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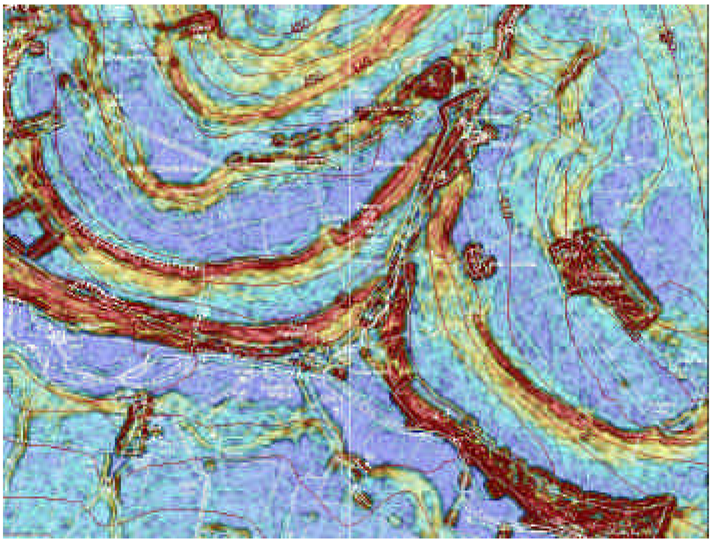
The application of NEXTMap digital elevation data to geological mapping in northeast England

Digital Geoscience Spatial Model Programme

System for Integrated Geospatial Mapping (SIGMA)

Internal Report IR/05/009



Sigma

SYSTEM FOR INTEGRATED GEOSPATIAL MAPPING

BRITISH GEOLOGICAL SURVEY

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INTERNAL REPORT IR/05/009

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S. M. Clarke

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Slope analysis map of the Nenthall area, Alston, Cumbria.

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British Geological Survey offices

Keyworth, Nottingham NG12 5GG

☎ 0115-936 3241 Fax 0115-936 3488
e-mail: sales@bgs.ac.uk
www.bgs.ac.uk
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☎ 028-9038 8462 Fax 028-9038 8461

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☎ 01491-838800 Fax 01491-692345

Sophia House, 28 Cathedral Road, Cardiff, CF11 9LJ

☎ 029–2066 0147 Fax 029–2066 0159

Parent Body

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

☎ 01793-411500 Fax 01793-411501
www.nerc.ac.uk

Foreword

This report presents the results of a study by the British Geological Survey (BGS) into the potential use of NEXTMap Britain digital elevation data (Intermap Technologies, 2003) in the geological survey process. The elevation of the land surface, or more correctly, relative changes in elevation (slope angles and breaks of slope) may be related to the underlying geology. Consequently, this report examines the possibilities of reprocessing NEXTMap Britain digital elevation data to give geologically useful information relating to the natural featuring of the landscape.

Acknowledgements

Many example areas from the North Pennines of England are used through out this report. They are all taken from 1:10 000 field slips surveyed over the period 2002-2004 by survey geologists of the BGS. The following colleagues are thanked for interpretations, comparisons and discussions of NEXTMap slope analysis techniques and for use of their geological survey field slips in this report:

Dr D. Millward for all areas taken from NY84NW.

C. Vye for all areas taken from NY74NW and NY75SW.

Additionally, B. Young and D. Lawrence are thanked for valuable discussions on slope analysis in these and other areas of Northern England, and L. Bateson and J. Ford for assisting in the NEXTMap data acquisition and reprocessing.

Contents

FIGURES

Summary

NEXTMap Britain is a collection of high-resolution, digital datasets including elevation of the UK landmass. This report examines methods of reprocessing these digital elevation data to produce data representing the slope angles and breaks-in-slope of a natural hillside that may relate to the bedrock or superficial geology. Digital elevation data for various parts of the North Pennines of England are reprocessed to produce *slope analysis maps* in which slope angles and breaks in slope are represented by shaded colours.

Slope analysis maps are then compared with detailed geological survey field slips for the same areas (produced without reference to the NEXTMap data or any processed derivative) in order to highlight some of the characteristic signatures in the slope analysis map produced by different features of the bedrock and superficial geology. The potential uses of slope analysis in mapping these features and interpreting geology are discussed.

Based on these studies of previously surveyed areas, the slope analysis map for an area of the North Pennines not previously surveyed is interpreted in terms of features and anomalies. From this interpretation, a traverse-based, ground survey can be planned to tie the signatures noted in the slope analysis map to features related to the geology (or otherwise). This test case shows the potential efficiency gains that slope analysis can bring to the survey process.

1 Introduction

Geological mapping involves the integration of all available data with standard field survey techniques in order to achieve the best possible positional accuracy and interpretation of geological boundaries placed on the map.

The recent purchase by NERC of the NEXTMap Britain digital elevation datasets for the onshore landmass of England and Wales provided another potential dataset that could be used to achieve this goal. Over the field season of 2004 several field survey staff working in the North Pennines of England attempted to integrate NEXTMap data into the field survey process. This report summarises their experiences and demonstrates the application of NEXTMap data to both bedrock and superficial geological mapping.

1.1 AIMS OF THE PROJECT

The absolute elevation of the land surface, as given by the raw NEXTMap data, is of little use in geological mapping other than contributing to an understanding of the geomorphology and therefore a regional appreciation of the geology. This project aims to look at techniques and methods by which the NEXTMap digital elevation data can be reprocessed to give useful information related to geology. The positive and negative aspects associated with applying these techniques to the different datasets available under the NEXTMap Britain banner are explored.

The methods of reprocessing are applied to the most appropriate NEXTMap datasets for a region of the North Pennines that has been mapped recently in detail at 1:10000 scale. The potential uses of the reprocessed NEXTMap data for identifying and delimiting useful topographical features related to both the bedrock geology and superficial deposits can be examined by comparing these data with the detailed field survey. Similarly, the limitations of such an approach can be assessed in the same manner.

Using the comparison between the reprocessed NEXTMap data and the detailed field survey as a guide to the geological interpretation of features evident in the former, the techniques are applied to an area of the North Pennies that has not been surveyed previously. In this way, this test will explore possible increases in efficiency to be gained by targeted ground survey guided by the NEXTMap interpretation.

The specific aims of this project are:

- To explore techniques of reprocessing the different datasets contained under the NEXTMap Britain banner in order to extract *slope angle* and *break-of-slope* information useful to geological surveying.
- To apply these techniques to an area of the North Pennines surveyed previously in detail at 1:10000 scale.
- To use the comparison between the reprocessed NEXTMap data and the detailed field survey to highlight anomalies in the former that may indicate particular features related to the bedrock geology.
- To apply a similar approach to highlight features related to the superficial deposits.
- To apply a similar approach to highlight features related to artificial deposits (worked and made ground).
- To use the comparison to highlight the limitations in the use of NEXTMap data in geological mapping.

- To apply the lessons learnt in these exercises to an area of the North Pennines prior to field survey, to determine if the techniques can increase efficiency by facilitating a more targeted approach to field mapping.

1.2 STUDY AREA

The area chosen for this study is part of the North Pennines of England just northeast of the market town of Alston, Cumbria (Figure 1.1). It is the area covered by Ordnance Survey quarter sheets NY74NE/NW, NY75SE/SW/NE and NY84NW. Of these sheets NY75NE was not surveyed prior to this study. All remaining sheets have been surveyed previously at 1:10000 scale and in great detail using modern field survey techniques and equipment. These sheets will provide the geological information for the comparative study.

The Carboniferous geology of North Pennines consists of near-horizontal to gently dipping, repeated Yordale cyclothems of limestone, siltstone, sandstone and coal. The upper Dinantian strata of the Alston Group, that form the bedrock of the lower slopes and valley bottoms, consist of complete or near-complete cyclothems. The Lower Namurian Stainmore Formation strata form the high hillsides and are predominantly sandstone and siltstone with little significant limestone. Outcrops are limited or, in many parts of the area, sparse but the differential weathering characteristics of the lithologies produce strong ledges with sharp breaks in slope that can be traced for some distance across the hillsides. Feature mapping is the primary survey technique in this area. The south- and south-west-facing sides of the valleys are strongly featured but the north- and north-east-facing sides are commonly poorly featured, with only subtle ledges, despite the presence of the same stratigraphy. The features in these slopes are masked by superficial glacial deposits (mostly till). The tops of the hills are largely grouse moor and, once again, the featuring is much more subtle due to the lack of resistant limestone within the succession and a superficial cover of both till and peat. There, access is difficult, the survey is time consuming and there is little or no bedrock geological information to be gleaned from these areas over and above that provided by the subtle features.

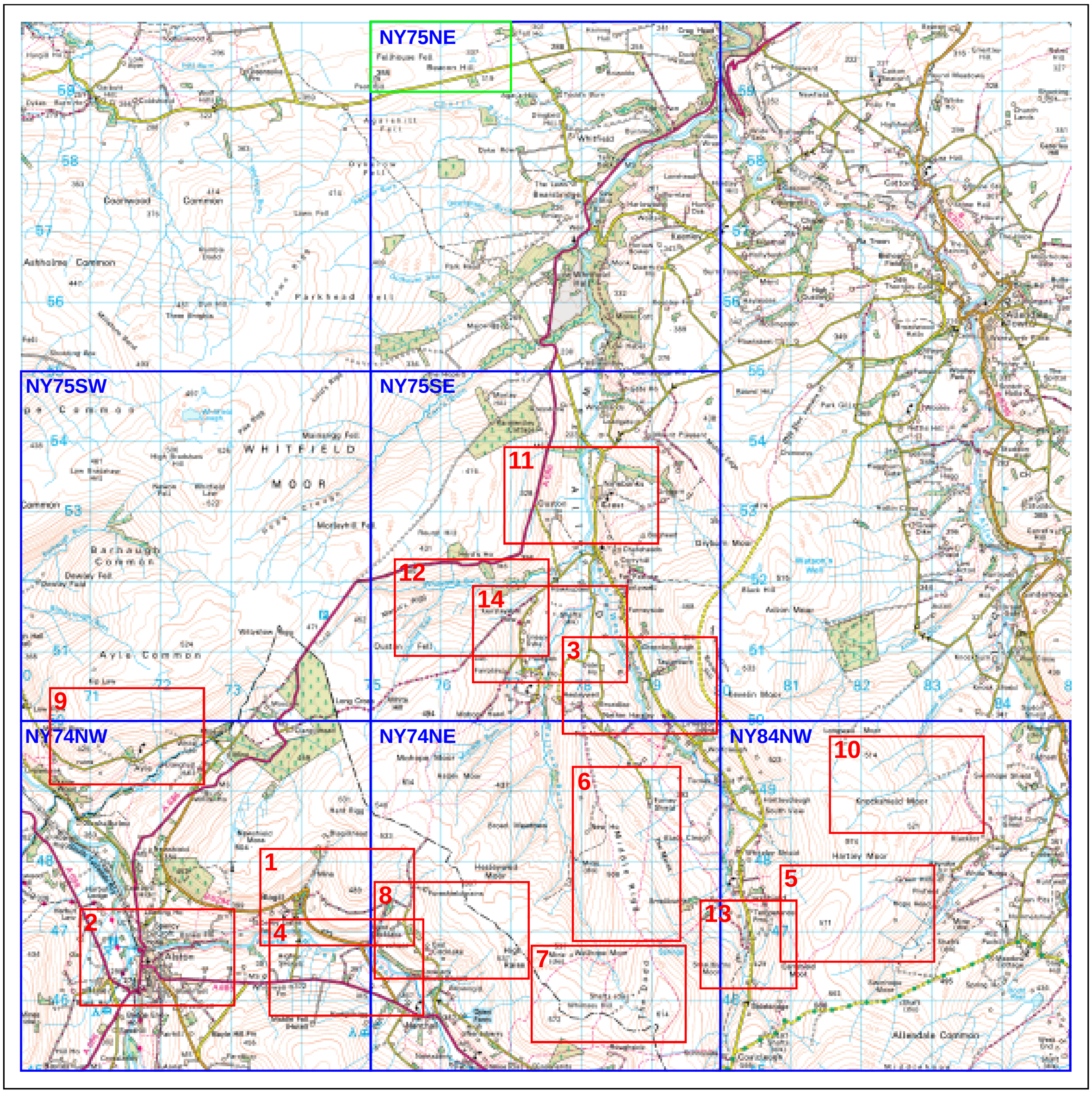
The concordant stratigraphy is disturbed at regular intervals by strong faults that vary in throw from less than a metre to tens of metres. These faults are often intensely mineralised and have been worked in the past for lead, zinc and barium minerals amongst others. Additionally, several coal seams within the strata have been worked from a large number of adit levels driven into the hillside. These industrial workings have left a legacy of worked and made ground that in places overprints the natural features produced by the differential weathering of the stratigraphy.

The low angle of dip combined with varied fault throws makes projection of strata under glacial deposits and through hills particularly problematic. Slight variations in assumed regional dip or fault throw produce marked differences in outcrop pattern.

The varied style of landscape, combined with problems of structural projection, make this area ideal for the application of digital slope angle and break-of-slope techniques. Strongly featured hillsides provide a control with which to analyse the results of NEXTMap reprocessing, and the less well-featured, superficially covered slopes provide a test of the use of these data in geological interpretation and structural projection. Areas of worked and made ground provide test cases for demonstrating and recognising manmade features of geological interest in the NEXTMap data, and areas of difficult access with little bedrock exposure provide good examples of the possible use of NEXTMap as an aid to a targeted, more efficient survey.

1.2.1 NEXTMap testing and analysis – specific study areas

Fourteen, small areas have been highlighted from NY74NE/NW, NY75SE/SW and NY84NW in order to demonstrate particular geological relationships and their characteristic signatures in the reprocessed NEXTMap data. These areas are indicated on Figure 1.1 and are as follows:



NY74NW — OS 1:10000 QUARTER SHEET

NY74NW & NY75SW SURVEYED BY C. VYE 2002 - 2003
NY74NE & NY75SE/NE SURVEYED BY S. CLARKE 2002 - 2004
NY84NW SURVEYED BY D. MILLWARD 2002 - 2003

5 — EXAMPLE STUDY AREA COVERED IN THIS REPORT (WITH NUMBER) SECTIONS 3, 4 & 5

SPECIFIC TEST AREA (FELLHOUSE FELL) SECTION 6

Figure 1.1 Location of the 14 study areas used in this report and the location of Fellhouse Fell area used as a test case in Section 6

- Area 1 – The south-facing slopes of the Nent Valley around the small hamlet of Blagill.
- Area 2 – The market town of Alston.
- Area 3 – The southwest-facing slopes of the West Allen Valley at Limestone Brae.
- Area 4 – The southwest-facing slopes of the Nent Valley at Nenthall.
- Area 5 – Carshield Moor.
- Area 6 – Dodd Hill.
- Area 7 – The Dodd & Wellhope Moor.
- Area 8 – East Cocklake & High Raise.
- Area 9 – Ayle Common.
- Area 10 – Knockshield Moor.
- Area 11 – West Allen Dale at Ouston.
- Area 12 – North-facing slopes of Whitewalls Burn.
- Area 13 – West Allen River at Barneycraig.
- Area 14 – Kirsleywell Row Mine & Mohope Valley.

For areas 1, 2 and 3, reprocessed NEXTMap data images have been produced for each of the datasets under the NEXTMap Britain banner in order to compare the merits of each dataset. For all other areas, images of selected reprocessed NEXTMap datasets are presented along with corresponding geological field slips and a combined image of the field slip and NEXTMap data.

Geological field slips are shown with varying degrees of geological interpretation and in varying stages of completeness. They are provided for a comparison of features (breaks of slope) mapped during field survey, and consequently represented on the field slips, with corresponding features evident in the reprocessed NEXTMap data. The geological interpretations (where shown) are the result of the field surveys combined with many other data sources (including, in some instances, NEXTMap data) and it is not implied that these interpretations can be derived directly from the NEXTMap image shown.

Each area has been selected as a good example of the use of NEXTMap in interpreting one or more geological features. Consequently, some areas are referred to more than once in the following sections. For this reason, the separate images (NEXTMap data, geological field slip and combined image) representing each area are not labelled as figures in the standard manner. Each image is labelled and referred to by area number as all images for each area are to be examined in conjunction with each other. Where areas represent more than one geological feature, separate regions of the image are highlighted accordingly, given an index letter and referred to by such in the text.

1.2.2 Application of techniques – Specific area

Areas 1 to 14 show many of the characteristic NEXTMap data signatures for different geological features. Based on the knowledge gained from these comparisons, part of NY75NE was selected as a test case for a targeted mapping exercise in which NEXTMap data could be used to plan a traverse of the countryside.

The area selected represents the northwest corner of NY75NE and covers 2 km^2 of Fellhouse Fell (Figure 1.1). This area was specifically selected as it is open moorland and represents a classic area in which there is likely to be little geological information obtained from ground survey, over and above that provided by the features, and walking over the ground is difficult and time consuming. In this area an interpretation of the NEXTMap data prior to field survey may allow a more targeted, traverse-based approach to the survey aimed at tying-in geological features with their NEXTMap signatures and facilitating an efficient geological survey and interpretation.

1.2.3 Additional reading

This report addresses the application of NEXTMap Britain digital elevation data sets to geological mapping in featured terrain. It provides summaries of both NEXTMap data acquisition and its subsequent reprocessing to provide slope angle and break-in-slope information, but it is not intended to be detailed review of either of these topics. For details of these processes, the reader is referred to:

Intermap Technologies 2003 Intermap handbook and quick start guide. Intermap Technologies Inc. Englewood Co, U.S.A. www.intermaptechnologies.com

Ford, J. *in prep*. Derivation of feature mapping elements from NEXTMap data. BGS Internal Report, *In prep*.

The use of NEXTMap data in slope analysis is one of several digital techniques aimed at landform recognition for use in geological mapping. Additional techniques, particularly relevant to this study include:

Hall, M., Howard, A.S., Aspden, J., Addison, R. & Jordan, C. 2004. The use of anaglyph images for geological feature mapping. BGS Internal Report IR/04/004

2 NEXTMap

NEXTMap Britain™ (Intermap Technologies, 2003) is the trademark for a group of digital datasets produced by *Intermap*; a company that specialises in acquiring digital elevation data of the Earth's surface using new advances in radar technology. By flying an aircraft along predetermined flight paths, Intermap are able to collect highly detailed and accurate digital elevation data using a process known as *interferometric synthetic aperture radar* (IFSAR). In short, the aircraft emits radio waves that bounce off the Earth's surface (or whatever else they hit) and are picked up by antennae mounted on the aircraft. The difference in the time taken for the signal to bounce of the ground and be detected by each antenna can be used to determine elevation.

Intermap process the received radar data to provide elevation values for closely spaced, georeferenced points over the Earth's surface. These elevation data are used to produce derived datasets:

- **DSM** (Digital Surface Model). This dataset is georeferenced, digital elevation values for the land surface *or* whatever the radar signal strikes first. In towns, the elevation data represent the heights of buildings, in the countryside they may represent the heights of trees, walls, embanked roads or the true height of the land if there is nothing built on it.
- **DTM** (Digital Terrain Model) This dataset is derived from the DSM by applying a proprietary '*cultural filter*' (Intermap Technologies, 2003) to remove the effects of buildings etc. and, theoretically, gives a true terrain model for the land surface only.

Both datasets represent georeferenced, digital elevation data corrected to OD.

2.1 SLOPE ANALYSIS

Elevation data are of little discernible use in geological interpretation other than on a regional scale where they can highlight upland and lowland areas. However, given that the data are both digital and gridded, they can be reprocessed to provide slope angle and break-of-slope information that is potentially of great use in featured terrain.

By calculating first- and second-order differentials of elevation with respect to spatial position, gradient (slope angle) and rate-of-change-of-gradient (break-of-slope) information can be derived from the elevation data. Slope analysis algorithms are provided as extensions to ARCmap GIS and a detailed methodology for producing slope angle and break-of-slope data from NEXTMap elevation data using these algorithms is provided by Ford (in press), and is not repeated here.

The resultant slope angle and break-of-slope datasets can be combined to produce a *slope analysis map*. Figure 2.1 demonstrates the original digital elevation data, derived slope angle and break of slope data and the combined slope analysis map for a strongly featured area of the North Pennines. The slope analysis map is produced by representing the slope angle data using the full RGB colour spectrum (with blue through to red representing low- through to high-angle slopes), overlain with the break-of-slope data coloured using a greyscale such that white through to black represents 'no break in slope' through to 'sharp, strong break in slope'. This method of representing slope analysis data is used in all the examples shown in this report.

2.2 SAMPLING AND ACCURACY

NEXTMap digital elevation data are gridded on a 5 m spacing in both the east and north directions. This position is GPS-controlled and georeferenced to the national grid. Given that the

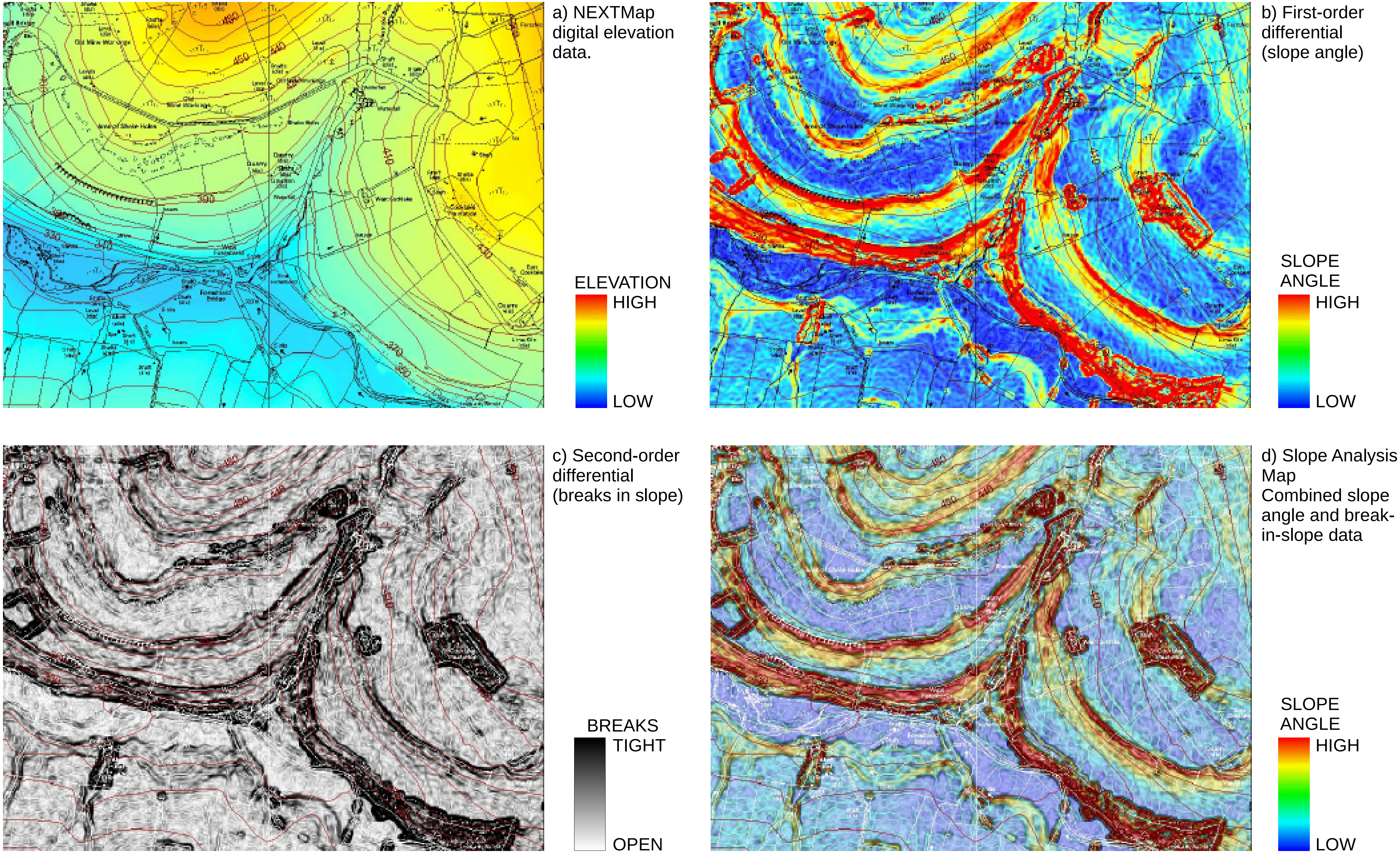


Figure 2.1 NEXTMap digital elevation data (a) can be reprocessed to give slope angle (b) and break-in-slope (c) information. These data are combined to give the slope analysis map (d).

defined accuracy of a 1:10000-scale geological survey is 10 m, any errors in lateral positional accuracy can be considered insignificant.

The five-metre grid spacing effectively defines the sampling frequency below which elevation changes will not be recorded. Any elevation differences, of whatever magnitude, that vary with a wavelength of less than five metres in the horizontal direction will not be imaged and, consequently, the features they produce will not be detectable in the slope analysis map. Such elevation differences may result from small rivers, ridges, walls, rock pinnacles, small outcrops or bench-like features that are less than 5 m in lateral extent. In practice, some of these features are imaged (particularly walls) and their processed response is visible in the slope analysis map. The OS base map overlay allows detection of these anomalies.

Intermap quote the vertical (elevation) accuracy as 1 m (%95). In practice, a vertical accuracy of 2 m (%100) is a more practical assumption. In theory, any elevation difference that is less than 2 m will not be imaged, whatever the wavelength. However, in practice, elevation changes of much less than this can be detected in certain circumstances. Given that the slope analysis map is an image of *changes in elevation* (gradient) rather than absolute elevation, small changes in elevation that occur over a short lateral distance and bound an area that is of constant elevation for an appreciable distance, can be imaged. This phenomenon has practical uses in identifying alluvial terrace deposits and artificial ground (sections 4.2.2 & 4.3).

2.3 ARTEFACTS

NEXTMap data are acquired at an angle. The radar signal is transmitted at an angle from the aircraft and corrected using the GPS information to reference the correct point on the ground from which it was returned (Intermap Technologies, 2003). There are many useful advantages for doing this, not least in the efficiency of the survey, but it can lead to two appreciable problems:

- **Foreshortening**
  As the acquisition aircraft flies towards a rapid change in elevation, such as a steep mountain, the data (acquired at an angle) are ‘squashed up’ in the horizontal direction by effects of the elevation change. This phenomenon is known as *foreshortening* and during the processing phase the data are ‘stretched’ to compensate. As a result, the data are degraded in the vicinity of large, steep gradients.

- **Shadowing**
  Similarly, emitting the signals at an angle results in a ‘shadow’ on the far side of steep-sided terrain or manmade objects. The data for these areas are missing and cannot be replaced. During data processing they are averaged from surrounding data.

Both foreshortening and shadowing can cause anomalous features in the slope analysis map.

In the examples presented here, natural, large, steep gradients are rare and as a consequence these anomalies are rare in open country. However, the presence of manmade features such as buildings, large walls and plantations can have significant shadowing and foreshortening effects on the surrounding countryside and such effects are propagated through to the slope analysis map. Intermap states that problems associated with foreshortening and shadowing can affect the quality of the data for up to 80 m from sharp changes in elevation. For practical purposes at 1:10000 scale, data within 100 m (1 cm) of large walls, plantations and buildings should be treated with extreme caution.

3 Dataset selection

The two elevation datasets provided by NEXTMap (DTM and DSM) are both of potential use in slope analysis and therefore geological interpretation. At first glance, the DTM dataset may appear to have greater applicability to geological mapping given that it represents the derived elevation of the natural land surface after the effects of cultural features such as buildings and roads have been removed. By contrast, the DSM represents the elevation of the first contact with the IFSAR radar pulse, be that the natural landscape, trees or buildings.

In this section, the slope analysis techniques outlined in Section 2 are applied to both NEXTMap datasets (DTM, DSM) for three separate areas of the North Pennines. In this way, the DTM can be compared with the DSM to assess their respective merits and application to geological mapping.

It is not the intention within this section to interpret the NEXTMap data in terms of characteristic signatures that relate to geological features (see sections 4, 5 and 6). The purpose is to compare the DTM and DSM datasets based on their signature response to manmade features (both geological and cultural) when compared to the underlying landscape and thus determine the most appropriate dataset(s) for use in interpretation of the geology.

3.1 EXAMPLE AREAS

Two areas within NY74 (Area 1 & Area 2) and one area within NY75 (Area 3) have been selected for this trial, based on their mix of natural features that are related to the bedrock geology and their cultural overprint of made ground, worked ground, trees and settlement features:

- Area 1 is the highly featured, south-facing hillside of the Nent valley around the village of Blagill. Here, the differential weathering of the limestones, compared with the interbedded sandstones and siltstones has produced broad, flat-topped features with steep, strong breaks in slope at their edges. In addition, intensely mineralised faults cut the area and have been worked. This area will produce a good comparison between both datasets as strong natural features, worked and made ground, and cultural features exist.
- Area 2 is the market town of Alston. On the ground, the influence of the underlying bedrock geology can be seen in the breaks of slope present within the town’s road network, but the presence of closely spaced buildings will make this area a good comparison between DSM (overprinted response from the buildings) and DTM (effect of buildings removed) datasets.
- Area 3 is the south-east-facing hillside of the West Allen valley. Here, a sequence of alternating sandstones and siltstones has produced strong featuring but on a smaller scale than that seen in Area 1. This area is not cut by worked mineral veins and most of the featuring is entirely related to the bedrock geology. It will act as a control as the filtering out of cultural response within the DTM dataset should have little effect in this area.

3.2 DATASET COMPARISON – DISCUSSION

The images representing areas 1, 2 & 3 demonstrate the results of reprocessing of NEXTMap DSM and DTM datasets to produce slope analysis maps. In each area, the slope angle interval represented by the full spectrum colour scale and the strength of break in slope interval represented by the greyscale are the same in each slope analysis map. In this way direct comparisons can be made. In all areas, blue represents slope angles of zero degrees; in areas 1 &

2 red represents slope angles of 25 degrees and greater and in Area 3 red represents slope angles of 30 degrees and greater. These colour ranges have been selected to best represent most of the data over the extent of the area.

The most striking difference between these images is that the DTM dataset severely attenuates the changes in slope angle indicated on the DSM slope analysis map. In Area 1 the severe attenuation within the DTM map of the extremely strong breaks in slope in the Nent valley hillside is clearly evident. In areas where the breaks in slope are strong but on a smaller and less extreme scale than Area 1, this smoothing effect can blur the boundaries of features and make separate features indistinguishable. In the DSM slope analysis map for Area 3, at least four and possibly 5 steep slopes, with distinct shallow slopes in between, are shown on the west facing slopes of the West Allen river. In the DTM map these separate features are blurred and only three can be distinguished with unclear breaks in slope between them.

In both areas 1 & 3 the signature of trees, plantations and buildings is clearly evident in the DSM slope analysis maps. The near vertical sides of these features produce very steep (dark red) slope angles with extremely strong breaks in slope (black lines) at the top and bottom of the feature. These effects mask the true nature of the underlying ground. The DTM dataset is particularly successful at removing these effects. Many of the strong anomalous signatures within the DSM slope analysis maps produced by such features are removed in the DTM maps. In Area 1, The DTM slope analysis map shows the shape of the natural slopes under the hamlet of Blagill that are obscured by the signature of buildings in the DSM map. However, Blagill is an example of extreme natural variations in topography with limited buildings and trees. In more densely urbanised areas or those with less extreme changes in slope, the DTM maps remove the overprint of the trees and buildings but do not tend to increase the clarity of form of the underlying slopes. In area 3, the removal of trees around Taylor Burn in the DTM map does not result in a clear image of the underlying features that are indicated to pass into and out of this wooded area on the DSM map. In area 2, the strong red-with-black-outline signatures of trees and buildings of Alston town centre are successfully removed in the DTM map but the signature of the underlying natural slopes on which Alston is built is imaged only slightly better.

In places the removal of trees and buildings from the data appears to have introduced some anomalies that, when processed to produce a slope analysis map, produce very strong phantom breaks of slope. Examples of these are evident at Low Skelgill on Area 2 and Far hilltop on Area 1.

The cultural filter (Intermap Technologies, 2003) that removes trees and building from the DTM dataset, also removes features relating to mining such as spoil heaps and worked ground features. Such features are clearly of use in geological mapping and their removal from the slope analysis map is not desirable. Examples of this can be seen to the east of Blagill Farm in Area 1.

3.3 DATASET SELECTION

In general, the DTM dataset successfully removes the effects of cultural features from the corresponding slope analysis maps. However, it also severely attenuates the slope variations in natural hillsides, sometimes to the point of masking and amalgamating a number of individual features present in the DSM slope analysis map into one large feature. Furthermore, the DTM dataset introduces anomalies that produce phantom features within the corresponding slope analysis maps.

It is clear from this trial on Areas 1, 2 and 3 that the best approach for slope analysis in Northern England is to use the DSM dataset as the base data for reprocessing into slope analysis maps. The imaging of trees and buildings within these data is an unfortunate side effect that must be ignored in analysis. In general, these features produce unique characteristic signatures in the slope analysis map and can be easily identified by the very high slope angles and extremely strong breaks of slope with the surrounding landscape. Comparison with the OS base map helps to highlight these features. The loss of resolution in the natural landscape produced by the DTM dataset is not an acceptable trade-off for slightly better imaging of some slopes under trees. Consequently, the DSM data are used throughout the remainder of this report.

4 Application of slope analysis to geological mapping

The presence of a relationship between the underlying geology and the shape of the topography is a useful aid to geological mapping. In settings where this relationship exists, such as the differential weathering of lithologies of contrasting hardness, or the intermittent presence of different superficial deposits, NEXTMap slope analysis can be a very useful tool in geological interpretation.

To understand the characteristic responses (or otherwise) of the slope analysis map to different, geologically related features in the landscape, the NEXTMap DSM data for previously surveyed ground in Northern England were reprocessed to give slope analysis maps that could be compared with the position and intensity of features mapped out from ground survey.

Using this approach it has been possible to relate characteristics in the slope analysis maps to geological boundaries (both bedrock and artificial) and in many instances to complete boundaries and solve correlation problems in poorly exposed ground. This section details some of the characteristic signatures that have been observed during this exercise and gives some examples from the study area.

4.1 BEDROCK MAPPING

Within the study area, the position of breaks of slope are strongly related to the underlying bedrock geology and hence can be used to determine the position of geological contacts and to correlate strata across hillsides. In some areas the features are very pronounced, but in others they are subdued by superficial deposits or by unfavourable relationships between the dip of the strata and the aspect of the topography. By comparing NEXTMap slope analysis maps of features with ground surveys in strongly featured terrain it is possible, in many cases, to trace geological boundaries through poorly featured ground and correlate between distributed outcrops. It is also possible to determine much more representative regional dips and, to some extent, delimit faulting using the patterns present in the slope analysis map. Some examples are detailed in this section.

4.1.1 Mapping concordant geological boundaries

Area 4 shows the Nent valley at Nenthall. On the north bank, alternating strata of limestone, siltstone and sandstone have weathered to produce very strong featuring. Two strong limestone units, the *Four Fathom Limestone* and the *Great Limestone* form broad, flat-topped benches, separated by steep slopes of interbedded sandstone and siltstone.

These features are evident in the NEXTMap DSM slope analysis map (Area 4A) as very low angle slopes (blue) juxtaposed against very steep angle slopes (red) with a very strong break in slope (dark line) between. This signature represents the convex break in slope at the front edge of the bench. The steep slopes become shallower down hill (red, grades to orange and yellow) before returning to near flat slopes. The concave break of slope at the base of each feature is less well defined and less well imaged than that convex break at the top.

Comparison of the slope analysis map with the geological field survey of these prominent features demonstrates that the reprocessed NEXTMap data is defining the slopes and breaks in slope accurately. The less well-defined concave break in slope results from varied deposits of head at the base of the steep slopes, derived from the upper slope above. These deposits degrade the quality of the break in slope (and therefore the darkness of the break in slope line), but its position is still reasonably well defined by the change in slope angle to near-flat ground. In some instances, sink holes (‘shake holes’) have formed in the limestone forming the top surfaces of the flat benches. As these features are formed by run-off from the slopes above, they generally form at the back of the bench features, at the break with the overlying slope. This phenomenon is visible in Area 4A and the coincidence of the shake holes marked by the Ordnance Survey and the concave break in slope derived from NEXTMap data is clear.

Geological boundaries are related to position of breaks in slope, but are not always coincident with them (particularly the convex break). In most cases, the position of the base of the resistant unit forming the flat bench can be found somewhere down the steep scarp slope at the bench edge. This position may or may not coincide with a concave break of slope; the relationship between the boundary and the feature has to be determined from ground survey. In Area 4A, the benches are composed of resistant limestone that forms a very strong and steep cliff at the bench edge, above the remainder of the slope. Field survey has shown that the base of the limestone is coincident with the base of the cliff and the underlying steep slope is formed of siltstone and/or sandstone. In Area 4A the base of the limestone cliff is clearly imaged as an additional strong break in slope within the bench edge slope. This break in slope coincides with the base of cliff sections marked by the Ordnance Survey and with the position of springs that emanate from the base of the limestone. In this instance, signatures in the NEXTMap slope analysis map can be related directly to geological boundaries and used to map them.

In Area 5, the features on the hillsides of Carrsheild Moor are formed by the differential weathering of interbedded sandstones and siltstones. The features are narrower and have less well-defined breaks in slope than those in Area 4. However, the alternating, gently sloping benches and steeps slopes are still evident and can be traced across the hillside. Comparison with field survey shows a strong relationship between the breaks in slope recorded on the ground and those indicated by the NEXTMap data. The correlation of these features around Blackway Head Hill is not perfectly clear from the field survey. The slope analysis map aids this correlation and hence the correlation of geological units around the hill. In this example, there is no additional break in slope that marks the base of the harder, bench-forming units and the position of geological boundaries, in relation to the NEXTMap slope analysis signatures, can only be determined from field survey.

Area 6 demonstrates a common correlation problem. Here, the west and (to a lesser extent) east sides of Dodd and Quarry hills are strongly featured. Exposures confirm thin sandstones forming bench features with interbedded siltstones forming the slopes. These features can be traced northwards to the spur of the hill where they become weak, indistinct and difficult to determine on the ground. The spur of Dodd Hill dips northwards at an angle similar to that of the regional dip. Slight differences in assumed regional dip can result in very large differences in the projection of the geology around the spur of the hill. As a result, a number of sandstone units may cross the ridge and correlate with features on the eastern side within the limits of Area 6, or the ridge may lie entirely within the same sandstone unit. Poor exposure does not clarify the situation. The NEXTMap slope analysis map goes some way to clarifying the situation. Subtle changes in slope angle can be observed on the spur of Quarry Hill that correlate with stronger features on the western side. This slope analysis signature suggests that a number of sandstone units (and the interbedded siltstone units) cross the spur of the hill (see Section 4.1.2 below).

From these examples it is clear that strong features formed by differential weathering and their breaks in slope can be determined from the NEXTMap slope analysis map and traced across the hillside. In the textbook example of Area 4 it is even possible to position the boundary of geological units from additional features they produce. In most cases (such as Areas 5 and 6), this is not possible and targeted ground survey is required to constrain the position of geological boundaries in relation to the features interpreted from the slope analysis map. However, even in these cases it is possible to map major features related to geological boundaries and to clarify correlation problems using the NEXTMap data.

4.1.2 Determining regional dip

In areas of gently dipping strata, it is difficult to obtain representative, regionally applicable stratal dips from outcrop measurements. Slight variations in assumed regional dip can result in appreciable differences in projection and correlation of strata.

The eastern part of Area 7 shows the top of Dodd Hill. The summit is capped by a strong and resistant sandstone that forms a plateau with steep sides. This feature is imaged well in the NEXTMap slope analysis map.

Subject to the assumption that the convex break of slope formed by this sandstone is at approximately the same stratigraphical level throughout the sandstone unit, its position with respect to the topographical contours can be used to determine a regional dip. The strata on Dodd Hill appear to dip gently towards the north and, significantly, this dip is less than that of the spur of Quarry Hill. This evidence, combined with the featuring visible on the crest of Quarry Hill in the slope analysis map of Area 6 (Section 4.1.1) supports an interpretation of interbedded sandstones and siltstones down the crest.

By contrast, the strong feature formed by the sandstone cap to Whimsey Hill in the western part of Area 7 appears to dip south-west, suggesting a structural high somewhere around Wellhopehead shafts. All available published mining data indicate that this is indeed the case and the strata form a gentle structural dome in this region. The gentle dip of the strata in all directions away from Wellhopehead combined with the quality of outcrop in this area makes it very difficult to determine the regional dips from field survey that are so evident in the slope analysis map.

Clearly, NEXTMap slope analysis can be very useful in determining regional dips, but perhaps more importantly, it can indicate the relationship between the regional dip and the dip of the topography. This relationship may be critical to the geological interpretation. In the examples shown in areas 6 and 7, the interpretation of regional dip, combined with the featuring evident in the slope analysis map, supports an interpretation of interbedded sandstones and siltstones crossing the spur of Dodd and Quarry hills rather than the alternative hypothesis that the crest ridge lies entirely within one sandstone unit.

4.1.3 Delimiting faulting and structure

The strata of the North Pennines are cut by strong faults and, with the exception of those that have been worked from the surface, there is little direct evidence for them at surface. Most large faults observable in stream sections can be interpreted in the landscape by the coincident curtailment, attenuation or offset of strong features related to the strata.

Consequently, faults do not have a strong, characteristic response in the NEXTMap slope analysis map. However, faults may be indicated in the data by the offset or curtailment of the characteristic signatures of slope angles and breaks of slope related to the strata they cut. As demonstrated in Area 4A, some successions can weather to produce particularly characteristic slope analysis signatures, particularly where a significantly resistant unit, such as a limestone, is present.

Area 8 shows the south-west-facing slopes of the Nent Valley at East Cocklake. This area is just south-east of Area 3 and the same characteristically strong signatures of the limestone benches can be observed in the slope analysis map. West Cocklake Farm (towards the west of the map) sits on the top of one of these benches. The bench is characterised by a near flat (blue) top and very steep (red) slope. A strong and sharp break in slope separates them. This characteristic response can be traced southeast from West Cocklake Farm around the hillside to East Cocklake Farm. At this point there is a sudden and quite abrupt change in slope angle of the top of the bench from near-flat (blue) to southerly dipping slopes (green and yellow). Similarly, the characteristically strong signature of the break in slope at the front of the bench ends and is replaced by the signature of a much gentler slope and weaker break (this relationship is slightly obscured by quarrying at East Cocklake but is still evident in the surrounding landscape). The abrupt termination of the limestone feature's signature suggests possible faulting. Similarly, further up the hillside above East Cocklake Farm and Cocklake Plantation the strong features formed by the interbedded sandstone and siltstone strata become subdued and disrupted.

This area is heavily worked from adit levels in the base of the Nent valley. Two large faults, the Carrs and Wellgill Cross Veins, with throws in the order of tens of metres, are known in this area. The field survey interpretation of Area 8 and the combined field survey and slope analysis map show the strong relationship between the changes in response of the landscape shown in the slope analysis map with the projected surface expression of these faults. Sudden changes in characteristic responses of strata and curtailment of strong features can indicate the position of faults although the trend of such faults may be difficult to determine. In Areas 8 faults that trend perpendicular to those shown on the field slip may be interpreted from attenuation of features within the NEXTMap slope analysis map.

Examination of the slope analysis map subsequent to field survey also suggests that there may be a small amount of offset on the south splay of the Carrs Cross Vein, 100 m north of West Cocklake Farm. Here, the position of the slope above the limestone bench feature and the offset in the break of slope that represents the front edge of the bench, suggest some displacement on this splay. This is not shown on the field survey interpretation as it was not recognised from ground survey and, although the splay is well recorded in adit levels, no throw has been stated in the literature.

Although offsets in, or curtailment of, characteristic stratal signatures in the slope analysis map can help delimit the position of faults, such strong signatures as those of the limestones shown in Area 8 are rare. In most cases, the signatures of the features shown in the slope analysis map are not characteristic enough to be as convincing. In these cases, attenuation or blurring of the feature's signature may indicate faulting. Area 9 shows the slopes of Ayle Common to be strongly featured although no one feature is particularly characteristic. These strong features are significantly attenuated and appear to be slightly offset for some 600 m in the hillside directly north of Alye. This pattern may suggest faulting in this area.

Areas 8 and 9 indicate that whilst faults do not produce features in their own right, their position may be inferred from the disruption of characteristic slope analysis signatures of the strata they cut. Of all the bedrock geology information that may be derived from the reprocessed NEXTMap slope analysis map, faulting is the most inconclusive. It is difficult to recognise faults unequivocally and many of the responses that may indicate faulting are also indicative of other scenarios, particularly the presence of superficial deposits (Section 4.2). The NEXTMap slope analysis map often proves more useful in delineating the course of a fault across the landscape when the presence of a fault is known from other data, rather than indicating the presence of a fault directly.

4.2 SUPERFICIAL & MASS-MOVEMENT DEPOSITS

The presence of a cover of superficial deposits tends to attenuate or completely overprint features produced by the underlying bedrock geology. In areas of intermittent or changing superficial cover, the superficial deposits may produce features in their own right or they may be suspected from the manner in which they attenuate bedrock features and their relationship to the topography. By comparing the field survey to the NEXTMap slope analysis map in areas of intermittent superficial cover it is possible to recognise characteristic responses in the slope analysis data that indicate particular superficial deposits.

4.2.1 Till & glacial deposits

In the North Pennines, the south-west-facing hillsides are largely free of glacial deposits. By contrast, the north- and north-east-facing slopes are usually covered with a significant superficial deposit of till and features produced by the underlying bedrock geology are entirely masked.

Till deposits may produce characteristic signatures in the NEXTMap slope analysis map if glacial drainage channels, drumlins or moraines are present. However, in northern England, these features are commonly not sufficiently large or adequately pronounced to produce signatures in the slope analysis map and till covered terrain is largely featureless. In many cases it is this characteristic *lack* of features, combined with an understanding of the bedrock geology that can be used to recognise till in the slope analysis map.

In Area 4B, the north-facing slopes of the Nent Valley are underlain by the same bedrock stratigraphy as the south-facing slopes. However, the presence of till on these slopes has completely masked the characteristic features of the bedrock geology seen in Area 4A. The signature of till in the slope analysis map is the complete lack of breaks on a slope of near constant gradient.

The slope analysis response of bedrock features where they have been masked by a superficial cover of till, compared with where they have not, can be used to delimit the edge of till deposits. In many cases this edge will produce a break of slope signature in its own right, albeit a small one. These breaks of slope are discordant with those representing differential weathering of bedrock strata and are typically locally irregular. If such signatures can be traced for some distance and attenuate the signatures of underlying bedrock features, they may represent the limit of till deposits. In Area 10, the strong slope analysis map signatures of the features present in the east-facing slopes of Knockshield Moor can be traced northwards for 500 m where they are severely attenuated. Similarly the features of Longwell Moor become attenuated down hill towards the north. In both cases, at the point of attenuation there is a poor quality and very irregular break in slope signature that marks the boundary of the till cover.

The NEXTMap slope analysis signature of till is not uniquely characteristic. As demonstrated in section 4.1.3 and Area 9 it is entirely possible for faulting to produce a similar attenuating effect on the bedrock features and, consequently, their corresponding slope analysis map signatures. However, given knowledge of the presence of till and till boundaries from other data sources, such as aerial photos, NEXTMap slope analysis can help to indicate the limits of till deposits.

4.2.2 Alluvium and river terraces

Alluvial flood plain deposits produce a feature and therefore characteristic signature in the slope analysis map. Flood plain terraces are usually near-horizontal and very smooth with an extremely strong and marked break in slope with the edge of the river valley. These characteristics combine to produce a unique signature.

In Area 4C, alluvial terraces of the River Nent are clear distinguishable by their near horizontal slopes (blue), bounded by the steeper slopes of the river valley with a very strong and well-defined break in slope between them. The near-planar nature of the top surface of such deposits results in a significant reduction in the ‘shimmering’ effect seen over much of the remainder of the map. This shimmering is the NEXTMap DSM slope analysis signature of small, short-lived changes in slope angle that produce small, short-lived breaks in slope. These occur on all natural slopes, even those that appear smooth, such as till covered slopes (Area 4B). Alluvial terraces are the only natural deposits to show a significant reduction in this shimmer. The only other deposits to show such a lack of shimmering are manmade, such as sports fields.

In Area 12, terrace deposits are visible along both banks of Whitewalls Burn, again distinguished by their near-horizontal attitude juxtaposed against the steep sides of the river valley and separated by a very sharp break in slope. The lack of shimmering is not evident in this case as the terraces are small and only just above the resolvable resolution of the NEXTMap data.

In Area 11, the large alluvial flood plain of the River West Allen is evident, separated from the first bench feature of the bedrock geology in the east-facing valley slope (on which Ouston stands) by a strong break in slope. Once again there is a significant reduction of shimmering in the alluvial deposits. Note also that there are slight increases in slope angle and marked breaks of slope within the flood plain. These are the poorly imaged edges of separate terraces within the floodplain deposits. The edge of the alluvial terraces with the river and separate terraces within the floodplain to the north of Area 11 are strongly masked by the signature of trees and walls on the floodplain.

The distinctly different geometric form of alluvial deposits compared with other superficial deposits and with featuring produced by bedrock geology enables easy and precise recognition of their signature in the NEXTMap slope analysis map.

4.2.3 Landslip

Landslips can be recognised on the ground by irregular shaped deposits that sit above the natural level of the landscape. The deposits are often characterised by small, short-lived scarps and bench like features within them and delineated by a steep back-scarp slope.

Landslips have a particularly unique NEXTMap slope analysis signature. They are characterised by a very steep slope representing the back-scarp that is both anomalous with the surrounding landscape and delimited from it by a very sharp break in slope. The steep back-scarp and corresponding break in slope are usually strongly arcuate. The deposit itself is characterised by varied slope angles with rapid changes in slope over a short distance. These changes result in very strong but short-lived break-in-slope features.

In area 4C these classic characteristics can be recognised in a number of small landslips along the southern bank of the River Nent. Note the strong break in slope with the surrounding hillside at the top of the back-scarp.

Larger scale landslips produce a stronger signature. In the slopes of the south side of Whitewalls Burn (Area 12) there is a large deposit of till and superficial material that has slipped over the bedrock geology. This probably resulted from the seepage of water out of the bottom of a strong, coarse sandstone that is exposed in the back-scarp. Area 12B shows the characteristic NEXTMap slope analysis signature to this. The back-scarp is imaged very clearly with a strong break in slope with both the natural landscape and the slip deposit. The deposit is characterised internally by short-lived irregular slopes and breaks of slope.

NEXTMap slope analysis is particularly useful in aiding the identification of landslip deposits as their existence is best identified from a distant view. Close up on the ground, the features they produce are often confusing, particularly when the slip is large, and they may be interpreted as relating to bedrock geology. The strong back-scarp and its clear discordance with those features that represent bedrock geology are commonly well imaged in the slope analysis map.

4.3 ARTIFICIAL DEPOSITS

It is important that both worked out and made ground are recognised and recorded correctly. As both are manmade deposits they commonly have characteristic NEXTMap slope analysis signatures. However, it is not always straightforward to distinguish these responses from those of cultural features, such as trees, buildings and walls.

4.3.1 Worked Ground

Worked ground has been artificially lowered, i.e. material (usually rock) has been purposefully removed. This can result in a near-vertical rock face and near-flat base to the worked area. The NEXTMap slope analysis signature of this is a steep slope representing the face and a near flat slope representing the base with a very strong break in slope between them. The slopes and separating break in slope are often short-lived and may be arcuate. They give the appearance of a 'blip' in the signature of the background landscape.

In Northern England, worked ground encompasses both quarries and hushed out mineral veins. In Area 13, there are large quarries in both the limestone and sandstone units that are exposed in the west bank of the West Allen River. Barneycraig Quarry, in limestone, gives the characteristic signature on the slope analysis map and is clearly distinguishable from the surrounding hillside. Ladlewell Quarry, in sandstone, is less classically shaped and hence has a less characteristic signature. However, it is clear from the NEXTMap slope analysis that there is some disruption to the hillside and strong evidence of manmade features.

Old mine workings, especially hushing, are harder to detect from their NEXTMap slope analysis signatures. They are commonly small scale and associated with contemporary buildings or later plantations that obscure the signature. Area 14 shows Kirsleywell Mine in the Mohope Valley. The Kirsleywell Row north and south veins are strongly hushed out and, although some indication of this can be found in the NEXTMap slope analysis map, much of the effect is masked by tress and buildings.

4.3.2 Made Ground

Made ground has been artificially elevated above the level of the natural landscape. The NEXTMap slope analysis signature is similar to that for worked ground but in many cases made ground it is also characterised by a lack of the shimmering effect as it is often completely planar.

In Northern England, made ground consists of spoil heaps and mine dumps in addition to cultural features and the former are clearly of interest to the geologist. Area 7B is the large spoil heaps of Wellhopehead Mine on Wellhope Moor and the NEXTMap slope analysis signature is the characteristic bright red blip in an otherwise smooth hillside. Area 14 shows the Kirsleywell Mine spoil dump. The spoil heap produces a slope analysis signature similar to trees and buildings but it is lobate in shape. This classic spoil heap shape helps to identify the signature of spoil from that of trees.

Worked and made ground can be identified from their NEXTMap slope analysis signatures although they are often difficult to distinguish from the signatures of cultural features. Many worked and made areas are marked on the OS base map and an analysis of slope does little to help in their identification. On the open fell many small quarries and spoil heaps are not marked and NEXTMap slope analysis can help in identifying these features for targeted ground survey. Here, the arcuate shape of quarries and the lobate shape of spoil heaps often distinguishes them from the circular response of lone trees.

5 The limitations of slope analysis using NEXTMap data

Areas one to fourteen demonstrate some of the characteristic signatures produced by NEXTMap slope analysis maps in response to slope angles and breaks in slope associated with bedrock and superficial geology. NEXTMap data can be interpreted in terms of these signatures and used to improve both positional accuracy and geological interpretation in the well-featured terrain of Northern England.

However, this study has also highlighted a number of scenarios in which an analysis of NEXTMap data is unable to provide useful geological information.

5.1 STEEP SLOPES

NEXTMap data are georeferenced and gridded with a 5 m interval in the map plane. Whilst in most cases this lateral grid spacing is more than sufficient for slope analysis at 1:10000 scale, on steep slopes this interval can severely curtail the recognition of characteristic NEXTMap slope analysis signatures, even in very well featured ground. Additionally, foreshortening effects degrade the quality of NEXTMap data in areas of steep terrain.

In Area 11, the steep hillside above Ouston is very strongly featured. From field survey it is clear that the features trend slightly obliquely to the strike of the hillside and are offset at approximately 500 m intervals by small faults. Despite their strength and clarity on the ground, these features are very poorly imaged in the NEXTMap slope analysis map and cannot be clearly distinguished from each other. Similarly, the steep slopes on the western edge of Area 5 are strongly featured but these features are not clearly imaged in the NEXTMap slope analysis map.

Steep slopes limit the width of bench-like features and separate features are not distinguishable in this setting. NEXTMap DSM slope analysis is of little help in interpreting these slopes.

5.2 LOW RELIEF FEATURES

The NEXTMap digital elevation data evaluated here are accurate to 2 m (Section 2.2). Clearly, any feature with an overall relief less than this will not be imaged in the slope analysis map as they are effectively masked by the slight relief variations in the feature itself. In general, the edges of river terraces and features of similar low relief will not be imaged.

In practice, it appears that spatial relationships between the relief of the feature and its lateral extent (width) are the governing factors that determine the likelihood of the feature being imaged in the slope analysis map. Slope analysis techniques detect the *difference* in elevation between neighbouring sample points, hence if a feature has a constant gradient for a significant lateral distance, a small and laterally constrained change in that gradient may be detectable even if the absolute elevation difference is less than 2 m. In practice, the only natural features to show such near constant gradients for some distance with sudden abrupt changes in elevation are river terraces.

Some of the terracing in the West Allen valley (Area 11), where the terraces are laterally extensive, is imaged in the slope analysis map. Note also that the fences that cross the terraces (about 1.5m high) are also imaged for the same reasons. In areas of less laterally extensive terracing such as Area 4 and Area 12, the strong terracing evident on the ground is not imaged in the slope analysis map.

5.3 RIDGES AND GROVES

The NEXTMap data reprocessing techniques presented here use ARCMap slope analysis routines to generate first- and second-order differentials from the gridded elevation data (Ford, *in press*). In practice, these routines do not calculate true mathematical differentials. The first-order calculation produces a scalar gradient of slope with no indication of dip direction. Consequently, the second-order calculation (rate of change of gradient) does not detect any difference between slopes of the same gradient magnitude but opposing directions. For these reasons, breaks in slope resulting from grove or ridge features (same gradient magnitude on either side) will not be imaged. This presents a potential problem in igneous terrains where dykes may be exposed as ridges, or structural terrains where faults may be exposed as grooves or valleys.

Techniques of slope *aspect* analysis, in which the rate of change of slope *facing* direction is used to detect breaks in aspect (Ford, *in press*), can go some way to helping in the detection of ridges and grooves. However, this technique is still in its infancy and needs further work to overcome a number of inherent problems.

5.4 PEAT

Unfortunately, peat deposits do not have a characteristic signature in the NEXTMap slope analysis map. There is no practical way to use this map to delimit the edge of peat deposits.

Area 7 shows the top of the Dodd and Wellhope Moor. This area is covered in extensive peat deposits on its northern side but there is no clear response to this in the slope analysis map. Subtle indicators may be present such the attenuation of features on the west side of The Dodd, strengthening of features on Smallburns Moor where peat is not present, and small, short-lived features on the flat top of The Dodd that result from Haggs within the peat. However, comparison of the slope analysis map and geological field slip for Area 7 shows that there is little discernable evidence in the slope analysis map for the position of the peat boundary.

Trials of NEXTMap slope analysis techniques in the peat-covered moorland of Northern England have so far failed to find away to image peat deposits in the slope analysis map.

6 Slope analysis – A test case

Sections 3, 4 and 5 have shown the uses and limitations of the slope analysis map in geological mapping. It is clear from these examples that NEXTMap slope analysis cannot replace the ground survey. Whilst the technique may indicate features related to the bedrock and superficial geology it does not provide answers to what those features actually represent and geological properties (such as lithology) cannot be derived from the data. It is a technique that can improve interpretation of the landscape and aid in the delimiting of geological boundaries both during map compilation and concurrently with the geological survey.

However, whilst NEXTMap slope analysis does not negate the need for the ground survey, it has the potential to improve efficiency in the field by facilitating targeted mapping in areas of poor exposure. In this section the possibilities of using NEXTMap slope analysis prior to field survey, in order to focus the mapping, are explored.

6.1 SLOPE ANALYSIS INTERPRETATION OF FELLHOUSE FELL

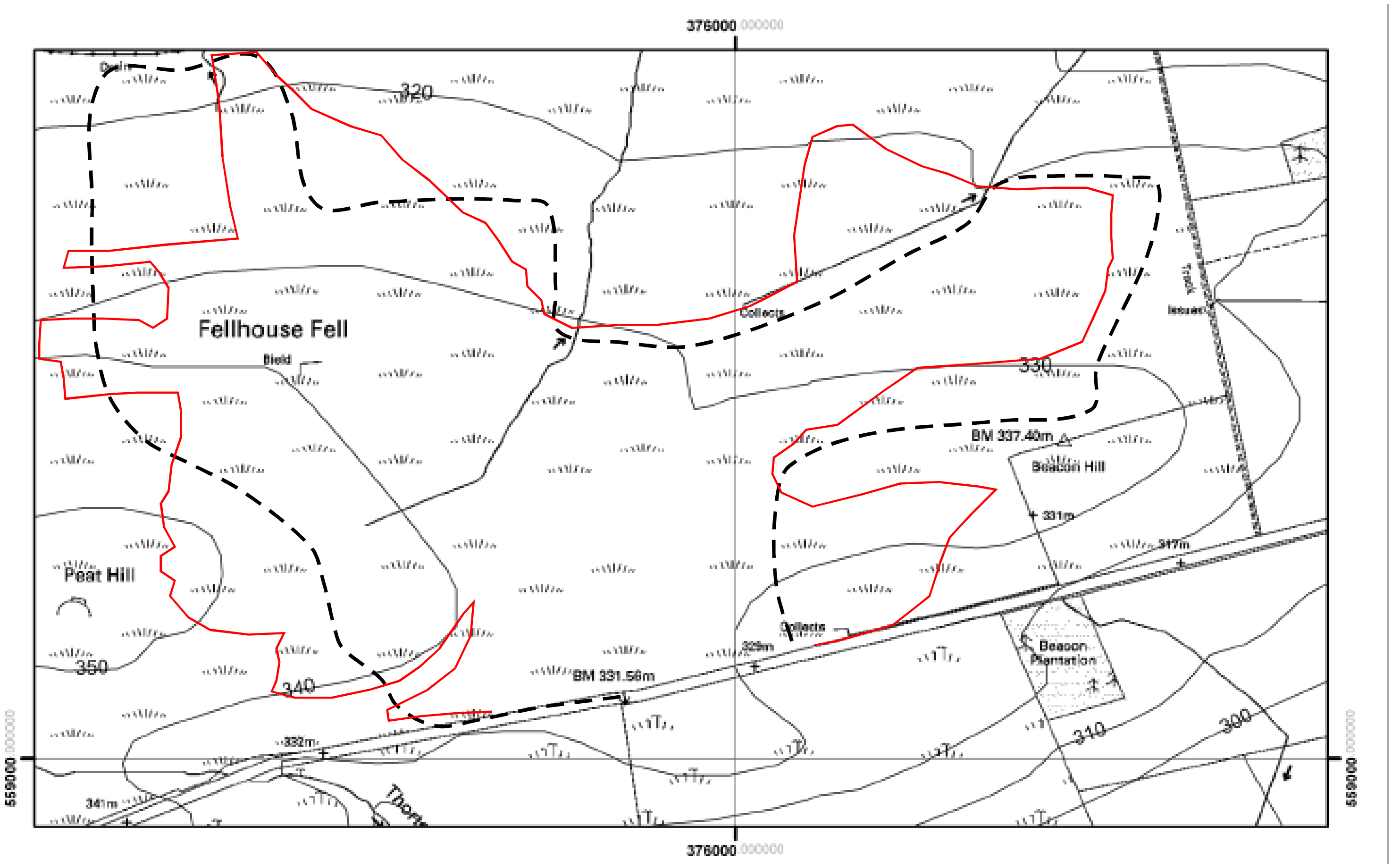
Figure 6.1a shows a 2 km^2 area of NY75NE known as Fellhouse Fell. This area is a classic example of moorland in which there is little geological information to be gained from a ground survey over and above the identification of features and their association with bedrock and / or superficial geological units. It is an excellent test case for NEXTMap slope analysis interpretation prior to ground survey. In this way, characteristic signatures and anomalies can be identified in the slope analysis map and a targeted field traverse planned to identify the geological relationships associated with those signatures and anomalies.

Figure 6.1b shows the NEXTMap slope analysis map for Fellhouse Fell. The characteristic signatures of a number of roughly parallel, bench-like features can be identified in the north-west corner, running obliquely to the sides of Peat Hill and Beacon Hill. The south sides of these two hills appear smooth with breaks of slope identifying their bases and flat tops. A number of particularly anomalous areas, with steep gradients of limited lateral extent, can be identified. A number of unclear areas, where signatures appear to die of become attenuated can also be identified. All areas are labelled on Figure 6.1b. Using this assessment, a targeted traverse of the area can be planned and is shown on Figure 6.1b.

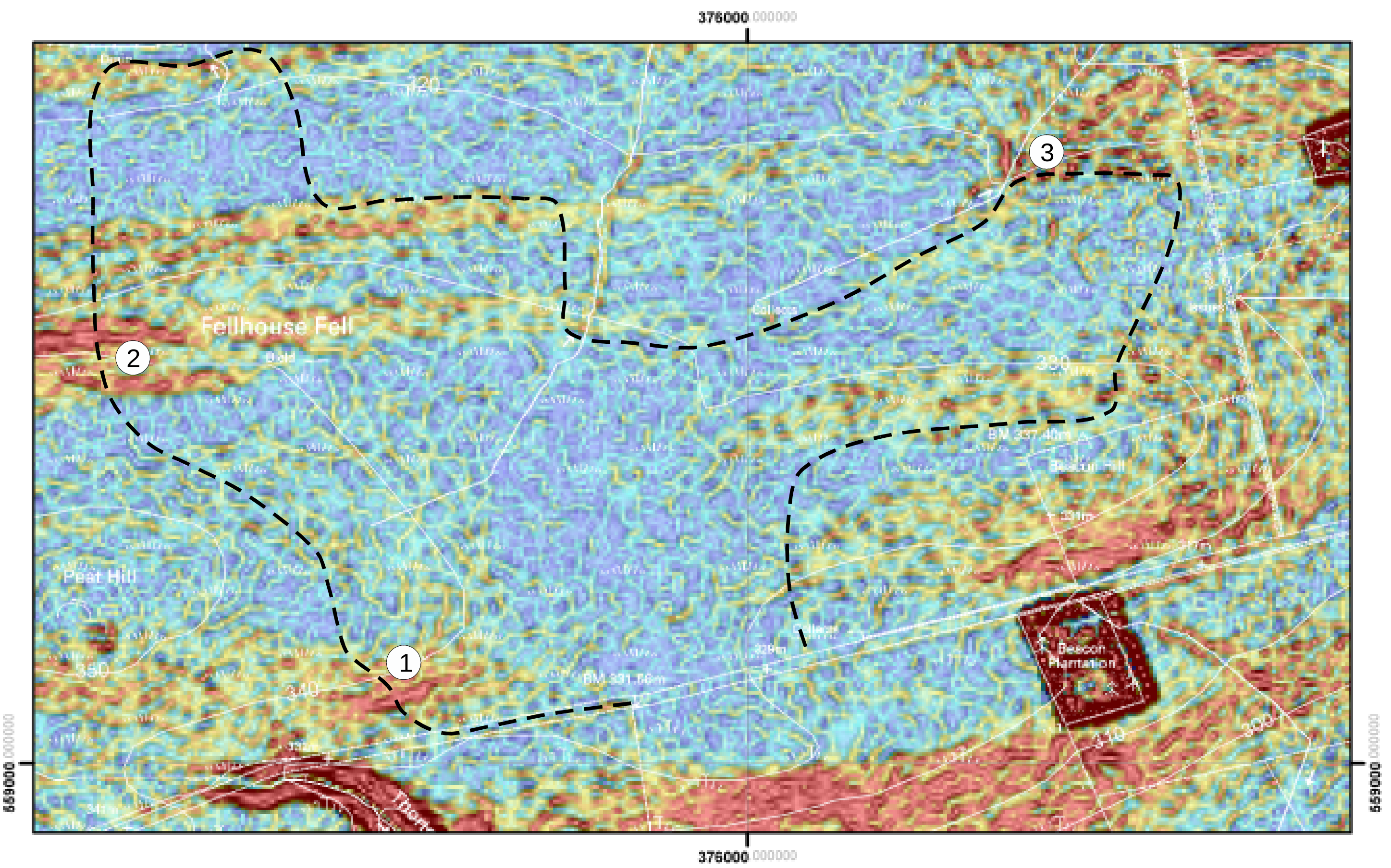
The field survey progressed by following the traverse line to intersect the features identified in the slope analysis map. The actual course shown is indicated by the GPS track-log on figure 6.1a.

From the traverse it was possible to identify the breaks in slope and associate them with the slope analysis signatures. Anomaly 1 – identified prior to field survey from the slope analysis map – was identified as a break of slope on the south side of Peat Hill. This is not recognised in the slope map and, consequently, it was followed on the ground during the survey. Similarly, anomaly 2 was recognised as an additional bench-like feature within the slope of the strong bench imaged on the slope analysis map. Anomaly 3 turned out to be two, small, disused quarries in sandstone. This is the only exposure in the area and demonstrates the advantage of a targeted approach based on the slope analysis interpretation. The remainder of the features identified on the slope analysis map were confirmed by the traverse. Figure 6.2 shows the results of the field survey. From the field survey, the remainder of the slope analysis map can be interpreted and is shown in Figure 6.2.

This approach represents a significant improvement in efficiency over the systematic, but blind, approach to the ground survey. The survey of these 2 km^2 of Fellhouse fell required one traverse and took 1.5 hrs. One day is a conservative estimate for the time required to systematically survey the area and follow all the features.

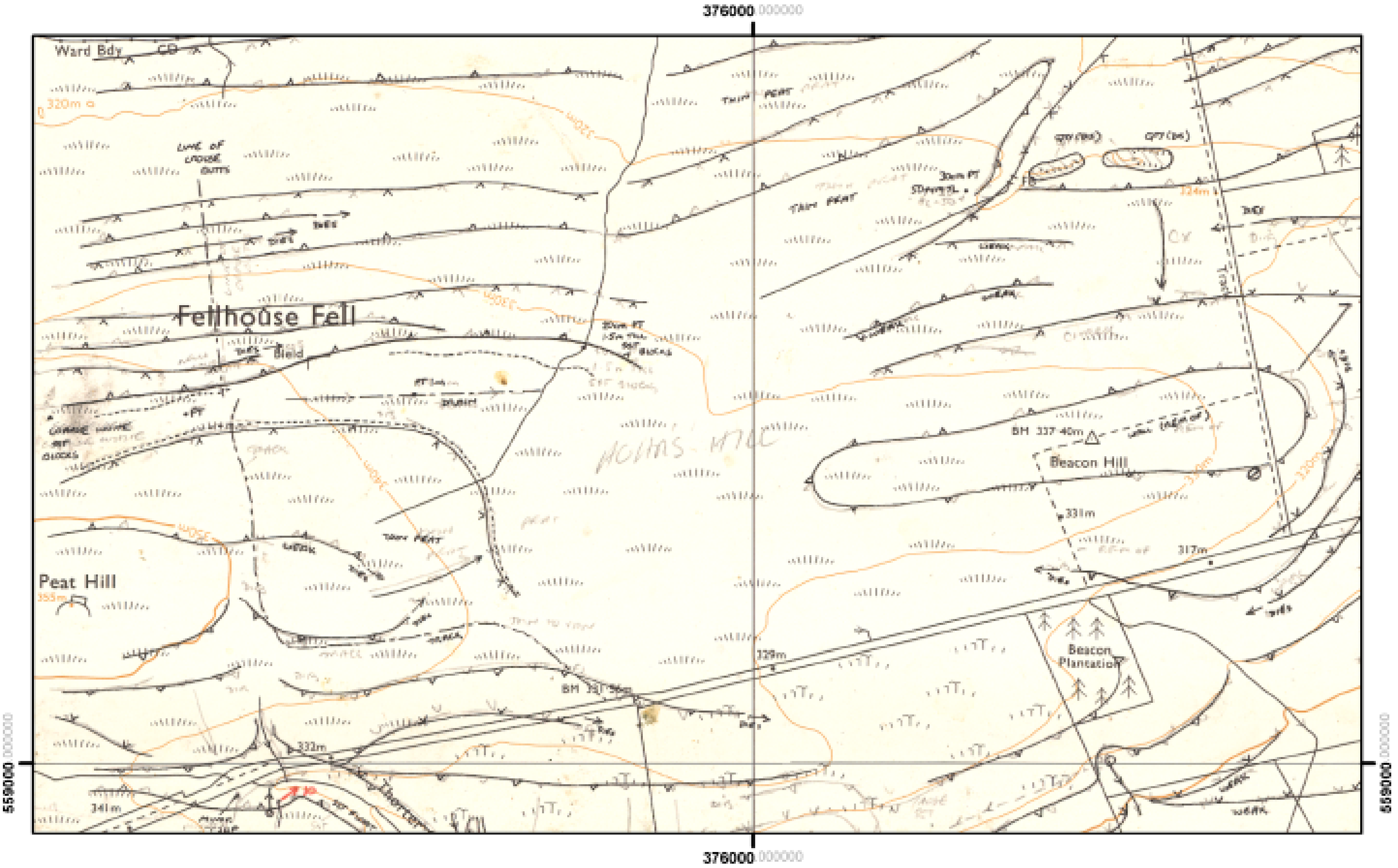


a) Topography and actual traverse line (red)



b) NEXTMap slope analysis showing intended traverse line and identified anomalies

Figure 6.1 - Test area topography and NEXTMap DSM Slope Analysis Map showing the intended traverse route and the actual traverse route during survey. Several anlomalies have been identified in the NEXTMap data as indicated.



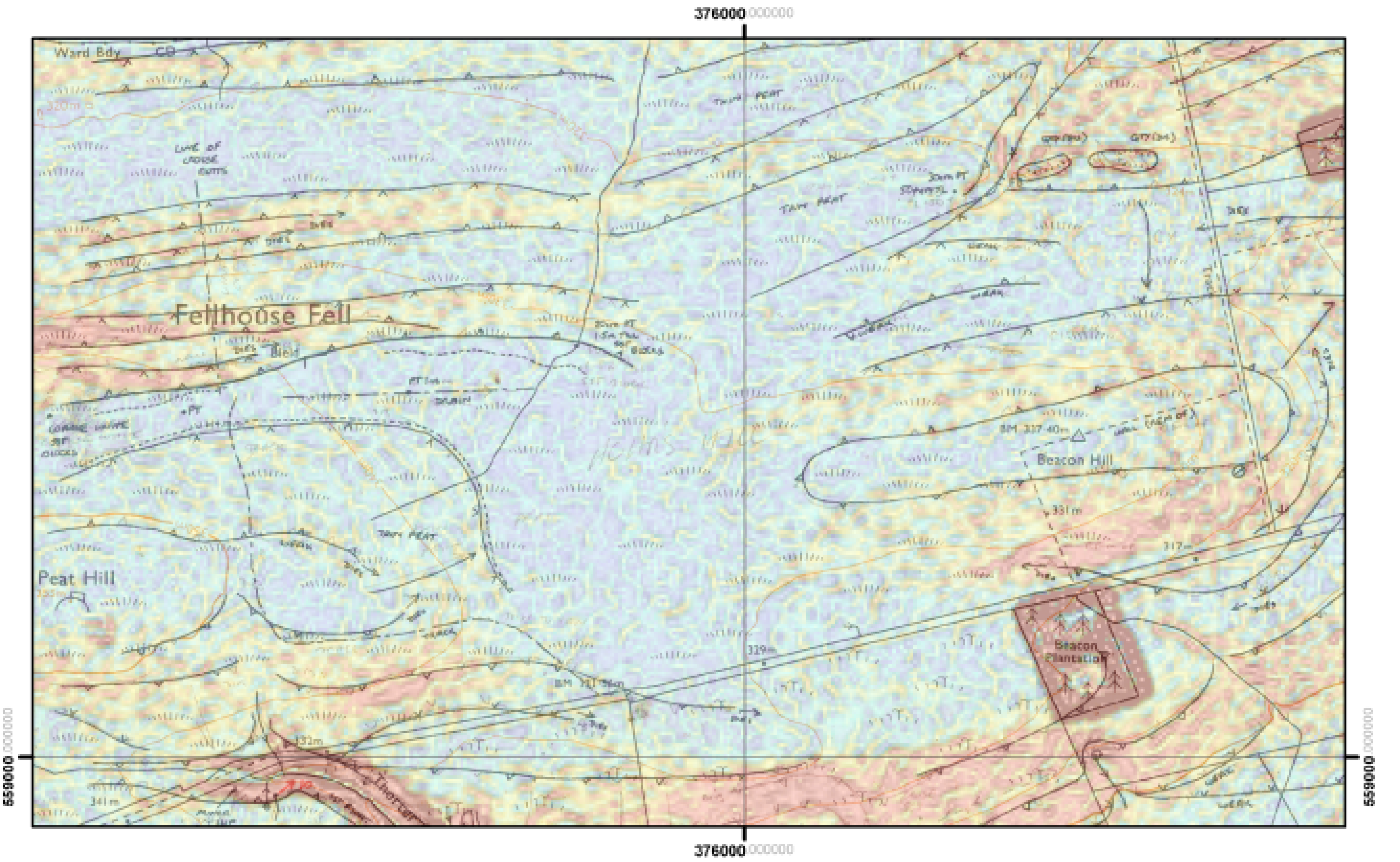


Figure 6.2 The feature interpretation resulting from NEXTMap slope analysis interpretation combined with field traverse shown in figure 6.1. The lower image shows the interpretation superimposed on the NEXTMap data.

It is clear from a quick assessment of the OS Base map and air photos that Fellhouse Fell has little in the way of useful geological information to be gleaned from it other than the features. The slope analysis interpretation allows a targeted traverse style survey to be planned with the aim of confirming features and / or anomalies shown in the slope analysis map. The remainder of the feature interpretation can be produced from a combination of the ground survey with the slope analysis map.

7 Conclusions

NEXTMap digital elevation data can be reprocessed to provide gradient and rate-of-change-of-gradient (break in slope) data. These data can be combined to produce a slope analysis map in which features related to both the bedrock and superficial geology can be identified.

In this study, slope analysis maps of parts of NY74NE/NW, NY75SE/SW and NY84NW in the North Pennines of England have been compared with detailed field surveys. The field survey in all areas was conducted without reference to NEXTMap data and provides an excellent control on the data interpretation.

The ability of the slope analysis approach to detect features in the landscape, related to both the bedrock and superficial geology, by their characteristic signatures in the slope analysis map is clear from the comparison of these maps with the geological survey slips.

It is also clear that slope analysis maps can help during the geological map compilation phase by allowing the geologist to make decisions with regard to the position of geological boundaries and faults, the relationships between topography and geology, the extent of superficial cover and in the completion of bedrock boundaries through areas covered in relatively thin till.

Perhaps the most significant use of slope analysis techniques is as a planning tool for targeted ground survey in remote areas of little geological exposure. An interpretation of slope analysis maps prior to ground survey can allow the geologist to plan targeted traverses that intercept features identified in the slope analysis data, identify the relationships between geological features and the NEXTMap slope analysis signatures and thus complete the interpretation between traverses based on the slope analysis map. In this way significant efficiency gains can be made in the mapping of remote and poorly exposed terrain.

Slope analysis maps are not without their problems. Cultural features have an unfortunate masking effects on the natural features in built-up or heavily wooded areas. Whilst DTM maps may help in well-featured urban areas they tend to introduce more anomalies than they remove in areas of smaller settlements, and smooth the signature of natural countryside to a point where the features are unclear. DSM maps produce much clearer signatures of the featuring in natural ground but the inclusion of cultural features in these data masks natural features in built-up areas. Despite these problems the DSM dataset has proved the most useful for geological mapping in Northern England.

NEXTMap slope analysis is not a replacement for the ground survey. It does not allow the geologist to make an interpretation of the geology, merely to make an interpretation of the features that may relate to the geology. Many different geological scenarios have similar slope analysis responses and ground survey is necessary to associate particular anomalies with particular aspects of the geology. NEXTMap data are also limited in use on their own. They should form an extra tool for the geologist to integrate with other datasets, particularly aerial photographs, in order to improve the geological interpretation. The combined interpretation of aerial photos and NEXTMap slope analysis maps is a particularly powerful technique. Many of the features recognisable in NEXTMap slope analysis maps can be observed in aerial photographs and in many case distinctions can be made between features with similar NEXTMap characteristics using the aerial photographs. However, aerial photographs are not to true scale and are not a map projection of the land surface. NEXTMap slope analysis maps can be used to precisely position features interpreted from aerial photography.

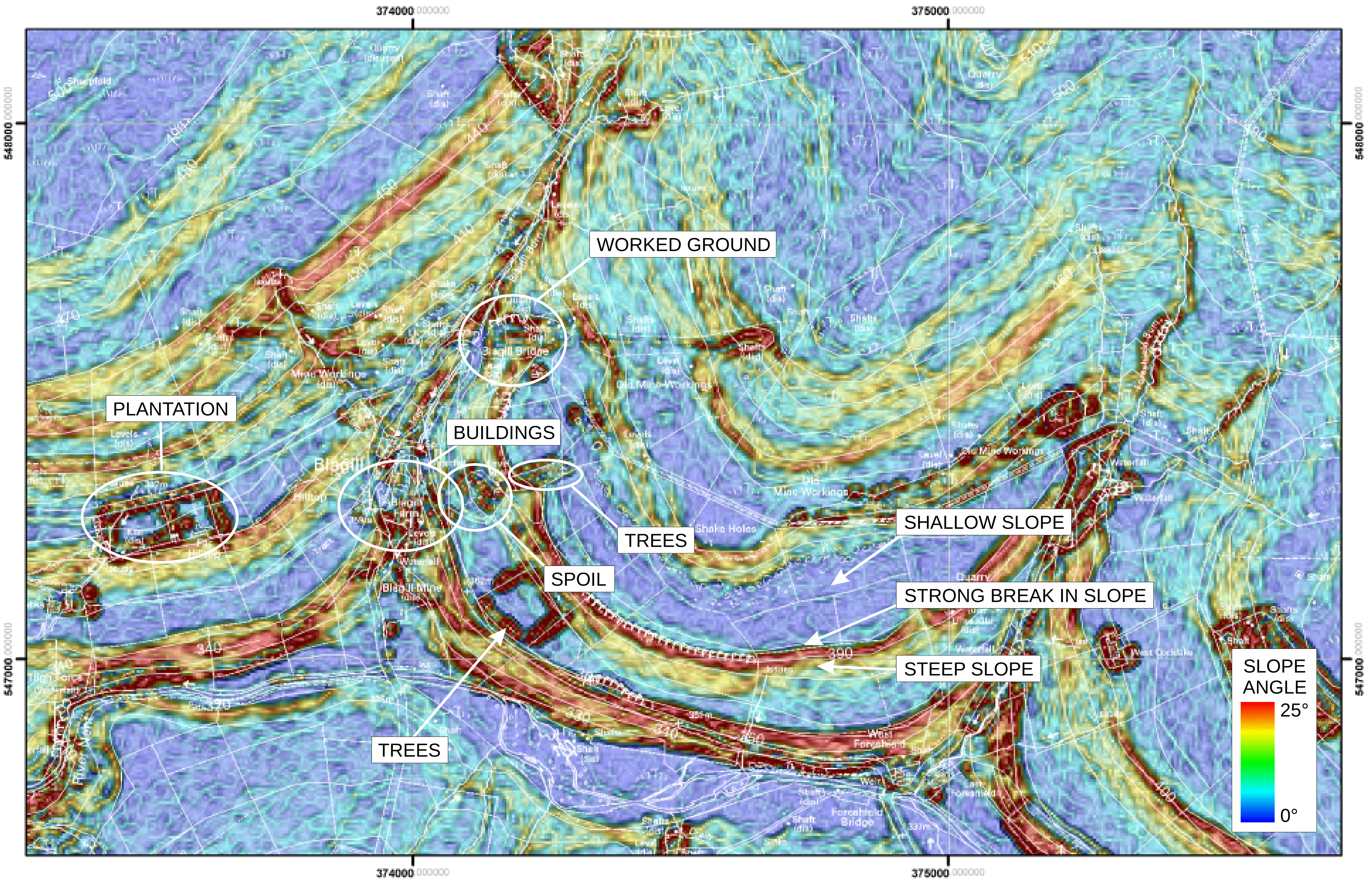
Given these relationships it is possible to use slope analysis maps to great effect in map compilation and survey planning. NEXTMap slope analysis maps are now use routinely during and after field survey in Northern England and are proving a very useful tool in the geological interpretation in this area. In similar terranes, where the bedrock is at or near surface and consists of lithologies with contrasting weathering characteristics that produce a strongly featured landscape, NEXTMap slope analysis techniques will prove equally beneficial.

References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

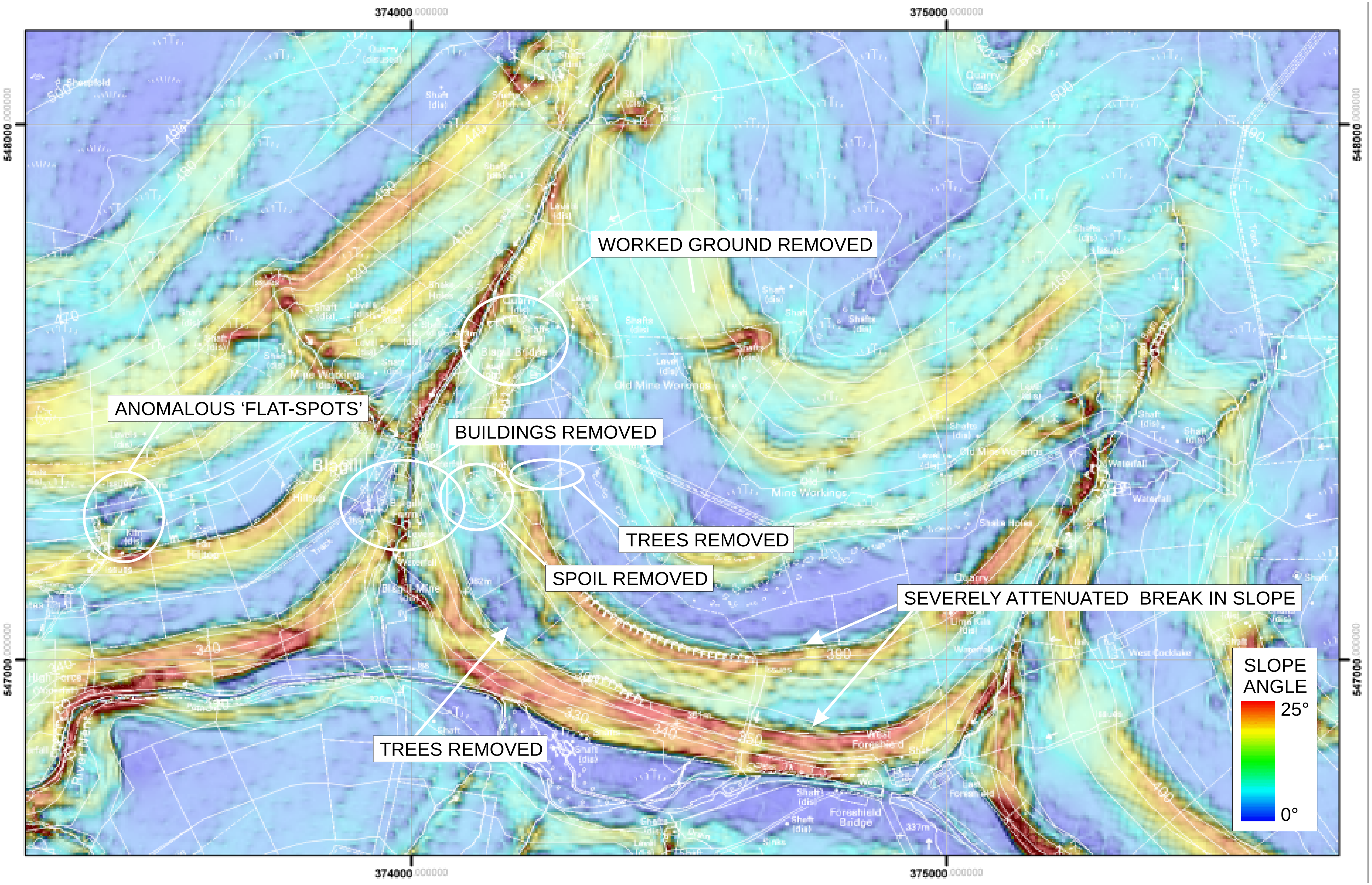
FORD, J. *in press* Derivation of feature mapping elements from NEXTMap data. *British Geological Survey Internal Report*. *In prep.*

INTERMAP TECHNOLOGIES. 2003. *Intermap product handbook and quick start guide*. (Intermap, Englewood, CO, U.S.A.) www.intermaptechnologies.com



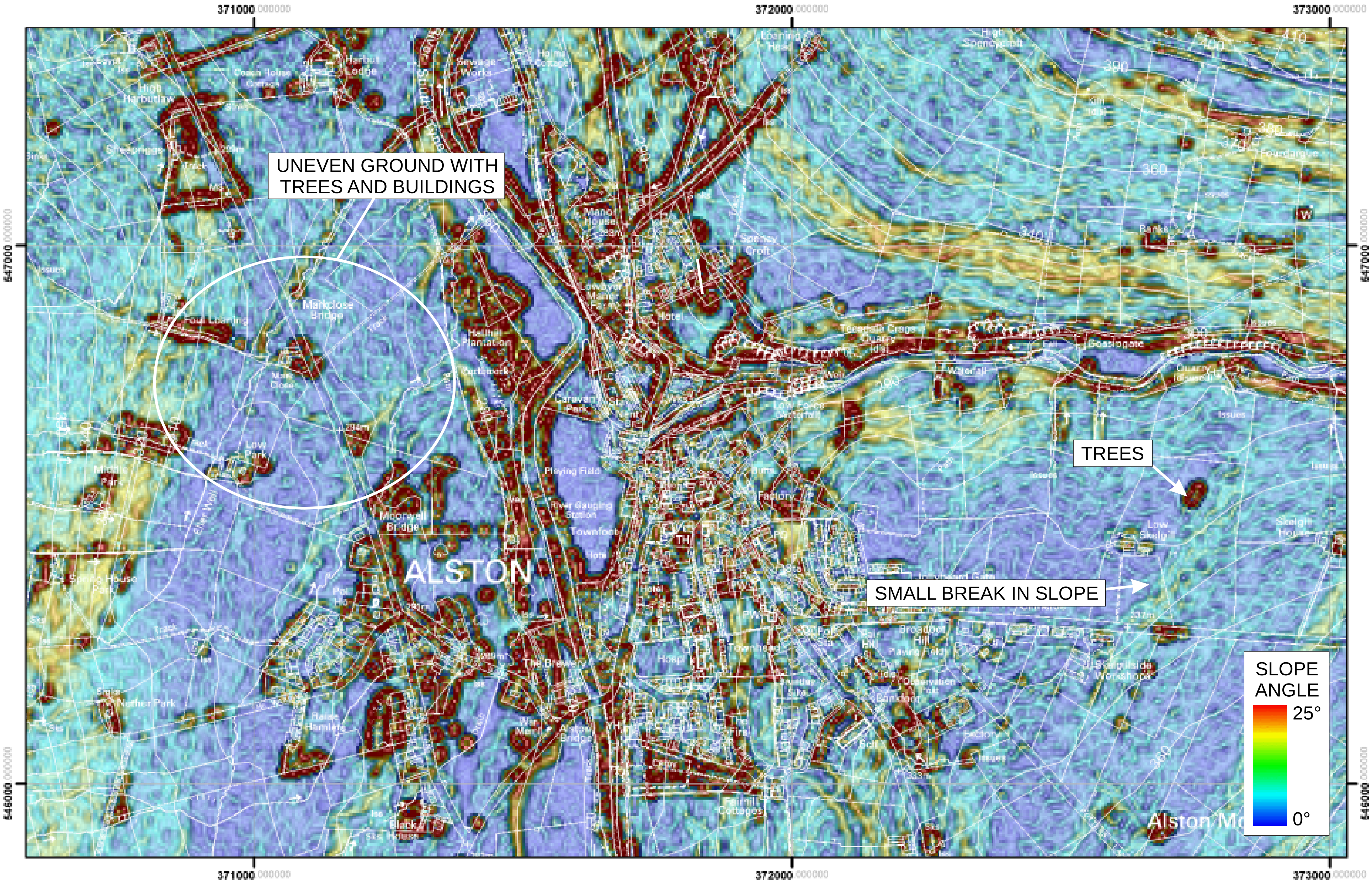
Area 1 - Blagill

Digital Surface Model



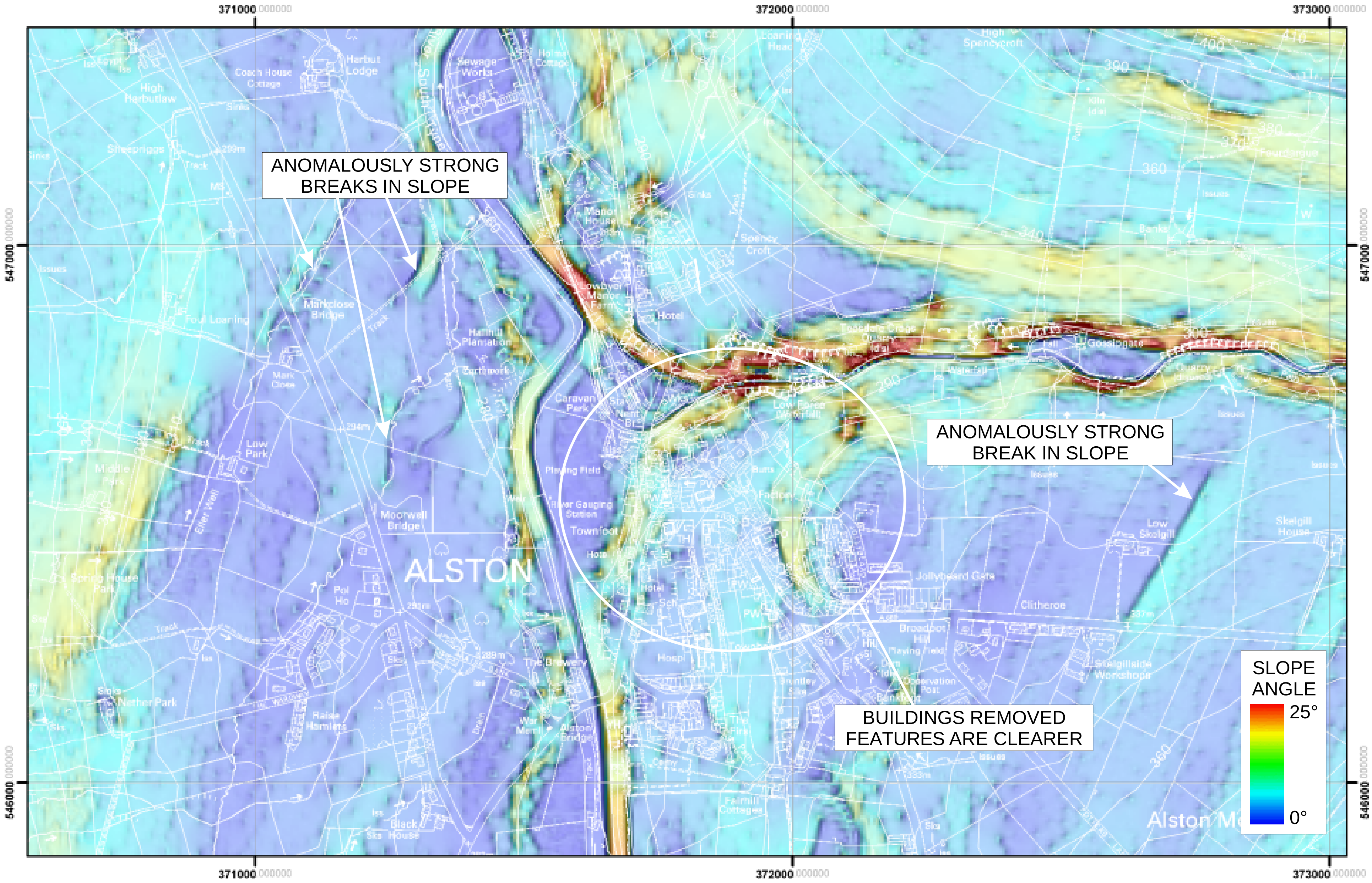
Area 1 - Blagill

Digital Terrain Model



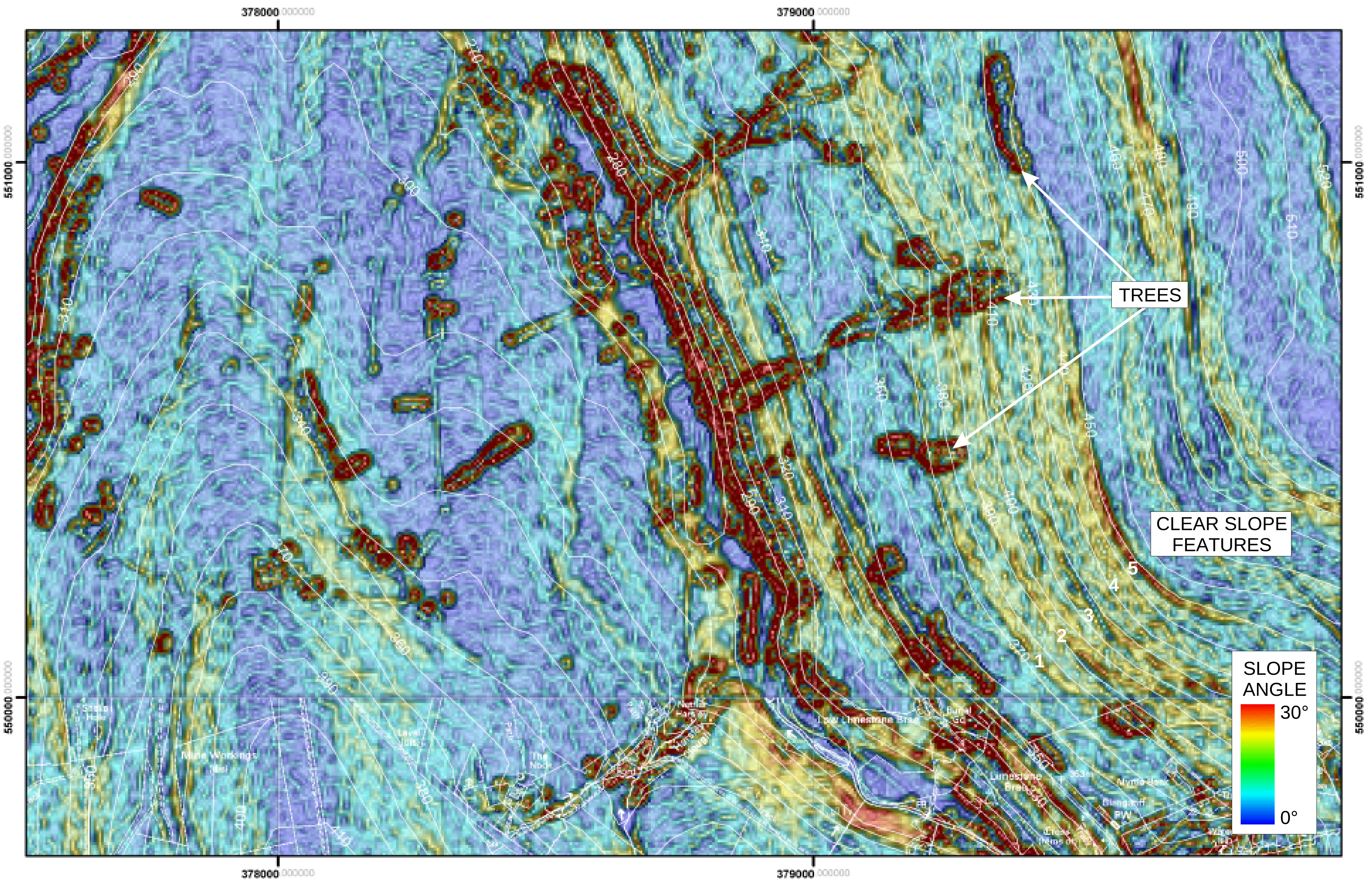
Area 2 - Alston

Digital Surface Model



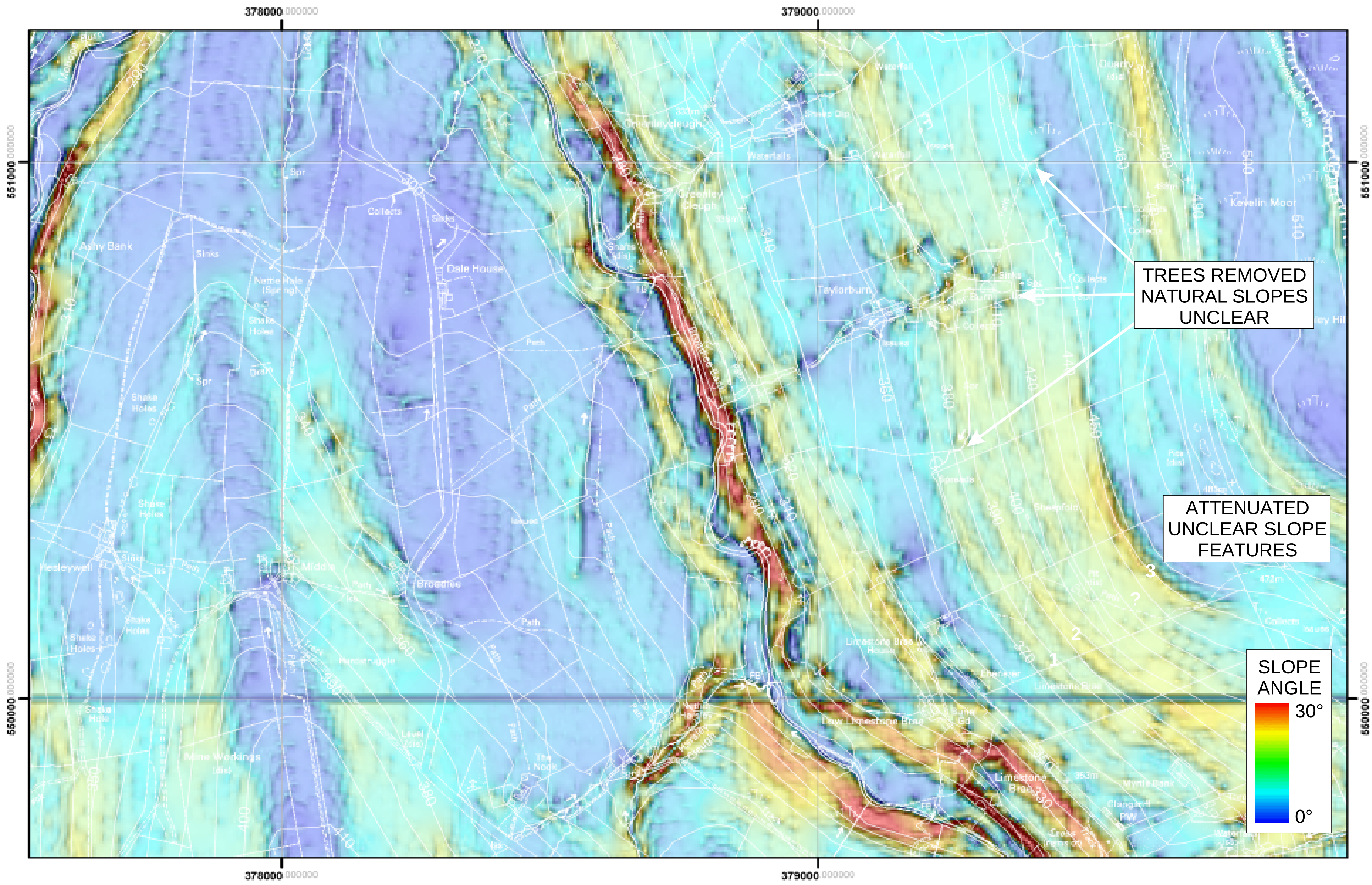
Area 2 - Alston

Digital Terrain Model



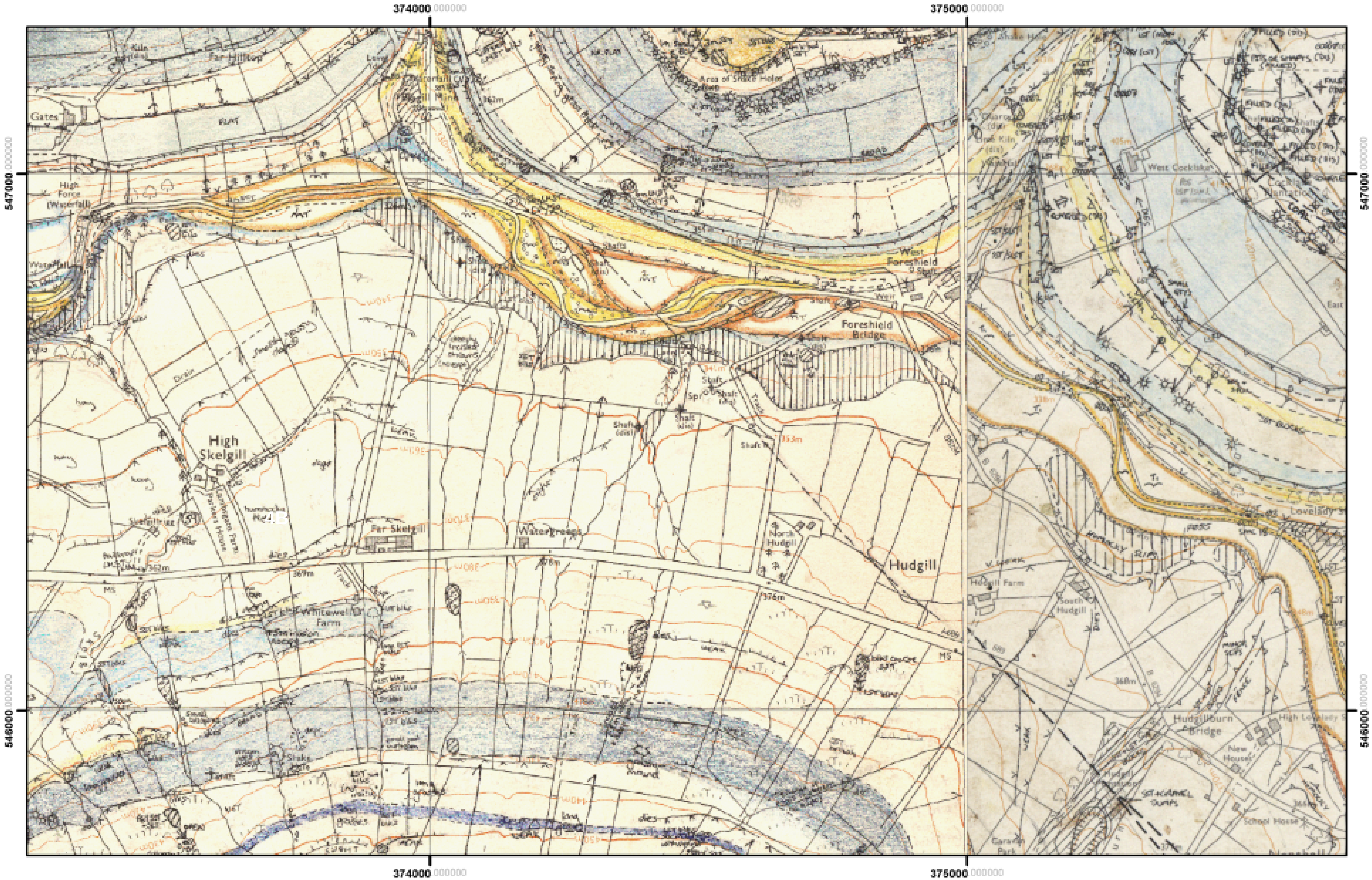
Area 3 - West Allen Valley at Limestone Brae

Digital Surface Model



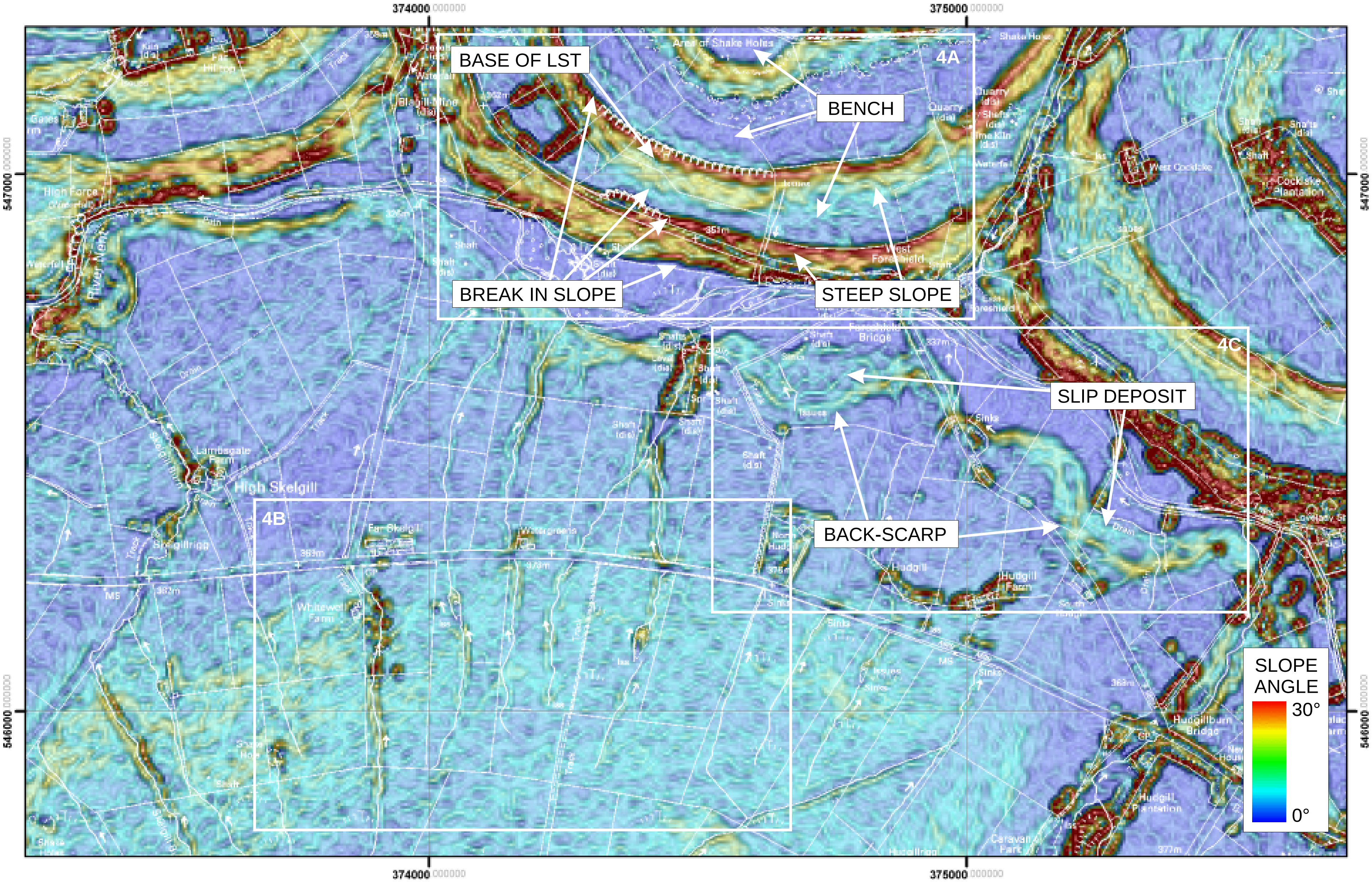
Area 3 - West Allen Valley at Limestone Brae

Digital Terrain Model



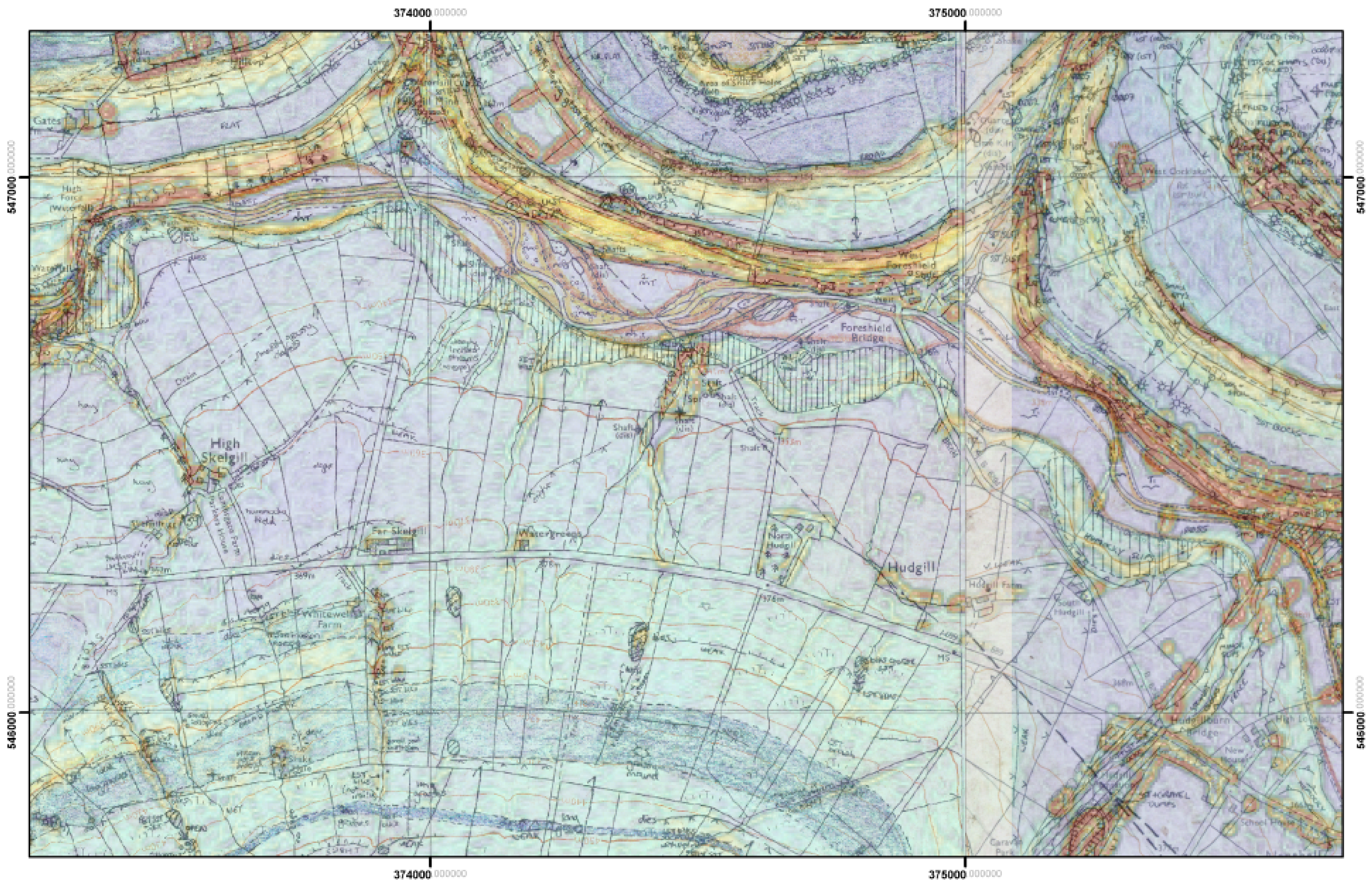
Area 4 - Nent Valley & Nenthall

Geological Field Slip



Area 4 - Nent Valley at Nenthall

Digital Surface Model

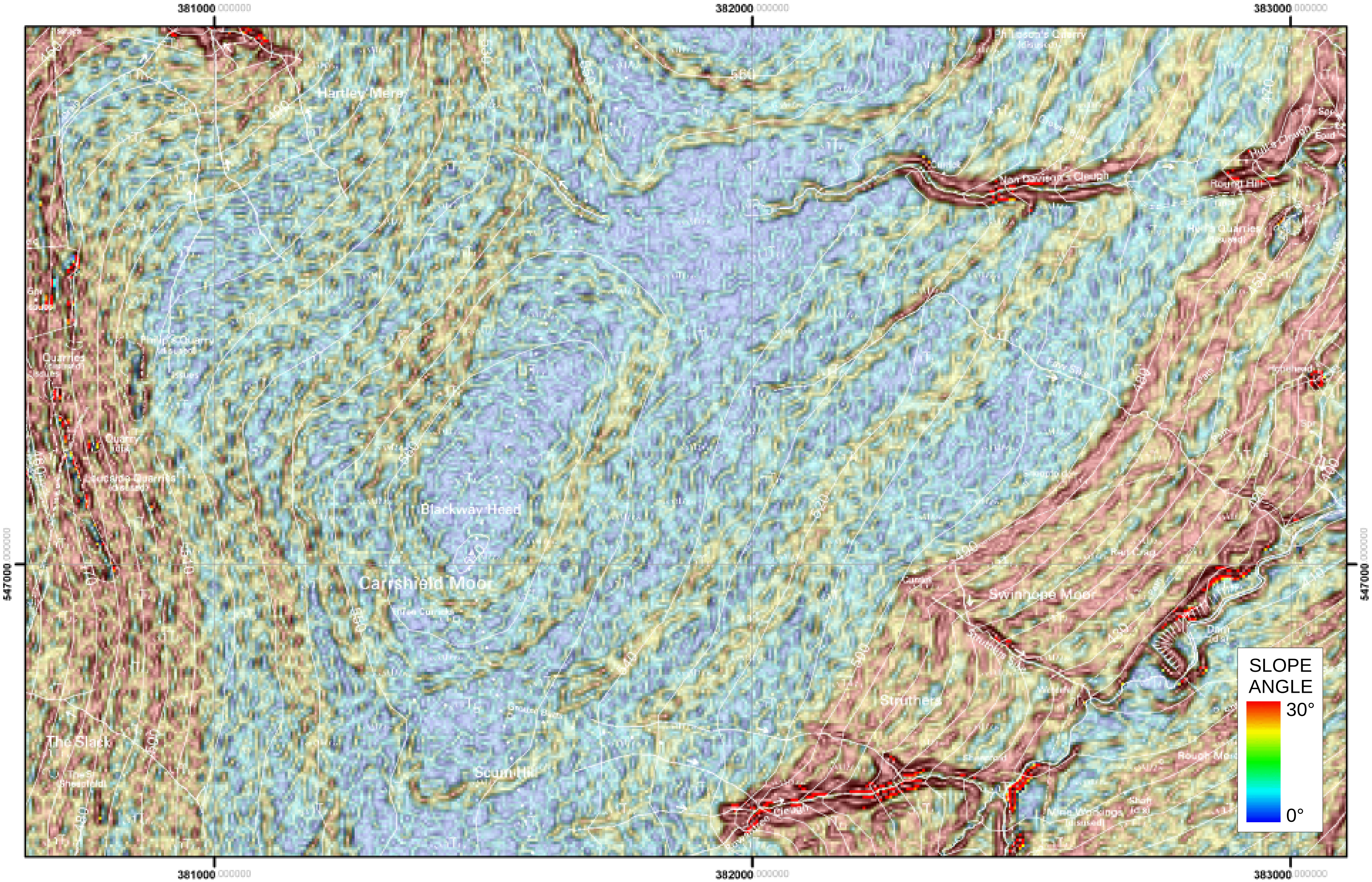


Area 4 - Nent Valley at Nenthall

Geological Field Slip and Slope Analysis Map

Area 5 - Carrshield Moor

Geological Field Slip

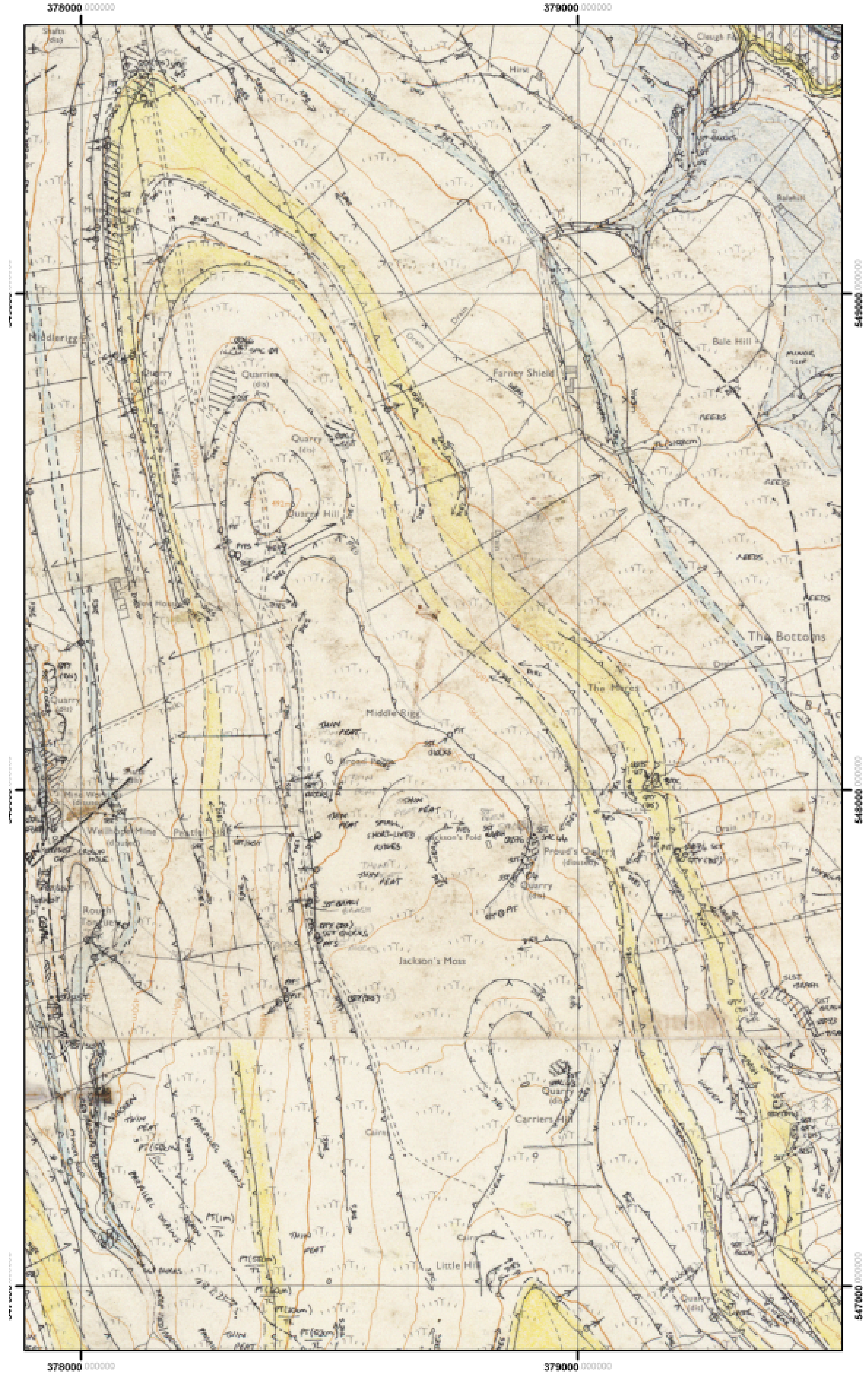


Area 5 - Carrshield Moor

DSM Slope Analysis Map

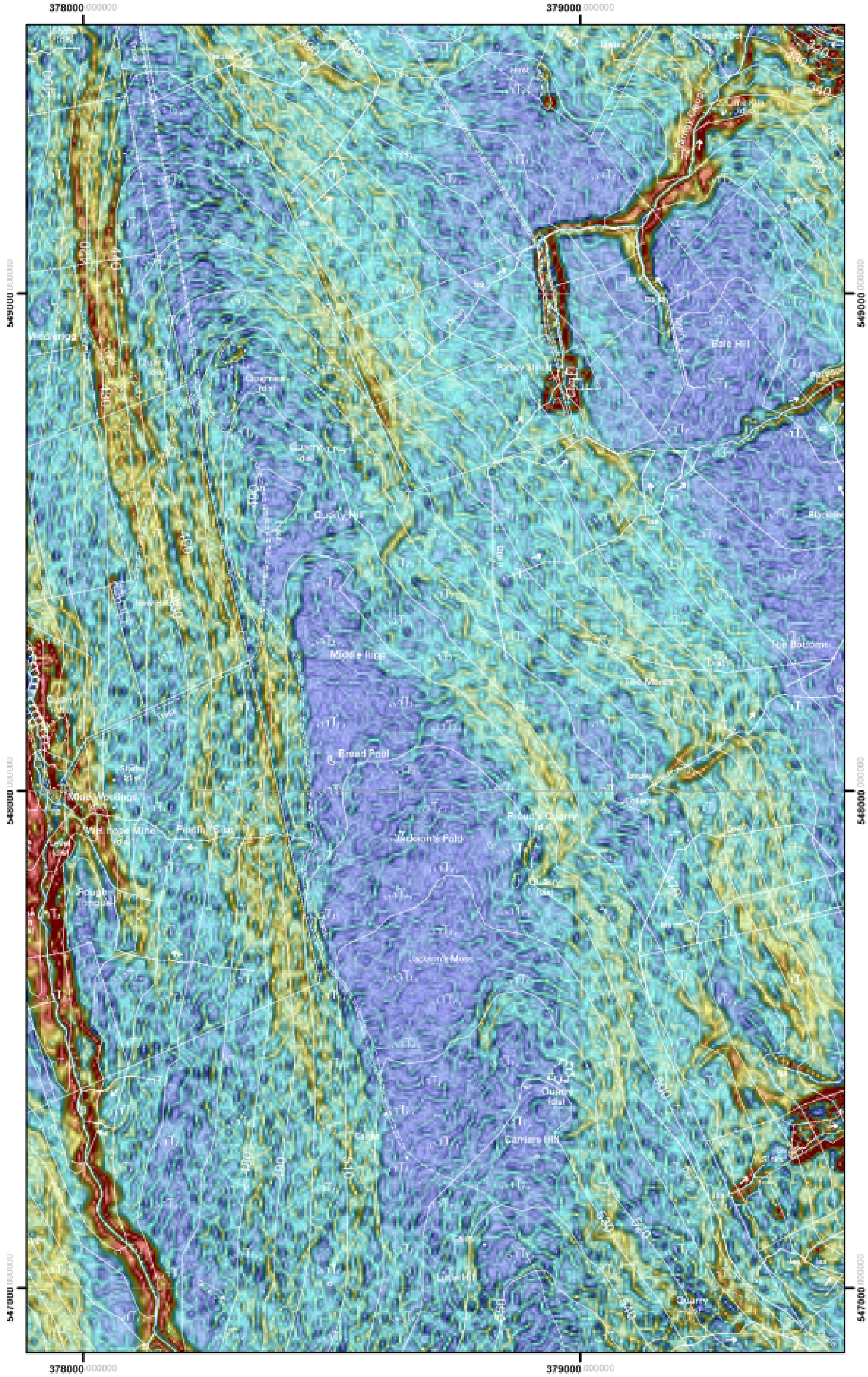
Area 5 - Carrshield Moor

Geological Field Slip and Slope Analysis Map



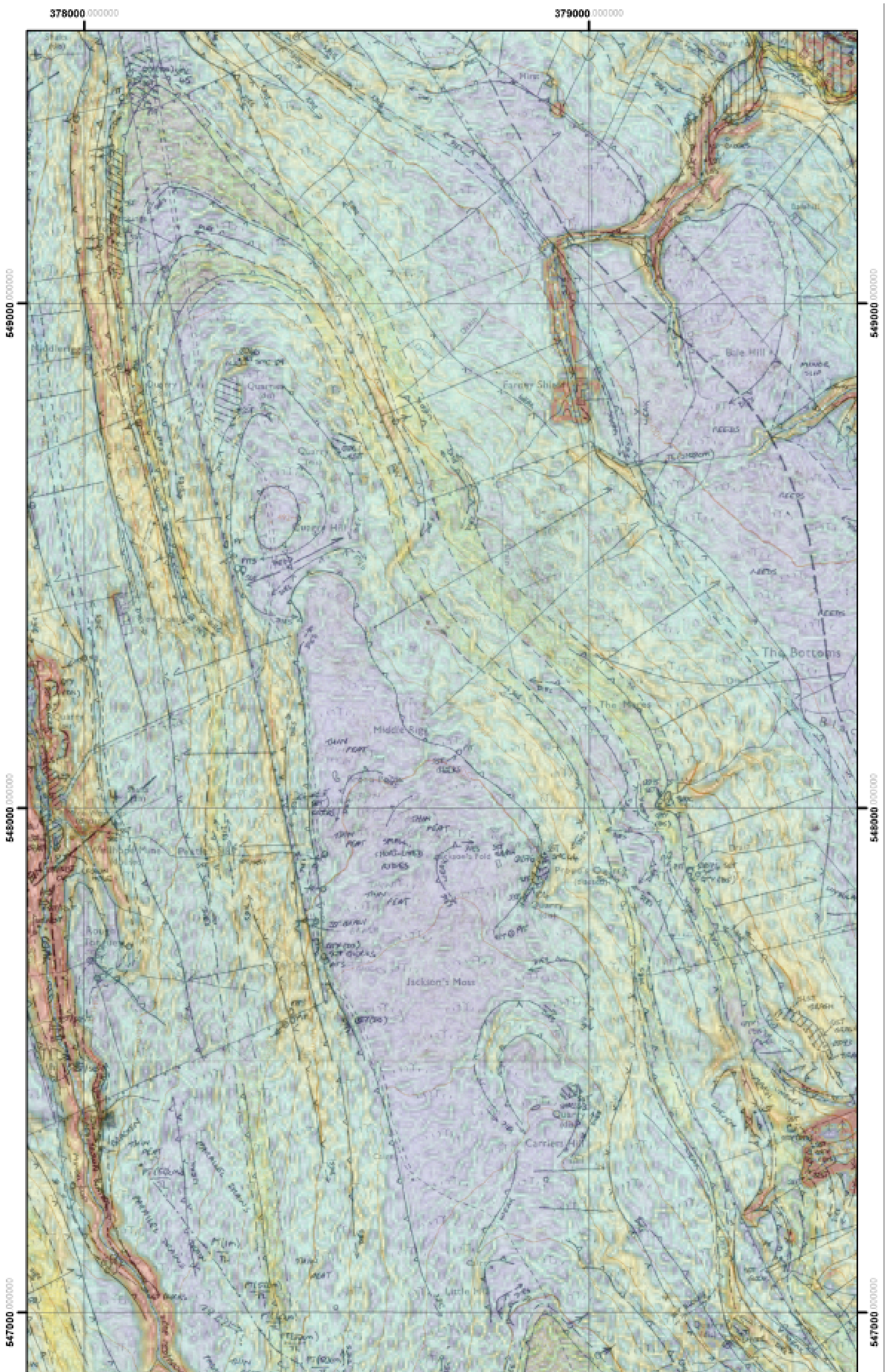
Area 6 - Dodd Hill

Geological Field Slip



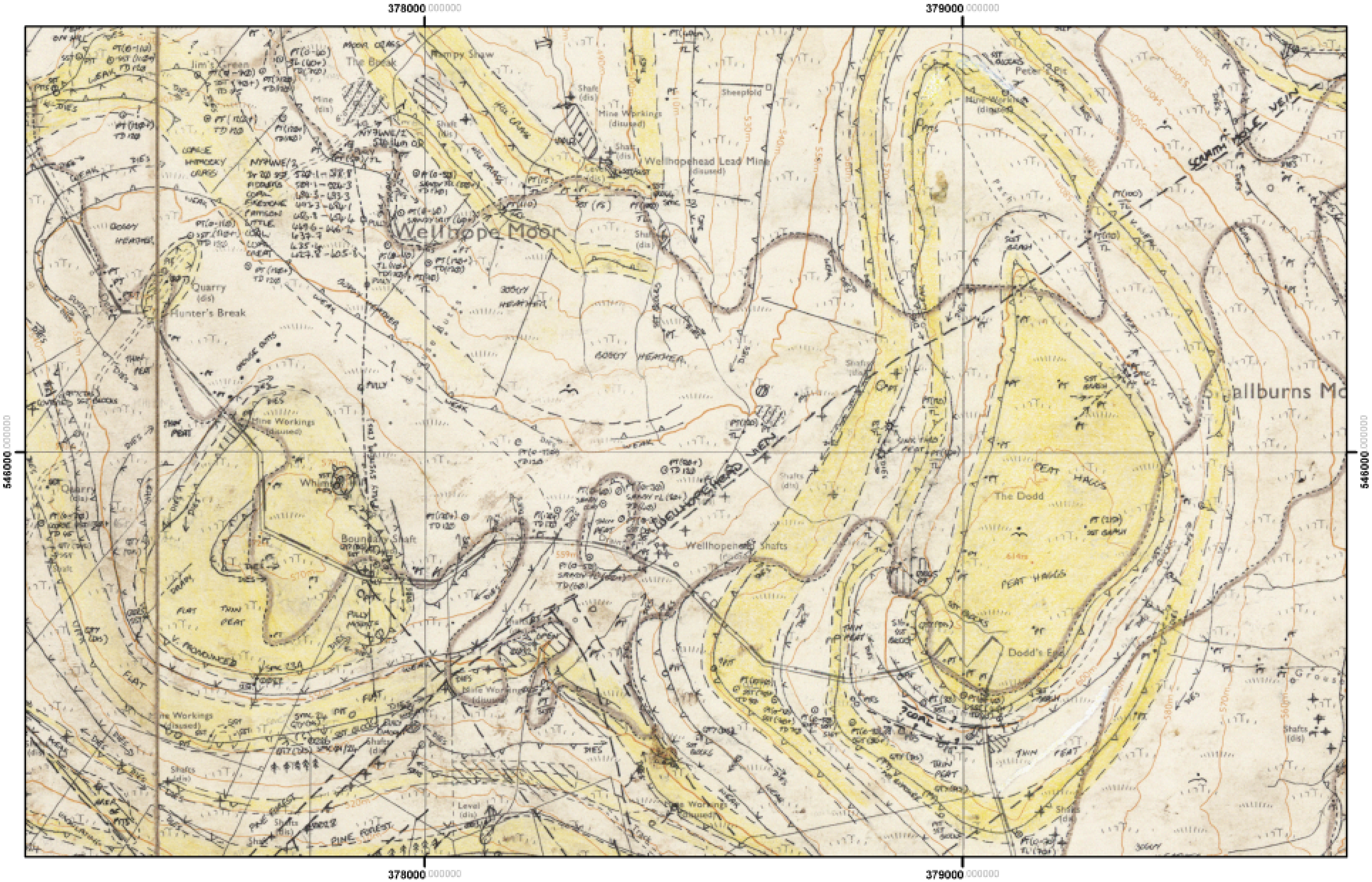
Area 6 - Dodd Hill

DSM Slope Analysis Map



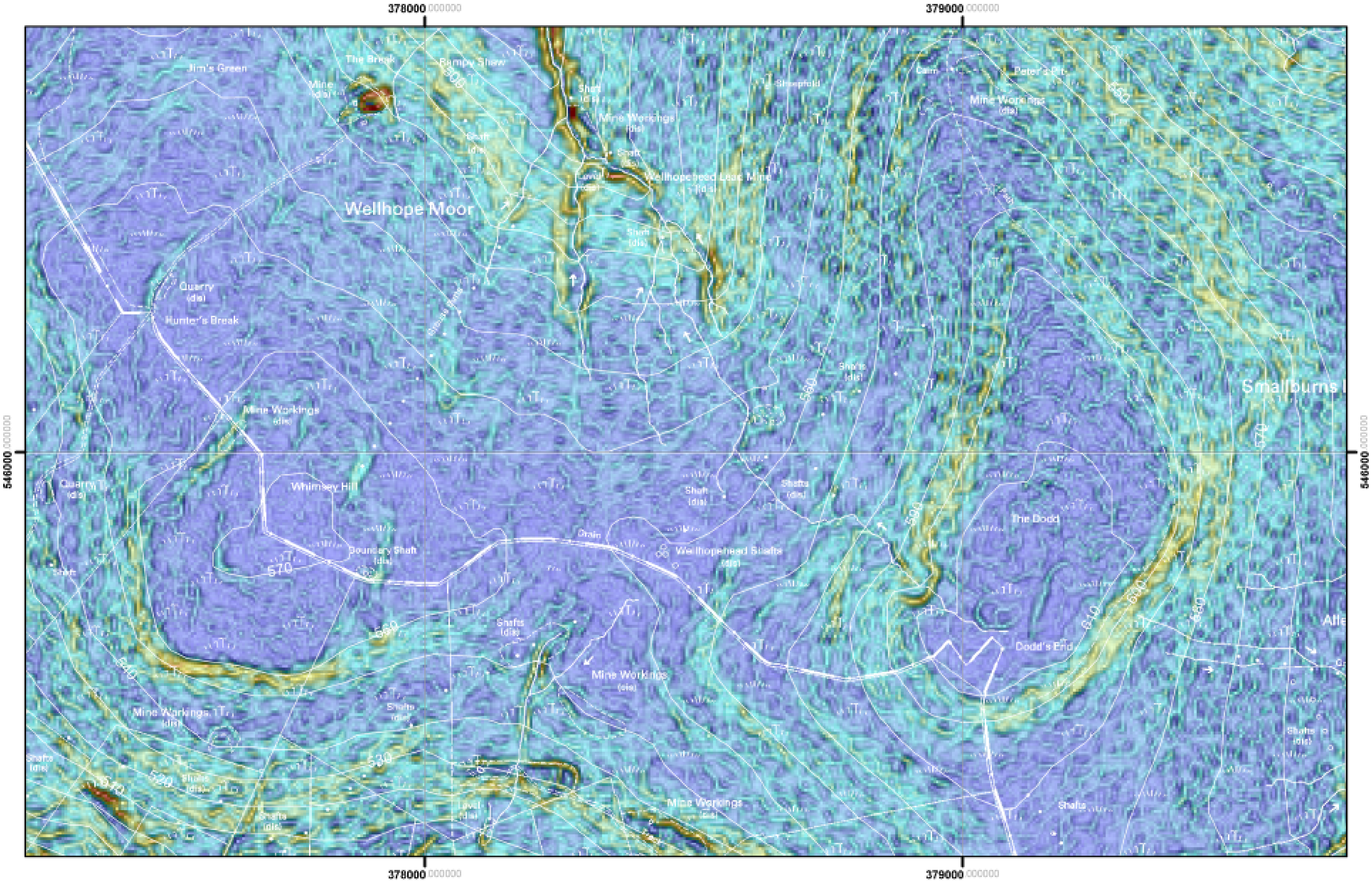
Area 6 - Dodd Hill

Geological Field Slip and Slope Analysis Map



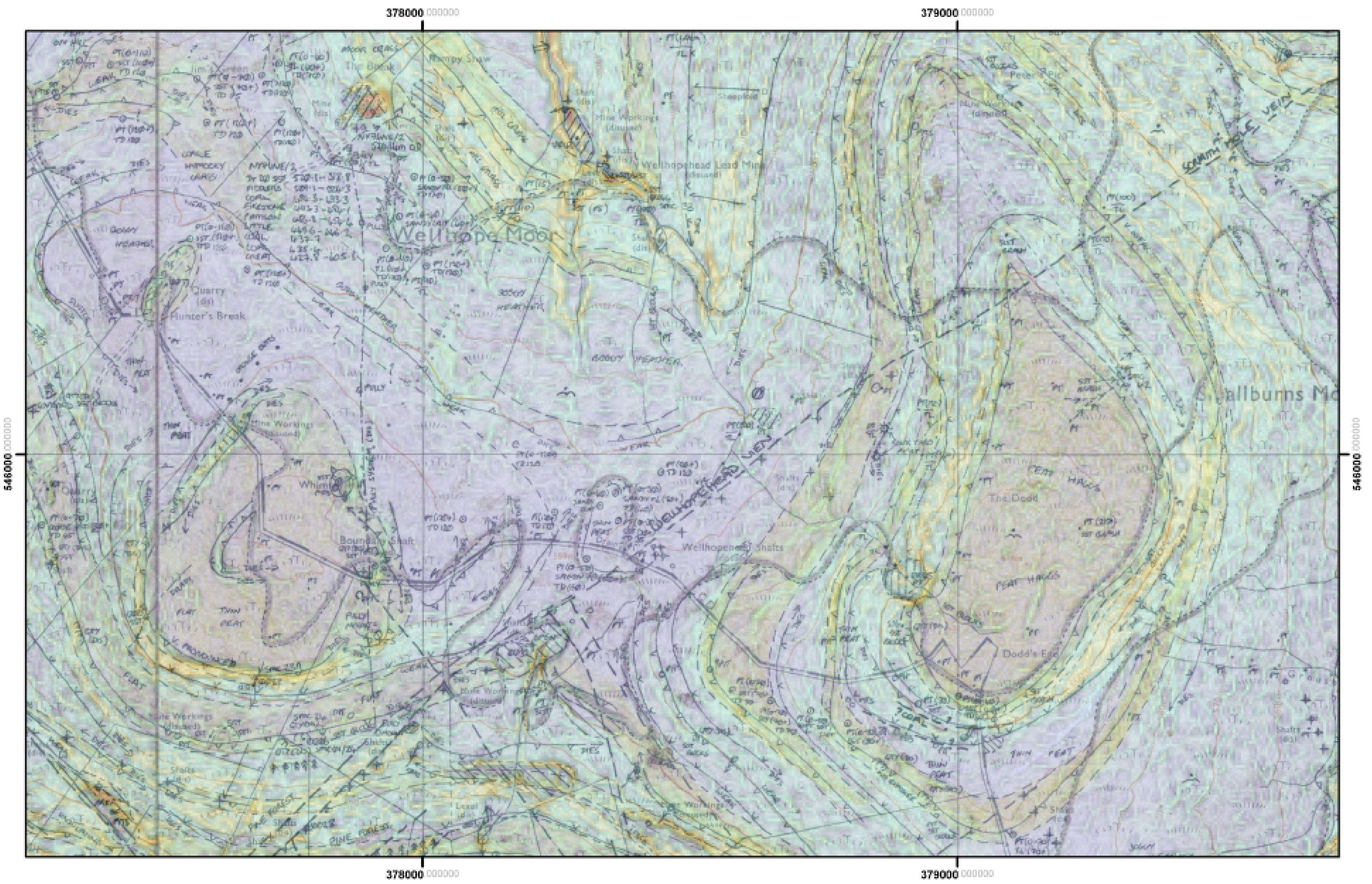
Area 7 - The Dodd and Wellhope Moor

Geological Field Slip



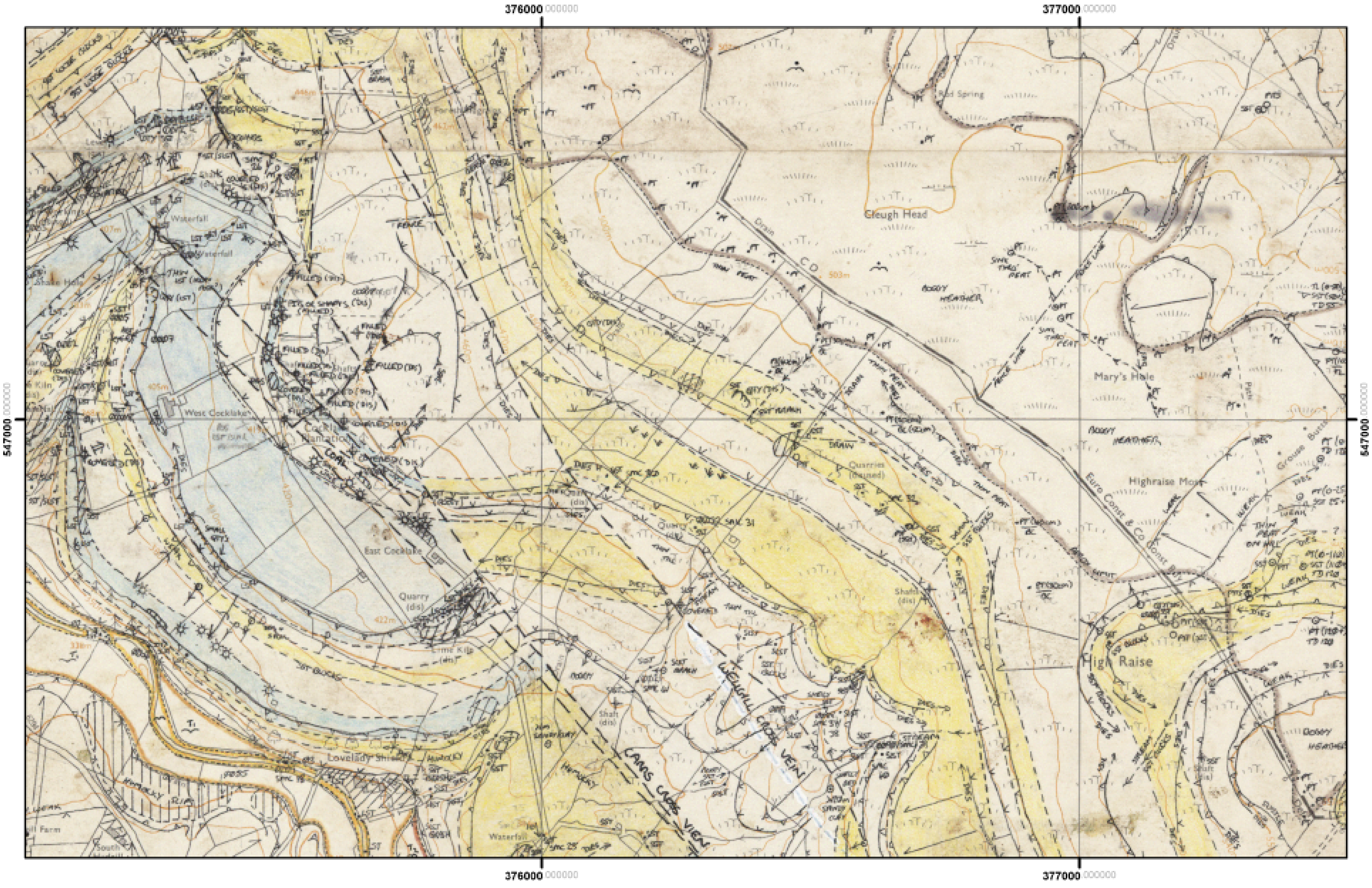
Area 7 - Dodd Hill & Wellhope Moor

DSM Slope Analysis Map



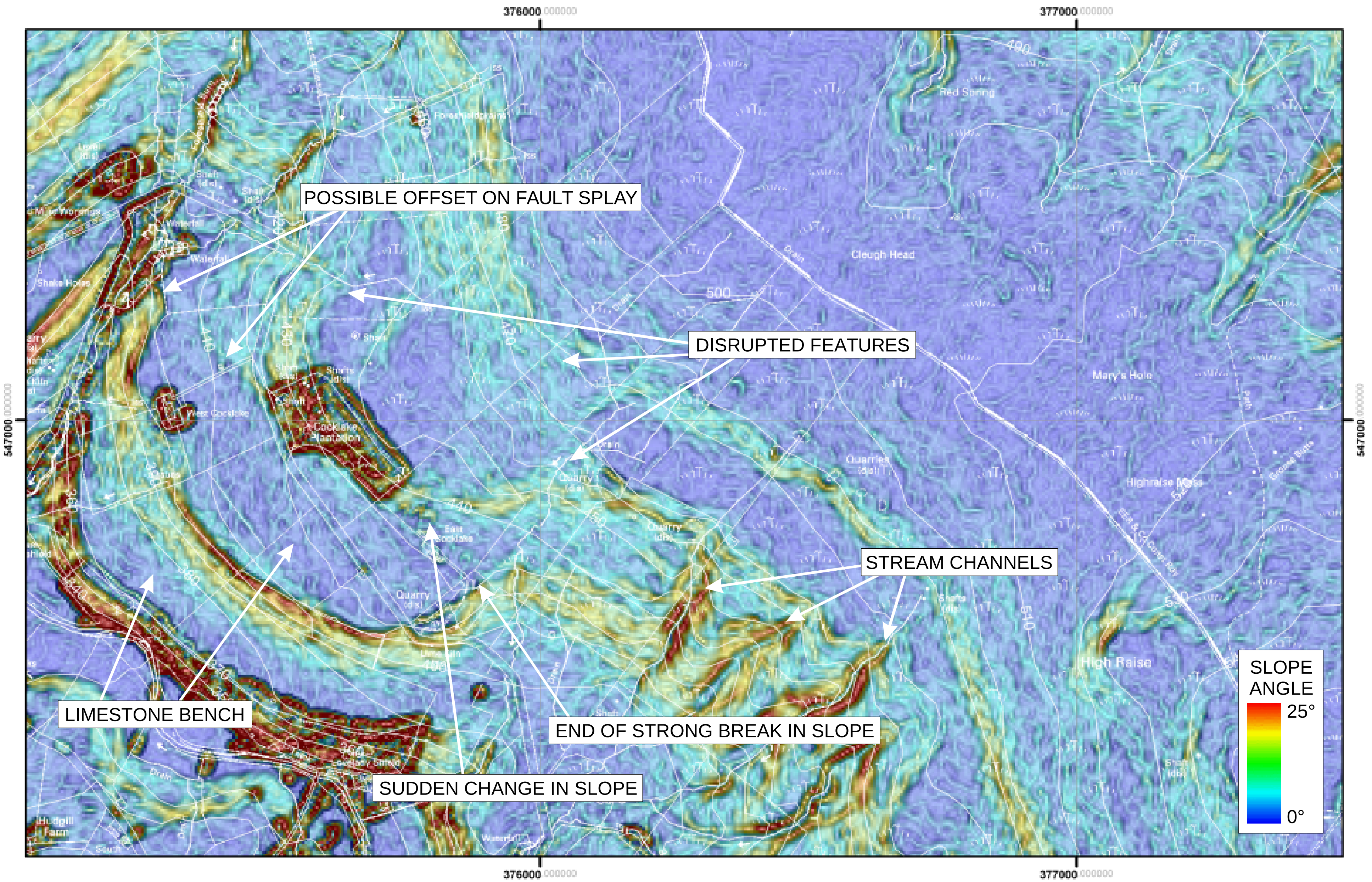
Area 7 - Dodd Hill and Wellhope Moor

Geological Field Slip and Slope Analysis Map



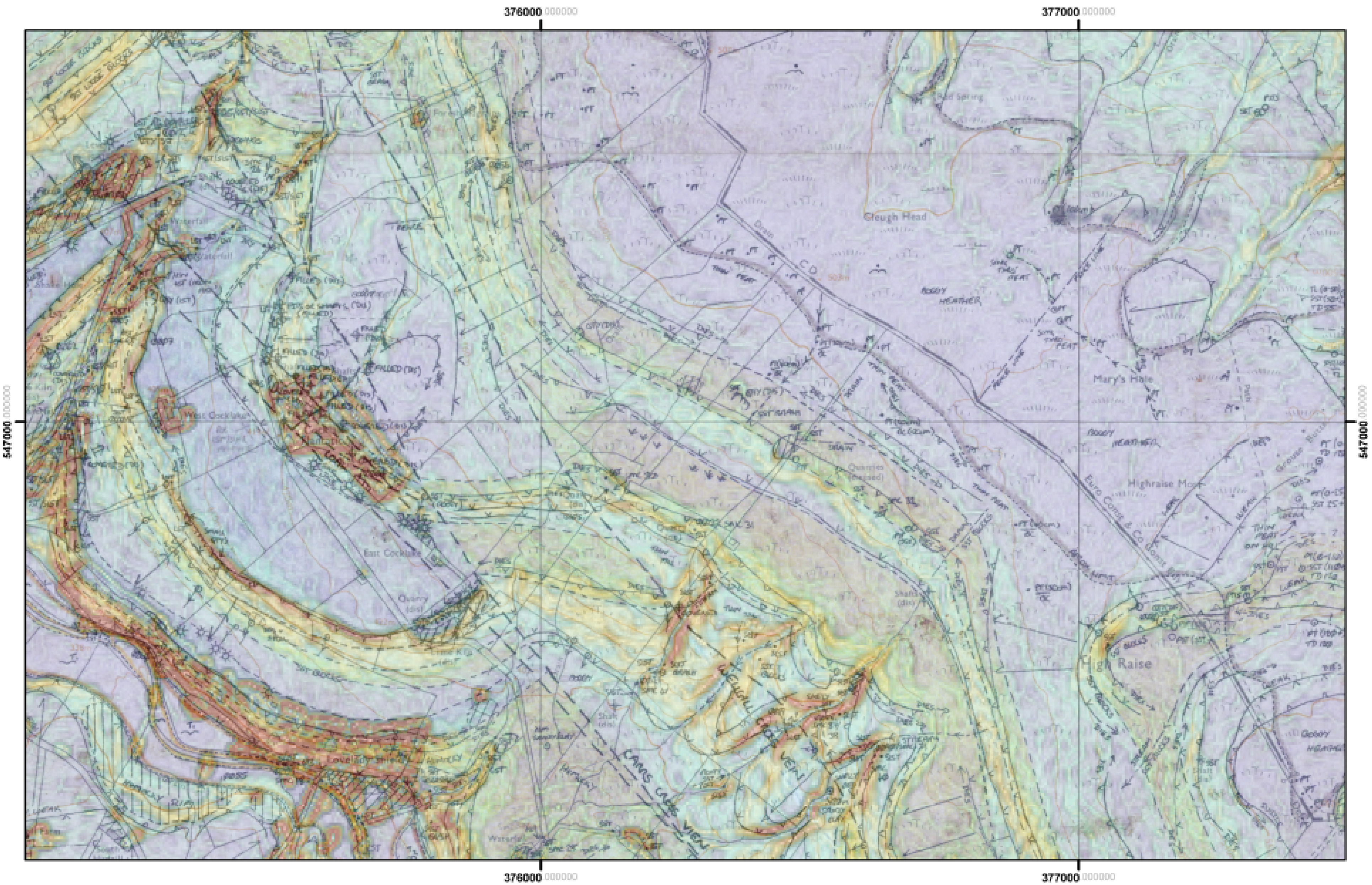
Area 8 - East Cocklake & High Raise

Geological Field Slip



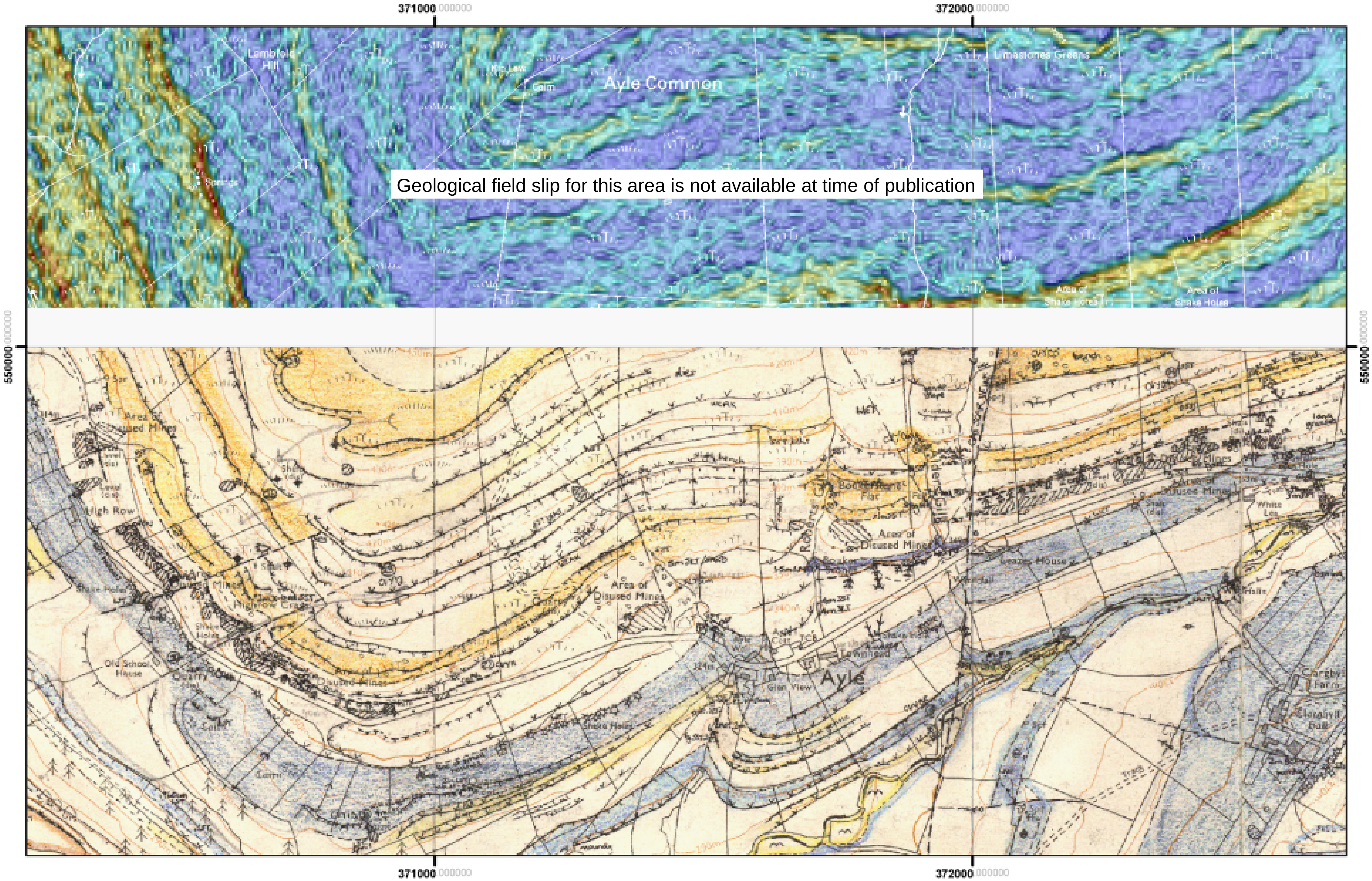
Area 8 - East Cocklake & High Raise

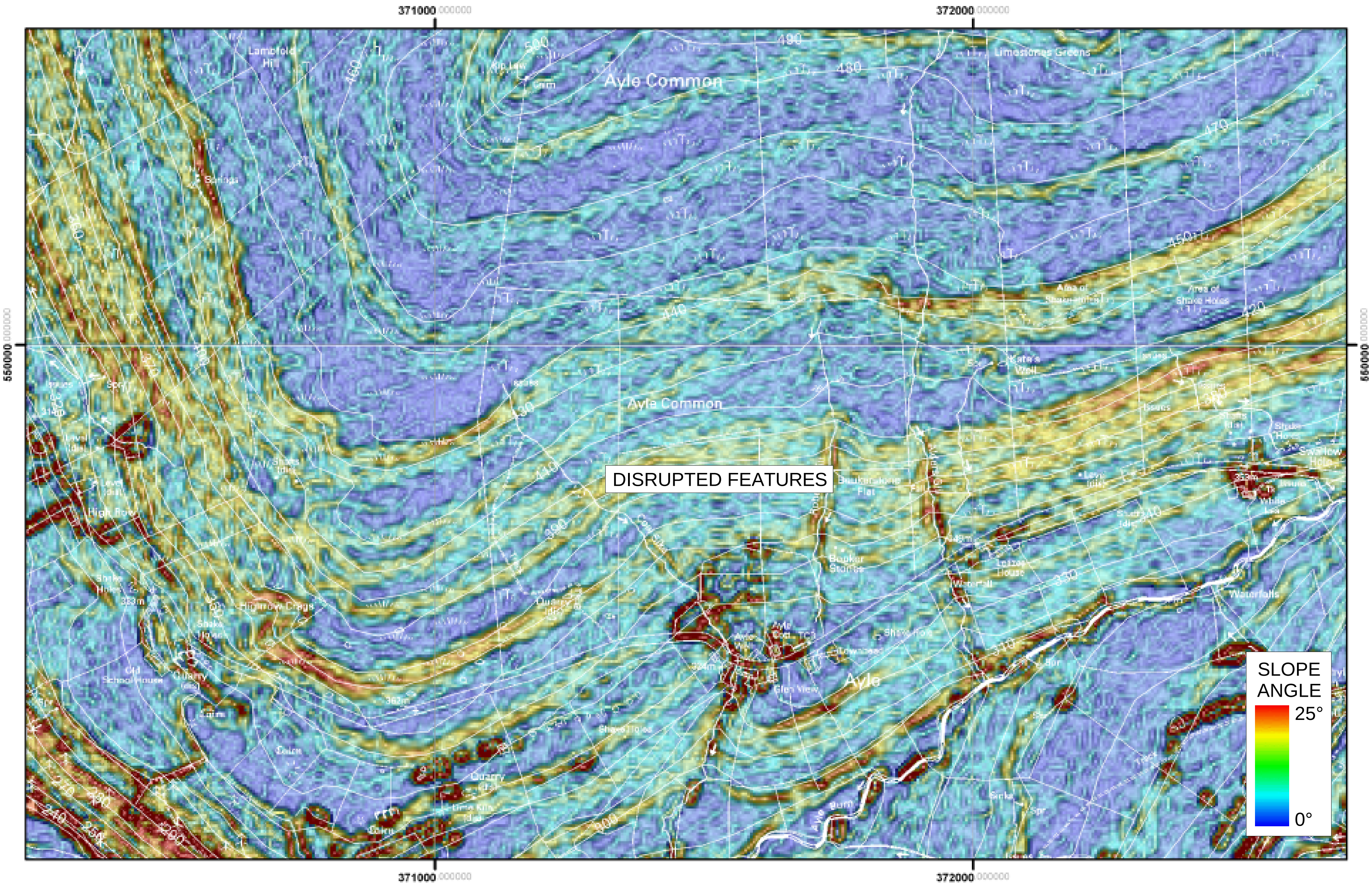
DSM Slope Analysis Map



Area 8 - East Cocklake & High Raise

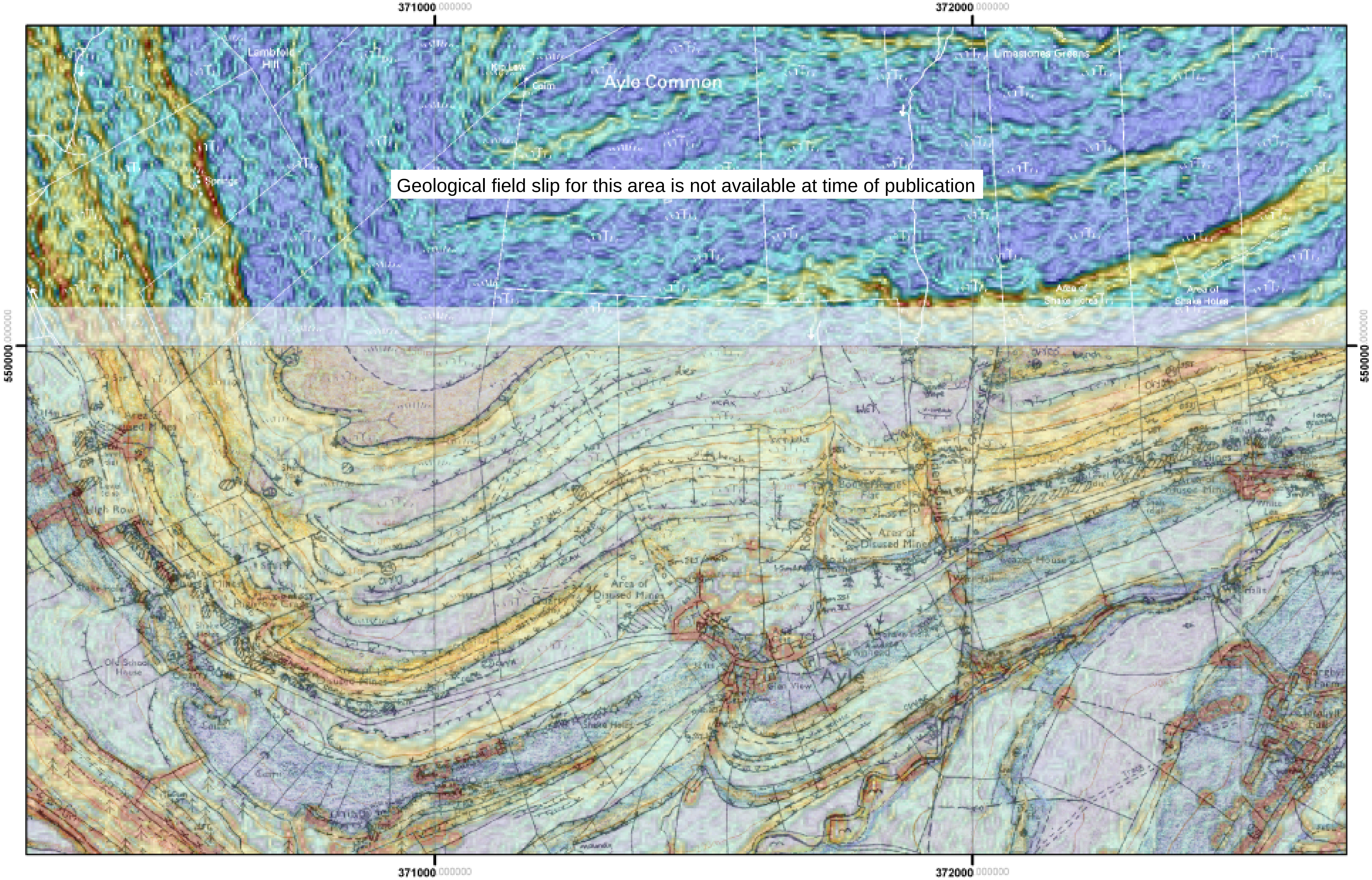
Geological Field Slip and Slope Analysis Map


371000
372000
550000
Ayle Common
Lambfold Hill
Geological field slip for this area is not available at time of publication
High Row
Old School House
Glen View
Ayle
Area of Disused Mines
Shake Holes



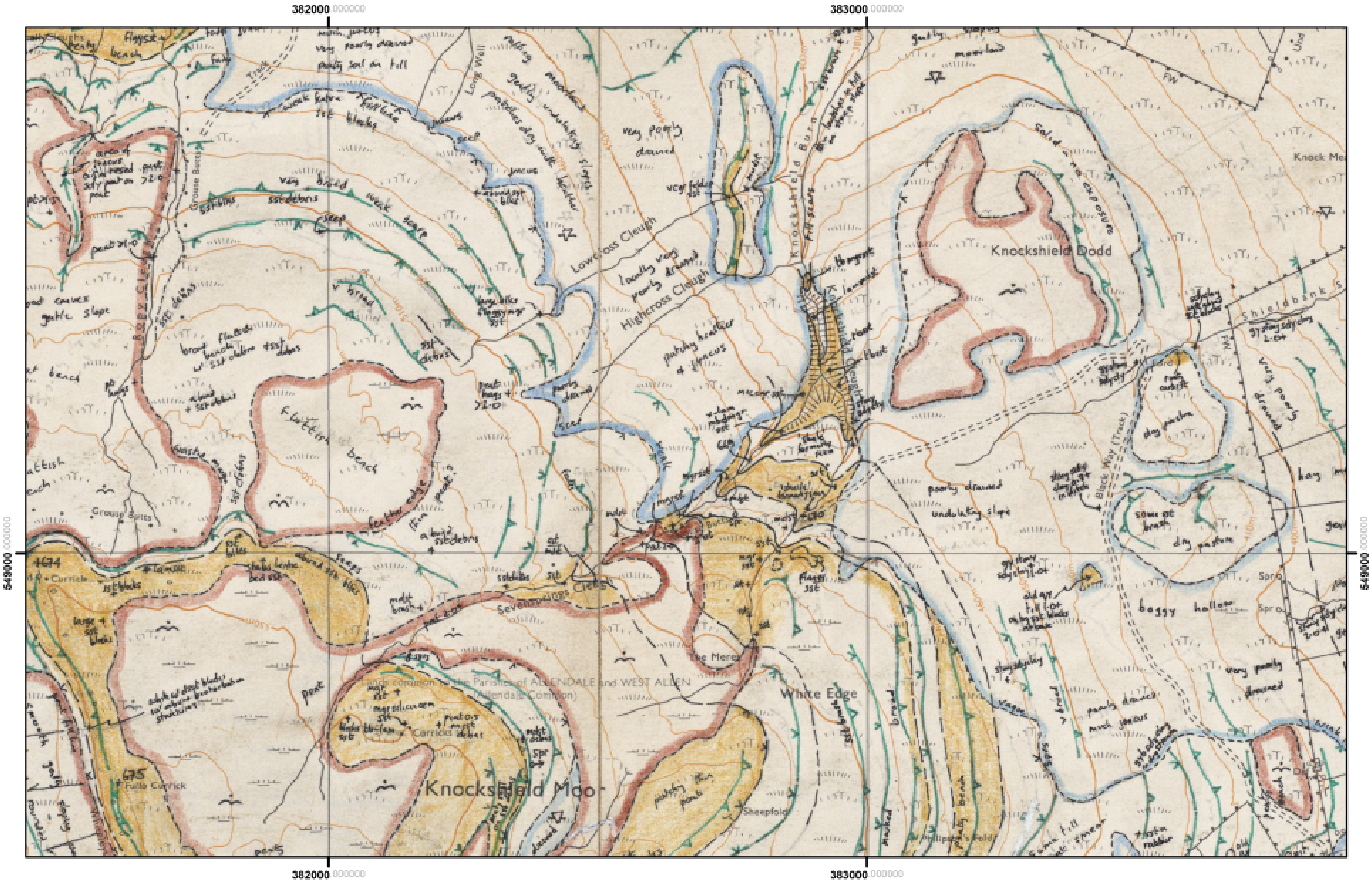
Area 9 - Ayle Common

DSM Slope Analysis Map



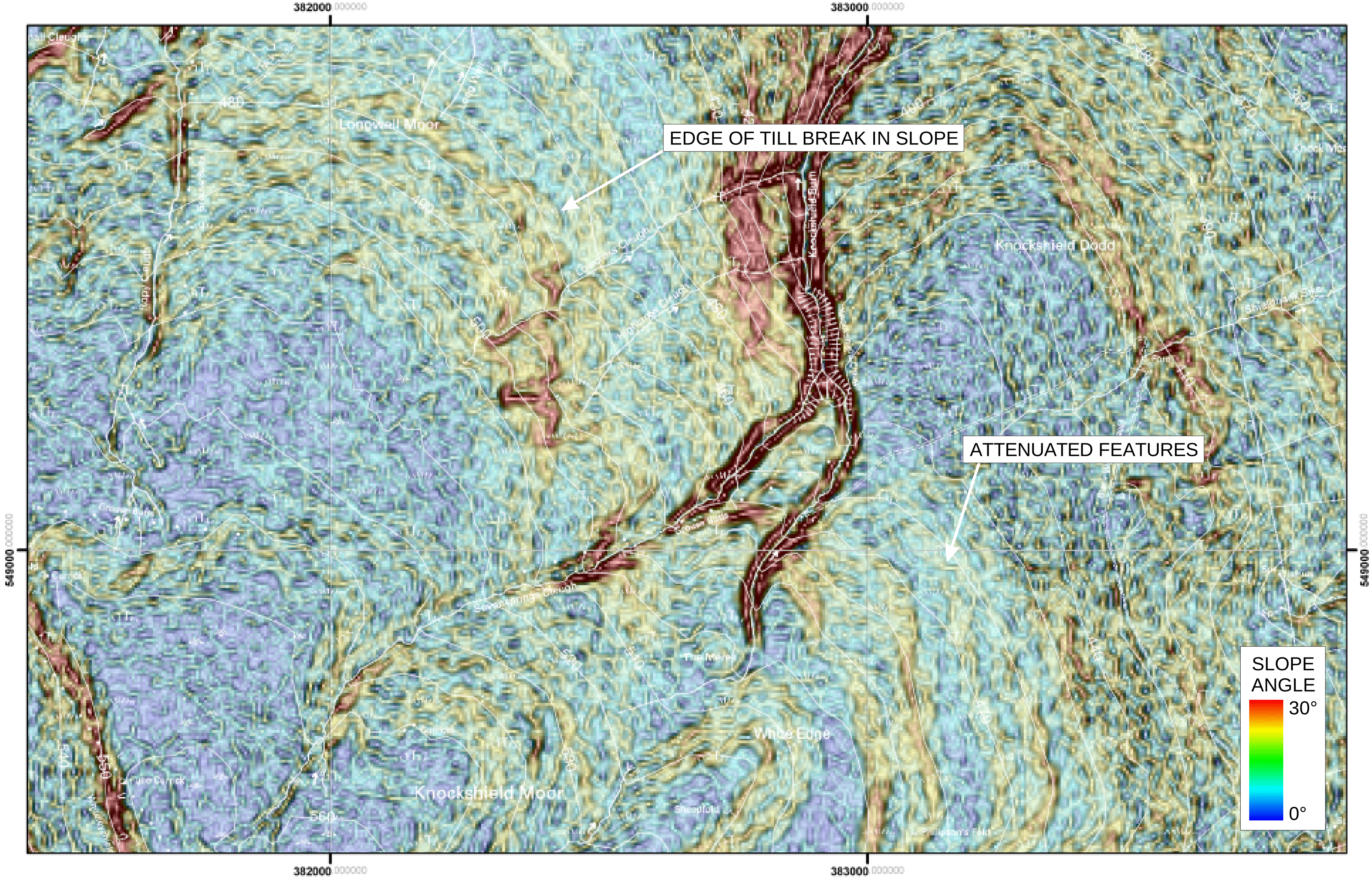
Area 9 - Ayle Common

Geological Field Slip and Slope Analysis Map



Area 10 - Knockshield Moor

Geological Field Slip



Area 10 - Knockshield Moor

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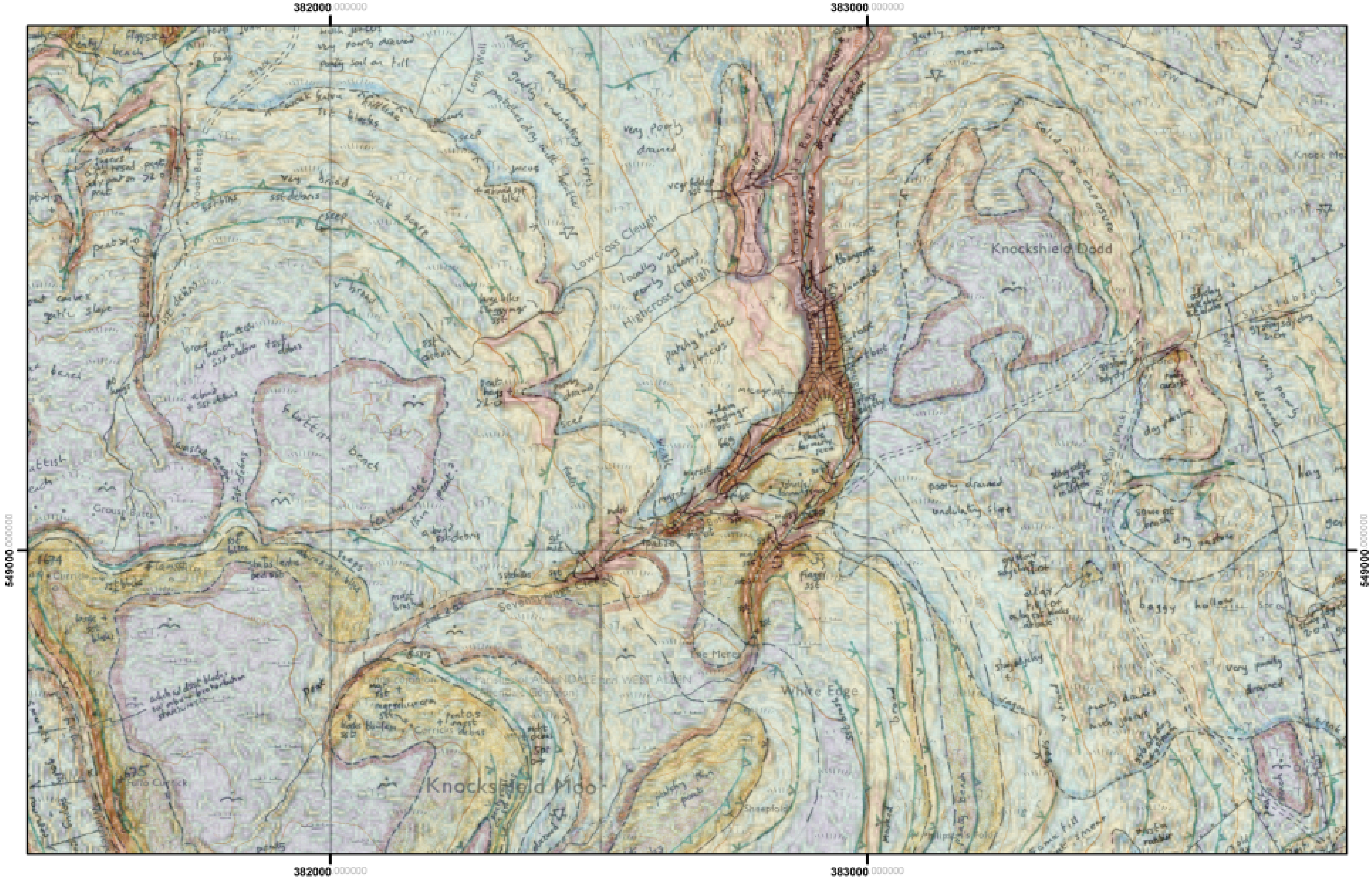

Area 10 - Knockshield Moor

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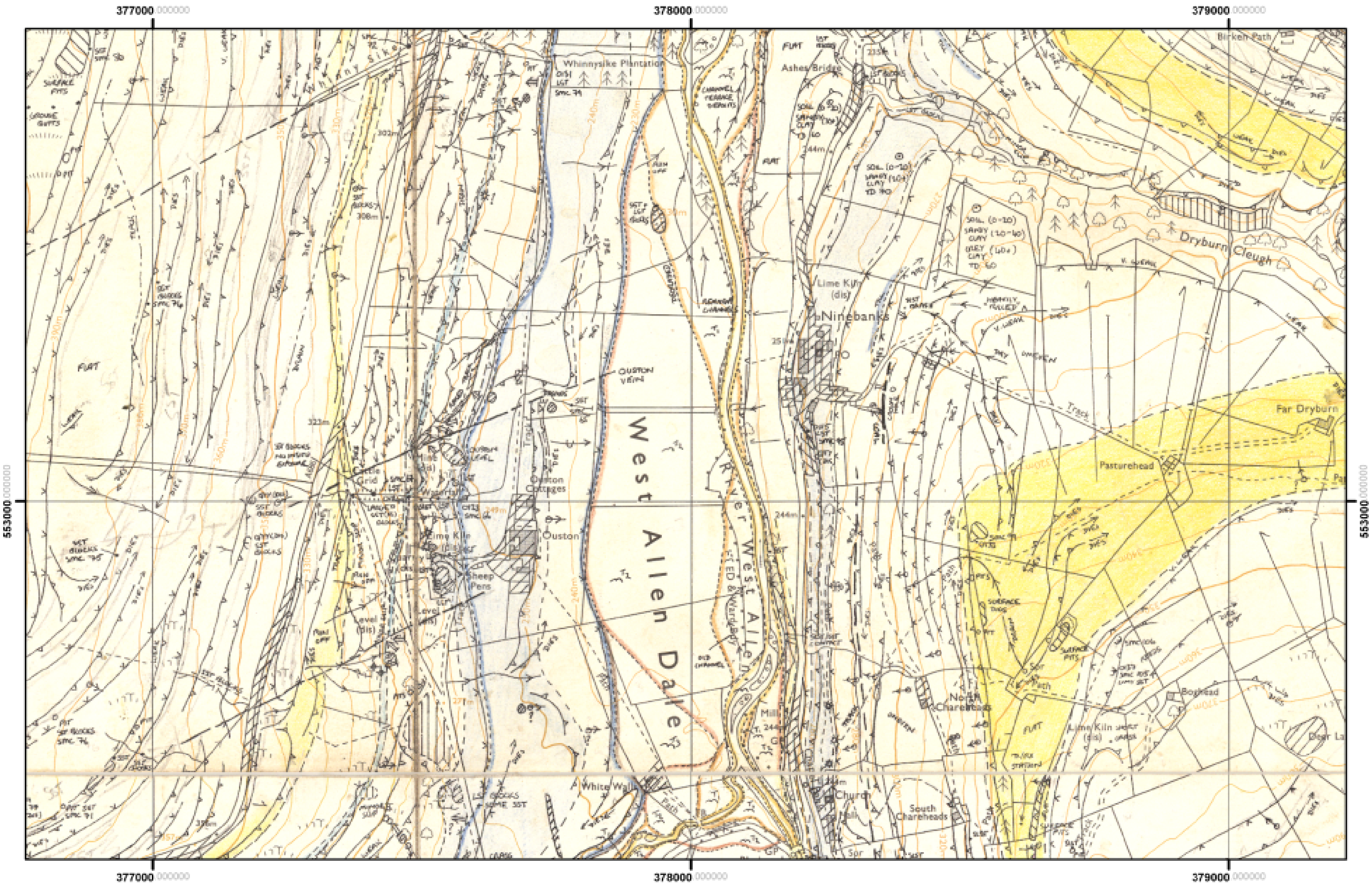
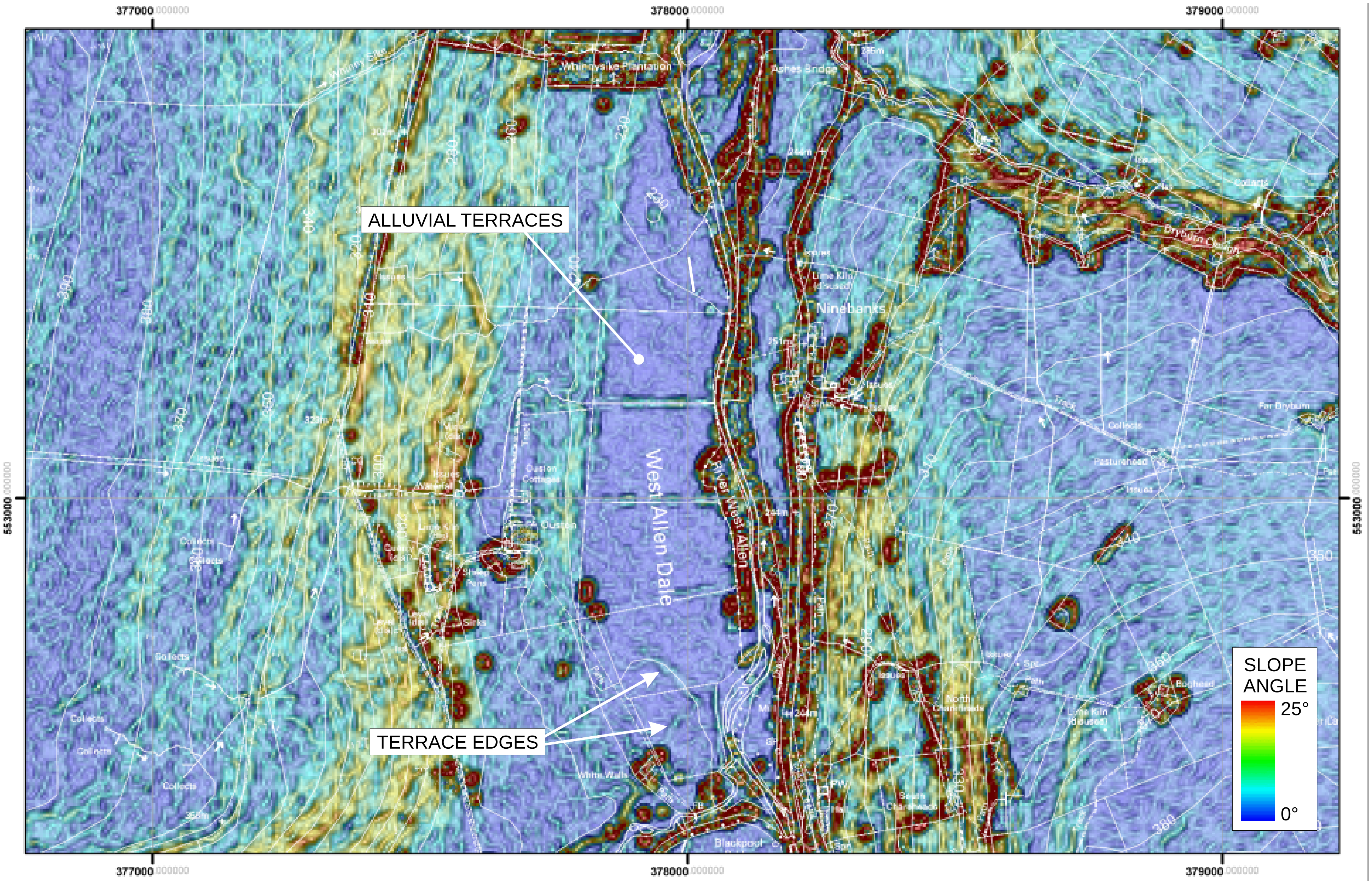


Area 11 - West Allen Valley at Ouston

Geological Field Slip

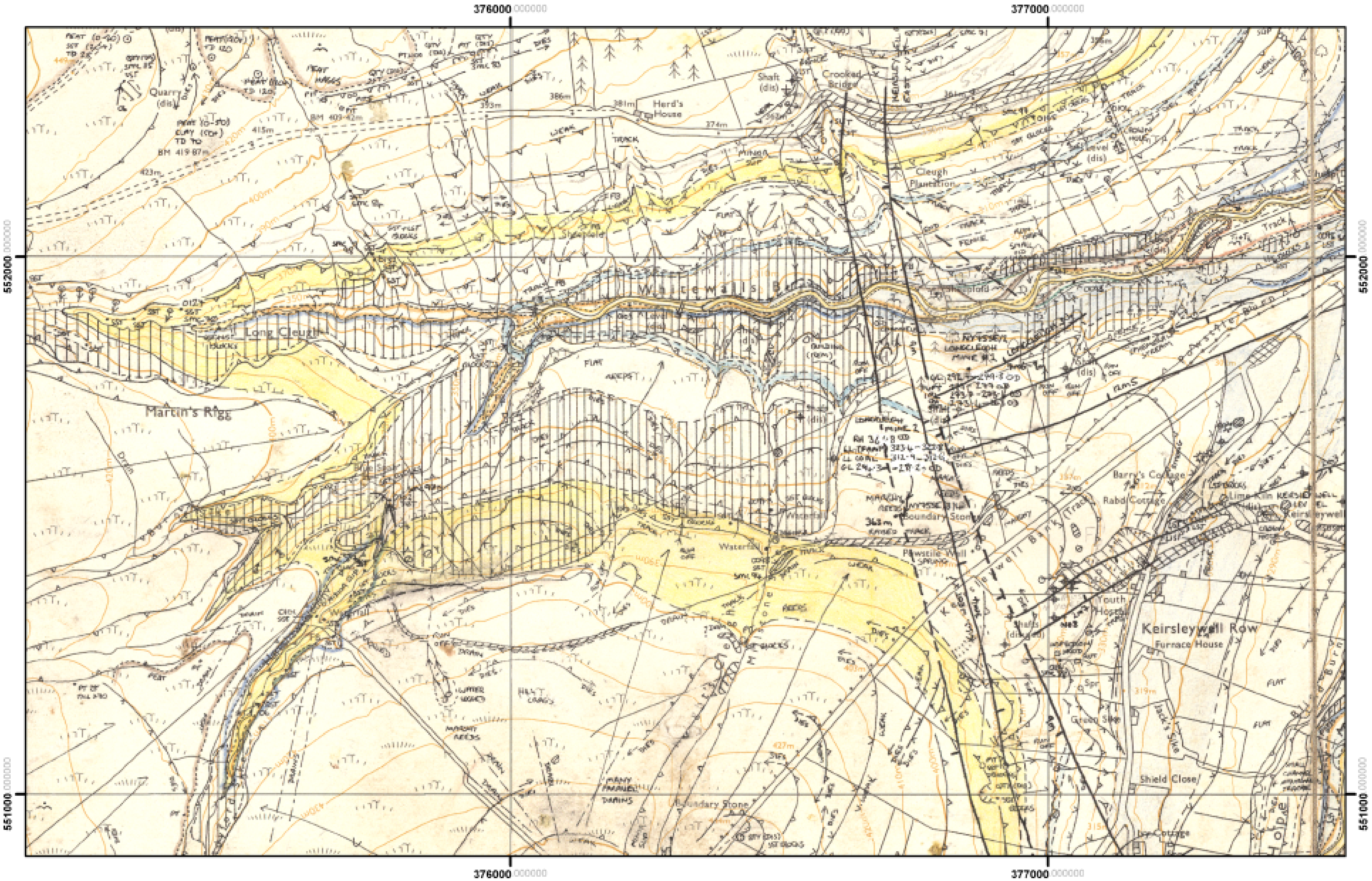


Area 11 - West Allen Valley at Ouston

DSM Slope Analysis Map

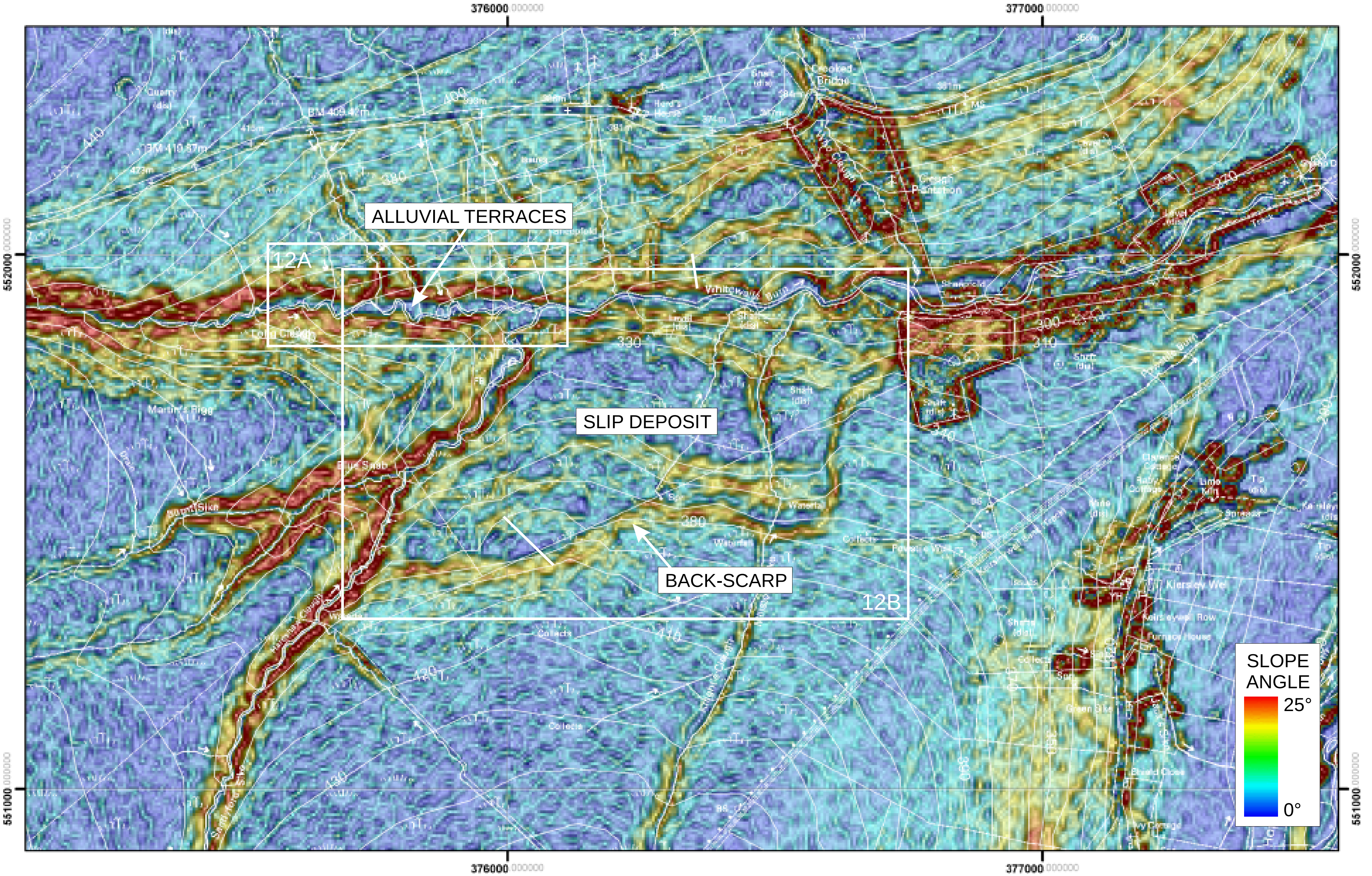
Area 11 - West Allen Valley at Ouston

Geological Field Slip and Slope Analysis Map



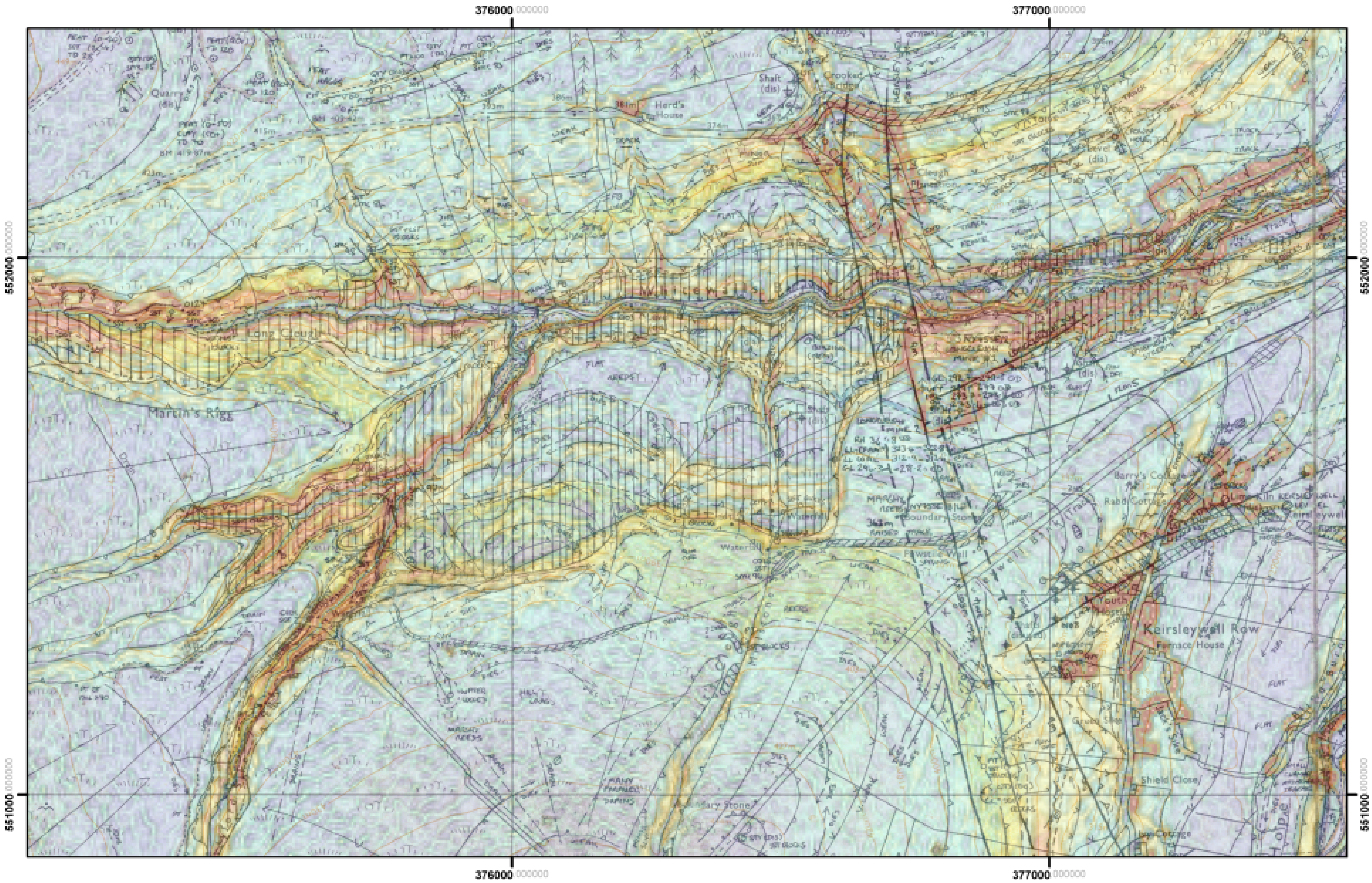
Area 12 - Whitewalls Burn

Geological Field Slip



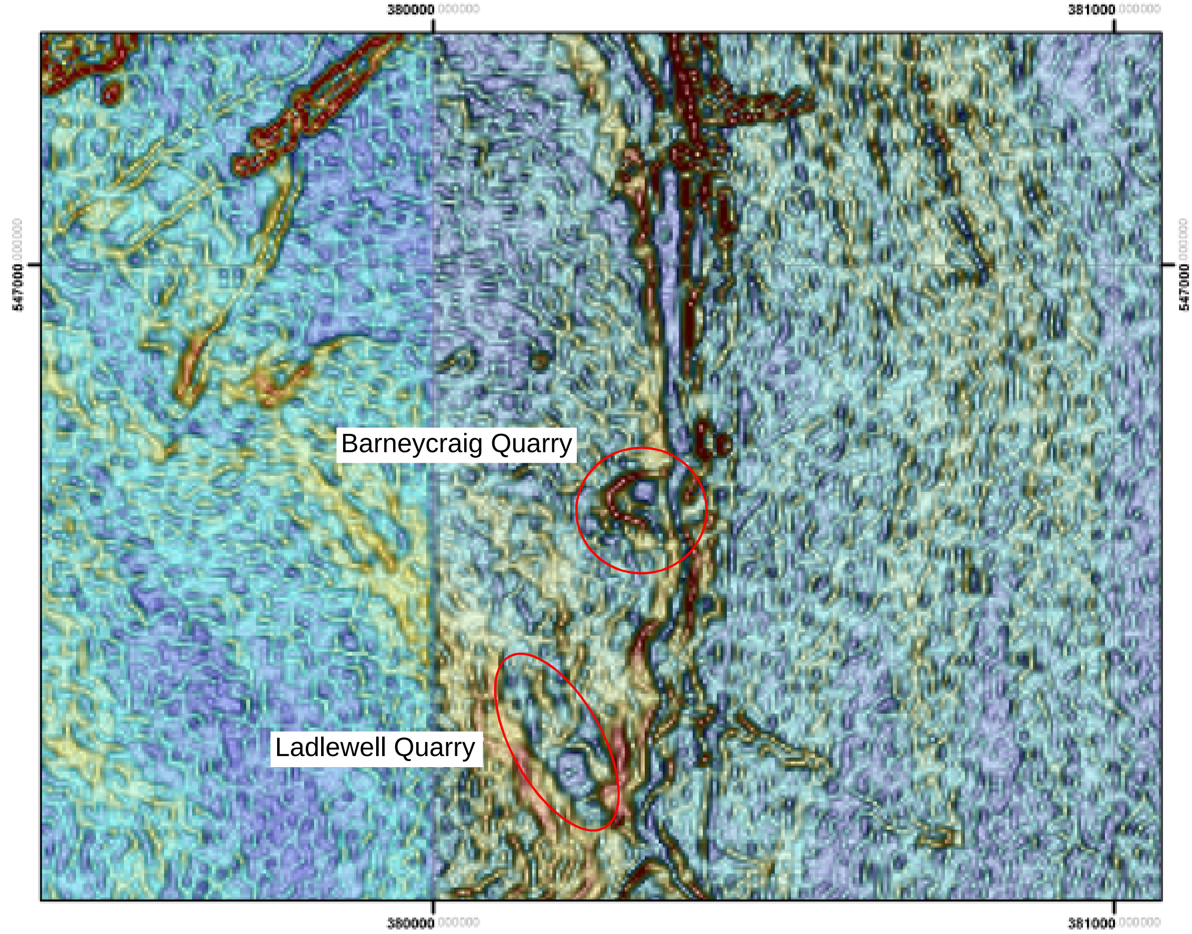
Area 12 Whitewalls Burn

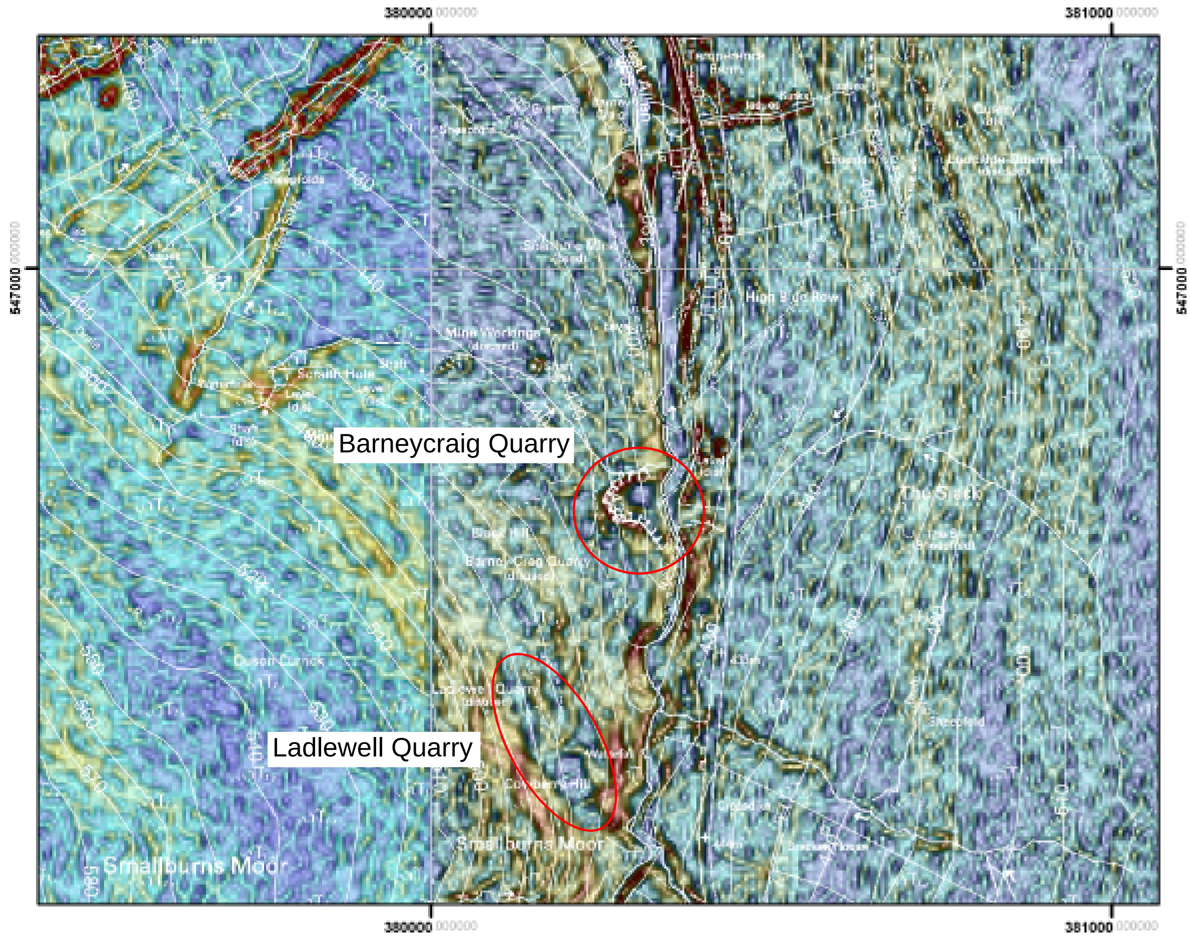
DSM Slope Analysis Map



Area 12 - Whitewalls Burn

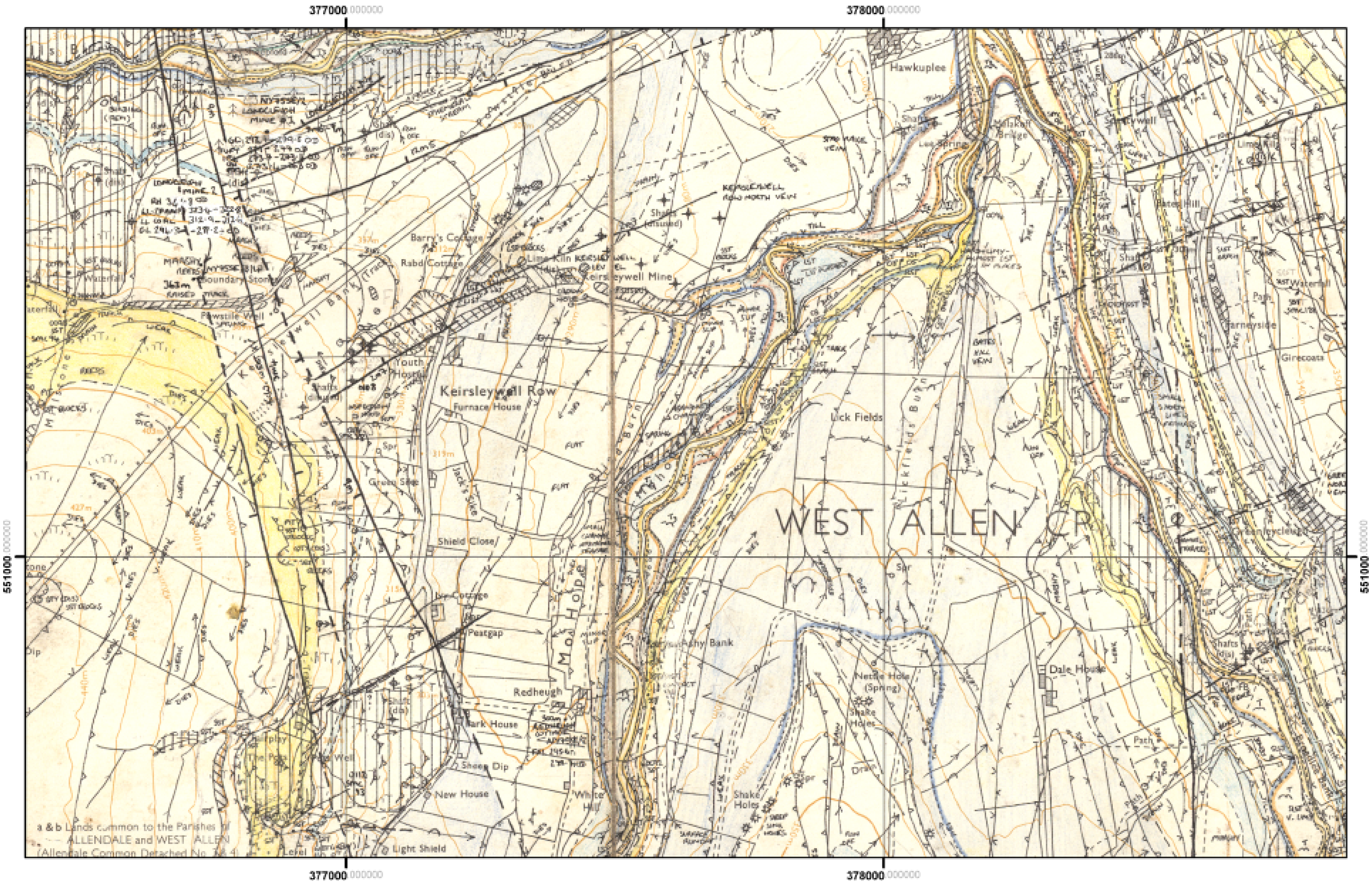
Geological Field Slip and Slope Analysis Map

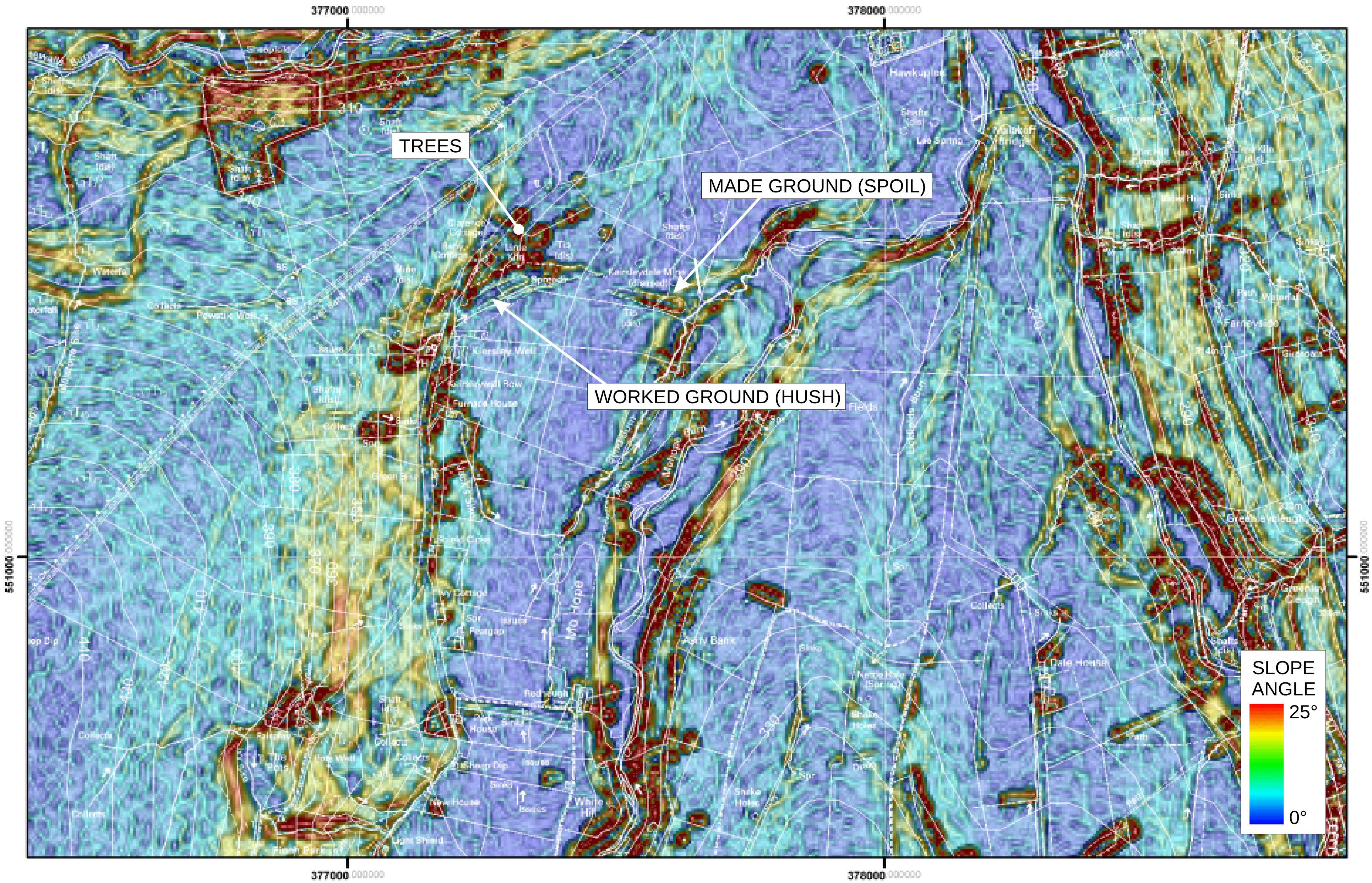




Area 13 - West Allen River at Barneycraig

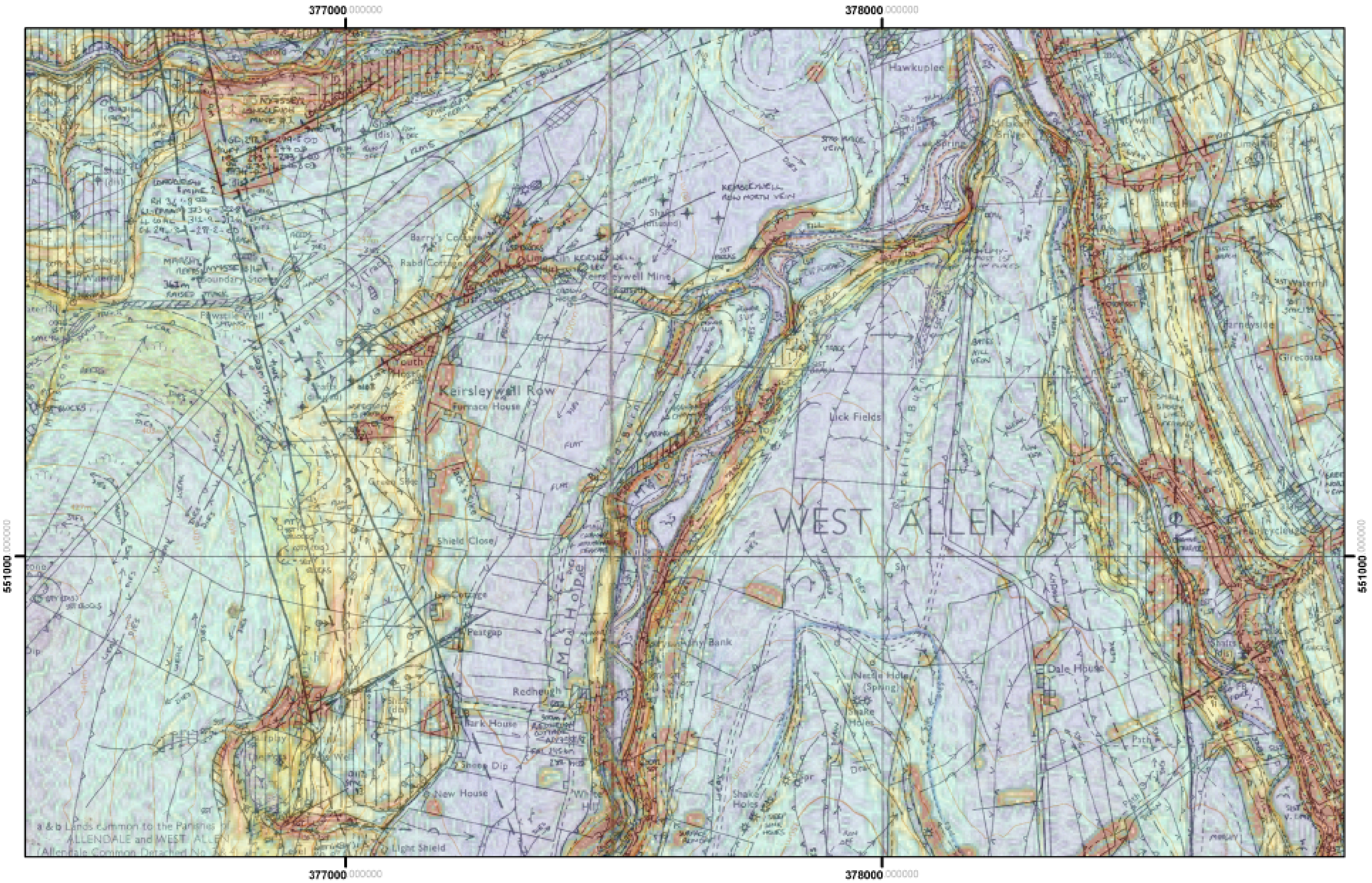
DSM Slope Analysis Map


377000
378000
551000
Hawkuplee
Lee Spring
Lime Kiln
Keirsleywell Mine
Barry's Cottage
Rabd Cottage
Pawstile Well
Boundary Stone
Waterfall
Youth Hostel
Keirsleywell Row
Furnace House
Green Slop
Shield Close
Ivy Cottage
Peatgap
Redheugh
Park House
Sheep Dip
New House
White Hill
Light Shield
Mohope
Lick Fields
WEST ALLEN CP
Nettle Hole (Spring)
Shake Holes
Dale House
Bates Hill
Farneyside
Girecoats
a & b Lands common to the Parishes of
ALLENDALE and WEST ALLEN
(Allendale Common Detached No. 3 & 4)



Area 14 - Kirsleywell Mine, Mohope

DSM Slope Analysis Map



Area 14 - Kirsleywell Mine, Mohope

Geological Field Slip and Slope Analysis Map