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Slope Monitoring at the Glan Ebbw Landslide, Blaina, South Wales: January to April 2016

Engineering Geology & GLW Programme

Internal Report IR/16/015

BRITISH GEOLOGICAL SURVEY

ENGINEERING GEOLOGY & GLW PROGRAMMES

INTERNAL REPORT IR/16/015

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Front cover

Photo of landslide at Glan Ebbw, Blaina, South Wales, taken 4th March 2016 by David Boon.

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Foreword

This report describes survey work carried out at a landslide site in Blaina, West Side, South Wales between January and April 2016. The survey was undertaken and funded by the British Geological Survey (BGS). The aim was to provide Blaenau Gwent Council Environment Department with a survey baseline against which further ground movement monitoring on the slope can be assessed.

Acknowledgements

We would like to thank Mr Fred Howells, the landowner of the affected ground, for his cooperation, and Engineers from the Technical Services Division of Blaenau Gwent CBC (Jessica Palfrey and Clive Rogers) whom initially reported the landslide to BGS and assisted on site during the field work. The authors would also like to thank the following BGS staff for their support: David Schofield (Chief Geologist Wales), Vanessa Banks (Team Leader for Shallow Geohazards and Risks), Rhian Kendall, and Helen Reeves (Director of Engineering Geology at BGS).

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Summary

On 22 December 2015 significant ground movement occurred on the slope at Glan Ebbw, on the west side of the Blaina valley in South Wales, UK [NGR: 319759, 207554]. The ground movement was attributed to reactivation of a dormant landslide system that was triggered by several days of persistent, intense rainfall. The ground movement continued over the following weeks and months. Independent survey and monitoring work undertaken by the British Geological Survey showed clear slope movement in the order of 10s to 100s of mm between 28 January and 4 April 2016. This study has been documented in this report.

The landslide occurred on private farmland and caused damage to a farmer's fencing, loss of grazing land and blockage of pipes and drains on farmland. The large flows of water issuing from the slope caused 'worry' amongst local residents (WalesOnline article, 17:50, 7 January 16: http://www.walesonline.co.uk/news/wales-news/worrying-landslip-sent-mud-rock-10701845), particularly tenants of houses on Glan Ebbw Terrace, which are located immediately down slope of the landslide (see cover photo). In response to the public concern the council immediately started a daily visual inspection of the slope to monitor the situation and this activity continued through December 2015 and January 2016.

The landslide was reported to the British Geological Survey (BGS) on 6 January 2016 by officers from Blaenau Gwent Council Technical Services Division (BGCBC) and, in response, the BGS provided immediate technical support in the form of practical assistance in setting up a ground monitoring system to enable collection of reliable monitoring data. The event was also added to the National Landslides Database (ID 20064). On 28 January 2016 two BGS engineering geologists carried out a Terrestrial Laser Scan (TLS) survey of the affected slope and installed seven ground pins to enable quantitative monitoring of deformation. Two repeat GPS surveys of the pin locations were carried out on 4th March and 8th April 2016. This report details the survey methods and presents the results of these surveys.

By 8 April 2016 the active landslide covered an area of approximately 1.6 ha, and was approximately 75 m wide and 300 m long, with a 600 m long perimeter. The landslide is classified as a secondary reactivation of an ancient, deep-seated complex landslide. It has developed on an east-facing 23 degree slope, a glacial valley carved in Carboniferous Coal Measures rocks.

The landslide was most likely triggered by prolonged intense rainfall. Antecedent rainfall conditions and high groundwater levels were also likely to be important contributory factors that led to the failure. There is a well known and documented history of ground instability in the South Wales Coalfield valleys associated with ancient and modern landslides and coal mining related slope instability (Conway et al 1980, and Jones & Siddle, 2000) and this slope has one of several intermittently active landslides that occur in the valley.

The reported landslide occurred within the boundary of a larger, pre-existing complex landslide that probably originally occurred following de-glaciation of the area during the Late Devensian ice age. The original landslide affected most of the hill slope and extended down as far as the gardens of the houses on Glan Ebbw Terrace.

The baseline survey was carried out soon after the new landslide first initiated and monitoring covers the subsequent three month period. The data collected and documented in this report provides high-quality ground reference data for comparison with any future movement studies.

1 Introduction

1.1 BACKGROUND

On 22 December 2015, Blaenau Gwent County Borough Council (BGCBC) were alerted to a landslide at West Side, Blaina. In response, the council started daily inspections which continued over the 2015 Christmas period. On 11 January 2016 Jessica Palfrey (Engineer BGCBC) reported the landslide to the BGS through the BGS web-pages with an exchange of photographs, of the landslide, e.g. Figure 1. After inspection of the photographs a BGS Engineering Geologist (David Boon) visited the site on 21st January 2015 and met with the landowner/farmer. At this point the landowner had been formally advised by the Council to commission a geotechnical inspection of the landslide by an independent geotechnical or engineering consultant.

The hazard posed to the houses and residents below the landslide was acknowledged early on by BGS who launched a responsive visit with approval from the Council and land owner. The response evolved to three visits to the site. The first survey on 28 January 2015 was led by David Boon who was accompanied by BGS Engineering Geologist Ashley Patton, and council engineer Jessica Palfrey. The primary objective was to make a reconnaissance of the site to provide information for entry into the BGS National Landslide Database. A second objective was to set up a baseline survey (Survey 1; Section 3.1). This included the installation of a network of ground pins for slope monitoring purposes, dGPS surveys of those pins and other features, photography, and a TLS survey of the slope to provide a high-accuracy baseline survey data set and digital elevation model (DEM) for the wider slope.

On 4 March 2016 the BGS and BGCBC engineers carried out a second visit (Survey 2; Section 3.2) to resurvey the ground pins. A comparison of survey data collected in January and March confirmed that significant ground movement had taken place on the slope within that period. The third and final site visit on 8 April 2016 (Survey 3; Section 3.3) involved a dGPS survey of the monitoring pins and surface features to form a baseline survey for the site.

Figure 1 Photograph of landslide-affected slope taken on 23 December 2015, shortly after the initial movement took place. Note the accumulation of saturated landslide debris forming debris cones (wet clayey sand) over the flat area, which is the toe of an ancient landslide. Note how the alluvial fan is prograding out to the east, blocking the field drains and diverting sediment-laden water across the path and towards the houses below. (Photo Courtesy of BGCBC).

1.2 LOCATION

The location of the landslide at Glan Ebbw is shown in Figure 2. It is located in the north east of the South Wales Coalfield in the Ebbw Valley, and on an east facing slope affected by previous natural slope instability. (Note: grid references referred to in the text and captions are given as six-figures).

1.3 SURVEY METHODS

During the first site inspection seven ground survey pins were installed by the BGS. These were a mixture of Ground Mark type 300 mm or 500 mm pins (Figure 3 A). During the installation four pre-existing steel pins and an old steel pole were discovered (Figure 3B & C). These items were also surveyed to provide additional monitoring points to the ground pin network. The presence of the existing steel pins suggests previous slope monitoring work has been undertaken on the slope, but the Council has no record of this.

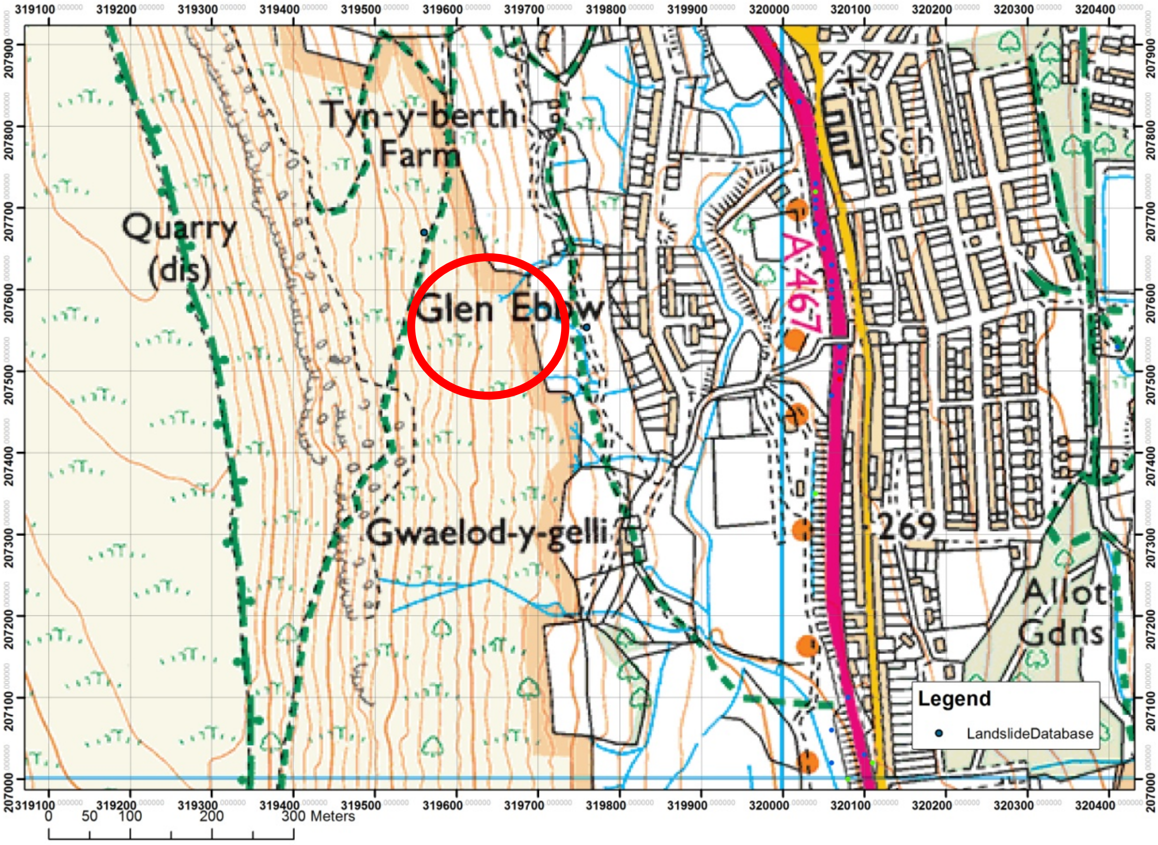

Figure 2 Location map: Extract from 1:25 000 scale Ordnance Survey map showing the location of the landslide (red circle) at Glan Ebbw, Blaina. Note the spelling on the OS map is incorrect; this should be 'Glan Ebbw', (not Glen), according to the local Council Engineers. ***Contains Ordnance Survey data © Crown Copyright 2016.***

Figure 3 Ground pin types and survey method. A: new 300 mm long pins with yellow cap; B: old steel pins; C: old steel pole. Note: GPS device Leica Viva GS14 used with 2 m long survey pole with tip positioned aligned in the centre of the top of the ground pins, except P11 which was measured from the ground surface on the south side of old painted steel pole as shown in C.

2 Geological Background

The area lies within the British Geological Survey 1:50 000 map Sheet 323, Abergavenny, Wales 1990). A geological map of the study area is shown in Figure 4. Further detail is provided in the geological memoir (Barclay, 1989).

2.1 BEDROCK

The landslide is developed in a steep east-facing slope in a glacial valley carved in Carboniferous Coal Measures rocks. The bedrock comprises sediments of cyclically-bedded mixed lithologies including mudstones, siltstone, sandstones, seatearths and coals of the Deri Formation and Llynfi Member (mudstone, siltstone, sandstone) of the Warwickshire Group (formerly named Llynfi Beds and Rhondda Beds of the Upper Coal Measures). The No.2 Rhondda coal seam sub-crops within the slope and is obscured by mass movement deposits, though its precise location is not certain (location shown as conjectural on the 1:10 000 scale geological map). Above this is the Brithdir Member, whose sandstone beds have been quarried for Pennant Sandstone and there is evidence of several small abandoned quarries and a layer of quarry spoil on the upper slopes immediately south of the head of the studied landslide. The bedrock locally dips gently (approximately 6 degrees) to the SSW, though the dip of the bedding across the slope may be locally variable as a result of tectonic (faults and folds) and mass movement (stress release, mining, landslide) related displacements.

2.2 SUPERFICIAL

A mantle of soliflucted head deposits and quarry spoil covers the slope; small coal spoil tips associated with the Brithdir seam or red ash levels are present at the top of the slope below the sandstone cliff. The site is covered by historic mass movement deposits, including landslide deposits and soliflucted head, colluvium or slope wash and possibly transported coal tip and sandstone quarry waste.

The colluvium slope debris has a matrix of predominantly sandy clay and clayey sand, and contains sub-rounded gravel to cobble grade clasts composed of locally sourced bedrock lithologies including sandstone, pebbly sandstone, siltstone, mudstone, coal and ironstone.

2.3 MASS MOVEMENT

Published 1:50 000 scale and 1:10 000 scale geological maps depict mass movement deposits indicative of landslide processes, across the entire slope. These processes are thought to have been active since soon after the end of the Late Devensian glaciation (c.15 000 years before present), and continue intermittently to the present day (Barclay, 1989). The previous BGS-led South Wales Coalfield landslip studies (Conway et al., 1986; Gostelow, 1977) also recorded landslide deposits at the site (ID: Blaina SWC:EB68). The ground deformation resulting from historic slope movements is evident from the presence of disturbed ground, also evident on recent aerial photographs (i.e. Google Earth).

During the site visit it was noted that the slope is mantled by several metres of landslide deposits (observed in the field to be typically gravelly sandy CLAY), head (possibly some soliflucted till), colluvium and quarry spoil. Extensive shallow and deep coal mining took place under the hill and in the valley (ARUP, 1985). There was no clear evidence of mine spoil on the landslide, though this would have certainly been disrupted by the mass movements. The Gwaelod-y-gelli farm house, located approximately 100 m to the south of the active part of the landslide, was built on undisturbed ground.

The reported December 2015 landslide event has been recorded in the National Landslide Database: ID 20064.

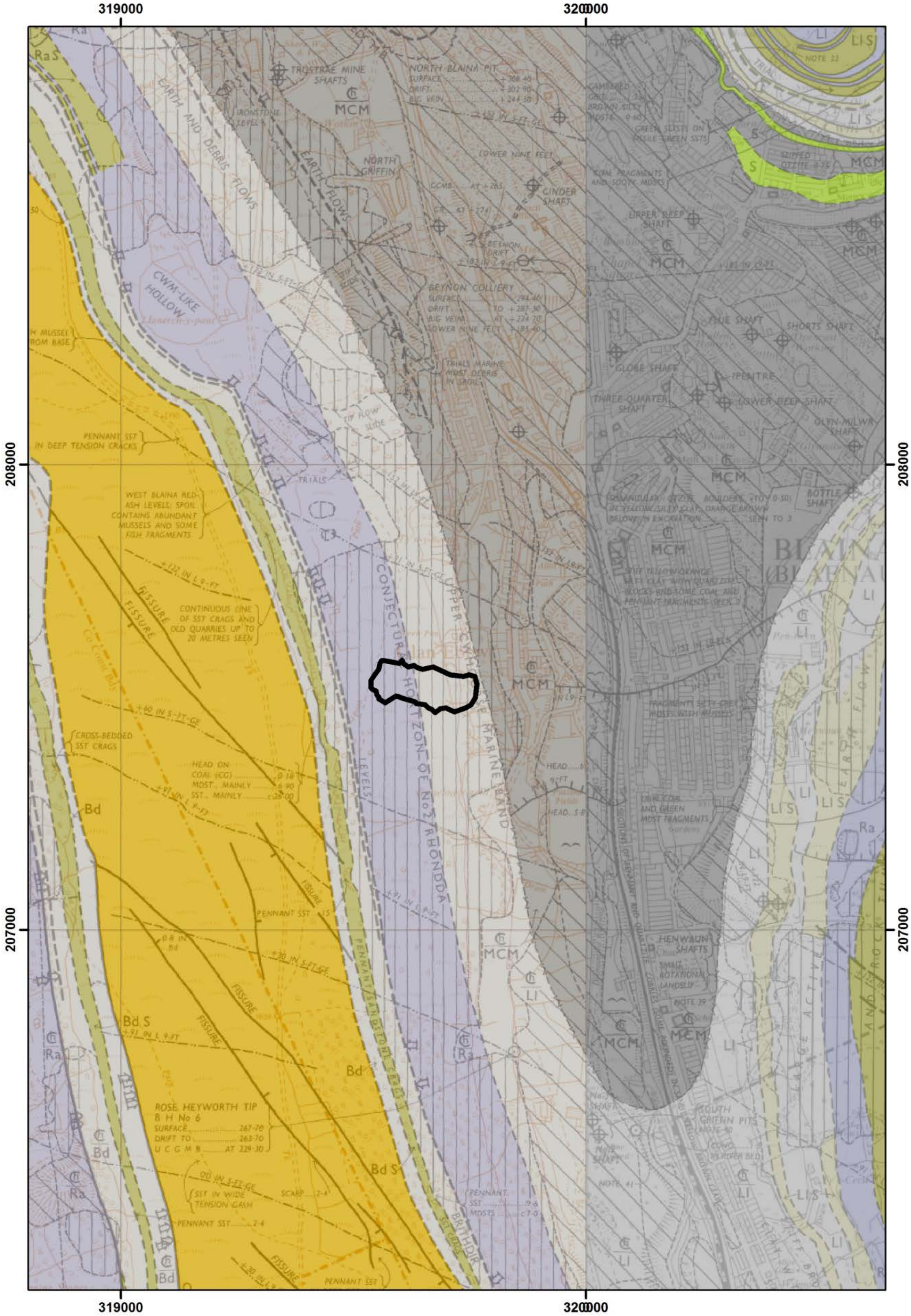

Figure 4 Extract from 1:10 000 geological map (sheet SO10NE, surveyed 1979). Bedrock Legend: MCM South Wales Middle Coal Measures Formation; LI Llynfi Member; Ra Deri Formation; Bd Brithdir Member. The black outline shows approximate footprint of the active landslide as of 8 April 2016. **Map grid coordinate system is British National Grid.**

3 Results

3.1 GROUND PIN SURVEY 1

The southern flank was inspected on foot on 28 January 2016. Ground levels were surveyed at several locations using a dGPS device to delineate the southern edge of the land-slipped ground, or southern flank, as shown in Figure 5. Major landslide morphological features, including the landslide backscarp and toe were noted and photographed. The northern flank was not inspected closely due to time restraints and safety concerns as the landslide was clearly active at this time and the ground was very wet, very soft and impassable across the mudflows. The GPS survey data (x,y,z) is provided in Appendix 1.

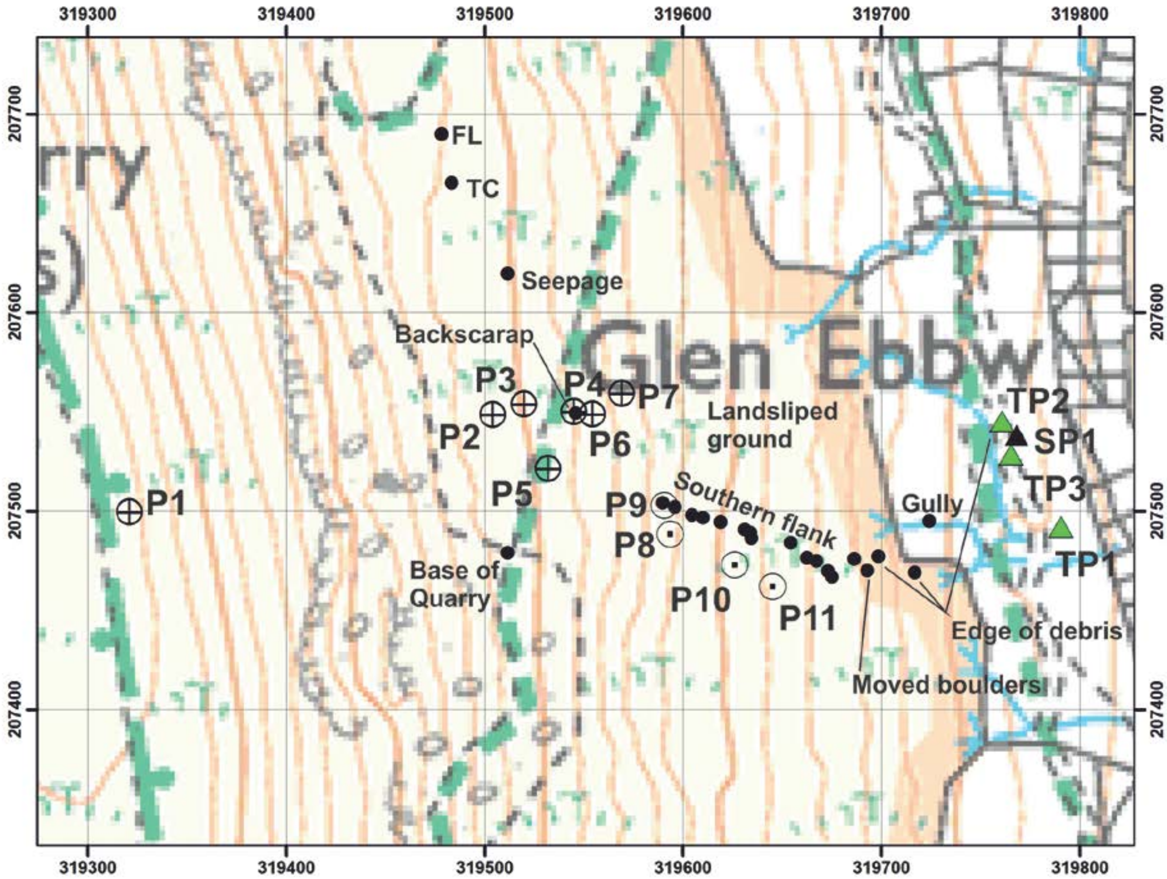

Figure 5 Map showing location of ground pins installed 28 January 2016 and dGPS points (Survey 1). P1, P2, P3, P4, P5, P6, P7 are 300mm long or 500mm long steel yellow capped pins. P8, P9, P10, P11 are old steel pins or poles discovered by chance whilst on site. Other observed features are also shown, such as FL=fence line, TC=tension crack, water seepage point, gulley, backscarp, landslide flank, base of old quarry with spoil heap of angular Pennant Sandstone boulders, downslope edge of debris, and recently moved boulders. SP1 is the TLS position and TP1-3 denote 'Tie Point' reference positions. Full dGPS point co-ordinates are included in Appendix 1. ***Contains Ordnance Survey data © Crown Copyright 2016.***

3.2 GROUND PIN SURVEY 2

The ground pins installed on 28 January were re-surveyed on 4 March 2016. The pin locations surveyed are shown in Figure 6. The northern flank of the landslide was not inspected in detail during the walk over due to time restraints and safety concerns, though photographs were taken from a distance. The survey data is provided in full in Appendix 1.

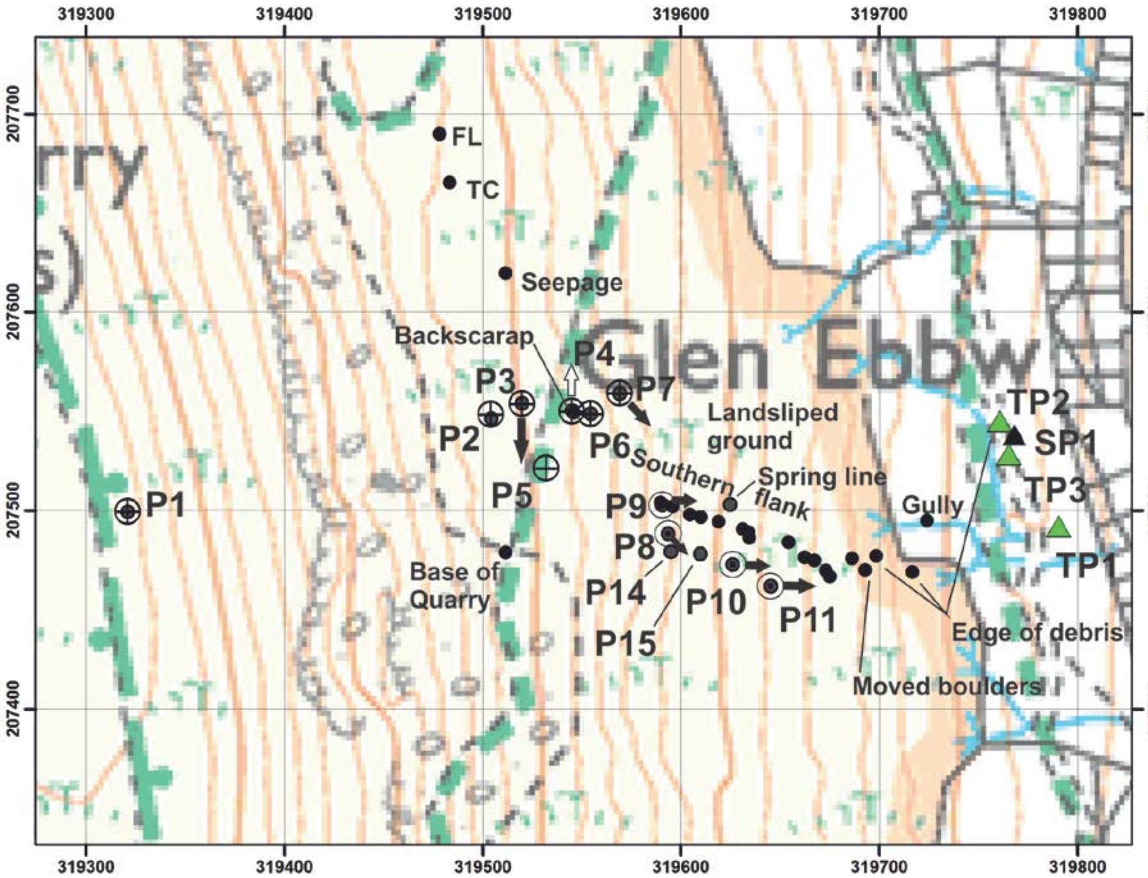

Figure 6 Map showing location of points re-surveyed on 4 Mar 16 (Survey 2). Two old steel pins were discovered and surveyed in, named P14 and P15. Arrows indicate relative movement direction based on difference between Survey 1 (28 Jan 16) and Survey 2 data. ***Contains Ordnance Survey data © Crown Copyright 2016.***

3.2.1 Ground movement between 28 January and 4 March 2016

The following section provides details of the changes in ground pin locations between Survey 1 on 28 January, and Survey 2 on 4 March 2016, based on GPS survey data. The survey data is provided in full in Appendix 1. The reported magnitudes take account of accuracy of the dGPS measurements (aggregated horizontal, x, y and vertical, z, 2D error) and are to be regarded as the minimum amount of movement that has occurred.

Pin 1 – The dGPS survey data suggests this pin moved vertically upwards by 630 mm in the time period. The upwards direction and large magnitude of movement is not reasonable given the geological context and a lack of any very recent ground deformation features in the hill top area. The pin was installed in ground considered by the authors to be relatively stable. The discrepancy between Pin 1 Survey 1 location and Survey 2 data was later considered to be an error, caused by a problem with the RINEX data in the processing stage. This pin was subsequently resurveyed again on 8 April 2016 and it was concluded that this pin had not moved since the previous survey on 4 March 2016.

Pin 2 – new pin, any small amounts of movement are not detectable as Survey 1 dGPS accuracy was very low.

Pin 3 – new pin, moved south by 150 mm in the period.

Pin 4 – new pin, moved north by 80 mm and vertically down by 90 mm (Suggests rotation related uplift or ground swelling as pin is located on a back-tilted landslide block).

Pin 5 – new pin, was not resurveyed in Survey 2, so change cannot be assessed for this period.

Pin 6 – new pin, moved vertically downward by at least 10 mm. (Suggests ground subsidence).

Pin 7 – new pin, moved 30 mm to south east in down slope direction.

Pin 8 – existing (old) steel pin, moved south east by 10 mm.

Pin 9 – existing (old) steel pin, may have moved east (in down slope direction) by up to 10 mm.

Pin 10 – existing (old) steel pin, moved east (in down slope direction) by up to 10 mm.

Pin 11 – existing (old) steel pin, moved east (in down slope direction) by 40 mm (Indicates some hill slope creep on southern flank of active landslide).

In summary, between 28 January and 4 March 2016, there was clear down-slope movement in the order of 10s to 100s of mm in five of the seven BGS ground pins. There was also ground movement in all four of the old steel pins.

3.3 GROUND PIN SURVEY 3

3.3.1 Cumulative movement between 28 January and 8 April 2016

Pin 1 – Only change between Survey 2 and 3 is considered due to the data accuracy issues with Survey 1. Pin did not likely move between Survey 1 and 3.

Pin 2 – Only change between Survey 2 and 3 is considered due to the data accuracy issues with Survey 1. Pin did not move between Survey 2 and 3.

Pin 3 – Pin moved south by 0.2 m between Survey 1 and Survey 3, with little vertical movement.

Pin 4 – Pin moved south by 0.12 m and down by 0.15 m. (Suggests further rotation of the northern side of the back-tilted landslide block where Pin 4 was located).

Pin 5 – Pin moved north by at least 10 mm between surveys 1 and 3.

Pin 6 – Pin moved down by at least 10 mm (landslide related ground subsidence).

Pin 7 –Pin has moved south by 27 mm, east by 44 mm and down by 11 mm. (The pin is located on a rotated landslide block, this is evidence for further down slope movement of the rotated block, and developments in the north, also associated with Pin 4 and Pin 6 movement events).

Pin 8 – existing (old) steel pin, moved south east by at least 7 mm (possible slope creep).

Pin 9 – existing (old) steel pin, did not move.

Pin 10 – existing (old) steel pin, moved east (in down slope direction) by at least 23 mm.

Pin 11 – existing (old) steel pin was not resurveyed during Survey 3. But moved east at least 40 mm between Survey 1 and Survey 2.

In summary, between 28 January and 4 April 2016, there was clear down-slope movement in the order of 10s to 100s of mm in five of the seven BGS ground pins. There was also clear ground movement in three of the four old steel pins resurveyed. The main backscarp was 9 m high at its highest point in the south.

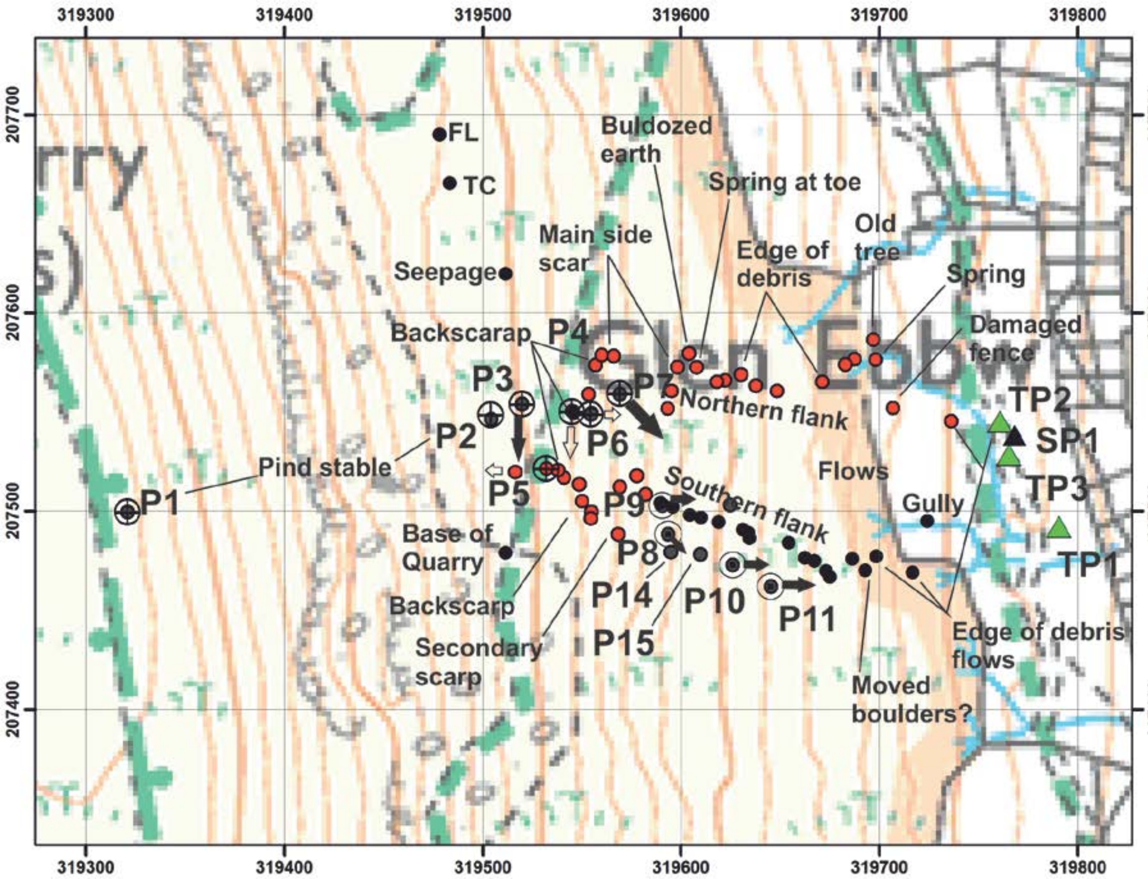

Figure 7 Map showing location of points resurveyed on 8 Apr 16 (Survey 3) and main field observations. Arrows indicate relative movement direction based on comparison with Survey 1 and 2 data. ***Contains Ordnance Survey data © Crown Copyright 2016.***

3.4 AREA AFFECTED BY GROUND MOVEMENT

Figure 8 shows the GPS and observation data points collected over the survey overlaid onto a recent colour aerial photograph. Figure 9 shows the main area of unstable ground inferred based on interpretation of this primary data.

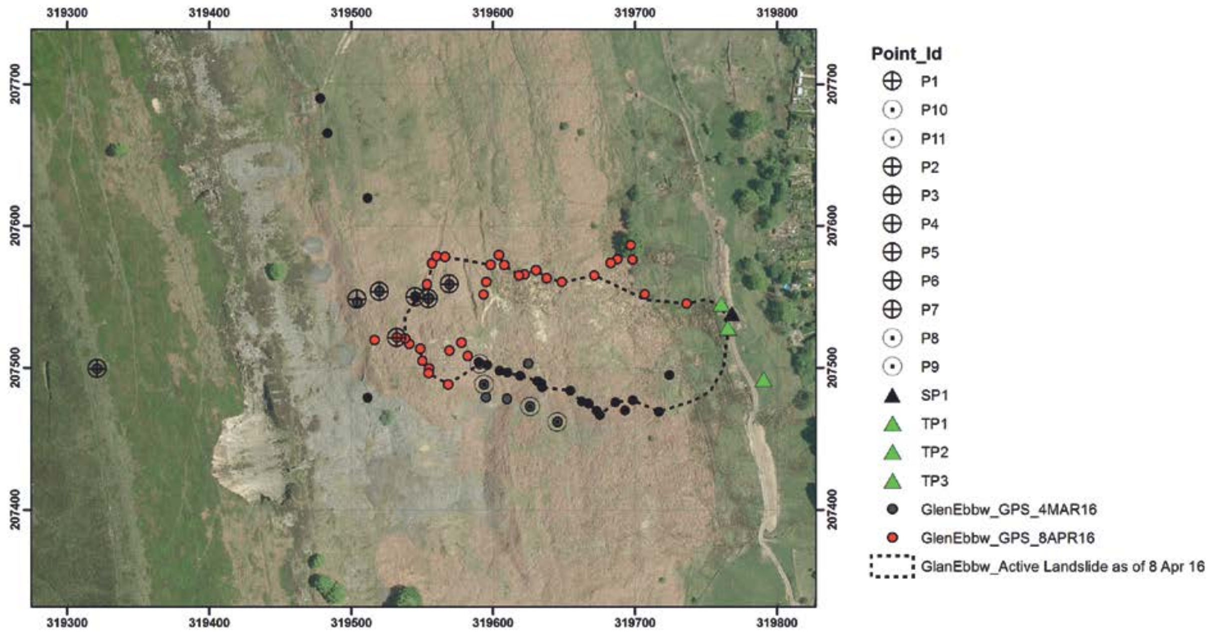

Figure 8 Plan of GPS survey points collected throughout study, overlaid on pre-event aerial photograph (c. 2010 vintage). RGB Aerial Photography – ©GeoPerspectives.

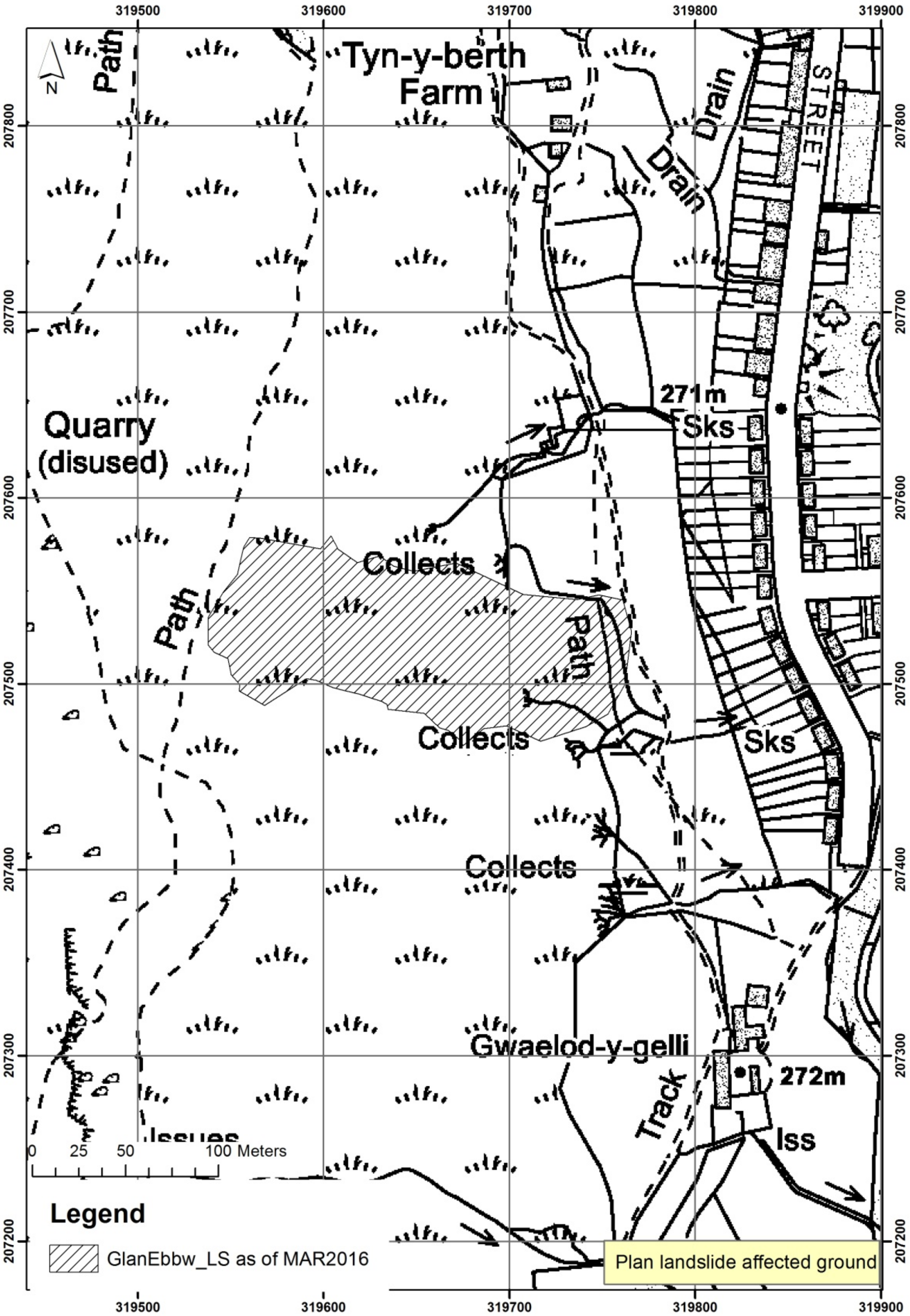

Figure 9 Plan showing area of recent ground movement (hatched), which covers 1.6 ha. The base map is the modern 1:25 000 OS B&W Topographic. ***Contains Ordnance Survey data © Crown Copyright 2016.***

3.5 TERRESTRIAL LASER SCAN (TLS) SURVEY

3.5.1 Method

The TLS survey was made on 28 January 2016 using a Reigl i800HA Light Detection And Ranging (LiDAR) laser scanner mounted on a tripod. The aim of the scan was to map the slope topography in detail with optimum accuracy. A major advantage of the modern TLS technique is the ability to acquire a large number of accurate survey points at a safe distance from hazards, and within a short time frame, thus making surveying very cost effective and safe for personnel. The main disadvantage of the terrestrial technique is that it is a ‘line-of-sight method’, and so does not capture features outside of the field of view of the scanner laser. In total, 553 115 survey points were collected in just under two hours from a single Scan Position (SP1), with two overlapping single scans (Scan003 and Scan005). Scan005 captured a reference reflector (TP1) which was set out in order to orient and geo-reference the scan. GPS measurements were also made on other solid features, such as the NE corner of a cattle feeder, for data QA purposes. The site set-up is shown in Figure 5 and Figure 10 and follows the survey methodology and processing approach routinely used by the BGS (Jones, 2013) for remote surveying purposes. Photographs were not collected with the scans due to a camera malfunction, but reflectance data was captured. The location of scanner position and tie point reflectors was measured very accurately (combined 3D accuracy of 2 cm) using a real-time kinematic Global Navigation Satellite System (GNSS) survey system, (also known as GPS) and these data were later used for geo-referencing the laser scan data (to derive an orientated point cloud). The GPS positions are provided in Figure 10 and in full in Appendix 1.

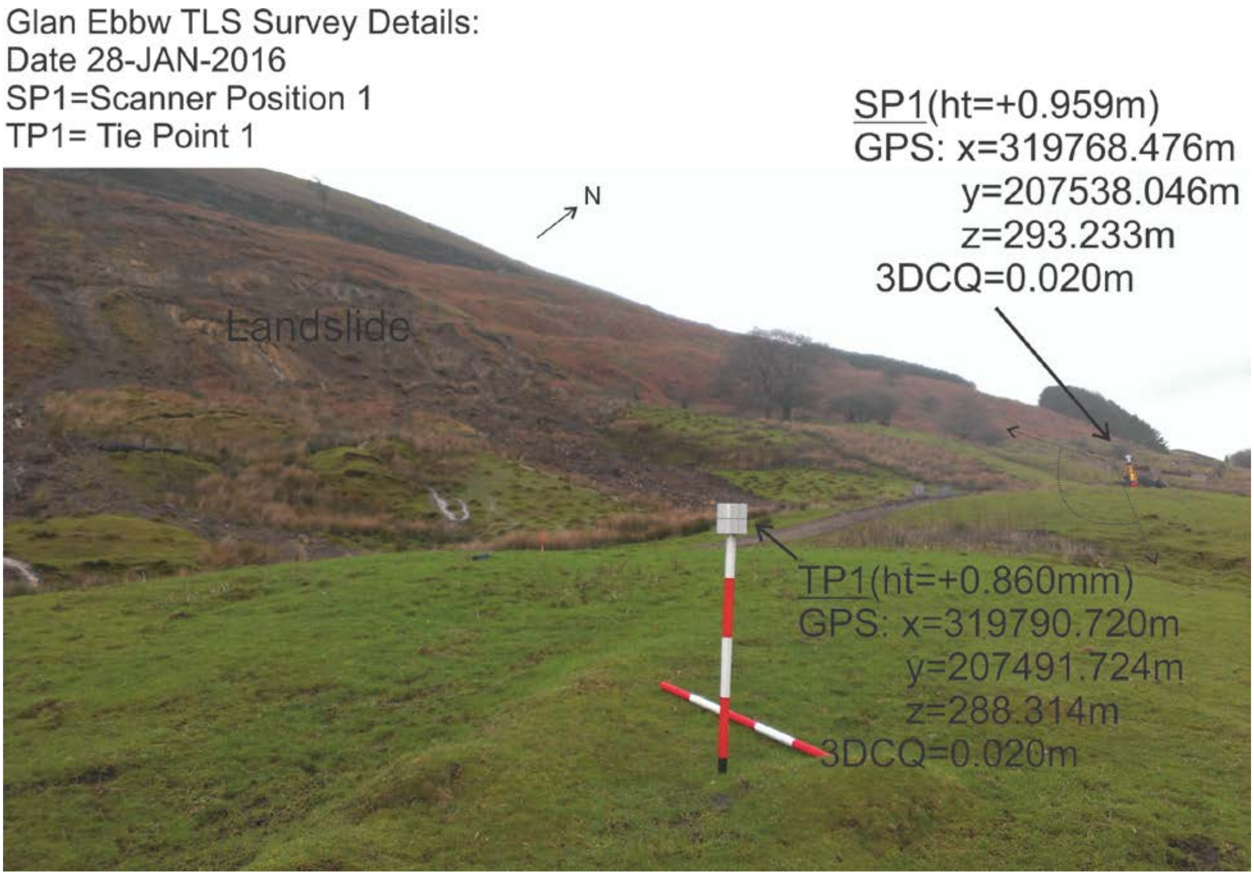

Figure 10 Annotated photo showing laser scan set up relative to the landslide-affected slope and tie point. Scanner position (SP1) and reflector ‘tie point’ position (TP1) were located at the foot of the slope.

3.5.2 Data processing

The scan points were processed in RiScanPro software (v1.8).

3.5.3 Results and discussion

The TLS survey produces topographic point data (or 'point cloud') with centimetre accuracy. LiDAR points were captured across much of the active landslide area and surrounding ground, as shown in the map in Figure 11. The range of the laser beam on the day was just over 500 m. This range was sufficient to capture the active part of the slope. The resulting dataset was of sufficient quality and point density to enable a variety of reliable derived information products to be generated for slope monitoring and communication purposes, including:

- **Topographic contours**. Contours can be drawn with any desired spacing, such as the 5 m contours shown in Figure 12,
- **Slope profiles**. The dimensions of the failed slope were measured virtually using the derived slope terrain model, as shown in Figure 13. These data were exported as .csv files and plotted in excel to produce an accurate slope profile through the centre line of the active landslide system, as shown in Figure 14. The landslide-affected ground has an average slope angle of 23 degrees (measured from crown to toe).
- **Slope change models**. Repeat TLS surveys enable slope change models and maps to be generated, useful for communication of where ground movement has occurred.
- **Ground/slope deformation maps**. Maps and models that show magnitude and direction of change (surface strains).

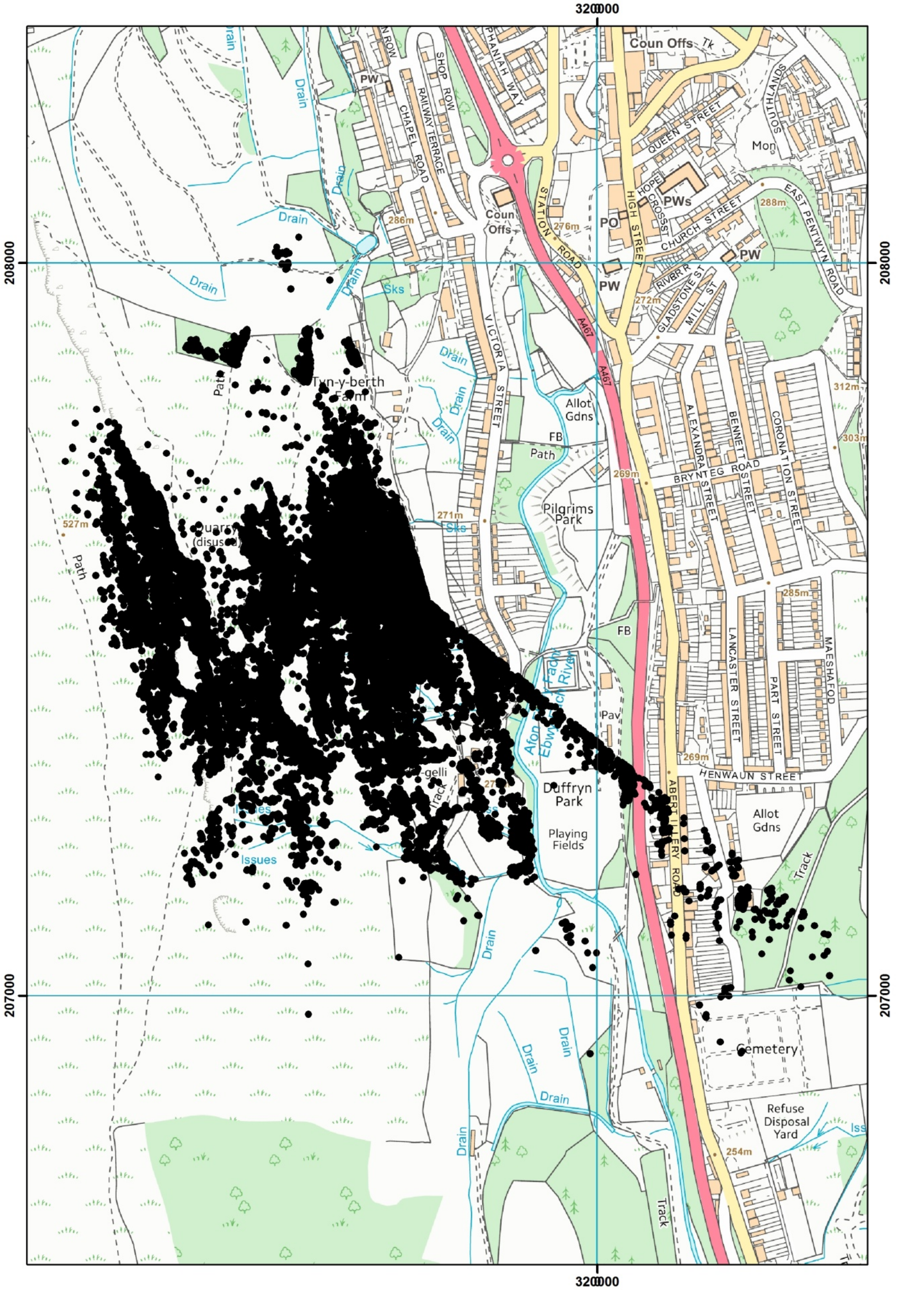

Figure 11 Distribution of TLS survey points (the point cloud) surveyed 28 January 2016. ***Contains Ordnance Survey data © Crown Copyright 2016.***

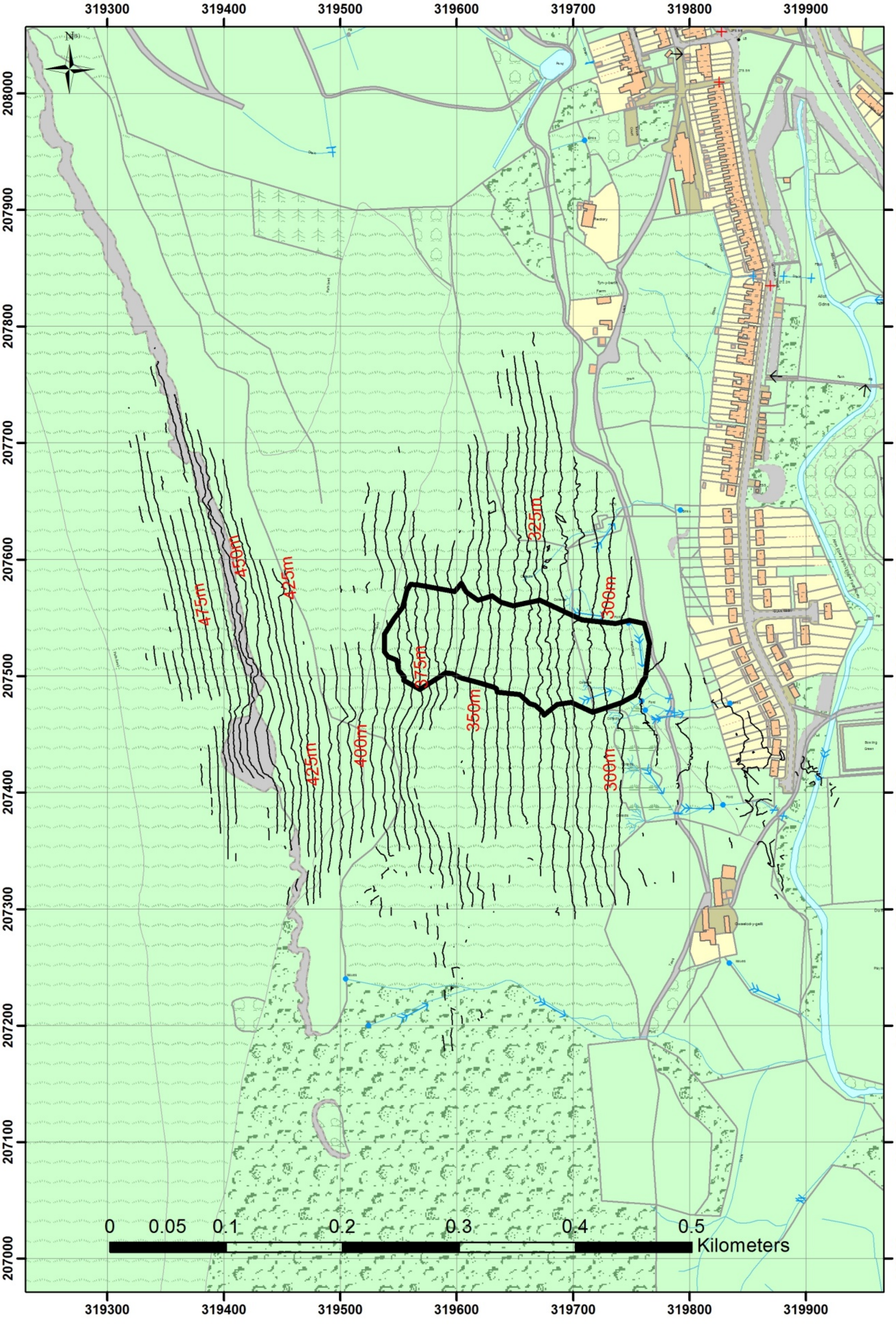

Figure 12 Map of 5 m topographic contours at Glan Ebbw derived from TLS data and draped on OS MasterMap2015 base map for context. Contains Ordnance Survey data © Crown Copyright 2016.

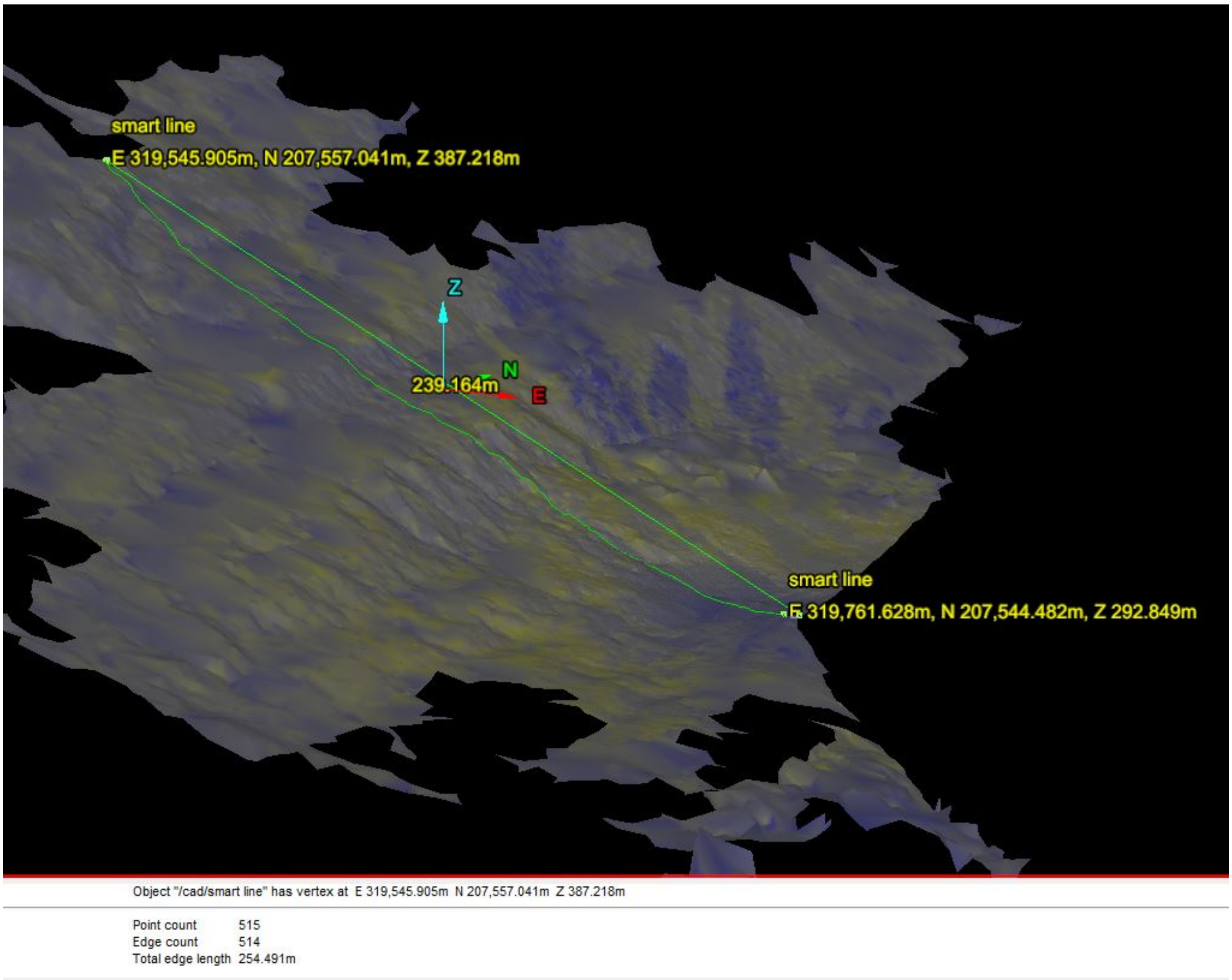

Figure 13 3D visualisation of the digital terrain model derived from triangulation of the TLS data points. Virtual field measurements on the terrain surface were made using Maptec data visualisation software. This allowed analysis of slope metrics, such as landslide dimensions, length, area and volume, and slope angle, as well as providing a virtual visualisation environment for interpretation of landslide features and processes. Data points were selected along the centre line of the landslide mass by defining a 'smart line', which is an analysis function of the Maptec software.

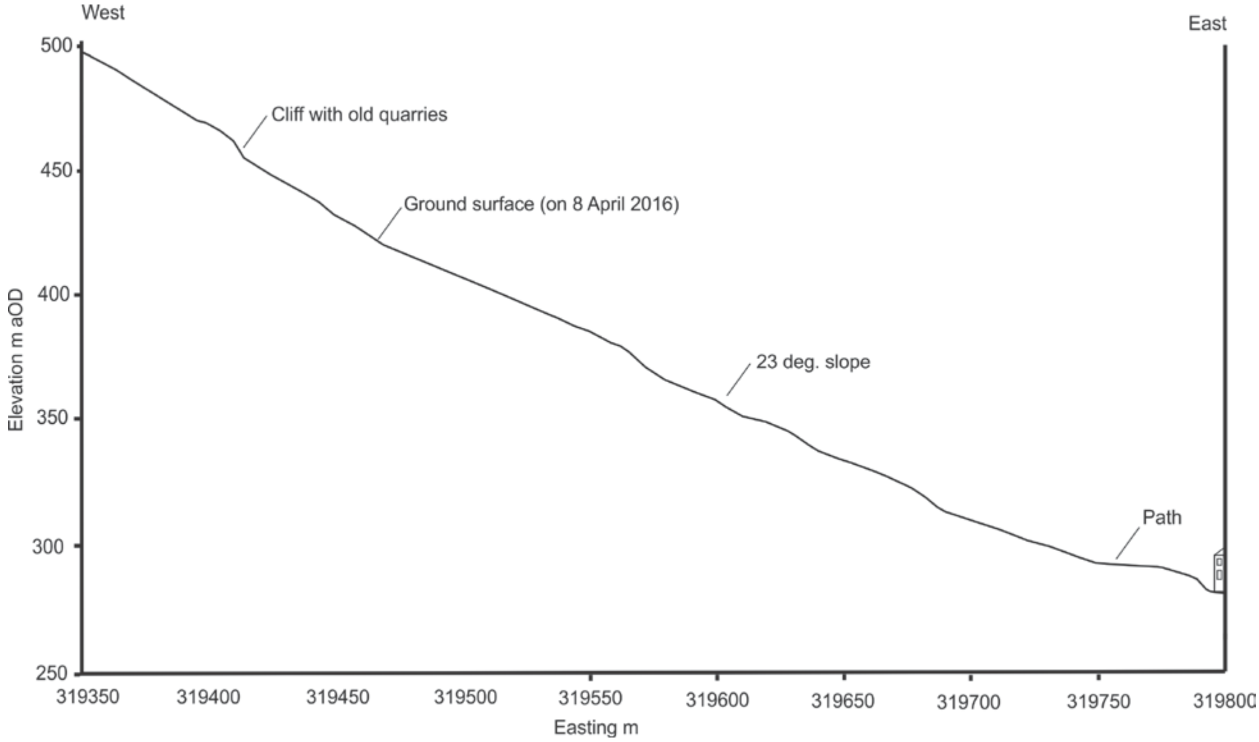

Figure 14 Slope profile orientated roughly through the centreline of the landslide, extracted from 28 January 2016 TLS data (see Figure 11 and Figure 13). Average slope angle of the failed slope (from crown to toe) is 23.2 degrees to the horizontal.

4 Interpretation of the landslide processes

4.1 FAILURE MECHANISM

Figure 15 shows a cross section through the slope illustrating the likely failure mechanism and relationship with the main geological units. The observational data that has been collected underpins an initial interpretation of the failure mechanisms. It is a complex landslide that can be divided into three main zones: **1. Upper slope**: contains a rotational landslide (ROT. in Fig. 14) within relict landslide and head deposits and possibly affecting weathered bedrock (Deri Member) below. This is likely sliding on a deep-seated (>5 m) basal slip surface coincident with the Rhondda No 2 coal seam or weathered clay-rich seatearths; **2. Middle slope**: the liberated mass cascades down over a positive break of slope (bedrock feature) forming a cluster of interacting deep-seated translational slides (TR) which if saturated become flow slides (FL). These form the main body of the landslide. **3. Lower slope**: water flowing from springs and coal seams combined with effective rainfall saturates the debris, increasing pore pressure and weight of material, which then fluidises (causing undrained loading) and cascades out over a second break of slope, focused via surface water-scoured gullies. This process generates shallow (<5 m) debris/earth flows that accumulate in debris cones on the flat ground on the lower slope.

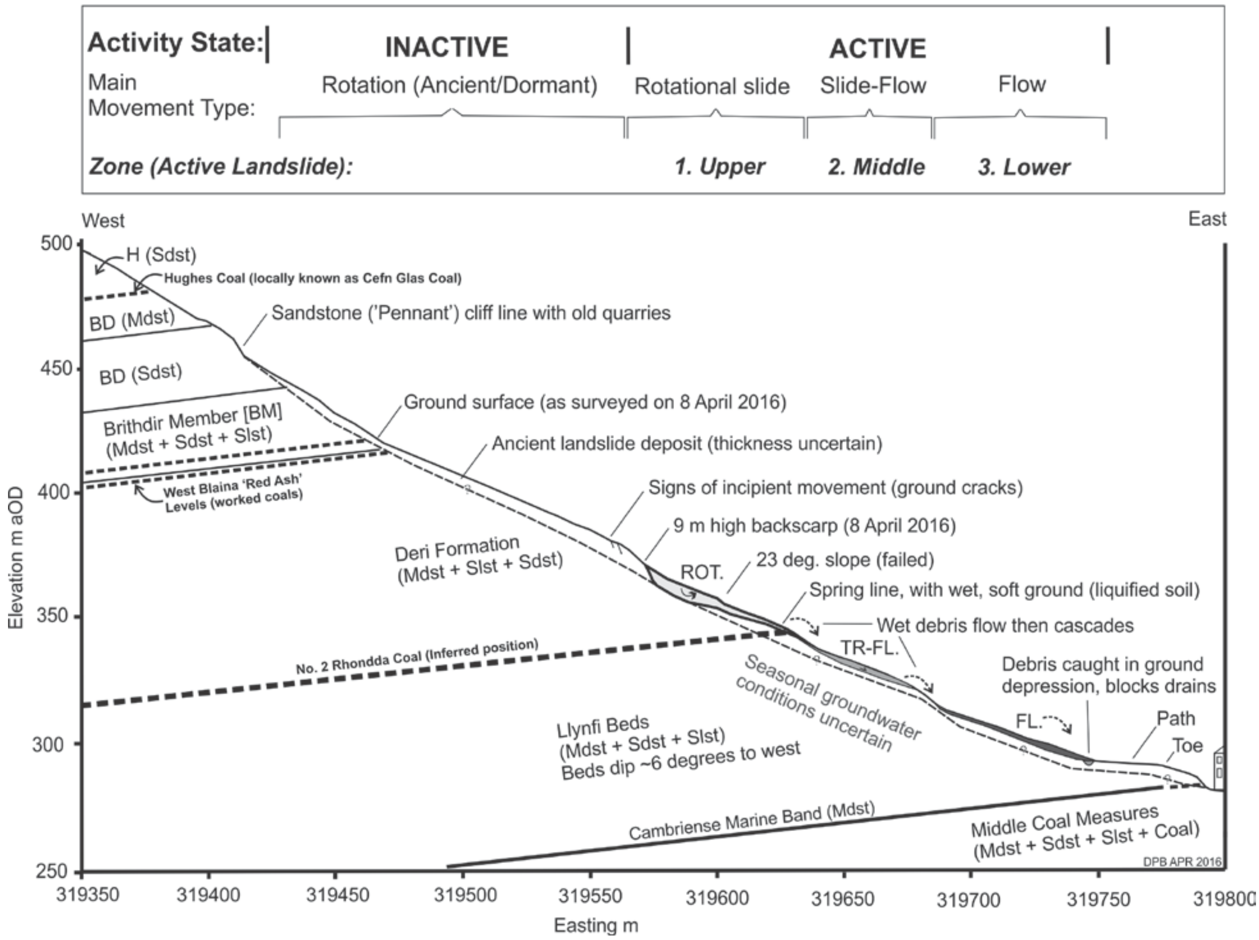

Figure 15 Conceptual Engineering Geological Model (2D) for the slope at Glan Ebbw. Ground surface extracted from TLS data. Geology based on 1:10 000 scale geological map data. H = Hughes Member of the Pennant Sandstone Formation, BD = Brithdir Member.

Below the lower slope the saturated debris/earth flow deposits (FL) are currently being trapped, and movement suspended, in a slight ground depression, which is part of the toe of an ancient landslide mass. As this basin (sediment trap) continues to fill with sediment its storage capacity decreases and without clearance the drainage ditches in this flat area are becoming blocked and ineffective. This excess surface water has resulted in a natural diversion of the drainage across the path (labelled in Figure 15). During intense rainfall events sediment-loaded water flows down the crest of the ancient landslide toe and either into the drain at the back of the gardens which catches the water and feeds it into Ebbw Fach River, or into the gardens of houses on Glan Ebbw Terrace. The control of this excess water is probably the most immediate threat posed to the properties and residents. Without regular inspection and maintenance the culvert at the back of the gardens will eventually become blocked with sediment and debris; it will become less effective, leaving the houses more exposed to the surface water flooding hazard, particularly during and immediately after intense rainfall events, and after rapid snow melt.

4.2 FUTURE MOVEMENT SCENARIOS

The landslide movement observed between December 2015 and April 2016 was mainly retrogressive and stemmed from the upper slope, with the main backscarp migrating upslope and extending laterally to the north. The rotated block in the upper slope dropped most on the southern side, exposing more of the bedrock on the main backscarp. As well as supplying debris for earth flows, delivery of new material and water to the mid-slope area, as illustrated in Figure

18, will have the effect of adding additional loading forces to the middle and lower parts of the slope. This increase in normal stress will take the slope further along the path to failure, and into a progressive phase of development, which in time could potentially destabilise the toe of the ancient landslide mass. This scenario could cause significant deep-seated ground movement within the vicinity of the properties on Glan Ebbw Terrace, assuming the ancient landslide mass became remobilised.

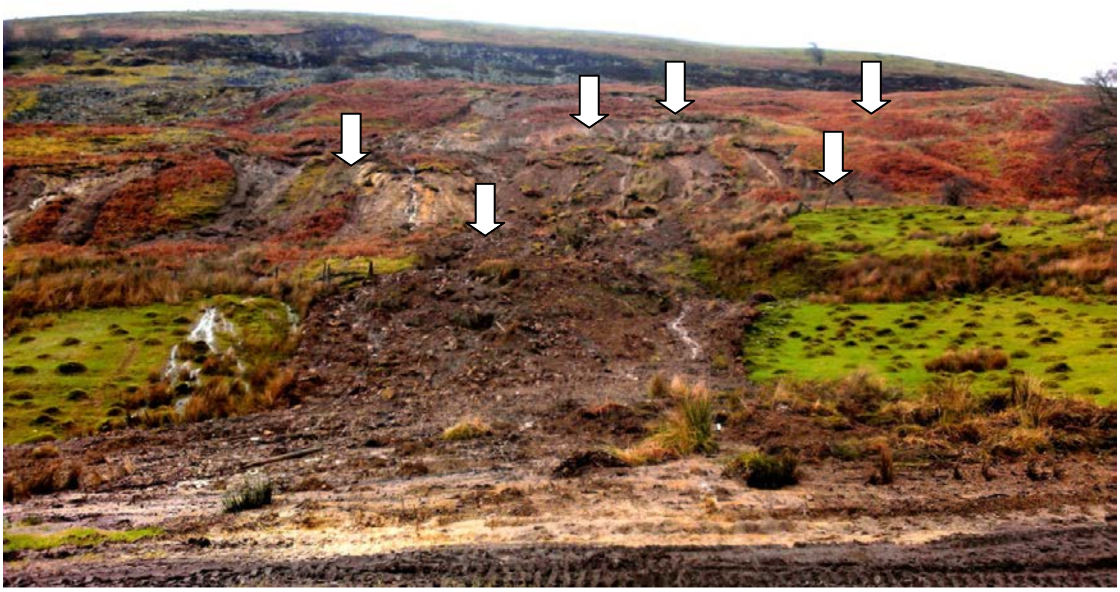

Figure 16 Photo of landslide-affected slope on 28 January 2016. Photo colour and contrast has been enhanced for clarity. Arrows show areas of noticeable change since December 23 2015.

Figure 17 Photo of landslide–affected slope at Glan Ebbw taken 4 March 2016. Photo colour and contrast has been enhanced for clarity. Note the now well-developed main back scarp on the southern side of the crown (white arrow), crown cracks on the northern side (grey arrow, right side), and compression and bulging of topsoil at the toe of the upper-slope rotation (zig zag arrow, middle right). This feature is arguably present, though less well developed, in the earlier 23 December 2015 photo (Figure 1) indicating retrogressive movement. The upper row of houses is located along Glan Ebbw Terrace.

Figure 18 Photo taken on 28 January 2016 after recent rainfall. Erosion on middle slope has been stripped-off the vegetation, exposing loose bare soil. During and just after heavy rainfall, loose soil debris is translated down-slope accelerating as it spills over a steep bench, and feeding earth flows that are forming debris fans on flat ground. Sediment-laden surface water was observed to flow across the flat path area, marked by the white arrow, and flows down towards the rear gardens of some of the houses on Glan Ebbw Terrace.

Figure 19 Small open fissure on un-slipped ground approximately 10 m from the southern flank of the landslide. The open fissure has exhumed fine-grained sand which has buried the ground cover vegetation. This feature, a mini sand volcano, provides evidence of fluidisation of sediment under conditions of excess pore water pressure in the slope, evidence that high pore pressures develop in the slope recently.

5 Conclusions

Significant ground movement occurred on a semi-rural hill slope at Glan Ebbw, West Side, Blaina, during the late December storms of 2015. Concerns from the local community were quickly raised and the council began monitoring the site immediately, but the situation worsened. On 28 January 2016 the BGS undertook a TLS survey of the slope and installed seven ground movement monitoring pins, with the aim of establishing a basic ground movement monitoring system and baseline topographic survey. Repeat visits were made on 4 March and 8 April 2016 to resurvey the ground pins. The survey data collected and presented within this report, which provides an independent, high-accuracy baseline data set for comparison with any further ground movement studies. A conceptual engineering geological model is also presented, which can be refined when new data and process understanding data becomes available.

The ground movement was associated with reactivation of an existing landslide mass and resulted in visible deformation of the hillside and degradation of pasture land. The physical damage to farmland and fences resulted from the formation of scarps, tension cracks and shallow soil thrusts within a pre-existing ancient landslide deposit. Soil erosion and subsequent deposition of sediment across the lower part of the slope, including onto footpaths, blocked drainage ditches and resulted in a natural diversion of surface water overland flows into residential gardens.

Interpretation of the ground deformation features, GNSS/GPS data and TLS data collected independently by the BGS indicates the landslide affected approximately 1.6 ha of rough grazing land between 28 January to at least 8 April 2016.

The survey recorded evidence that the landslide debris had reduced the capacity of a drainage ditch located by the path at the foot of the slope; the existing drainage ditch and surrounding ground depression was still catching the debris flows in April 2016, but this was staring to reach capacity and excess muddy surface water was escaping over the bank and towards the houses. Consolidation and dying out of the wet sediment in the depression slightly reduces the volume of the debris pile over time, but it is still growing in mass as debris flows continue to accumulate during rainfall events.

Ongoing ground movement may continue to affect the slope and environs over the coming months and years, with movements most likely to be triggered by intense rainfall events and/or when groundwater levels are high. It is also quite possible that during heavy rainfall events sediment-loaded surface water, and landslide debris flow sediment, could spill over into the residential gardens, or even as far as the houses and onto the public highway. There is also potential for the upper part of the landslide system to expand upslope and laterally across the slope, mobilising a larger volume of soil and rock and increasing the intensity of debris flows.

Reasonable steps that could be taken to manage the immediate hazard in the short-term, and to avoid third-party damages, include (i) maintenance of the surface water drainage ditches at the foot of the slope and (ii) continued regular inspection of the slope with ground movement monitoring. In the mid- to long-term, a strategy for funding and implementing improvements to the surface and groundwater drainage, possibly extending to hard engineering works, will need to be developed in combination with a holistic land management strategy.

5.1 RESEARCH POTENTIAL

This report has established that the landslide at Glan Ebbw was a reactivation of a much larger pre-existing landslide system. The movement observed so far can be linked to a combination of high pore-water pressure in the slope after intense rainfall, heightened groundwater levels with emergent springs, and slopes already susceptible to generating landslides. These ground conditions are widespread in the Blaina Valley and in many of the South Wales Coalfield valleys. Human activities may have also played a role in making the slope unstable, as the site has a history of sandstone quarrying which produced spoil heaps which redistributed forces across the slope. Furthermore, the legacy of coal mining may have also altered the subsurface conditions, potentially affecting groundwater drainage flow paths, introducing subsurface voids, ground deformation in the form of local to regional subsidence and uplift, and production of spoil.

Further research at the site has the potential to benefit the regional understanding and should be focused on supporting hazard and risk assessment, and land-use planning. Cost-effectiveness can be achieved through a phased approach, whereby data that is collected is used to priorities subsequent phases of data collection and analysis. Collaboration with public sector research institutions and local University departments (through hosting MSc/PhD student projects) would be cost effective. The following activities would be beneficial:

- Public engagement with the residents and landowner on state of stability, preparedness, hazard communication, evacuation planning and good land management practices.
- Landowner consultation with professionals, such as experienced and qualified geotechnical engineers or chartered engineering geologists (CGeol).
- Further observational monitoring including: (1) expansion of the current ground pin monitoring network with regular re-surveys, (2) repeat laser scanning (e.g. 6-monthly or annually, or after significant movement occur, ideally during winter and spring months when surface vegetation is low), to provide updated digital elevation models and production of slope change and deformation maps
- Analysis of rainfall data from winter 2015 to better understand storm and antecedent rainfall trigger thresholds in this slope.
- Desk study, detailed geomorphological and geological mapping, to enhance the Conceptual Engineering Geological Model presented in this report (Figure 15), followed by an Observational Engineering Geological Model and an Analytical Model, if required, following the Total Geological History approach described by Fookes et al (2001).
- An analytical slope stability model to assess the residual stability of the failed and un-failed parts of the slope, using LiDAR data to obtain the slope profile, would require geotechnical data. This may necessitate intrusive investigation, including drilling, in-situ sampling and geotechnical testing, as well as the installation of ground monitoring and groundwater level monitoring infrastructure, potentially including non-intrusive geophysics, sampling and materials testing to characterise the slope materials and properties. Further to this, a 'back-analysis' of the recent failure could be performed to assess the physical conditions and geotechnical parameters at failure, and provide confidence in the sensitivity of the other models.
- Consider options for other in-situ advanced monitoring technologies (e.g. geophysics/ALERT or PRIME systems, tilt meters, borehole inclinometers, ground based radar, airborne UAV, semi-automated surveying system using total station).
- A systematic review of tips and slips in the rest of the BGCBC area, using all available information including National Landslide Database, published geological maps, historic and modern air photos and LiDAR, existing research reports (e.g. Conway et al 1980, Jones & Siddle 2000), Coal Authority data and mine abandonment plans, and previous consultancy reports. This data should be managed in a future-proofed central database in a format accessible to council staff.
- Analysis of EA/NRW airborne LiDAR data with the newly acquired Terrestrial LiDAR data, to trial and evaluate the usefulness of combining existing remote sensed datasets (e.g. Open available EA Airborne LiDAR data with TLS data, and InSAR data) for slope monitoring purposes.

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7 Appendix 1

The following tables provide the GNSS/GPS point location data, including horizontal and vertical accuracy. Note P1_1 denotes Pin 1, Survey 1; P2_2 denotes Pin 1, Survey 2, etc...

Survey 1 - 28 JAN 2016

Point_Id	Description	Easting (x1)	Northing (y1)	Orth_height (1z)	Time	Quality_Horiz_pos_M	Quality_hgt_pos_M	Quality_pos_and_hgt_comb_M
BACKSCARP	Back_Scarp	319545.885	207549.197	387.030	01/28/2016 13:25:43	0.011	0.017	0.020
BASE	Ground_point	319768.240	207536.725	293.225	01/28/2016 10:32:43	0.016	0.024	0.029
BASEUARRY	Base_of_Quarry	319511.458	207478.760	399.818	01/28/2016 12:48:13	0.397	0.862	0.949
CREAVAS1	Crevasse	319271.027	207628.718	525.101	01/28/2016 11:27:13	0.010	0.021	0.023
CREAVAS2	Crevasse	319242.325	207745.420	524.258	01/28/2016 11:30:13	0.377	0.715	0.808
EDGE10	Flank_of_landslide	319654.224	207484.070	331.225	01/28/2016 15:23:57	0.014	0.022	0.026
EDGE11	Flank_of_landslide	319662.380	207476.216	328.962	01/28/2016 15:25:24	0.013	0.021	0.025
EDGE12	Flank_of_landslide	319667.215	207474.792	327.249	01/28/2016 15:26:21	0.011	0.018	0.021
EDGE14	Flank_of_landslide	319686.182	207475.739	318.455	01/28/2016 15:32:03	0.010	0.016	0.019
EDGEDEB1	Edge_of_debris	319698.411	207477.219	311.261	01/28/2016 15:37:06	0.010	0.016	0.019
EDGEDEB2	Edge_of_debris	319716.852	207469.005	305.180	01/28/2016 15:40:19	0.009	0.015	0.017
EDGSTR	Flank_with_stream	319595.880	207501.880	356.305	01/28/2016 14:58:48	0.016	0.024	0.029
EDGSTR1	Flank_with_stream	319604.535	207498.019	352.929	01/28/2016 15:01:44	0.009	0.023	0.025
EDGSTR2	Flank_with_stream	319610.017	207496.592	350.398	01/28/2016 15:03:00	0.016	0.038	0.041
EDGSTR3	Flank_with_stream	319618.995	207494.361	346.798	01/28/2016 15:04:09	0.017	0.038	0.042
EDGSTR4	Flank_with_stream	319631.211	207490.476	341.815	01/28/2016 15:09:04	0.012	0.022	0.025
FL	Flank_of_landslide	319478.336	207689.835	408.200	01/28/2016 12:22:43	0.029	0.092	0.096
FLANK	Flank_of_landslide	319589.781	207504.001	361.047	01/28/2016 14:52:41	0.013	0.028	0.030
FLFL1	Fence_top_of_slope	319478.260	207689.929	407.534	01/28/2016 12:23:43	0.138	0.441	0.462
GULLY	Gully_body_of_slide	319724.226	207494.856	302.133	01/28/2016 15:45:20	0.010	0.015	0.018
MOVEDBOULDERS	Recently_disturbed_boulders	319692.850	207469.992	315.735	01/28/2016 15:34:10	0.011	0.018	0.021
P1	Newly installed Ground_Pin	319321.041	207499.343	517.804	01/28/2016 11:21:43	0.012	0.025	0.028
P2	Newly installed Ground_Pin	319504.118	207548.402	398.616	01/28/2016 12:44:57	2.378	3.666	4.370
P3	Newly installed Ground_Pin	319519.912	207553.739	397.830	01/28/2016 13:48:18	0.048	0.066	0.082
P4	Newly installed Ground_Pin	319545.163	207550.063	387.580	01/28/2016 13:44:56	0.053	0.053	0.074
P5	Newly installed Ground_Pin	319532.049	207521.426	393.451	01/28/2016 13:50:47	0.042	0.069	0.080
P6	Newly installed Ground_Pin	319554.371	207548.652	382.497	01/28/2016 13:55:59	0.016	0.022	0.027
P7	Newly installed Ground_Pin	319569.250	207559.047	373.063	01/28/2016 14:09:21	0.012	0.020	0.024
P8	Existing Steel Ground_Pin	319593.505	207488.270	359.424	01/28/2016 14:49:21	0.016	0.022	0.027
P9	Existing Steel Ground_Pin	319590.563	207502.753	361.370	01/28/2016 14:54:11	0.011	0.019	0.022
P10	Existing Steel Ground_Pin	319626.107	207472.805	345.905	01/28/2016 15:14:18	0.020	0.041	0.046
P11	Existing Steel Ground_Pin	319645.266	207461.900	336.381	01/28/2016 15:18:30	0.013	0.020	0.024
SCAR	Back_Scar	319673.093	207469.789	324.742	01/28/2016 15:28:36	0.009	0.016	0.018
SCAREDGE	Back_Scar	319675.115	207466.592	324.438	01/28/2016 15:29:43	0.010	0.017	0.020
SCARP	Back_Scar	319633.932	207489.024	339.880	01/28/2016 15:11:11	0.011	0.020	0.023
SCARP1	Back_Scar	319634.601	207486.145	340.119	01/28/2016 15:11:58	0.013	0.023	0.027
SEEPAGE	SEEPAGE	319511.656	207619.604	390.442	01/28/2016 12:27:47	2.155	3.599	4.195
SP1	Scan_Position1	319768.476	207538.046	293.233	01/28/2016 15:54:46	0.011	0.017	0.020
TC1	Tension_Crack	319483.414	207665.341	405.159	01/28/2016 12:25:13	0.848	2.421	2.566
TP1	Tie_Point1	319790.720	207491.724	288.314	01/28/2016 15:50:56	0.011	0.017	0.020
TP2	Ground_Marker	319761.074	207544.969	293.477	01/28/2016 16:01:00	0.014	0.021	0.025
TP3	Top_Corner_of_CattleFeeder	319765.607	207528.087	293.549	01/28/2016 16:04:28	0.009	0.014	0.016

Survey 2 - 4 MAR 2016

Point_Id	Easting (x2)	Northing (y2)	Orth_height (z2)	Quality_Horiz_pos_M	Quality_hgt_pos_M	Quality_pos_and_hgt_comb_M
P1_2	319321.048	207499.331	518.471	0.007	0.012	0.014
P2_2	319504.351	207546.19	404.002	0.008	0.019	0.021
P3_2	319519.934	207553.953	397.781	0.009	0.016	0.019
P4_2	319545.174	207550.202	387.738	0.008	0.013	0.015
P5_2	319590.541	207502.74	361.396	0.005	0.005	0.007
P6_2	319554.384	207548.627	382.459	0.010	0.013	0.016
P7_2	319569.298	207558.999	373.038	0.011	0.015	0.019
P8_2	319593.534	207488.239	359.45	0.009	0.012	0.015
P9 (not surveyed)						
P10_2	319626.148	207472.804	345.896	0.008	0.011	0.014
P11_2	319645.325	207461.899	336.4	0.009	0.012	0.015
OSBM11722 (OS marker)	319321.048	207499.331	518.471	0.0075	0.0145	0.014
P14_2	319594.851	207479.043	359.107	0.0099	0.0122	0.016
P15_2	319609.893	207478.107	351.073	0.0093	0.0123	0.015
SPRING WATER SAMPLE	319624.83	207503.036	345.386	0.0104	0.0153	0.019
WEST SIDE PIN2	319440.028	207971.393	395.554	0.0097	0.0208	0.016
WEST SIDE PIN	319358.145	208016.844	421.876	0.0068	0.0141	0.023

Survey 3 - 8 APR 2016

Point Id	Date/Time	Easting	Northing	Ortho. Hgt.	Posn. Qlty	Hgt. Qlty	Posn. + Hgt. Qlty
debrisedge	04/08/2016 12:24	319736.4356	207545.2239	296.4098	0.0084	0.0118	0.0145
breakinfence	04/08/2016 12:21	319706.9736	207551.8358	309.9416	0.0068	0.0101	0.0122
tree	04/08/2016 12:16	319696.8695	207586.3967	311.5128	0.5488	0.6472	0.8486
spring	04/08/2016 12:15	319698.1855	207576.2276	311.0391	0.0085	0.0121	0.0148
p11 3	04/08/2016 12:13	319687.5611	207576.3496	315.0635	0.0081	0.0124	0.0148
old scar	04/08/2016 12:12	319682.6420	207573.8609	316.7746	0.0065	0.0102	0.0121
edgeofdebris4	04/08/2016 12:09	319671.2918	207565.0244	323.9663	0.0074	0.0117	0.0138
edgeofdebris3	04/08/2016 12:07	319648.3770	207560.4250	335.3361	0.0072	0.0120	0.0140
edgeofdebris2	04/08/2016 12:05	319637.6885	207563.3096	338.9578	0.0072	0.0121	0.0141
edgeofdebris	04/08/2016 12:02	319630.2181	207568.7106	342.7958	0.0082	0.0132	0.0156
side scarp	04/08/2016 11:59	319622.2436	207565.6829	349.5052	0.0080	0.0134	0.0156
old pin	04/08/2016 11:58	319618.1491	207565.0999	350.7566	0.0065	0.0107	0.0125
spring at toe	04/08/2016 11:55	319607.8401	207572.2739	352.2191	0.0068	0.0117	0.0135
buldozed toe	04/08/2016 11:54	319604.0033	207579.4918	353.7162	0.0069	0.0118	0.0137
main side scar	04/08/2016 11:50	319598.2171	207572.5501	357.5563	0.0058	0.0103	0.0118
main back scar	04/08/2016 11:47	319557.0631	207573.5567	379.4337	0.0045	0.0048	0.0066
scar	04/08/2016 11:36	319554.7589	207549.1606	382.2251	0.0091	0.0154	0.0179
p6 3	04/08/2016 11:35	319554.3882	207548.6376	382.4519	0.0077	0.0128	0.0150
MAIN BACK SCAR	04/08/2016 11:34	319553.5704	207558.8713	380.9431	0.0077	0.0122	0.0144
P07 3	04/08/2016 11:32	319569.2975	207558.9825	373.0187	0.0081	0.0124	0.0149
main BACK SCAR	04/08/2016 11:30	319560.1036	207578.6806	377.3082	0.0073	0.0116	0.0138
main side scarB	04/08/2016 11:29	319566.1848	207578.2994	374.5495	0.0072	0.0122	0.0142
main side scar T	04/08/2016 11:29	319566.1626	207578.3021	374.5558	0.0085	0.0135	0.0160
minor scarb	04/08/2016 11:21	319594.9968	207560.5246	359.9200	0.0103	0.0180	0.0208
minor scar	04/08/2016 11:19	319593.3343	207551.6437	361.2155	0.0246	0.0087	0.0261
p08 3	04/08/2016 11:10	319593.5070	207488.2375	359.4346	0.0104	0.0169	0.0198
p14 3	04/08/2016 11:07	319594.8466	207479.0178	359.1022	0.0091	0.0142	0.0168
p10 3	04/08/2016 11:01	319626.1578	207472.7988	345.9110	0.0077	0.0121	0.0143
basebackscarp	04/08/2016 10:54	319577.4647	207517.6624	366.5806	0.0104	0.0163	0.0193
p9 3	04/08/2016 10:48	319590.5441	207502.7555	361.3812	0.0086	0.0144	0.0168
sideofmainscarp	04/08/2016 10:45	319582.1769	207508.4141	366.6948	0.0077	0.0131	0.0152
mainbackscarp	04/08/2016 10:43	319569.3012	207512.0969	375.1603	0.0069	0.0116	0.0134
lowerbackscarp	04/08/2016 10:38	319568.2856	207488.3656	375.7016	0.0065	0.0116	0.0133
tensioncrack	04/08/2016 10:34	319554.8138	207499.5045	383.7432	0.0084	0.0140	0.0163
newbackscarp5	04/08/2016 10:33	319554.3885	207496.1571	384.0027	0.0084	0.0156	0.0177
newbackscarp4	04/08/2016 10:31	319550.1692	207504.7669	383.6965	0.0081	0.0149	0.0170
newbackscarp3	04/08/2016 10:29	319548.5248	207513.4911	385.3612	0.0070	0.0132	0.0149
newbackscarp1	04/08/2016 10:28	319541.0854	207516.7783	388.1683	0.0071	0.0132	0.0150
newbackscarp	04/08/2016 10:27	319537.8589	207520.6375	389.5351	0.0082	0.0144	0.0166
oldbackscarp	04/08/2016 10:25	319516.3233	207519.6473	399.2703	0.0069	0.0129	0.0147
p5 3	04/08/2016 10:21	319532.0316	207521.3639	393.4222	0.0078	0.0145	0.0164
p4 3	04/08/2016 10:16	319545.1564	207550.1820	387.7358	0.0073	0.0136	0.0154
p3 3	04/08/2016 10:14	319519.9330	207553.9391	397.7976	0.0078	0.0157	0.0175
p2 3	04/08/2016 10:05	319504.3292	207546.1841	403.9969	0.0079	0.0152	0.0171
P1 3	04/08/2016 09:20	319321.0226	207499.3410	518.4693	0.0089	0.0148	0.0173
OSBM11722 3	04/08/2016 08:58	318716.3854	208490.1958	551.0954	0.0067	0.0097	0.0118