-earth geomatics surveys at the Keyworth office of the BGS.***

It follows on from two reports entitled “Ground-Based Geomatics Surveys: Specification for Terrestrial LiDAR Scanning” (Jones, 2019) and “Ground-based geomatics for geohazard mapping, modelling and characterisation” (Jones et. al., 2020). This report also follows on from a report that reviews ground-based geomatics research undertaken by organisations outside the BGS (Jones, 2015<sup>A</sup>), a report discussing current and future practice of ground-based geomatics surveys in the BGS (Jones, 2014<sup>A</sup>) and a manual on data collection and processing (Jones, 2015<sup>B</sup>).

The first part of this report acts as an introduction to the field of ground-based geomatics, describing what it is and talks about the most common geomatics applications used in the BGS.

The report then goes on to discuss the capacity of the BGS Keyworth office and explains what type of Terrestrial LiDAR Scanning (**TLS**), Mobile Mapping Solution (**MMS**), Global Navigation Satellite System (**GNSS**), Unmanned Aerial Systems (**UAS**) and Software applications are available.

The report then goes on to describe, in more detail, the current ground-based and near-earth geomatics capability of the BGS Keyworth office. The report then talks about the applications that the BGS has carried out, and highlights three case studies where these applications have been carried out, and combined.

All the work detailed in this report has been carried out by the author, with the aid of the following: Matthew Kirkham & Luke Bateson (both BGS) and Peter Hobbs (BGS – retired).

Please also refer to <https://www.bgs.ac.uk/geology-projects/geomatic-surveys/> for more information.

# Contents

|                                                |    |
|------------------------------------------------|----|
| Forward .....                                  | i  |
| Contents .....                                 | ii |
| 1 Introduction .....                           | 1  |
| 2 Capacity.....                                | 2  |
| 3 Capability .....                             | 6  |
| 4 Applications .....                           | 10 |
| 4.1 Slaithwaite Dam, Kirklees, Yorkshire ..... | 11 |
| 4.2 Hollin Hill, Ryedale, Yorkshire .....      | 17 |
| 4.3 Aldbrough, South Yorkshire .....           | 22 |
| Appendix 1 LiDAR Survey Locations.....         | 27 |
| References.....                                | 36 |

## FIGURES

|                                                                                                   |           |
|---------------------------------------------------------------------------------------------------|-----------|
| <b>Figure 1 - Current BGS Terrestrial LiDAR Scanners .....</b>                                    | <b>3</b>  |
| <b>Figure 2 - Leica Pegasus Backpack Mobile Mapping Solution .....</b>                            | <b>3</b>  |
| <b>Figure 3 – GS10 system acting as on-ice ground control at Virkisjokull, Iceland .....</b>      | <b>4</b>  |
| <b>Figure 4 – Current BGS Unmanned Aerial Systems.....</b>                                        | <b>4</b>  |
| <b>Figure 5 – Scanning the active lava dome of the Soufrière Hills Volcano, Montserrat.....</b>   | <b>8</b>  |
| <b>Figure 6 – Pegasus Backpack mounted on an e-trike in Tenby, Wales .....</b>                    | <b>8</b>  |
| <b>Figure 7 – Low Cost GNSS unit on OS Trig. Point at Herstmonceux. Sussex .....</b>              | <b>9</b>  |
| <b>Figure 8 – DJI M210 with thermal camera at Aldbrough, Yorkshire .....</b>                      | <b>9</b>  |
| <b>Figure 9 – Aerial view of Slaithwaite Reservoir.....</b>                                       | <b>12</b> |
| <b>Figure 10 – Aerial view of the Dam .....</b>                                                   | <b>12</b> |
| <b>Figure 11 – Point cloud of Dam generated from Leica Pegasus walk-over survey .....</b>         | <b>13</b> |
| <b>Figure 12 – Point cloud of Dam generated from Riegl VZ-1000 scan .....</b>                     | <b>14</b> |
| <b>Figure 13 – Point cloud of Tunnel generated from Faro X-330 scan .....</b>                     | <b>14</b> |
| <b>Figure 14 – Point cloud of Dam generated from DJI Matrice 210RTK imagery.....</b>              | <b>15</b> |
| <b>Figure 15 – DEM of Slaithwaite Dam and surrounding area.....</b>                               | <b>15</b> |
| <b>Figure 16 – DEM of Slaithwaite Dam Tunnel.....</b>                                             | <b>16</b> |
| <b>Figure 17 – Location (and geology) of the Hollin Hill landslide .....</b>                      | <b>17</b> |
| <b>Figure 18 – Aerial photograph of Hollin Hill landslide with geophysical survey plan .....</b>  | <b>17</b> |
| <b>Figure 19 – Annotated photograph of the Hollin Hill landslide .....</b>                        | <b>18</b> |
| <b>Figure 20 – Conceptual model of the Hollin Hill landslide .....</b>                            | <b>18</b> |
| <b>Figure 21 – Point cloud of three parts of the field generated from Riegl VZ-1000 scan ....</b> | <b>19</b> |
| <b>Figure 22 – Photogrammetric image generated from DJI Matrice 210RTK UAV.....</b>               | <b>20</b> |

|                                                                                                                                |    |
|--------------------------------------------------------------------------------------------------------------------------------|----|
| Figure 23 – Thermal images generated from DJI Inspire 1 Raw UAV.....                                                           | 20 |
| Figure 24 – Digital Elevation Model (DEM) of Hollin Hill .....                                                                 | 21 |
| Figure 25 – Location of test site at Aldbrough .....                                                                           | 22 |
| Figure 26 – Rotational landsliding is the primary mechanism at Aldbrough .....                                                 | 23 |
| Figure 27 – Point cloud of Cliff top generated from Pegasus walk-over survey.....                                              | 23 |
| Figure 28 – Point cloud of Cliff top generated from VZ-1000 scan .....                                                         | 24 |
| Figure 29 – Point cloud generated from DJI M210RTK photogrammetric image.....                                                  | 24 |
| Figure 30 – Point cloud generated from DJI M210RTK oblique photogrammetric image ..                                            | 25 |
| Figure 31 – Digital Elevation Model (DEM) of the cliffs at Aldbrough, from combined data<br>sets (Pegasus, VZ-1000 & UAS)..... | 25 |
| Figure 32 – Thermal image of the cliffs at Aldbrough .....                                                                     | 25 |
| Figure 33 – Point cloud generated from DJI M300RTK and Zenmuse L1 LiDAR module..                                               | 26 |
| Figure 34 – Close-up of Ord generated from DJI M300 .....                                                                      | 26 |
| Figure 35 – DTM of Aldbrough using the combined information provided from <i>all</i> surveys<br>.....                          | 26 |
| Figure 36 – 3D Model of the cliff at Aldbrough.....                                                                            | 26 |

# 1 Introduction

Geomatics is defined in the International Organization for Standardization (ISO/TC 211) series of standards (Anon, 1994) as the discipline concerned with the collection, distribution, storage, analysis, processing, and presentation of geographic data or geographic information. This broad term applies to both science and technology, and integrates the more specific disciplines and technologies of geodesy, surveying, mapping, positioning, navigation, cartography, remote sensing, photogrammetry, and geographic information systems. The discipline of geomatics continues to be one of the fastest expanding global markets (Jones, 2015). Geomatics is driven by technology and, at present, there is a huge demand for land, hydrographic, and engineering surveyors who are able to utilise this technology fully. This is due to a high media profile, the changing nature of mapping and spatial data management worldwide, the need for faster and more accurate data gathering, and the growth in European Union and national governments' spatial data agendas and legislation. As the underpinning information provider of the land and property lifecycle, geomatics is of fundamental importance to society (Jones & Hobbs, 2021).

The most common geomatics applications in the British Geological Survey (BGS) use a terrestrial light detection and ranging (LiDAR) scanner (TLS) or the Pegasus Backpack mobile mapping solution (MMS) and a Global Navigation Satellite System (GNSS) in order to obtain a terrestrial equivalent of an airborne LiDAR survey and create a 3D model. Combining a terrestrial LiDAR scanner with a high-resolution digital camera and a high-precision differential GNSS enables colored point-clouds, textured triangulated surfaces, or orthophotos with depth information to be accurately geo-referenced and captured. The relative distance, elevation angle and azimuthal angle between the laser and the subject are measured in each scan and, once processed, a 3D surface model can be generated. From the 3D models created, a variety of products are derived including digital surface models (**DSM**), digital terrain models (**DTM**), virtual outcrop models (**VOM**), cross-sections, area and volume calculations, 3D photo-realistic video "fly-throughs", discontinuity maps, stratigraphic facies profiles, attributed 3D reservoir models, fossil assemblage maps, surface deformation feature recognition layers, soil erosion maps, cave surveys and change models. TLS allows geological outcrops to be digitally captured with unprecedented resolution and accuracy (Buckley et al., 2008). Structure from motion photogrammetry (**SfM**) has emerged as an alternative viable technology, whether deployed on an Unmanned Aerial System (UAS) or otherwise. It is lighter, more compact, cheaper to buy and repair, and has lower power requirements than TLS (Jones & Bateson, 2021). The BGS has six multi-rotor and two fixed-wing small (<20 kg) UAVs, which it uses to collect data for ground surface and geological investigations.

## 2 Capacity

The geomatics data acquisition equipment, detailed below, and the majority of the associated processing/visualisation software have been purchased under Capital funds. Ongoing license charges (software) are funded from project funds.

The BGS has four Terrestrial LiDAR Scanners (TLS), each with differing accuracies, measurement rates and scanning ranges ([Figure 1](#)), ([Jones, 2015](#))

1. Riegl LPM-2K (No longer in use)
2. Riegl LPM-i800HA
3. Riegl VZ-1000
4. Faro Focus 3D X-330

The BGS has a Leica Pegasus Backpack Mobile Mapping Solution (MMS) that allows for continuous, GNSS aligned, laser scanning and photogrammetry to be undertaken whilst moving ([Figure 2](#)), ([Jones, 2019](#))

1. Leica Pegasus Backpack

The BGS has a range of Leica Global Navigation Satellite Systems (GNSS) that can be utilised for a range of applications ([Figure 3](#)); acting as a base-station for airborne surveys, for differential positioning of boreholes, and for kinematic surveys ([Jones, 2015](#))

1. 1 x GS50 GIS system (No longer in use)
2. 2 x System 500 systems (No longer in use)
3. 2 x System 1200 (SmartRover) systems (One in use)
4. 2 x GS15 (Viva) systems
5. 1 x GS08 Plus system
6. 2 x GS14 systems
7. 2 x GR10 (Base Station) systems (One permanently located at Skaftafell, Iceland)
8. 6 x GS10 (Single Frequency) systems
9. 1 x GS18T (Tilt) system
10. The BGS has a range of other survey equipment available ([Jones, 2015](#))
11. 1 x Leica TCR1205 Theodolite Positioning System (TPS)
12. 3 x Leica Electronic Level
13. 2 x Leica Disto Laser Distance Measure
14. 1 x Laser Technology Inc. TruPulse Laser Range Finder

The BGS has four multi-rotor (<20 kg) Unmanned Aerial Systems (UAS) available ([Figure 4](#)) used for ground surface and geological investigations, utilising a variety of sensors ([Jones & Bateson, 2021](#))

1. DJI Phantom 4 (Used for training purposes only)
2. DJI Inspire 2
3. DJI Matrice 210 RTK
4. DJI Matrice 300 RTK

**Riegl LPM-800HA**



**Riegl VZ-1000**



**Faro Focus X-330**



**Figure 1 - Current BGS Terrestrial LiDAR Scanners**



**Figure 2 - Leica Pegasus Backpack Mobile Mapping Solution**



Figure 3 – GS10 system acting as on-ice ground control at Virkisjokull, Iceland



Figure 4 – Current BGS Unmanned Aerial Systems

The BGS has a large choice of software packages available (Jones, 2015) and a number of high-specification PC's capable of handling the acquired digital data. Software to process and output the acquired survey data is listed below. With the exception of Virtualis GeoVisionary, Paradigm GOCAD and Esri ArcGIS, all these proprietary processing and visualisation software packages fall under single user license restrictions, and as such are either loaded onto dedicated PC's or controlled by 'dongle' technology

1. Riegl RiScanPro (Acquisition & processing - Riegl VZ scanners)
2. Riegl RiProfile (Acquisition & processing - Riegl LPM scanners)
3. Faro Scene (Acquisition & processing - Faro scanner)
4. Leica Infinity (Post-processing – GNSS, TPS and UAV)
5. Maptek I-Site Studio (Point-cloud processing and modelling)
6. Golden Software Surfer (Gridding scanner data)
7. Cloud Compare (3D Point-cloud processing)
8. Paradigm GOCAD (Integration with other surfaces e.g. GPR)
9. Applied Imagery Quick Terrain Modeler (3D model creation)
10. Blue Marble Global Mapper (3D mapping and visualisation)
11. Esri ArcGIS (2D mapping and visualisation)
12. Virtualis GeoVisionary (3D mapping and visualisation)
13. Split-FX (Rock-fracture analysis)
14. DSE (Rock-fracture analysis)
15. DJI Terra (3D analysis, mapping and visualisation)
16. Pix4D Mapper (Photogrammetric processing and mapping)
17. PhotoScan (Photogrammetric processing)

### 3 Capability

The BGS geomatics capabilities have been utilised in a variety of scientific studies (Jones, 2014<sup>B</sup>) such as the monitoring of actively growing volcanic lava domes and rapidly retreating glaciers; coastal erosion and platform evolution; inland and coastal landslide modelling; mapping of geological structures and fault boundaries; rock stability and subsidence feature analysis; geo-conservation and public understanding of science (Jones et al., 2020). These capabilities can be utilised alongside airborne LiDAR and other remote sensing techniques in order to provide a range of complimentary applications, or information (Jordan & Napier, 2015). It is clear that LiDAR scanning technology is playing an increasingly important role in the acquisition of 3D spatial environmental data worldwide. This technology and its applications are certain to develop further as the rapidity and accuracy of data acquisition, and associated monitoring and modelling capabilities, become more widely recognised.

The developments in, and applications of, geomatics at the BGS in the last two decades have demonstrated the wide capability of this and related techniques in the field. Advances in technology have meant that the applications of LiDAR in the field of engineering geology have expanded dramatically over this time period:

1. The BGS uses Riegl and Faro terrestrial LiDAR scanners (Figure 1) because of their flexibility, range and portability. We have a very long-range scanner that can make measurements at distances of over 2000 m, a medium-range scanner that can make accurate measurements at distances of up to 800 m and a high-speed short-range (300 m) scanner that can take measurements at a rate of 972000 points/second with an accuracy of  $\pm 3$  mm. The newest model is the Riegl VZ-1000, which can scan up to 1400 m, with an accuracy of  $\pm 8$  mm and a measurement rate of 62000 points/second. A high-resolution digital camera coupled with a Leica GNSS (Global Navigation Satellite System) enables coloured point-clouds, textured triangulated surfaces or orthophotos, with intensity and depth information, to be captured, accurately geo-referenced and processed. Modern Terrestrial LiDAR Scanners (TLS) have significantly increased the level of resolution and accuracy achievable, and the speed of data acquisition. The ability to capture and measure changes in geological features with time by repeat surveys has revolutionised ground-based geomatics research, such as the monitoring of actively growing volcanic lava domes (Figure 5) and rapidly retreating glaciers; coastal erosion and platform evolution; inland and coastal landslide modelling; mapping of geological structures and fault boundaries; rock stability and subsidence feature analysis; geo-conservation and public understanding of science (Jones et al., 2020).
2. The BGS has become one of the first companies in the UK to purchase the Leica Pegasus Backpack, a wearable reality-capture sensor platform, enabling us to carry out 3D mapping of long coastal (or inland) sections, landslides and other unstable surfaces, ice sheets and glaciers, railway lines, roads and other linear features (Figure 2). Disaster responders will be able to capture data in 3D, on foot, in danger zone areas. Utilising Simultaneous Localisation and Mapping (**SLAM**) technology and high precision the Inertial Measurement Unit (**IMU**) ensure the achievement of accurate positioning even during GNSS outages, and with the addition of the external light-source, precise scanning of tunnels and cave systems is possible. The backpack can also be vehicle mounted, for mobile mapping, or pole mounted, for lowering into voids or sinkholes. This technology has been used for the pre-planning stage of the initial geological modelling input for the Bacton Sandscaping project; for inland landslide monitoring at the Hollin Hill Landslide Observatory and for coastal landslide monitoring at the Aldbrough Coastal Observatory, both in North Yorkshire; and for 3D surveying and change analyses of an incipient block failure near Dover, Kent. It has been used for the pre-design survey of the internal and external facades of Nottingham Castle; and for the scanning of the BGS Geological Walkway, for incorporation into Minecraft. It has also been used to trial a survey of the mineshaft systems at the Heights of Abraham, Derbyshire; and a trial of its use on an e-trike in calculating tidal sand volumes at Tenby, Wales (Figure 6).

3. Current GNSS units operate to sub-centimetre accuracy, with in-built IMU's, and can be used to acquire accurate surveys of static or moving ground (Figure 3), as well as non-linear features, including watercourses where the depth to the bed cannot be recorded as easily as other features. The ability to combine different technologies (LiDAR, GNSS, UAS) to create a system greater than the sum of its parts has resulted in a powerful tool to research and industry. The BGS is in the process of developing a Low Cost GNSS system as a rugged "disposable" solution for monitoring the movement of a landslide, the flow velocity of a glacier, volcanic deformation, coastal evolution, or differential ground subsidence (Figure 7). In addition, UAS can now be fitted with digital cameras, thermal detectors, multispectral cameras and LiDAR scanners (such as the one that BGS has recently acquired) to provide highly accurate data, with full-coverage 2D and 3D models.
4. Structure from motion photogrammetry (SfM) has emerged as an alternative viable technology to TLS, whether deployed on an unmanned aerial system (UAS) or otherwise. It is lighter, more compact, cheaper to buy and repair, and has lower power requirements than TLS. The BGS has four multi-rotor systems which it uses to collect data for ground surface and geological investigations (Figure 4) which it uses to collect data for ground surface and geological investigations (Jones & Bateson, 2021) utilising a variety of sensors including optical (RGB), radiometric thermal, multispectral, methane, CO2 and LiDAR. They are used in such fields as surveillance, filmmaking, scientific research, surveying, disaster relief, law enforcement archaeology, forestry and agriculture, as well as recreation. The BGS, like many other organisations, are able to utilise the usability and portability of these aircraft to create photogrammetric RGB and thermal images and point clouds using SfM techniques, at a fraction of the cost of using a system mounted on an aeroplane. The resultant data, though not as accurate as that obtained from TLS, should still be considered more than adequate for most uses, and gives the ability to create both 2D and 3D full colour models. The BGS has recently acquired a new UAS platform with a LiDAR module; the DJI Matrice M300RTK and Zenmuse L1, which integrates a Livox Lidar module, a high-accuracy IMU, and a camera with a 1-inch CMOS on a 3-axis stabilised gimbal. This forms a complete solution that gives real-time 3D LiDAR data throughout the day, efficiently capturing the details of complex structures and delivering highly accurate reconstructed models of geomorphological features such as inland or coastal processes (Figure 8).



**Figure 5 – Scanning the active lava dome of the Soufrière Hills Volcano, Montserrat**



**Figure 6 – Pegasus Backpack mounted on an e-trike in Tenby, Wales**



**Figure 7 – Low Cost GNSS unit on OS Trig. Point at Herstmonceux. Sussex**



**Figure 8 – DJI M210 with thermal camera at Aldbrough, Yorkshire**

## 4 Applications

The BGS has been carrying out ground-based geomatics surveys, both in the UK and overseas, since 2000, consisting of almost 450 surveys at over 200 different scanning locations (See [Appendix](#)). These can be split into three types of work:

### 1. Long-term monitoring work

- a. Rock stability analysis work on the cliffs at Brotton in North Yorkshire ([Jones et. al., 2006](#))
- b. Coastal Landslide monitoring at the Aldbrough Coastal Observatory in North Yorkshire ([Hobbs et.al. 2019<sup>A</sup>](#); [Hobbs et. al. 2019<sup>B</sup>](#))
- c. Change monitoring and volume calculations on the volcanic dome of the Soufriere Hills Volcano in Montserrat ([Jones et. al. 2006](#); [Donnelly et. al. 2006](#); [Loughlin et. al. 2010](#); [Ryan et. al. 2010](#))
- d. Coastal erosion monitoring along the Holderness and East Anglian coasts ([Rumson et. al. 2019](#); [Poulton et. al., 2006](#))
- e. Glacier evolution and monitoring at the Virkisjokull Ice Observatory in Iceland ([O' Dochartaigh et. al. 2019](#); [Philips et. al., 2014](#); [Philips et. al. 2013](#))
- f. Upland soil erosion monitoring at the Longmynd, Shropshire and DEFRA pilot study on 10 sites across England and Wales ([Glendell et. al. 2017](#))
- g. Inland landslide monitoring at the Hollin Hill Landslide Observatory in North Yorkshire ([Chambers et. al. 2011](#)) and other sites across the UK ([Gibson et. al. 2003](#); [Rowlands et. al. 2003](#); [Hobbs et. al. 2002](#))

### 2. Commercial work

- a. Rock stability analysis work on sections of the Rock of Gibraltar
- b. Confined space scanning at the Hellfire Caves, in Buckinghamshire
- c. LiDAR modelling of archaeological features in Farndon Fields, Nottinghamshire ([Tapete et. al. 2017](#))
- d. Structural glaciological modelling of a concentrated 'pulsed' axial glacier flow in Kviarjökull, Iceland ([Philips et. al. 2017](#))
- e. Pre-planning modelling of the Bacton area prior to a large Landscaping project
- f. Terrestrial LiDAR scanning for interpretation of the Chalk for the Lower Thames Crossing
- g. Long-term monitoring of the erosion at Hunstanton Cliffs, Norfolk
- h. Trials in the use of the Pegasus Backpack on tidal sand volumes at Tenby, Wales

### 3. Research work

- a. Geological structure mapping and reservoir potential modelling of the Permian Sandstone in Nottinghamshire and Cumbria
- b. Geomorphological mapping of rapidly retreating glacial features in Svinafellsjökull and Virkisjökull, Iceland ([Everest et. al. 2017](#))
- c. Geo-conservation work at Crime Rigg Quarry in County Durham
- d. Fault mapping at Hutton's Unconformity at Siccar Point, in Berwickshire
- e. Pre-design survey of the internal and external facades of Nottingham Castle
- f. Surveying of the mineshaft systems at the Heights of Abraham, Derbyshire, using the Pegasus Backpack

- g. Scanning of the BGS Geological Walkway, for incorporation into Minecraft for the BGS
- h. 3D surveying and change analyses of an incipient block near Dover, Kent ([Hobbs et. al. 2019<sup>c</sup>](#))

This list is far from exhaustive but gives an idea of the diversity and scope of the work carried out using ground-based geomatics techniques at the BGS. For information about the type of Terrestrial LiDAR Scanning undertaken on behalf of the BGS refer to the report entitled “Ground-Based Geomatics Surveys: Specification for Terrestrial LiDAR Scanning” ([Jones, 2019](#)).

More recently the BGS has been carrying out surveys where it is possible to combine all the aspects of the on-earth and near-earth geomatics techniques in order to create a final product that is greater than the sum of its parts. Three locations were chosen in order to determine the effectiveness of combining these techniques. The sites are at (1) Slaithwaite, (2) Hollin Hill and (3) Aldbrough.

#### 4.1 SLAITHWAITE DAM, KIRKLEES, YORKSHIRE

Slaithwaite Reservoir was constructed in about 1797 to supply the Huddersfield Canal and impounds the waters of Merry Dale Clough, a tributary of the River Colne. The reservoir ([Figure 9](#)) has a surface area of 46,000 m<sup>2</sup> and an estimated volume of ~175,000 m<sup>3</sup>. The dam is oriented roughly north south and is built at the east end of the reservoir ([Figure 10](#)). It is a ~17 m high earth fill dam with a reported puddle clay core. It has a 120 m long crest and a curved downstream slope with a slope angle ranging from ~25° in the upper parts to ~18° in the lower parts. The reservoir is still used for supplying the canal and is currently managed by the Canal and River Trust (CRT).

CRT had commissioned SOCOTEC Monitoring LTD to implement geophysical monitoring in collaboration with the BGS to investigate suspected leakage issues. A PRIME\* system was installed in July 2021 aiming to identify the origin of the leakage.

*\*PRIME is a low-cost system specifically designed to remotely monitor ‘at risk’ geotechnical assets (e.g. embankments; cuttings; dams). PRIME combines emerging geophysical ground-imaging technology with innovative data telemetry, web portal access and intelligent monitoring.*



**Figure 9 – Aerial view of Slaithwaite Reservoir**



**Figure 10 – Aerial view of the Dam**

The dam at Slaithwaite Reservoir was surveyed using Riegl VZ-1000 & Faro Focus X-330 Terrestrial LiDAR Scanners, Leica GS14 & GS18T Global Navigation Satellite Systems, Leica Pegasus Backpack Mobile Mapping System and DJI Matrice 210RTK Unmanned Aerial System.

The following gives a brief outline of the survey set-up and survey:

- The Leica GS14 was set-up as a base station, for post-processing of the Leica Pegasus Backpack data
- Five Ground Control Points (**GCP**) were placed across the dam, along with the landing pad, and positioned using the Leica GS18T Network RTK GNSS
- A walk-over survey of the entire dam was carried out using the Leica Pegasus Backpack MMS ([Figure 11](#))
- A single high-resolution scan was taken from the centre of the dam (above the tunnel entrance) using the Riegl VZ-1000 TLS, positioned using the Leica GS18T Network RTK GNSS ([Figure 12](#))
- A series of five scans were taken of the tunnel entrance and tunnel using the Faro Focus X-330 TLS, initially positioned using the Leica GS18T Network RTK GNSS unit and the scan taken with the Riegl VZ-1000 TLS ([Figure 13](#))
- Two photogrammetric surveys (North-South & East-West) were carried out using the DJI Matrice 210RTK UAS ([Figure 14](#))

The results of these individual surveys show the differences in the colour, resolution, coverage and point density of each technique. These images show the relative merits of each technique:

- VZ-1000 contains the greatest point density
- VZ-1000 & Matrice 210RTK display the best colour
- VZ-1000 & X-330 have the best resolution
- Pegasus & Matrice 210RTK afford the best coverage

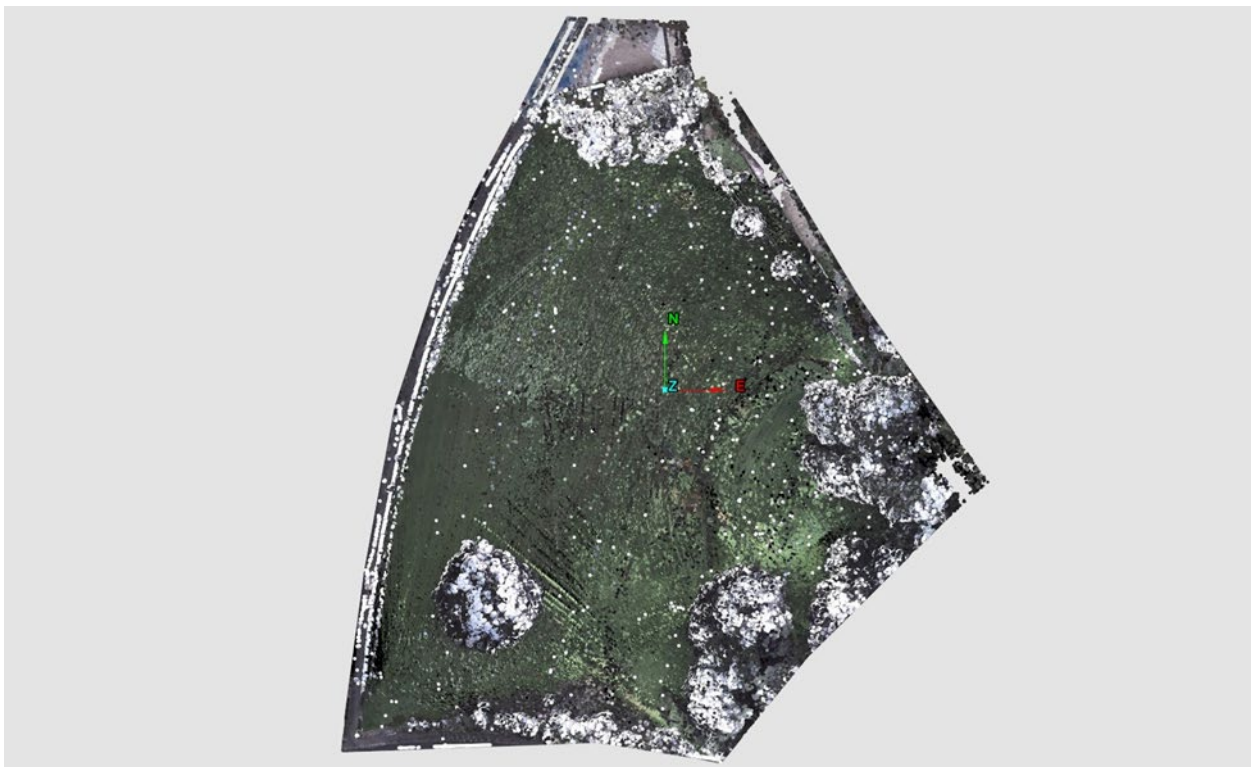


**Figure 11 – Point cloud of Dam generated from Leica Pegasus walk-over survey**



**Figure 12 – Point cloud of Dam generated from Riegl VZ-1000 scan**

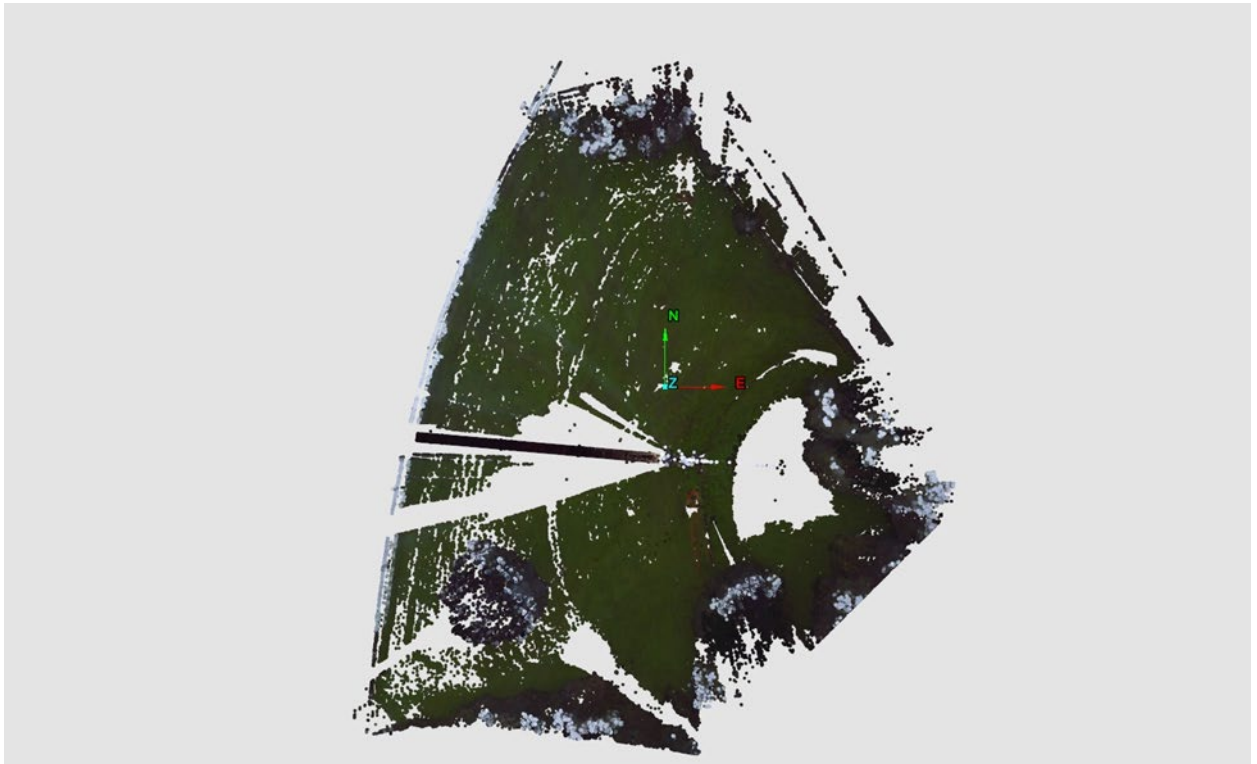


**Figure 13 – Point cloud of Tunnel generated from Faro X-330 scan**



**Figure 14 – Point cloud of Dam generated from DJI Matrice 210RTK imagery**

Utilising all the point cloud data, by combining them together enables the creation of a Digital Elevation Model (DEM) for the Dam, the Tunnel and the surrounding area ([Figures 15 & 16](#)).

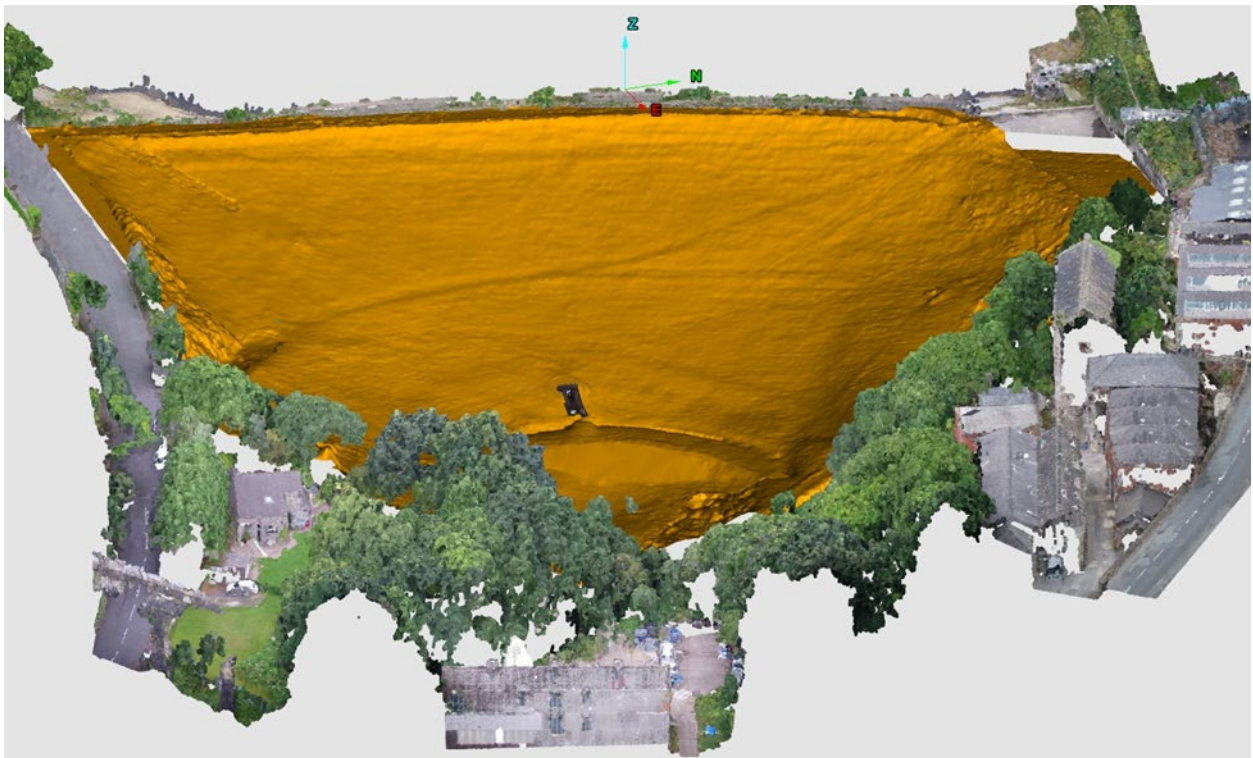


**Figure 15 – DEM of Slaithwaite Dam and surrounding area**

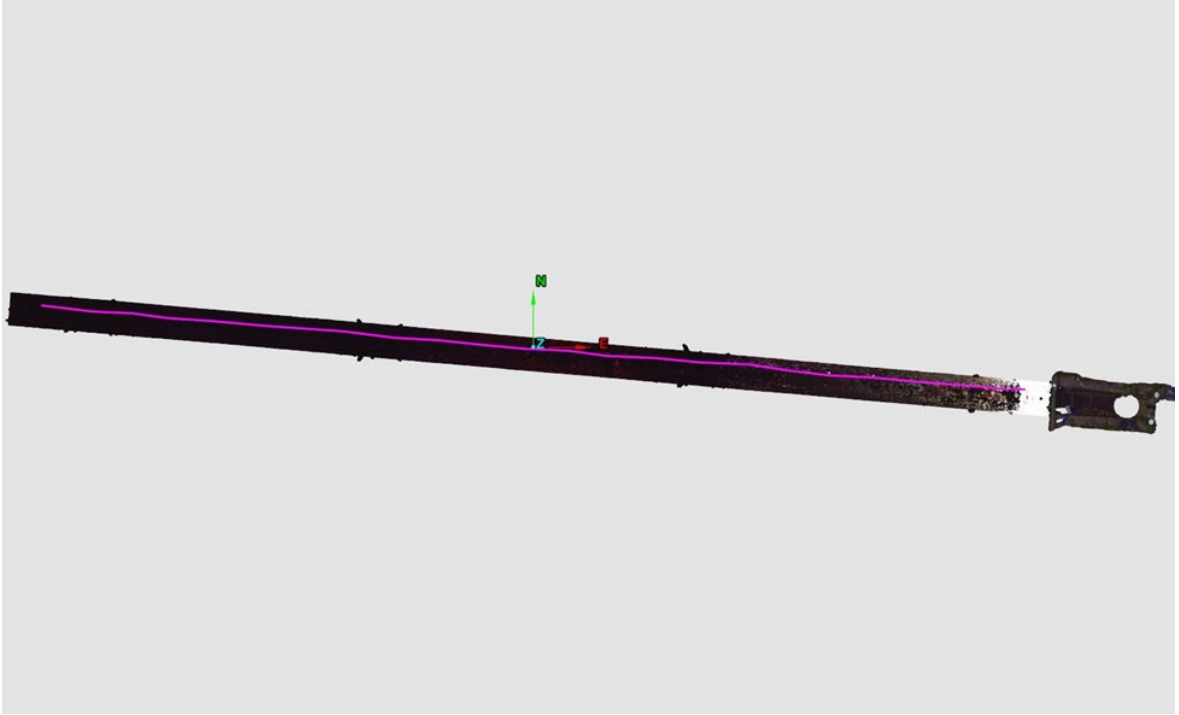


**Figure 16 – DEM of Slaithwaite Dam Tunnel**

## 4.2 HOLLIN HILL, RYEDALE, YORKSHIRE

The BGS has operated a field observatory site at Hollin Hill, in North Yorkshire, since 2004. It brings together a combination of field surveying, geomorphological, geophysical, engineering and hydrogeological expertise at BGS.

The landslide lies to the north of York (Figure 17), is several hundred metres wide and extends some 200 m down slope (Figure 18). It is located on the south facing side of a degraded Devensian ice-margin drainage channel; the slope has an angle of approximately 12°. This landslide is National Landslide Database ID 15659/1.

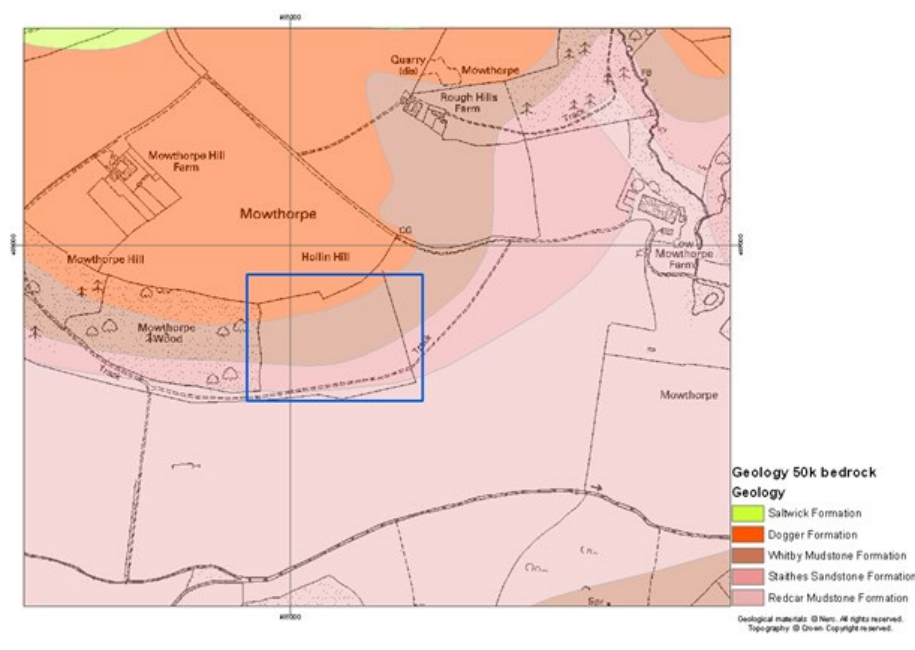


**Figure 17 – Location (and geology) of the Hollin Hill landslide**

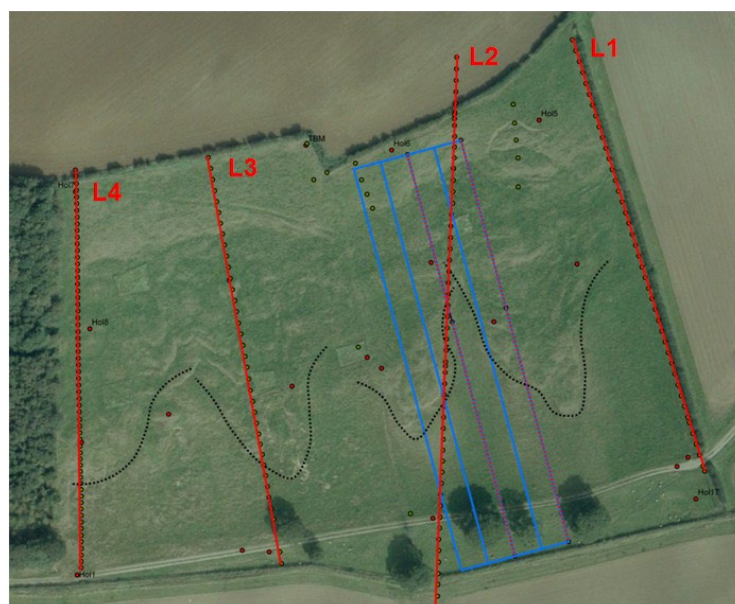


**Figure 18 – Aerial photograph of Hollin Hill landslide with geophysical survey plan**

The slope at Hollin Hill consists of Redcar Mudstone (Lower Lias) at the base, with an outcrop of the Staithes Sandstone Formation (Middle Lias) running across the middle section of the slope. The Whitby Mudstone Formation (Upper Lias) overlies this, with the upper part of the slope composed of the Dogger Formation. Both the Redcar Mudstone and the Whitby Mudstone are

highly susceptible to landsliding, and movement across the entire slope is due to these two Formations.

The landslide is largely caused by the movement of the Whitby Mudstone Formation, which is highly prone to landsliding. The landslide is characterised by shallow rotational failures at the top of the slope in the Whitby Mudstone, which move through an area of translational landslide movement and “cascade” over the *in situ* Staithes Sandstone Formation feeding into four larger-scale slow-moving (i.e. tens of centimetres per year) lobes of slumped material at the bottom of the slope. Relatively little is known about the hydrogeology of the site. However, a spring line extends across the base of the slope where the Staithes Sandstone overlies the underlying Redcar Mudstone Formation (Figures 19 and 20).

The morphology of the slope is complex with numerous isolated shallow failures and slumping. Locally the slope becomes very steep where slipped material has accumulated to form lobes.

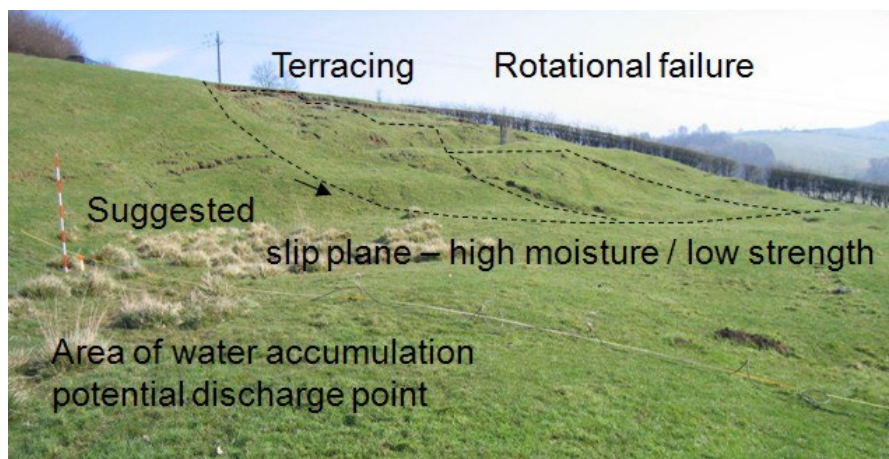


Figure 19 – Annotated photograph of the Hollin Hill landslide

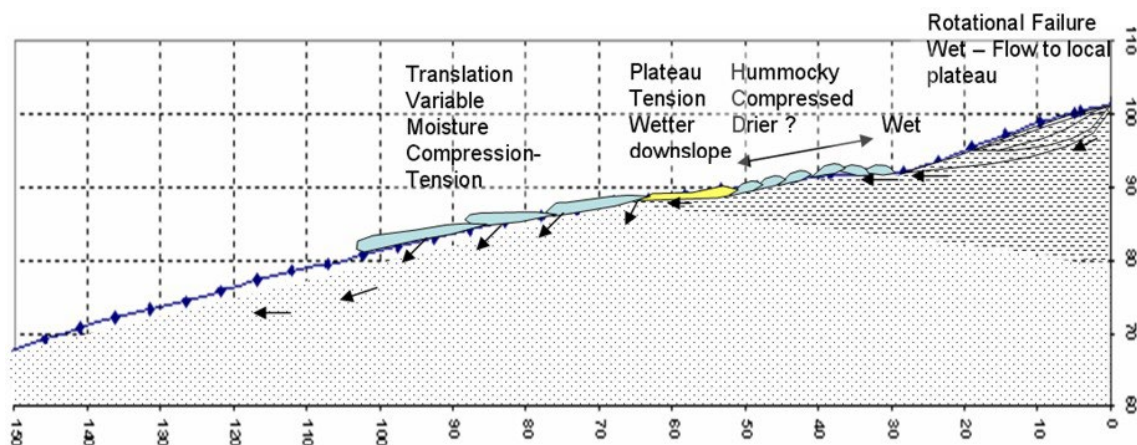


Figure 20 – Conceptual model of the Hollin Hill landslide

The field, and landslides, at Hollin Hill were surveyed using a Riegl VZ-1000 Terrestrial LiDAR Scanner, a Leica GS18T Global Navigation Satellite System and DJI Matrice 210RTK & Inspire 1 Unmanned Aerial Systems.

The following gives a brief outline of the survey set-up and survey:

- Six Ground Control Points (**GCP**) were placed across the dam and positioned using the Leica GS18T Network RTK GNSS

- Five high-resolution scans were taken across the field area (two across the top, one in the middle, 2 across the bottom) using the Riegl VZ-1000 TLS, positioned using the Leica GS18T Network RTK GNSS ([Figure 21](#))
- Two photogrammetric surveys (North-South & East-West) were carried out using the DJI Matrice 210RTK UAS ([Figure 22](#))
- A thermal imaging survey was carried out using the DJI Inspire 1 UAS ([Figure 23](#))

The results of these individual surveys show the differences in the colour, resolution, coverage and point density of each technique. The following gives a brief outline of the survey set-up and survey:

- Matrice 210RTK displays the best colour
- Inspire 1 Raw displays the best thermal imagery
- VZ-1000 contains the greatest point density, albeit in a much smaller section of the field
- VZ-1000 has the best resolution
- Matrice 210RTK and Inspire 1 Raw afford the best coverage

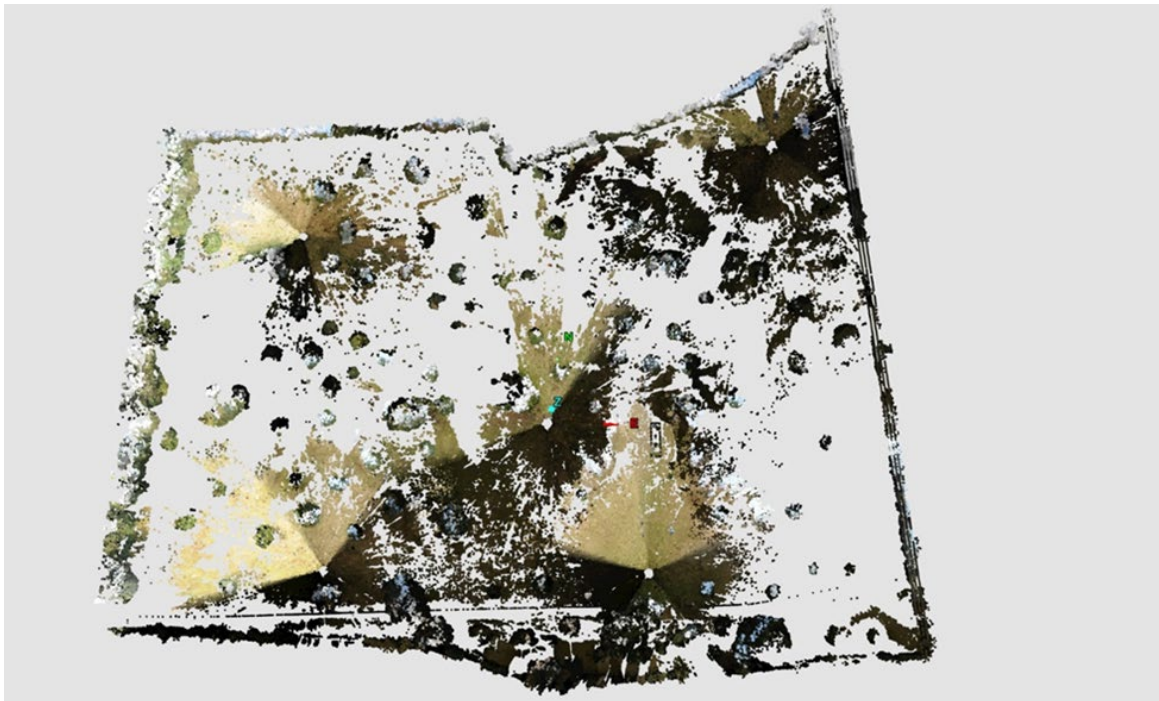


**Figure 21 – Point cloud of three parts of the field generated from Riegl VZ-1000 scan**



**Figure 22 – Photogrammetric image generated from DJI Matrice 210RTK UAV**

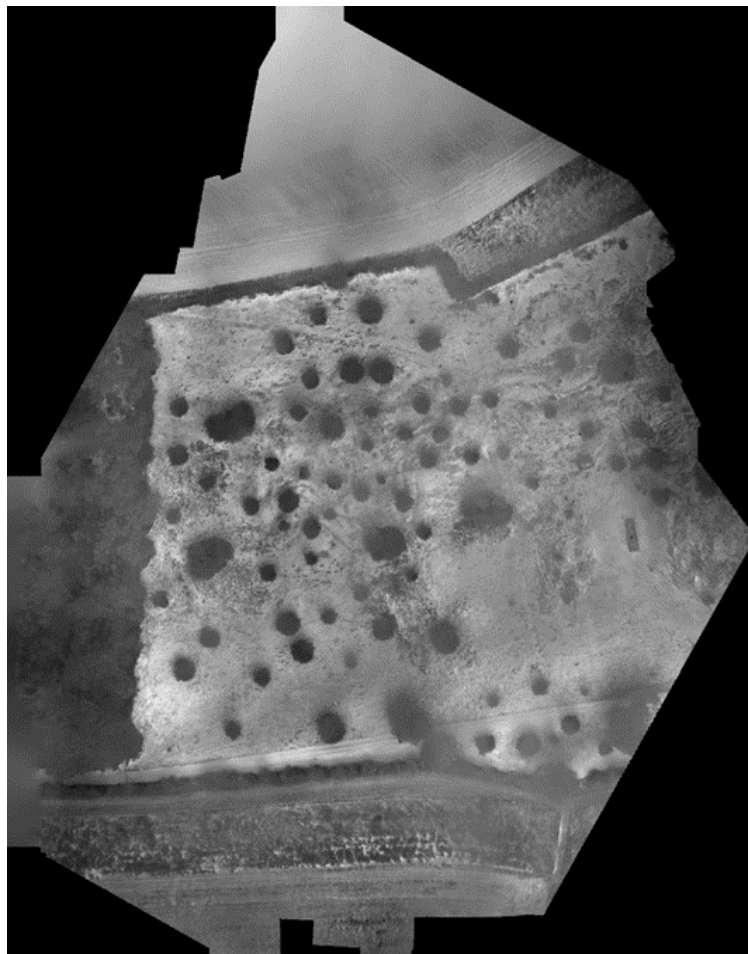


**Figure 23 – Thermal images generated from DJI Inspire 1 Raw UAV**

Utilising all the point cloud data, by combining them together enables the creation of a Digital Elevation Model (DEM) for the field and the surrounding area ([Figure 24](#)).

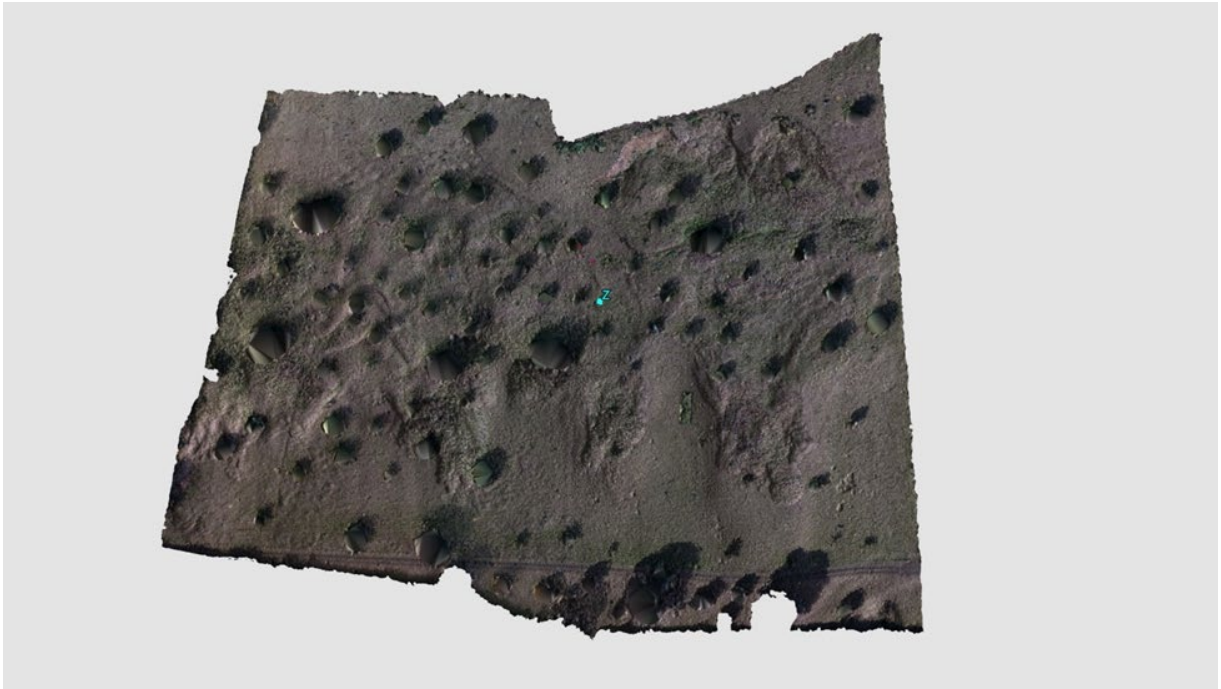


**Figure 24 – Digital Elevation Model (DEM) of Hollin Hill**

### 4.3 ALDBROUGH, SOUTH YORKSHIRE

The BGS's test site at Aldbrough is located approximately midway on the extensive Holderness coast in South Yorkshire [NGR525770 439605]. Aldbrough is situated about 10km southeast of Hornsea. The ~300m stretch is centred on the road accessing the Caravan Park (Figure 25). The cliff faces northeast, is low (17m) and of regular height. It consists of till and is actively receding, both by toppling and rotational mechanisms (Figure 26). Refer to BGS research report OR/11/063 for a detailed discussion of the Aldbrough project including the geology, geomorphology and geotechnics.

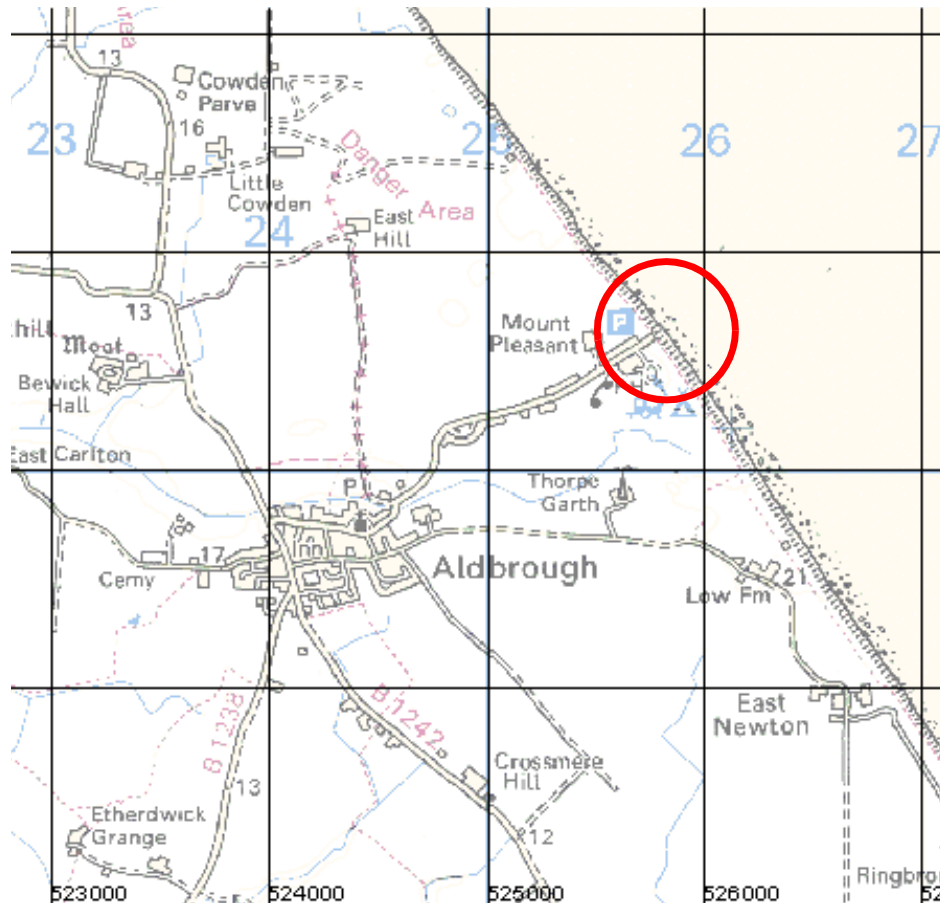


Figure 25 – Location of test site at Aldbrough



## Figure 26 – Rotational landsliding is the primary mechanism at Aldbrough

The cliffs at the Aldbrough Coastal Landslide Observatory was surveyed using a Riegl VZ-1000 Terrestrial LiDAR Scanner, Leica GS14 & GS18T Global Navigation Satellite Systems, a Leica Pegasus Backpack Mobile Mapping System and a DJI Matrice 210RTK Unmanned Aerial System.

The following gives a brief outline of the survey set-up and survey:

- The Leica GS14 was set-up as a base station, for post-processing of the Leica Pegasus Backpack data
- Six Ground Control Points (**GCP**) were placed across the top of the cliffs, along with the landing pad, and positioned using the Leica GS18T Network RTK GNSS
- A walk-over survey of top of the cliffs (500 m North & 500 m South) was carried out using the Leica Pegasus Backpack MMS ([Figure 27](#))
- Eleven high-resolution scans were taken across the top of the cliffs (500 m North & 500 m South) using the Riegl VZ-1000 TLS, positioned using the Leica GS18T Network RTK GNSS ([Figure 28](#))
- Four photogrammetric surveys (North-South & East-West) (2 x 500 m North & 2 x 500 m South) and one high-density oblique photogrammetric survey (200 m centred on the road) were carried out using the DJI Matrice 210RTK UAS ([Figures 29 & 30](#))
- Two high-density thermal surveys (200 m North & 200 m South) were carried out using the DJI Matrice 210RTK UAS

The results of these individual surveys show the differences in the colour, resolution, coverage and point density of each technique. The following gives a brief outline of the survey set-up and survey:

- Matrice 210RTK displays the best colour and thermal imagery
- VZ-1000 contains the greatest point density and resolution
- Pegasus Backpack and Matrice 210RTK afford the best coverage

Utilising all the point cloud data, Pegasus, VZ-1000 & UAS, and combining them together enables the creation of a DEM ([Figure 31](#)) and a thermal image ([Figure 32](#)) for the cliffs and the surrounding area at Aldbrough.



Figure 27 – Point cloud of Cliff top generated from Pegasus walk-over survey

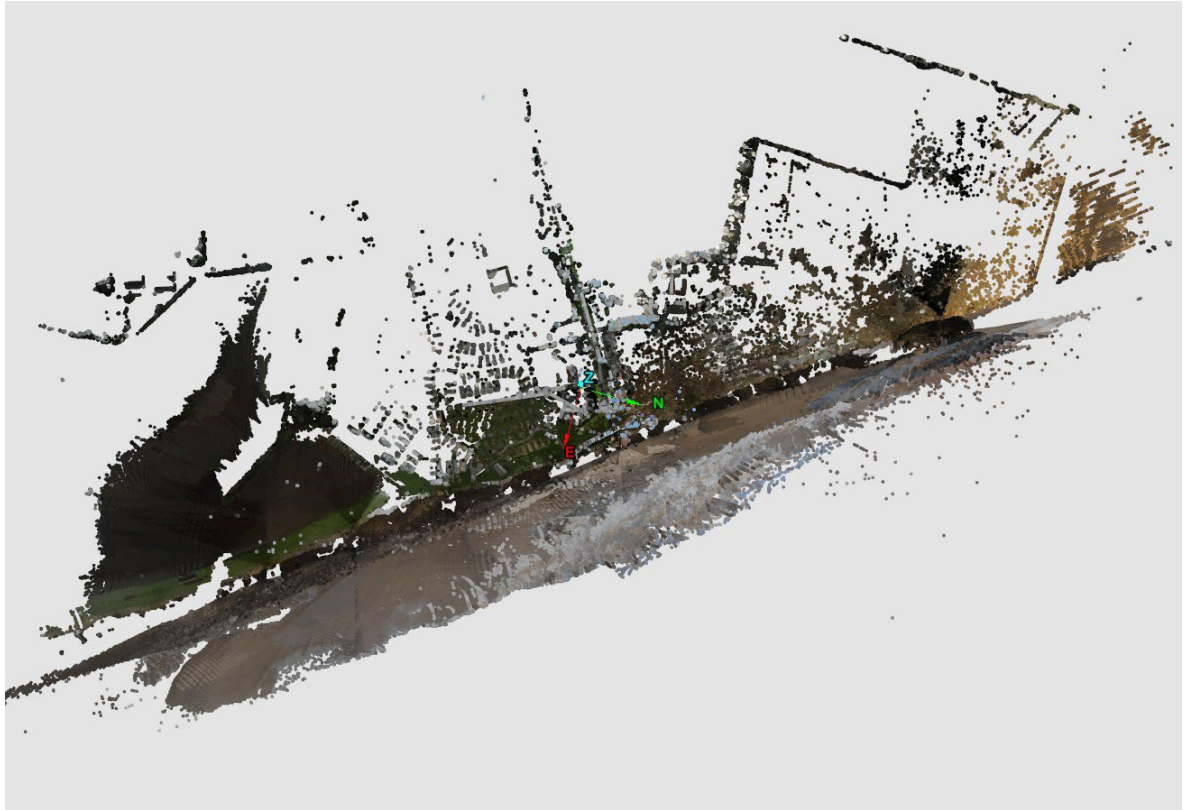


Figure 28 – Point cloud of Cliff top generated from VZ-1000 scan



Figure 29 – Point cloud generated from DJI M210RTK photogrammetric image



Figure 30 – Point cloud generated from DJI M210RTK oblique photogrammetric image

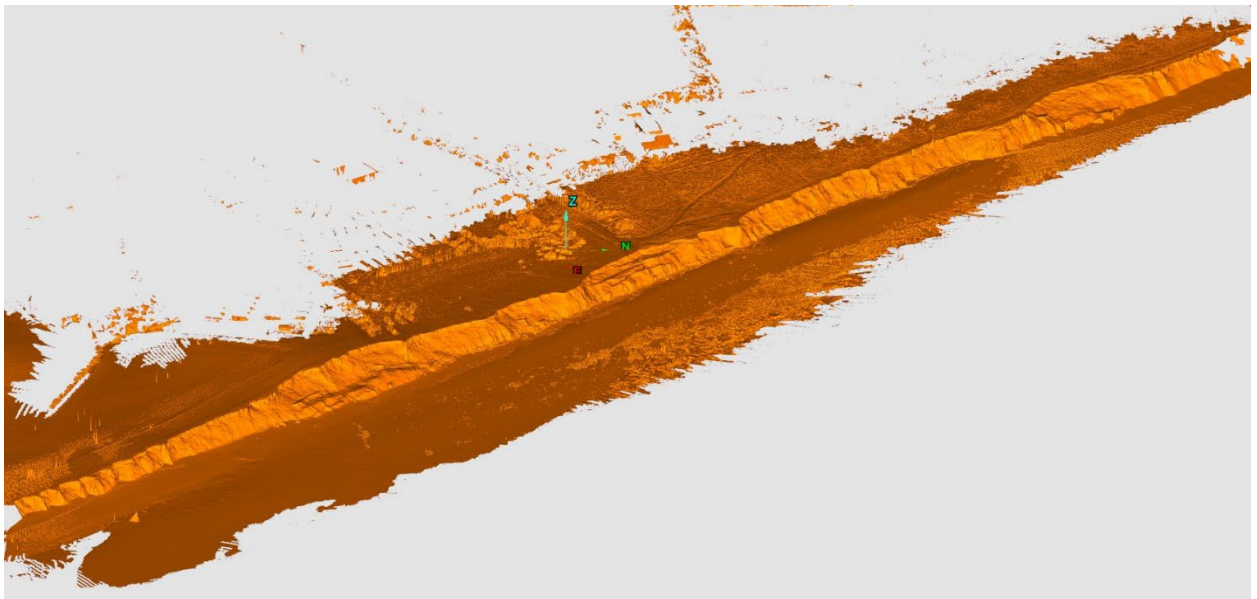


Figure 31 – Digital Elevation Model (DEM) of the cliffs at Aldbrough, from combined data sets (Pegasus, VZ-1000 & UAS)

**Thermal image here!**

Figure 32 – Thermal image of the cliffs at Aldbrough

Looking at the various technologies in isolation we can see that there are gaps in the point clouds generated from the Pegasus (Figure 27), VZ-1000 (Figure 28) and from the nadir and oblique

surveys of the UAS (Figures 29 & 30). Looking at Figure 31 it can be seen that there are no gaps in the combined data that has been used to create the final DEM.

With the addition of the newly acquired DJI M300RTK and Zenmuse L1 LiDAR module the BGS is able to add aerial (UAS) LiDAR (Figure 33) to the Aldbrough, and other, sites giving the ability to look at geomorphological landforms, such as the 750 m long Ords, in a much easier way, and in greater detail (Figure 34). The L1 is able to generate multiple returns and as such is able to create a DTM (Figure 35) more easily, by eliminating trees and vegetation automatically. Combining all these elements allows us to create a fully immersive 3D model of the cliffs (Figure 36).

**Point Cloud from M300 here!**

**Figure 33 – Point cloud generated from DJI M300RTK and Zenmuse L1 LiDAR module**

**Close-up of Ord here!**

**Figure 34 – Close-up of Ord generated from DJI M300**

**DTM from L1 here!**

**Figure 35 – DTM of Aldbrough using the combined information provided from *all* surveys**

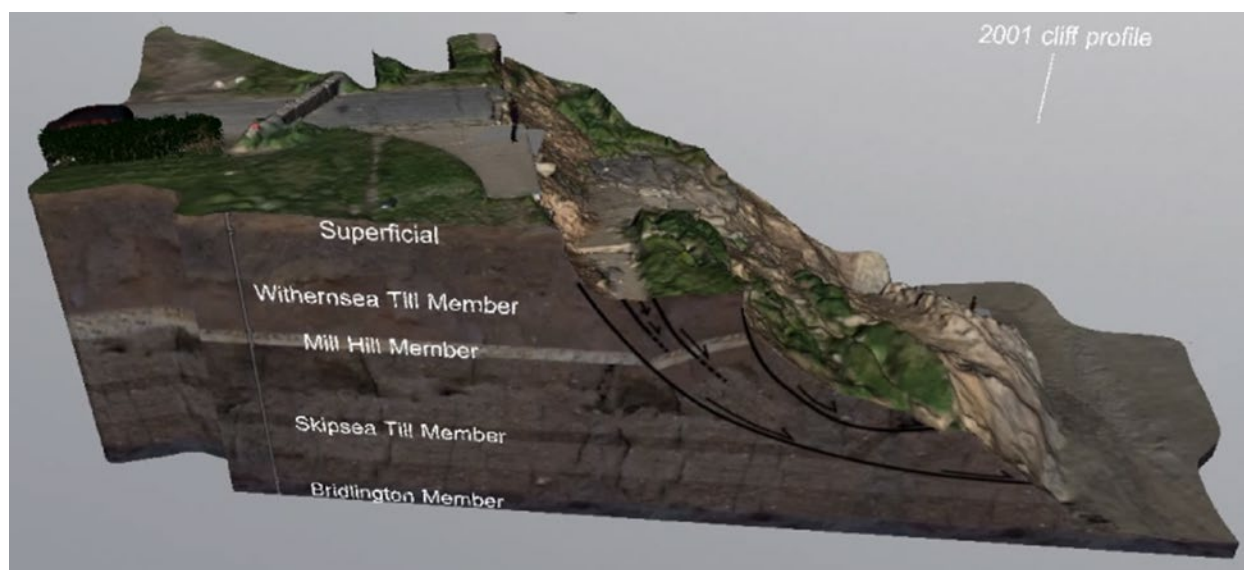


**Figure 36 – 3D Model of the cliff at Aldbrough**

## Appendix 1 LiDAR Survey Locations

| Name                       | Location        | Type            | Lithology                  | Year       | Surveys |
|----------------------------|-----------------|-----------------|----------------------------|------------|---------|
| <b>UK:</b>                 |                 |                 |                            |            |         |
| Greenburn Mine             | Ayrshire        | Surface Mine    | Coal Measures Group        | 2014       | 1       |
| Spireslack Opencast        | Ayrshire        | Surface Mine    | Coal Measures Group        | 2014       | 1       |
| Kensworth Chalk Pit        | Bedfordshire    | Quarry          | Chalk Group                | 2018       | 1       |
| Siccar Point               | Berwickshire    | Unconformity    | Strathden Group/Gala Group | 2008       | 1       |
| Glan Ebbw                  | Blaenau Gwent   | Landslide       | Pennant Group              | 2016       | 1       |
| Southern Scar              | Brecon Beacons  | Erosion Feature | Peat                       | 2014, 2015 | 2       |
| Waun Fach                  | Brecon Beacons  | Erosion Feature | Peat                       | 2014, 2015 | 2       |
| Hellfire Caves             | Buckinghamshire | Cave            | Upper Chalk Formation      | 2014       | 1       |
| Dunnet Bay                 | Caithness       | Beach           | Till                       | 2005       | 1       |
| Sandside Bay               | Caithness       | Beach           | Till                       | 2007       | 1       |
| Scrach Track               | Carmarthenshire | Unconformity    | Scrach Formation           | 2011       | 1       |
| Telychian Quarry           | Carmarthenshire | Quarry          | Wormwood Formation         | 2011       | 1       |
| Telychian RD               | Carmarthenshire | Road Cutting    | Wormwood Formation         | 2011       | 1       |
| Trefawr Track              | Carmarthenshire | Section         | Trefawr Formation          | 2011       | 1       |
| Frogsmouth Quarry          | Cheshire        | Quarry          | Sherwood Sandstone Group   | 2011       | 1       |
| Newquay                    | Cornwall        | Sea Cliff       | Dartmouth Group            | 2007       | 1       |
| Crime Rigg Quarry          | County Durham   | Quarry          | Yellow Sands Formation     | 2011       | 1       |
| Moor House                 | County Durham   | Erosion Feature | Till                       | 2014       | 1       |
| Applethwaite               | Cumbria         | Erosion Feature | Skiddaw Group              | 2014       | 1       |
| Brundholme                 | Cumbria         | River Scour     | Till                       | 2017       | 1       |
| Castle Rock                | Cumbria         | Outcrop         | Borrowdale Volcanic Group  | 2016       | 1       |
| Howgill Fells <sup>1</sup> | Cumbria         | Erosion Feature | Till                       | 2014       | 1       |

|                    |            |                 |                           |                                    |   |
|--------------------|------------|-----------------|---------------------------|------------------------------------|---|
| Howgill Fells2     | Cumbria    | Erosion Feature | Till                      | 2015                               | 1 |
| Nateby             | Cumbria    | Erosion Feature | Till                      | 2015                               | 1 |
| River Greta        | Cumbria    | River Scour     | Till                      | 2017, 2018                         | 2 |
| Wescoe Woods       | Cumbria    | River Scour     | Till                      | 2017                               | 1 |
| Curbar Edge        | Derbyshire | Outcrop         | Millstone Grit            | 2015(2), 2017, 2019 (2)            | 5 |
| Mam Tor            | Derbyshire | Outcrop         | Bowland Shale Formation   | 2013, 2014(2)                      | 3 |
| Rowlee Bridge      | Derbyshire | River Cliff     | Millstone Grit            | 2007                               | 1 |
| Snake Pass         | Derbyshire | Erosion Feature | Peat                      | 2014(2)                            | 2 |
| Budleigh Salterton | Devon      | Sea Cliff       | Otter Sandstone Formation | 2013(2)                            | 2 |
| Exwell Barton Farm | Devon      | Erosion Feature | Alluvium                  | 2014                               | 1 |
| Flat Tor Pan       | Devon      | Erosion Feature | Peat                      | 2014                               | 1 |
| Hangingstone Hill  | Devon      | Erosion Feature | Peat                      | 2014                               | 1 |
| Sidmouth           | Devon      | Sea Cliff       | Otter Sandstone Formation | 2009, 2013                         | 2 |
| Starcross          | Devon      | Erosion Feature | Alluvium                  | 2014                               | 1 |
| Black Ven          | Dorset     | Landslide       | Lias Group                | 2001, 2002, 2003, 2004, 2005, 2008 | 6 |
| Burton Bradstock   | Dorset     | Sea Cliff       | Bridport Sand Formation   | 2012(2), 2014                      | 3 |
| Chesil Beach       | Dorset     | Beach           | Kimmeridge Clay Formation | 2018, 2019                         | 2 |
| Devonshire Head    | Dorset     | Sea Cliff       | Lias Group                | 2012                               | 1 |
| Hive Beach         | Dorset     | Sea Cliff       | Lias Group                | 2012                               | 1 |
| Lulworth Cove      | Dorset     | Sea Cliff       | Purbeck Group             | 2014                               | 1 |
| Spittles           | Dorset     | Beach           | Lias Group                | 2014                               | 1 |
| Stair Hole         | Dorset     | Sea Cliff       | Purbeck Group             | 2014                               | 1 |
| Stonebarrow Hill   | Dorset     | Sea Cliff       | Lias Group                | 2001, 2002, 2003, 2004             | 4 |
| Ware Cliff         | Dorset     | Sea Cliff       | Lias Group                | 2001, 2003                         | 2 |
| Lyell Centre       | Edinburgh  | BGS Site        | Not Geological            | 2021                               | 1 |

|                   |                          |              |                             |                                                                                                                                                                              |    |
|-------------------|--------------------------|--------------|-----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Aldbrough         | East Riding of Yorkshire | Sea Cliff    | Till                        | 2001, 2002(2), 2003, 2004(2), 2005, 2006(2), 2007, 2009(2), 2010(2), 2011(2), 2012(5), 2013(3), 2014(2), 2015(4), 2016(4), 2017(4), 2018(4), 2019(4), 2020(3), 2021(2), 2022 | 52 |
| Dimlington        | East Riding of Yorkshire | Sea Cliff    | Till                        | 2006, 2009, 2010(2)                                                                                                                                                          | 4  |
| Easington         | East Riding of Yorkshire | Sea Cliff    | Till                        | 2004, 2005, 2006                                                                                                                                                             | 3  |
| Easington Lagoons | East Riding of Yorkshire | Lagoon       | Tidal Flat Deposits         | 2006                                                                                                                                                                         | 1  |
| Runswick Bay      | East Riding of Yorkshire | Sea Cliff    | Lias Group                  | 2001                                                                                                                                                                         | 1  |
| Speeton           | East Riding of Yorkshire | Sea Cliff    | Speeton Clay Formation      | 2001, 2002, 2003, 2004                                                                                                                                                       | 4  |
| Spurn Head        | East Riding of Yorkshire | Coastal Site | Tidal Flat Deposits         | 2005, 2009                                                                                                                                                                   | 2  |
| Bowscar Quarry    | Eden Valley              | Quarry       | Penrith Sandstone Formation | 2010                                                                                                                                                                         | 1  |
| Cowraik Quarry    | Eden Valley              | Quarry       | Penrith Sandstone Formation | 2010                                                                                                                                                                         | 1  |
| LazenbyEst_4      | Eden Valley              | River Cliff  | Penrith Sandstone Formation | 2010                                                                                                                                                                         | 1  |
| LazenbyEst_CC     | Eden Valley              | River Cliff  | Penrith Sandstone Formation | 2010                                                                                                                                                                         | 1  |
| LazenbyEst_FH     | Eden Valley              | River Cliff  | Penrith Sandstone Formation | 2010                                                                                                                                                                         | 1  |
| Oglebird Scar     | Eden Valley              | River Cliff  | Penrith Sandstone Formation | 2010                                                                                                                                                                         | 1  |
| Chafford Hundred  | Essex                    | Outcrop      | Upper Chalk Formation       | 2017                                                                                                                                                                         | 1  |
| Fivestar          | Essex                    | Outcrop      | Upper Chalk Formation       | 2017                                                                                                                                                                         | 1  |
| Purfleet          | Essex                    | Outcrop      | Upper Chalk Formation       | 2017                                                                                                                                                                         | 1  |
| Purfleet Tesco    | Essex                    | Outcrop      | Upper Chalk Formation       | 2017, 2019                                                                                                                                                                   | 2  |

|                        |                 |              |                                 |                  |   |
|------------------------|-----------------|--------------|---------------------------------|------------------|---|
| Laverton               | Gloucestershire | Embankment   | Lias Group                      | 2014             | 1 |
| Severn Estuary         | Gloucestershire | Gravel Waves | Tidal Flat Deposits             | 2008             | 1 |
| Oxwich Bay             | Gower           | Landslide    | Oxwich Haed Limestone Formation | 2019             | 1 |
| Sunny Hill             | Hertfordshire   | Gravel Pit   | Raglan Mudstone Formatiuon      | 2011             | 1 |
| Bluewater              | Kent            | Outcrop      | Upper Chalk Formation           | 2017, 2018       | 2 |
| Botony Bay             | Kent            | Outcrop      | Upper Chalk Formation           | 2017             | 1 |
| Broadstairs            | Kent            | Sea Cliff    | Upper Chalk Formation           | 2017             | 1 |
| Chatham                | Kent            | Outcrop      | Upper Chalk Formation           | 2017             | 1 |
| Chatham Garage         | Kent            | Outcrop      | Upper Chalk Formation           | 2017             | 1 |
| Chatham Travis Perkins | Kent            | Outcrop      | Upper Chalk Formation           | 2017             | 1 |
| Cliffe                 | Kent            | Outcrop      | Upper Chalk Formation           | 2017             | 1 |
| Dover Cliffs           | Kent            | Sea Cliff    | Upper Chalk Formation           | 2019, 2020(2)    | 3 |
| Ebbsfleet              | Kent            | Outcrop      | Upper Chalk Formation           | 2019             | 1 |
| Folkestone Warren      | Kent            | Landslide    | Lower & Middle Chalk Formations | 2001, 2002, 2003 | 3 |
| Fort Amherst           | Kent            | Outcrop      | Upper Chalk Formation           | 2017             | 1 |
| Frindsbury (S)         | Kent            | Outcrop      | Upper Chalk Formation           | 2019             | 1 |
| Frindsbury (N)         | Kent            | Outcrop      | Upper Chalk Formation           | 2017, 2019       | 2 |
| Kingsdown              | Kent            | Sea Cliff    | Upper Chalk Formation           | 2017             | 1 |
| Lion Gorge             | Kent            | Quarry       | Upper Chalk Formation           | 2019             | 1 |
| Northfleet             | Kent            | Outcrop      | Upper Chalk Formation           | 2017, 2018       | 2 |
| Northfleet Lidl        | Kent            | Outcrop      | Upper Chalk Formation           | 2019             | 1 |
| Pindon                 | Kent            | Quarry       | Upper Chalk Formation           | 2018             | 1 |
| Pegwell Bay            | Kent            | Sea Cliff    | Upper Chalk Formation           | 2017             | 1 |
| Samphire Hoe           | Kent            | Sea Cliff    | Upper Chalk Formation           | 2017             | 1 |
| Shakespeare Beach      | Kent            | Beach        | Upper Chalk Formation           | 2018(2)          | 2 |
| St. Margaret's Bay (S) | Kent            | Sea Cliff    | Upper Chalk Formation           | 2017(2)          | 2 |

|                        |                 |                 |                                      |                                                                                             |    |
|------------------------|-----------------|-----------------|--------------------------------------|---------------------------------------------------------------------------------------------|----|
| St. Margaret's Bay (N) | Kent            | Sea Cliff       | Upper Chalk Formation                | 2017(2)                                                                                     | 2  |
| Strood                 | Kent            | Quarry          | Upper Chalk Formation                | 2017 (2), 2019                                                                              | 3  |
| Swanscombe             | Kent            | Quarry          | Upper Chalk Formation                | 2019                                                                                        | 1  |
| Thurock                | Kent            | Outcrop         | Upper Chalk Formation                | 2017                                                                                        | 1  |
| Warden Point           | Kent            | Sea Cliff       | London Clay Formation                | 2001, 2002, 2003, 2004                                                                      | 4  |
| Forest of Bowland      | Lancashire      | Erosion Feature | Peat                                 | 2014, 2015                                                                                  | 2  |
| Bradgate Park          | Leicestershire  | Outcrop         | Charnian Supergroup                  | 2008, 2013, 2015                                                                            | 3  |
| Brown's Hill Quarry    | Leicestershire  | Quarry          | Marlstone Rock Formation             | 2008                                                                                        | 1  |
| Charnwood              | Leicestershire  | Outcrop         | Charnian Supergroup                  | 2017(4)                                                                                     | 4  |
| Croft Quarry           | Leicestershire  | Quarry          | South Leicestershire Diorite Complex | 2014                                                                                        | 1  |
| North Quarry           | Leicestershire  | Quarry          | Charnian Supergroup                  | 2008                                                                                        | 1  |
| Ratho                  | Lothian         | Quarry          | Midland Valley Sill Complex          | 2007                                                                                        | 1  |
| Bacton                 | Norfolk         | Sea Cliff       | Till                                 | 2019                                                                                        | 1  |
| Happisburgh            | Norfolk         | Sea Cliff       | Till                                 | 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2009(2), 2010, 2011, 2013, 2016, 2018, 2019 | 16 |
| Sidestrand             | Norfolk         | Sea Cliff       | Crag Group                           | 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2016                                        | 9  |
| West Runton            | Norfolk         | Sea Cliff       | Upper Chalk Formation                | 2011                                                                                        | 1  |
| Weybourne              | Norfolk         | Sea Cliff       | White Chalk Subgroup                 | 2000, 2001, 2002, 2003, 2004                                                                | 5  |
| Aislaby                | North Yorkshire | Landslide       | Lias Group                           | 2016                                                                                        | 1  |
| Brotton                | North Yorkshire | Sea Cliff       | Lias Group                           | 2005(2), 2006                                                                               | 3  |
| Coldstones Quarry      | North Yorkshire | Quarry          | Millstone Grit Group                 | 2012                                                                                        | 1  |
| Ripon                  | North Yorkshire | Sinkhole        | Gypsum                               | 2019(3)                                                                                     | 3  |
| Robin Hood's Bay       | North Yorkshire | Sea Cliff       | Lias Group                           | 2001, 2002, 2003, 2004                                                                      | 4  |
| Runswick Bay           | North Yorkshire | Beach           | Lias Group                           | 2018(2)                                                                                     | 2  |
| Sleights               | North Yorkshire | Landslide       | Redcar Mudstone Formation            | 2016                                                                                        | 1  |

|                      |                   |                  |                                  |                        |   |
|----------------------|-------------------|------------------|----------------------------------|------------------------|---|
| Whitby               | North Yorkshire   | Landslide        | Lias Group                       | 2012                   | 1 |
| Whitby Lighthouse    | North Yorkshire   | Sea Cliff        | Lias Group                       | 2002, 2004             | 2 |
| Road                 | Northamptonshire  | Railway Cutting  | Blisworth Limestone Formation    | 2005                   | 1 |
| Berry Hill           | Nottinghamshire   | Quarry           | Sherwood Sandstone               | 2019, 2020             | 2 |
| Besthorpe            | Nottinghamshire   | Church           | Not Geological                   | 2013, 2014             | 2 |
| BGS                  | Nottinghamshire   | BGS Site         | Not Geological                   | 2012, 2015(2), 2017(2) | 5 |
| Farndon              | Nottinghamshire   | Archeological    | Anthropologic Deposits           | 2015 (2)               | 2 |
| Keyworth Cutting     | Nottinghamshire   | Embankment       | Lias Group                       | 2015                   | 1 |
| Park Tunnel          | Nottinghamshire   | Tunnel           | Sherwood Sandstone               | 2009(2)                | 2 |
| Victoria Centre      | Nottinghamshire   | Exposure         | Sherwood Sandstone               | 2009                   | 1 |
| Llangynidr           | Powys             | Embankment       | Glaciofluvial                    | 2015                   | 1 |
| Talla                | Scottish Borders  | Soil Observatory | Peat/Till                        | 2007, 2009, 2010       | 3 |
| West Linton          | Scottish Borders  | Buildings        | Not Geological                   | 2014                   | 1 |
| Long Mynd            | Shropshire        | Erosion Feature  | Stretton Group                   | 2010, 2011             | 2 |
| Pitch Coppice Quarry | Shropshire        | Quarry           | Lower Elton Formation            | 2011                   | 1 |
| Sunnyhill Quarry     | Shropshire        | Quarry           | Leintwardine Formation           | 2011                   | 1 |
| Migneint1            | Snowdonia         | Erosion Feature  | Till                             | 2014, 2015             | 2 |
| Migneint2            | Snowdonia         | Erosion Feature  | Till                             | 2014, 2015             | 2 |
| Bath                 | Somerset          | Landslide        | Lias Group                       | 2003                   | 1 |
| Blagdon              | Somerset          | Test Site        | Mercia Mudstone Group            | 2015(2), 2016(2)       | 4 |
| Milverton            | Somerset          | Erosion Feature  | Alluvium                         | 2015                   | 1 |
| Woolcombe            | Somerset          | Erosion Feature  | Alluvium                         | 2015                   | 1 |
| Mainshill Opencast   | South Lanarkshire | Surface Mine     | Coal Measures Group              | 2014                   | 1 |
| Capel Green          | Suffolk           | Quarry           | Crag Group                       | 2019                   | 1 |
| Pakefield            | Suffolk           | Sea Cliff        | Happisburgh Glacigenic Formation | 2019                   | 1 |
| Southwold            | Suffolk           | Sea Cliff        | Crag Group                       | 2019                   | 1 |

|                         |                |                |                             |                                             |            |
|-------------------------|----------------|----------------|-----------------------------|---------------------------------------------|------------|
| Beachy Head             | Sussex         | Sea Cliff      | Upper Chalk Formation       | 2001, 2002, 2003, 2017                      | 4          |
| Birling Gap             | Sussex         | Sea Cliff      | Upper Chalk Formation       | 2018                                        | 1          |
| Brighton Marina         | Sussex         | Sea Cliff      | Upper Chalk Formation       | 2017                                        | 1          |
| Cuckmere Haven          | Sussex         | Sea Cliff      | Upper Chalk Formation       | 2017                                        | 1          |
| Newhaven                | Sussex         | Sea Cliff      | Upper Chalk Formation       | 2017                                        | 1          |
| Peacehaven              | Sussex         | Sea Cliff      | Upper Chalk Formation       | 2017                                        | 1          |
| Rottingdean             | Sussex         | Sea Cliff      | Upper Chalk Formation       | 2017                                        | 1          |
| Saltdean                | Sussex         | Sea Cliff      | Upper Chalk Formation       | 2017                                        | 1          |
| Seven Sisters           | Sussex         | Sea Cliff      | Upper Chalk Formation       | 2018                                        | 1          |
| Tillingham              | Sussex         | Marsh          | Thames Group                | 2020                                        | 1          |
| Tynemouth               | Tyne and Wear  | Sea Cliff      | Pennine Coal Measures Group | 2013                                        | 1          |
| Firth of Forth          | West Lothian   | Tidal Deposits | Intertidal Deposits         | 2011                                        | 1          |
| Wren's Nest             | West Midlands  | Quarry         | Coalbrookdale Formation     | 2011(2)                                     | 2          |
| Broadway                | Worcestershire | Landslide      | Lias Group                  | 2002                                        | 1          |
| Eggleshope              | Yorkshire      | Lead Mine      | Mine Waste                  | 2021, 2022                                  | 2          |
| Hollin Hill             | Yorkshire      | Landslide      | Lias Group                  | 2006, 2007, 2008, 2009, 2011, 2020, 2021(2) | 8          |
| Slaithwaite             | Yorkshire      | Dam            | Marsden Formation           | 2021(2)                                     | 2          |
|                         |                |                | <b>157</b>                  |                                             | <b>328</b> |
| <b><u>OVERSEAS:</u></b> |                |                |                             |                                             |            |
| Montserrat (Volcano)    | Caribbean      | Volcano        | Andesite                    | 2005, 2006(2), 2007, 2008, 2009             | 6          |
| Montserrat (MVO)        | Caribbean      | Buidling       | Not Geological              | 2006                                        | 1          |
| Montserrat (Landslide)  | Caribbean      | Landslide      | Soufriere Hills Deposits    | 2007                                        | 1          |
| Montserrat (Belham)     | Caribbean      | Valley         | Flow Deposits               | 2009                                        | 1          |
| Newfoundland            | Canada         | Outcrop        | Precambrian                 | 2017(16), 2019(16)                          | 32         |
| Caumont                 | France         | Quarry         | Chalk                       | 2017                                        | 1          |
| Fecamp                  | France         | Sea Cliff      | Chalk                       | 2017                                        | 1          |
| Le Petite Dale          | France         | Outcrop        | Chalk                       | 2017                                        | 1          |

|                        |                             |             |                                    |                                                         |           |
|------------------------|-----------------------------|-------------|------------------------------------|---------------------------------------------------------|-----------|
| Seinneville            | France                      | Sea Cliff   | Chalk                              | 2017                                                    | 1         |
| Tilleul                | France                      | Sea Cliff   | Chalk                              | 2017                                                    | 1         |
| Gibraltar              | Gibraltar                   | Rock-Face   | Gibraltar Limestone                | 2010                                                    | 1         |
| Milos                  | Greece                      | Intrusion   | Breccia                            | 2016, 2017                                              | 2         |
| Kviarjokull            | Iceland                     | Glacier     | Ice                                | 2014                                                    | 1         |
| Melasveit (Belgholt)   | Iceland                     | Sea Cliff   | Glaciomarine Deposits              | 2014                                                    | 1         |
| Melasveit (Quiet Bay)  | Iceland                     | Sea Cliff   | Glaciomarine Deposits              | 2014                                                    | 1         |
| Melasveit (South)      | Iceland                     | Sea Cliff   | Glaciomarine Deposits              | 2014                                                    | 1         |
| Svinafell              | Iceland                     | Glacier     | Ice                                | 2010                                                    | 1         |
| Virkisjokull           | Iceland                     | Glacier     | Ice                                | 2009, 2010, 2011, 2012, 2013,<br>2014, 2016, 2017, 2018 | 9         |
|                        |                             |             | <b>18</b>                          |                                                         | <b>63</b> |
| <b><u>PEGASUS:</u></b> |                             |             |                                    |                                                         |           |
| River Greta            | Cumbria                     | River Scour | Till                               | 2018                                                    | 1         |
| Weightman's Wood       | Cumbria                     | Landslide   | Till                               | 2018                                                    | 1         |
| Curbar Edge            | Derbyshire                  | Outcrop     | Millstone Grit                     | 2019                                                    | 1         |
| Mam Tor                | Derbyshire                  | Outcrop     | Bowland Shale Formation            | 2017, 2018                                              | 2         |
| Heights of Abraham     | Derbyshire                  | Cave        | Limestone                          | 2018(2)                                                 | 2         |
| Aldbrough              | East Riding of<br>Yorkshire | Sea Cliff   | Till                               | 2018(4), 2019(4), 2020(3),<br>2021(2), 2022             | 14        |
| Oxwich Bay             | Gower                       | Landslide   | Oxwich Haed Limestone<br>Formation | 2019                                                    | 1         |
| Botley                 | Hampshire                   | Embankment  | Wittering Formation                | 2020                                                    | 1         |
| Withey Beds            | Hertsfordshire              | Embankment  | Seaford Chalk Formation            | 2020                                                    | 1         |
| Dover Cliffs           | Kent                        | Sea Cliff   | Upper Chalk Formation              | 2019, 2020(2)                                           | 3         |
| Bacton                 | Norfolk                     | Sea Cliff   | Till                               | 2019                                                    | 1         |
| Warden                 | Northumberland              | Embankment  | Till                               | 2019                                                    | 1         |
| Ripon                  | North Yorkshire             | Sinkhole    | Gypsum                             | 2019                                                    | 1         |
| Runswick Bay           | North Yorkshire             | Beach       | Lias Group                         | 2018                                                    | 1         |

|                      |                          |           |                                  |                        |                           |
|----------------------|--------------------------|-----------|----------------------------------|------------------------|---------------------------|
| Berry Hill           | Nottinghamshire          | Quarry    | Sherwood Sandstone               | 2019, 2020             | 2                         |
| BGS                  | Nottinghamshire          | BGS Site  | Not Geological                   | 2018                   | 1                         |
| Nottingham Castle    | Nottinghamshire          | Castle    | Not Geological                   | 2018                   | 1                         |
| Sutton Bonnington    | Nottinghamshire          | GTB Site  | Mercia Mudstone Group            | 2018                   | 1                         |
| Tenby Beach (North)  | Pembrokeshire            | Beach     | Old Red Sandstone                | 2020                   | 1                         |
| Tenby Beach (South)  | Pembrokeshire            | Beach     | Old Red Sandstone                | 2020                   | 1                         |
| Pakefield            | Suffolk                  | Sea Cliff | Happisburgh Glacigenic Formation | 2019                   | 1                         |
| Southwold            | Suffolk                  | Sea Cliff | Crag Group                       | 2019                   | 1                         |
| Birling Gap          | Sussex                   | Sea Cliff | Upper Chalk Formation            | 2018                   | 1                         |
| Eggleshope           | Yorkshire                | Lead Mine | Mine Waste                       | 2021, 2022             | 2                         |
| Hollin Hill          | Yorkshire                | Landslide | Lias Group                       | 2018(2), 2020, 2021(2) | 5                         |
| Slaithwaite          | Yorkshire                | Dam       | Marsden Formation                | 2021                   | 1                         |
|                      |                          |           | <b>26</b>                        |                        | <b>49</b>                 |
| <b><u>UAS</u></b>    |                          |           |                                  |                        |                           |
| Aldbrough            | East Riding of Yorkshire | Sea Cliff | Till                             | 2021, 2022             | 2                         |
| Lyell Centre         | Edinburgh                | BGS Site  | Not Geological                   | 2021                   | 1                         |
| BGS                  | Nottinghamshire          | BGS Site  | Not Geological                   | 2021(2)                | 1                         |
| Gresham Marsh        | Nottinghamshire          | Marsh     | Sherwood Sandstone Group         | 2021                   | 1                         |
| Hatfield Moors       | Yorkshire                | Moorland  | Chester Formation                | 2022                   | 1                         |
| Hollin Hill          | Yorkshire                | Landslide | Lias Group                       | 2021                   | 1                         |
| Slaithwaite          | Yorkshire                | Dam       | Marsden Formation                | 2021(2)                | 2                         |
|                      |                          |           | <b>7</b>                         |                        | <b>9</b>                  |
|                      |                          |           |                                  |                        |                           |
| <b><u>TOTAL:</u></b> |                          |           | <b><u>208 SITES</u></b>          |                        | <b><u>449 SURVEYS</u></b> |

# References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact [libuser@bgs.ac.uk](mailto:libuser@bgs.ac.uk) for details). The library catalogue is available at: <https://of-ukrinerclib.oclc.org/folio/>.

- ANON. 1994. ISO/TC 211 GEOGRAPHIC INFORMATION/GEOMATICS. [ONLINE]. STOCKHOLM: ISO, 1994. [VIEWED JULY 2020]. AVAILABLE FROM: [HTTPS://WWW.ISO.ORG/COMMITTEE/54904.HTML](https://www.iso.org/committee/54904.html)
- BUCKLEY, S.J., HOWELL, J.A., ENGE, H.D. & KURZ, T.H. 2007. TERRESTRIAL LASER SCANNING IN GEOLOGY; DATA ACQUISITION, PROCESSING AND ACCURACY CONSIDERATIONS. JOURNAL OF THE GEOLOGICAL SOCIETY OF LONDON (MAY 2008), 165(3):625-638
- CHAMBERS, J.E.; WILKINSON, P.B.; KURAS, O.; FORD, J.R.; GUNN, D.A.; MELDRUM, P.I.; PENNINGTON, C.V.L.; JONES, L.D.; WELLER, A.L.; HOBBS, P.R.N. AND OGILVY, R.D. 2011. THREE-DIMENSIONAL GEOPHYSICAL ANATOMY OF AN ACTIVE LANDSLIDE IN LIAS GROUP MUDROCKS, CLEVELAND BASIN, UK. GEOMORPHOLOGY, 125 (4). 472-484. 10.1016/J.GEOMORPH.2010.09.017
- DONNELLY, L., JONES, L.D., PALMER, M. AND DILKES, C. 2006. ENGINEERING GEOLOGICAL AND GEOTECHNICAL ASPECTS OF THE SOUFRIERE HILLS VOLCANIC ERUPTION, MONTSEERAT. *IAEG2006 ENGINEERING GEOLOGY FOR TOMORROW'S CITIES*. NOTTINGHAM, UK, SEPTEMBER 2006
- EVEREST, J., BRADWELL, T., JONES, L. AND HUGHES, L. 2017. THE GEOMORPHOLOGY OF SVÍNAFELLSJÖKULL AND VIRKISJÖKULL-FALLJÖKULL, SOUTHEAST ICELAND: A LANDSYSTEM OF RAPID GLACIAL RETREAT. JOURNAL OF MAPS.
- GIBSON, A. D., FORSTER, A., POULTON, C. V. L., ROWLANDS, K. A., JONES, L. D., HOBBS, P. R. N. AND WHITWORTH, M. C. Z. 2013. AN INTEGRATED METHOD FOR TERRESTRIAL LASER SCANNING SUBTLE LANDSLIDE FEATURES AND THEIR GEOMORPHOLOGICAL SETTING. PROC. ANN. CONF. ON SCALES AND DYNAMICS. *REMOTE SENSING & PHOTOGRAMMETRY SOCIETY (RSPSoc)*. 10-12<sup>TH</sup> SEPT, 2003. UNIVERSITY OF NOTTINGHAM
- GLENDELL, M., MCSHANE, G., FARROW, L., JAMES, M. R., QUINTON, J., ANDERSON, K., EVANS, M., BENAUD, P., RAWLINS, B., MORGAN, D., JONES, L. D., KIRKHAM, M., DEBELL, L., QUINE, T. A., LARK, M., RICKSON, J. AND BRAZIER, R. E. 2017. TESTING THE UTILITY OF STRUCTURE FROM MOTION PHOTOGRAMMETRY RECONSTRUCTIONS USING SMALL UNMANNED AERIAL VEHICLES AND GROUND PHOTOGRAPHY TO ESTIMATE THE EXTENT OF UPLAND SOIL EROSION. *EARTH SURFACE PROCESSES AND LANDFORMS*. MARCH 2017
- HOBBS, P.R.N., JONES, L.D., KIRKHAM, M.P., HOLYOAKE, S.J., PENNINGTON, C.V.L., DASHWOOD, C., BANKS, V.J. AND REEVES, H.J. 2019<sup>A</sup>. ESTABLISHMENT OF A COASTAL LANDSLIDE OBSERVATORY AT ALDBROUGH, EAST RIDING OF YORKSHIRE, UK. QUARTERLY JOURNAL OF ENGINEERING GEOLOGY AND HYDROGEOLOGY, 25 JUNE 2019
- HOBBS, P.R.N., JONES, L.D., KIRKHAM, M.P., PENNINGTON, C.V.L., MORGAN, D.J.R. AND DASHWOOD, C. 2019<sup>B</sup>. COASTAL LANDSLIDE MONITORING AT ALDBROUGH, EAST RIDING OF YORKSHIRE, UK. QUARTERLY JOURNAL OF ENGINEERING GEOLOGY AND HYDROGEOLOGY, 21 AUGUST 2019
- HOBBS, P.R.N., JONES, L.D., KIRKHAM, M.P., PENNINGTON, C., MORGAN, D.J.R., NEDUMPALLILE, N., REEVES, H. AND HOLYOAKE, S. 2019<sup>C</sup>. MONITORING SURVEY OF INCIPIENT CHALK 'SET' BLOCK FAILURE AT FAN BAY, 'WHITE CLIFFS OF DOVER' (NATIONAL TRUST), 2019 – 2020. BRITISH GEOLOGICAL SURVEY INTERNAL REPORT No. IR/19/036
- HOBBS, P.R.N., HUMPHREYS, B., REES, J., TRAGHEIM, D., JONES, L., GIBSON, A., ROWLANDS, K., HUNTER, G. & AIREY, R. 2002. MONITORING THE ROLE OF LANDSLIDES IN 'SOFT CLIFF' COASTAL RECESSION. IN: INSTABILITY PLANNING AND MANAGEMENT. (EDS, MCINNES, R.G. AND JAKEWAYS, J.) THOMAS TELFORD, ISLE OF WIGHT, 589-600
- JONES, L.D. & BATESON, L.B. 2021. COMBINING NEAR-EARTH AND ON-EARTH GEOMATICS CAPABILITIES INTO A SINGLE 3D MODEL. BRITISH GEOLOGICAL OPEN REPORT OR/21/054
- JONES, L.D. & HOBBS, P.R.N. 2021. THE APPLICATION OF TERRESTRIAL LiDAR FOR GEOHAZARD MAPPING, MONITORING AND MODELLING IN THE BRITISH GEOLOGICAL SURVEY. REMOTE SENS. 2021, 13, DOI.ORG/10.3390/
- JONES, L.D., KIRKHAM, M. & HOBBS P.R.N. 2020. GROUND-BASED GEOMATICS FOR GEOHAZARD MAPPING, MODELLING AND CHARACTERISATION. BRITISH GEOLOGICAL OPEN REPORT OR/20/019
- JONES, L.D. 2019 GROUND-BASED GEOMATIC SURVEYS: SPECIFICATION FOR TERRESTRIAL LiDAR SCANNING. BRITISH GEOLOGICAL SURVEY OPEN REPORT No. OR/20/033
- JONES, L.D. 2015<sup>A</sup>. GROUND-BASED GEOMATIC SURVEYS AT THE BGS - A REVIEW OF RESEARCH AND APPLICATIONS OUTSIDE BGS. BRITISH GEOLOGICAL SURVEY INTERNAL REPORT No. IR/15/005
- JONES, L.D. 2015<sup>B</sup>. GROUND-BASED GEOMATIC SURVEYS AT THE BGS – A MANUAL FOR BASIC DATA COLLECTION AND PROCESSING. BRITISH GEOLOGICAL SURVEY OPEN REPORT No. OR/15/057
- JONES, L.D. 2014<sup>A</sup>. GROUND-BASED GEOMATIC SURVEYS AT THE BGS - REVIEW UPDATED DECEMBER 2014. BRITISH GEOLOGICAL SURVEY INTERNAL REPORT No. IR/14/069
- JONES, L.D. 2014<sup>B</sup>. MEASURING OUR CHANGING EARTH. PLANET EARTH, AUTUMN 2014, p28-29

- JONES, L.D., PEARSON, S.G., HOBBS, P.R.N. AND GIBSON, A.D. 2006. CLIFF STABILITY AT HUNT CLIFF, BROTON, CLEVELAND (PHASE 3): RESURVEY, MARCH 2006. BRITISH GEOLOGICAL SURVEY COMMISSIONED REPORT CR/06/152
- JORDAN, C.J. & NAPIER, B. 2015. DEVELOPING DIGITAL FIELDWORK TECHNOLOGIES AT THE BRITISH GEOLOGICAL SURVEY. GEOLOGICAL SOCIETY SPECIAL PUBLICATIONS, 436, 219-229
- LOUGHLIN, S.C., LUCKETT, R., RYAN, G., CHRISTOPHER, T., HARDS, V., DE ANGELIS, S., JONES, L. AND STRUTT, M. 2010. AN OVERVIEW OF LAVA DOME EVOLUTION, DOME COLLAPSE AND CYCLICITY AT SOUFRIERE HILLS VOLCANO, MONTSERRAT, 2005-7. GEOPHYSICAL RESEARCH LETTERS, 37, L00E16, doi:10.1029/2010GL042547
- O' DOCHARTAIGH, B. E., MACDONALD, A. M., BLACK, A. R., EVEREST, J., WILSON, P., DARLING, W. G., JONES, L. AND RAINES, M. 2019. GROUNDWATER – MELTWATER INTERACTION IN PROGLACIAL AQUIFERS AMID RAPID GLACIER RETREAT. *HYDROLOGY AND EARTH SYSTEM SCIENCES*. 2019, 120
- PHILLIPS, E., EVEREST, J., EVANS, D. J., A., FINLAYSON, A., EWERTOWSKI, M., GUILD, A. AND JONES, L. D. 2017. CONCENTRATED, "PULSED" AXIAL GLACIER FLOW: STRUCTURAL GLACIOLOGICAL EVIDENCE FROM KVIÁRJÖKULL IN SE ICELAND
- PHILIPS, E., FINLAYSON, A. & JONES, L. 2013 FRACTURING, BLOCK-FAULTING AND MOULIN DEVELOPMENT ASSOCIATED WITH PROGRESSIVE COLLAPSE AND RETREAT OF A POLAR MARITIME GLACIER: VIRKISJÖKULL-FALLJÖKULL, SE ICELAND. *JOURNAL OF GEOPHYSICAL RESEARCH: EARTH SURFACE*. 118(3), 1545-1561
- PHILIPS, E., FINLAYSON, A., BRADWELL, T., EVEREST, J. & JONES, L. 2014. STRUCTURAL EVOLUTION TRIGGERS A DYNAMIC REDUCTION IN ACTIVE GLACIER LENGTH DURING RAPID RETREAT: EVIDENCE FROM FALLJOKULL, SE ICELAND. *JOURNAL OF GEOPHYSICAL RESEARCH: EARTH SURFACE*.
- POULTON, C.V.L., LEE, J.R., JONES, L.D., HOBBS, P.R.N., & HALL, M. 2006. PRELIMINARY INVESTIGATION INTO MONITORING COASTAL EROSION USING TERRESTRIAL LASER SCANNING: CASE STUDY AT HAPPISBURGH, NORFOLK, UK: *BULLETIN OF THE GEOLOGICAL SOCIETY OF NORFOLK*, 56, 45-65
- ROWLANDS, K., JONES, L. & WHITWORTH, M. 2003. PHOTOGRAPHIC FEATURE: LANDSLIDE LASER SCANNING: A NEW LOOK AT AN OLD PROBLEM. *QUARTERLY JOURNAL OF ENGINEERING GEOLOGY*, 36, 155-158
- RUMSON, A. G., HALLETT, S. H., BREWER, T. R. AND JONES, L. D. 2019. THE APPLICATION OF DATA INNOVATIONS TO GEOMORPHOLOGICAL IMPACT ANALYSES IN COASTAL AREAS: AN EAST ANGLIA, UK, CASE STUDY. *OCEAN & COASTAL MANAGEMENT*, 181, NOVEMBER 2019
- RYAN, G., LOUGHLIN, S.C., JAMES, M., JONES, L., CALDER, E., CHRISTOPHER, T., STRUTT, M. AND WADGE, G. 2010. GROWTH OF THE LAVA DOME AND EXTRUSION RATES AT SOUFRIERE HILLS VOLCANO MONTSERRAT, WEST INDIES, 2005-8. *GEOPHYSICAL RESEARCH LETTERS*, 37, L00E08, doi:10.1029/2009GL041477
- TAPETE, D., BANKS, V., JONES, L., KIRKHAM, M. AND GARTON, D. 2017. CONTEXTUALISING ARCHAEOLOGICAL MODELS WITH GEOLOGICAL, AIRBORNE AND TERRESTRIAL LiDAR DATA: THE ICE AGE LANDSCAPE IN FARNDON FIELDS, NOTTINGHAMSHIRE, UK. *JOURNAL OF ARCHAEOLOGICAL SCIENCE*. 81 (2017), 31-48