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Aerial Photograph Interpretation of landslides on the Sheffield Sheet

Physical Hazards Programme

Open Report OR/08/019

BRITISH GEOLOGICAL SURVEY

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Aerial Photograph Interpretation of landslides on the Sheffield Sheet

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Summary

This report describes an interpretation of aerial photographs carried out as part of a survey of landslides in the area covered by British Geological Survey 1:50 000 sheet 100 (Sheffield). The difficulties associated with mapping landslides in an area of extensive residual and mass movement deposits are also discussed.

1 Introduction

This aerial photograph interpretation was carried out to compliment BGS field surveys undertaken in the area around Sheffield between 2005 and 2006. Although this survey forms part of an ongoing investigation into landslides in the region around Sheffield (The Dark Peak and Pennine Fringe), the spatial extent of the survey described by this report is constrained to the extents of the 1:50 000 British Geological Sheet 100 (Sheffield), (Figure 1).

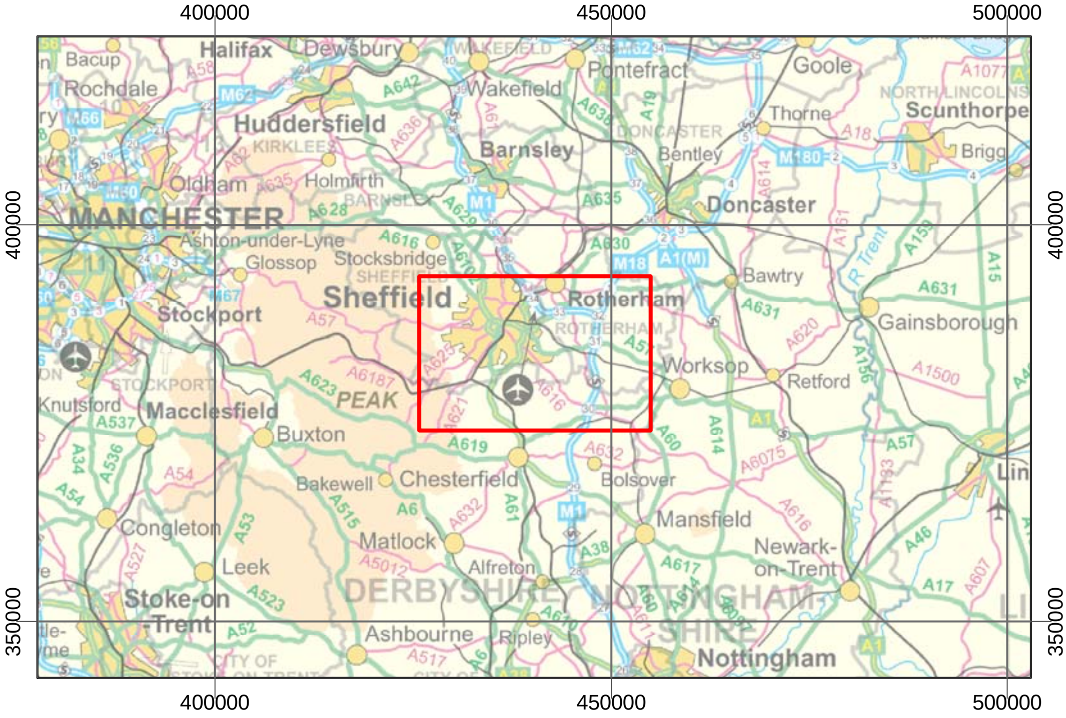

Figure 1: Location and extent of Sheffield sheet

2 Sheffield landslide environment

2.1 LANDSLIDE SUSCEPTIBILITY

Prior to aerial photograph interpretation, the BGS GeoSure Landslide Hazard Dataset (Version 2) was interrogated and a map showing GeoSure ratings for the Sheffield sheet was produced (Figure 2). The aim of this stage of the investigation was to highlight areas that may have concentrations of landslides, which would warrant more detailed attention during the aerial photograph interpretation. The Geosure map showed that in the east of the sheet the geology and topography were not favourable toward producing conditions for landsliding. The flat topography and strong lithologies (limestones) produced low susceptibility scores on Geosure (mainly B). In the west of the sheet a topography of incised valleys and steep slopes combined with relatively weak lithologies such as the Pennine Coal Measures and Millstone Grit to produce higher susceptibility scores (C and D).

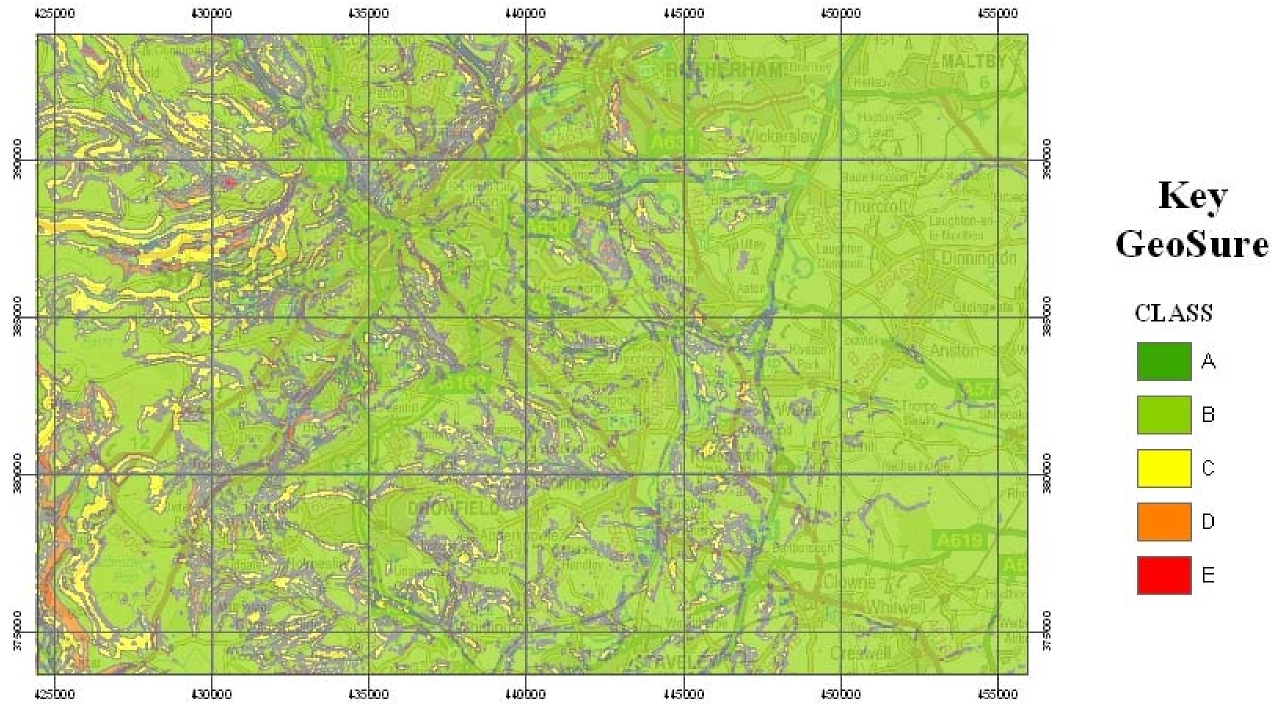

Figure 2: GeoSure v2, Landslide Susceptibility ratings for the area covered by the Sheffield Sheet. Susceptibility to landslide processes are described by ratings A (very low susceptibility) to E (very high susceptibility).

2.2 GEOLOGY AND GEOMORPHOLOGY

The Upper Carboniferous Millstone Grit Group and Pennine Coal Measures Group dominate the geology of the region with some Permo-Triassic (Cadeby Formation) material outcropping in the east (Figure 3). The rocks of the Sheffield sheet generally dip eastward at a low angle with the oldest formations outcropping in the furthest west of the sheet. The Namurian Millstone Grit Group comprises an alternating sequence of weak to moderately strong shales and moderately strong to strong sandstones. Sandstones dominate the Millstone Grit Group although it is underlain by Namurian mudstones of the Edale Shale Group (previously stratigraphically combined as the Millstone Grit Series, Aitkenhead *et al*., 2002). Resting conformably on the Millstone Grit and covering the majority of the Sheffield Sheet are the Westphalian Pennine Coal Measures Group. The outcrop, in places over 12 miles wide, comprises weak to strong, grey mudstones, siltstones, sandstones and coals (Aitkenhead *et al*., 2002). The Permo-Triassic Cadeby Formation unconformably overlies the Pennine Coal measures outcropping over an area of around 70km^2 on the Sheffield Sheet. The Cadeby Formation comprises weak to strong dolomitic limestone, marls and sands (Eden *et al*., 1957).

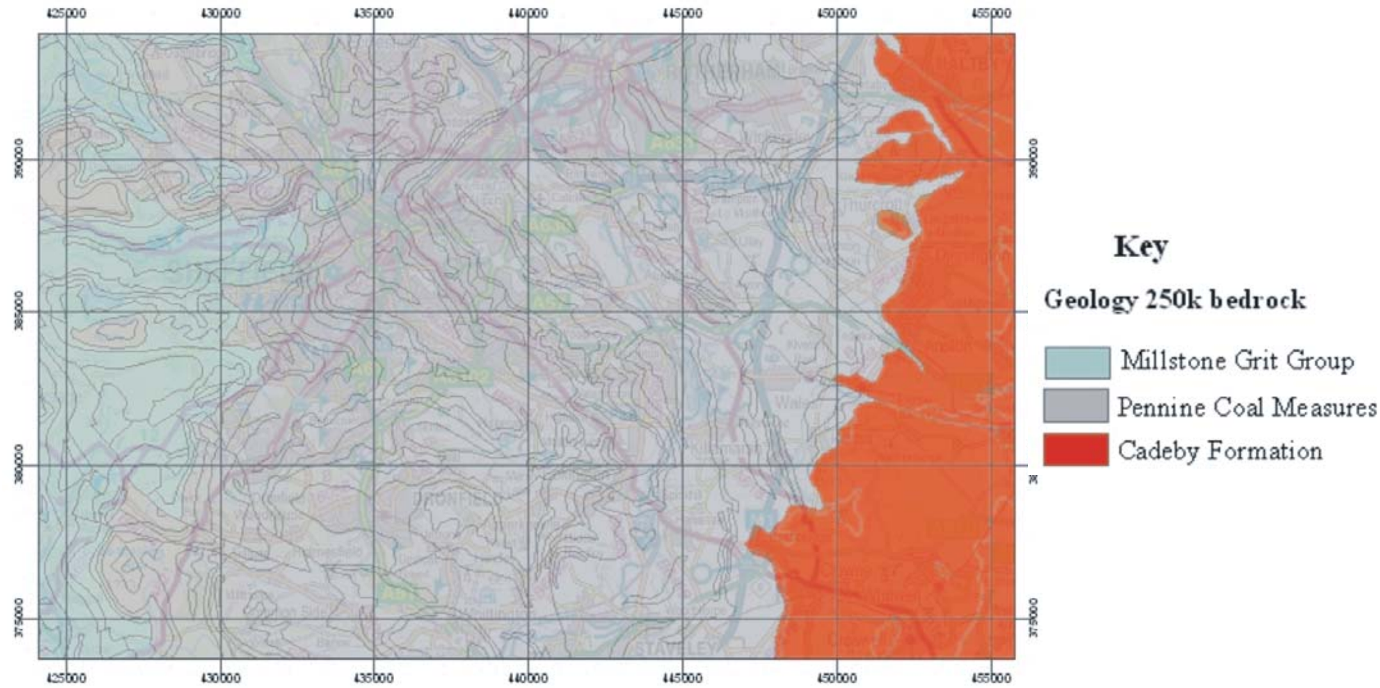

Figure 3: Generalised geology of the Sheffield sheet

In the western margins of the Sheffield sheet the Millstone Grit Group is deeply dissected by a number of rivers producing an incised topography that merges into a series of complex scarp and dip slopes (Figure 4). The Millstone Grit forms wide plateau areas that terminate in gritstone edges or cliffs up to 20 m in height. An elevation model produced from NEXTMap data demonstrates these geomorphological features (Figure 4).

The Pennine Coal measures form a dissected plateau that dips toward the east. The sandstone beds within the Pennine coal measures are thinner and thus form less steep scarp slopes than those of the Millstone Grit (Figure 5). East of the River Rother the Pennine Coal Measures are less dissected and the Cadeby formation forms a plateau like dip slope (Eden *et al.*, 1957). The topography and terrain is much more subdued in this section of the Sheffield Sheet and there are no steep escarpments or valleys as on the other geological formations (Figure 6). The area within the Sheffield sheet lies outside the Devensian glacial maximum but was subject to periglacial conditions leading to the formation of Head deposits through solifluction and other mass movement processes. Landsliding across the Pennines was commonly triggered at the end of the Devensian during a period of ice withdrawal (Aitkenhead, 2002). Oversteepened slopes became unstable and a phase of landsliding was initiated. However, since the Sheffield sheet lies south of the Devensian ice limits and this is therefore not a likely cause of landsliding in the present study area.

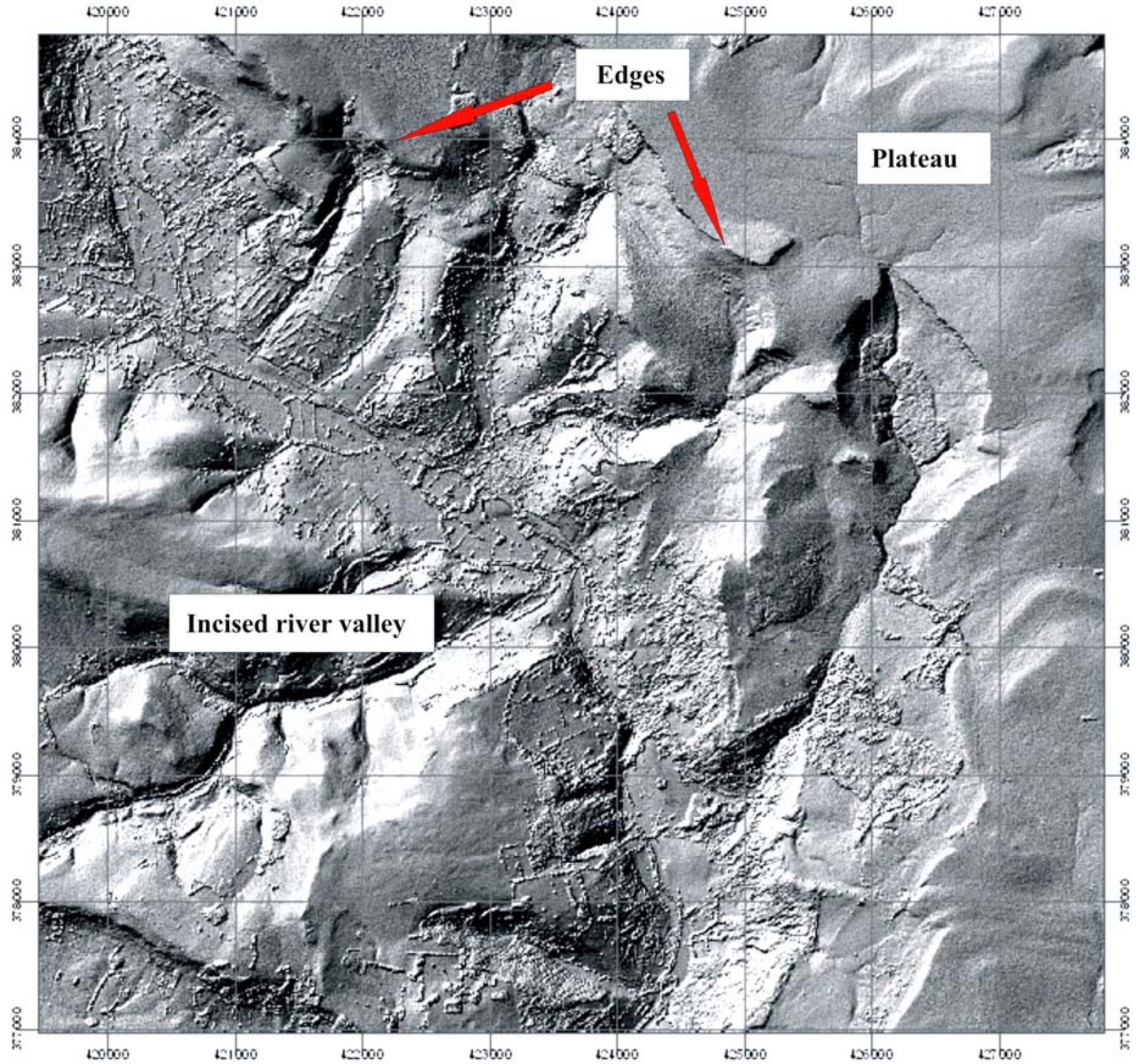

Figure 4: Topography associated with the Millstone Grit Group. The image was produced from NEXTMAP data. NEXTMAP is a digital terrain model captured at a 5m resolution using airborne radar technology.

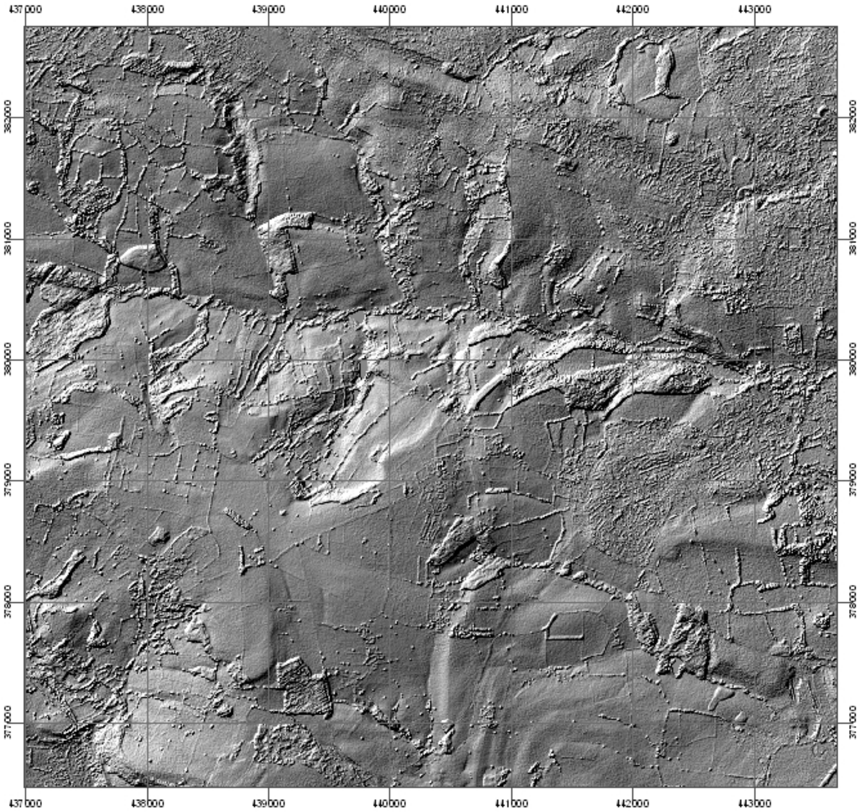

Figure 5: Topography associated with the Pennine Coal Measures (Image taken from NEXTMAP digital terrain model.)

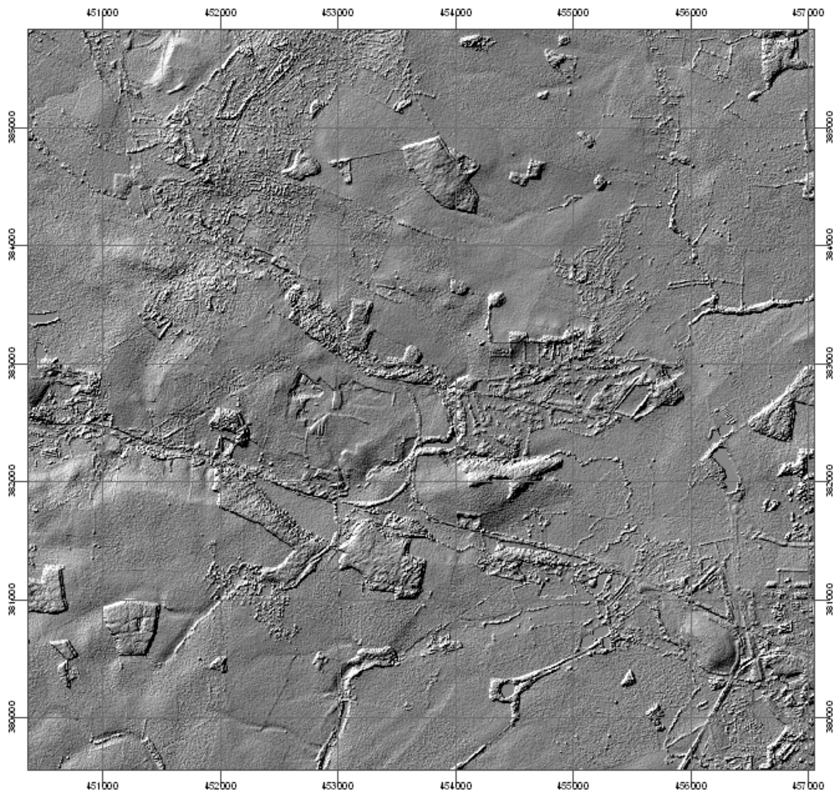

Figure 6: Topography associated with the Cadeby dolomitic limestone Formation (Image taken from NEXTMAP digital terrain model.)

3 Remote Sensing

Remote sensing involves obtaining information about the ground surface without having any contact with it, commonly using aerial photographs, satellite and radar images (Mantovani *et al.*, 1996). In this study aerial photographs were used to investigate the presence, morphology and distribution of landslides in the Sheffield area.

3.1 AERIAL PHOTOGRAPH INTERPRETATION

Aerial photograph interpretation is a basic component of any office based geomorphological investigation. Originally developed to map topography, aerial photographs are now a key component of modern site investigations for engineering projects (BS5930:1999). The use of aerial photographs has developed so that terrain features can be mapped directly including presence of rock outcrops, river and streams, springs, thickness of weathering grade and minor rock structures (Lawrance *et al.*, 1993).

Aerial photographs are useful in the production of landslide inventories because the distinct morphology created by landslides is readily identifiable (Mantovani *et al.*, 1996). Aerial photographs show up surface morphology including hummocky terrain, arcuate scarps and tension cracks (Mason and Rosenbaum, 2002). Changes in vegetation and disrupted drainage are also visible in aerial photographs and are equally important to the mapping of instability (Table 1). At a scale of 1:10,000 aerial photographs can detect objects as small as 1.3 x 1.3m whilst at 1:50,000 the minimum detectable size increases to 7.5 m x 7.5 m (Tribe and Leir, 2004). During this investigation, stereo pairs of photographs were viewed and landslides recorded on a proforma as well as on 1:10,000 maps as appropriate.

3.2 AERIAL PHOTOGRAPHS

Three runs of photographs covered the Sheffield Sheet, a total of 74 photographs. The photographs were colour, taken at a scale of 1:25,000 and were flown by Infoterra. Most of the photographs were taken in October 1997 with one set taken in June 1995.

	Terrain features	Relation to slope stability	Photographic characteristics
Morphology	Concave/convex slope features	Landslide niche and deposits.	Concave/convex anomalies in stereo model.
	Hummocky terrain	Micro relief associated with shallow or retrogressive movement.	Course surface texture in contrast to surroundings.
	Back tilting of slope facets	Rotational movement.	Oval/elongate depressions with imperfect drainage.
Vegetation	Clearings in vegetation on steep slopes	Absence of vegetation on headscarp or on slide body.	Light toned elongate areas.
	Irregular linear clearances along slope	Slip surface of translational slide.	Denuded areas with light tones.
	Disrupted, disordered and partly dead vegetation	Slide blocks and differential movements in body.	Irregular sometimes mottled grey.
Drainage	Seepage and spring lines	Springs on front lobe and where failure plane outcrops.	Dark patches sometimes in curved pattern, enhanced by differential vegetation.
	Interruption of drainage pattern	Drainage anomaly caused by head scarp.	Drainage line abruptly broken off on slope by steeper relief.
	Areas with stagnated drainage	Landslide niche, back tilted block, hummocky relief on slide body.	Tonal differences with darker tones associated with wetter areas.

Table 1.1: Morphology of landslides detectable from aerial photographs (After Soeters and van Westen, 1996).

4 Landslides

A simple and widely used definition of a landslide is that of Varnes' (1978):

"*A downward and outward movement of slope forming materials under the influence of gravity*".

The International Geotechnical Societies' UNESCO Working Party on World Landslide Inventory (WP/WLI), initiated at the International Symposium on Landslides (Lausanne, 1988), produced a more recent definition of a landslide:

"*The movement of a mass of rock, earth or debris down a slope*" (Cruden, 1991).

Classification of landslides can be made on the basis of numerous factors including the type of movement occurring, the material involved, speed of movement, the geometry of the slide area and the degree of development (Figure 7). Commonly in the UK the landslide classification used is either Hutchinson (1968) or Varnes (1978), both of which use type of movement to establish groups of landslide classes (Crozier, 1986). The BGS uses modified versions of Varnes (1978) and Department of the Environment (1990) as the basis for its landslide classification (McMillan and Powell, 1999).

Typically there are three main mechanisms of landsliding: falls, slides and flows. Falls of material occur from a steep or free face and involve the movement of material under the force of gravity but do not involve sliding on a shear surface. Movement associated with falls involves the descent of material by falling, rolling and saltation (Griffiths, 2005). Slides occur on a definable shear surface and are further subdivided dependant on the shape of the shear surface into either rotational or translational failures. In flows the moving mass is composed of individual particles not coherent units or blocks of material. Movement involves continuous, irreversible deformation of material.

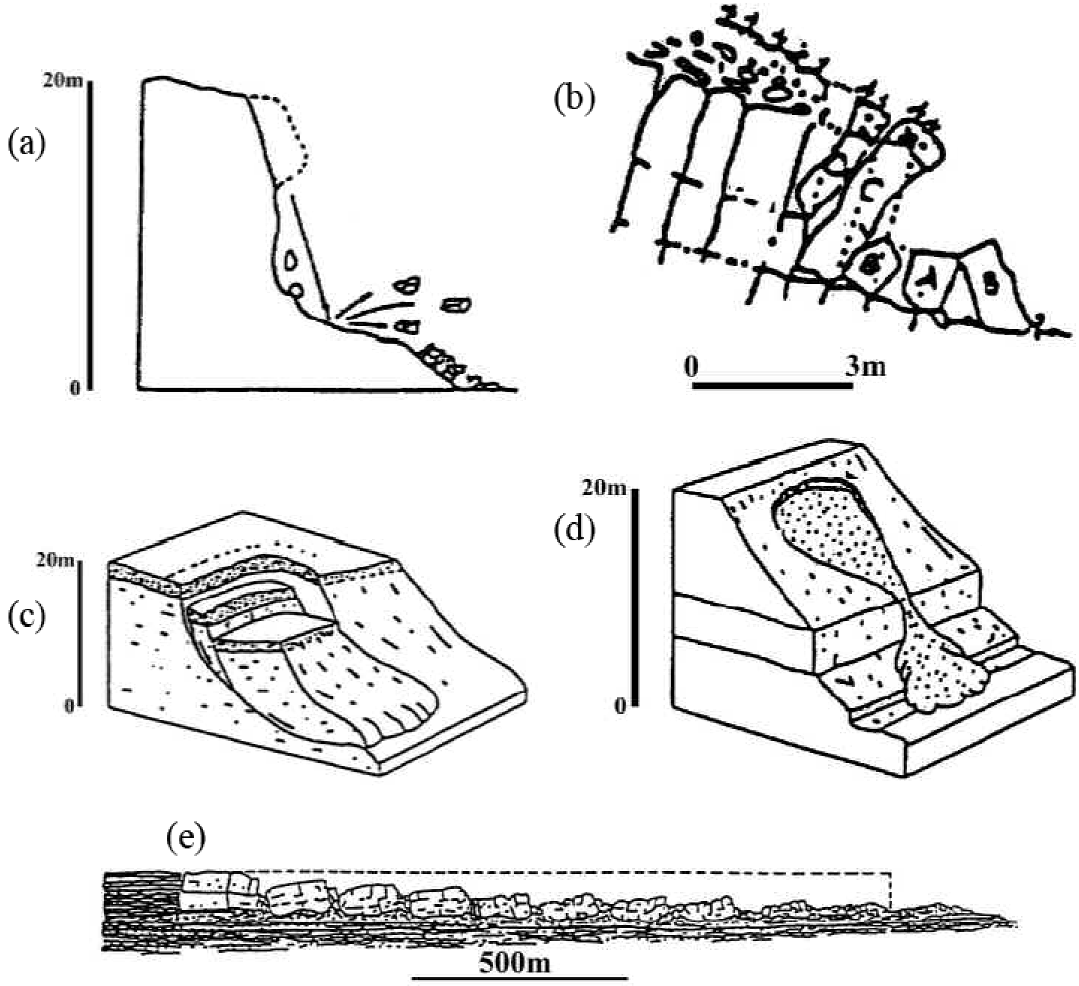

Figure 7: Five fold classification of landslide types modified from Varnes (1978).

A) Fall B) Topple C) Slide D) Flow E) Spread (after Cruden and Varnes, 1996).

4.1 KNOWN LANDSLIDE DISTRIBUTION

Prior to the current investigation 71 landslides were recorded, either on the IGS 1:50 000 Geological Map Sheet 100 (Sheffield) or in the BGS National Landslide Database. During the aerial photograph interpretation these recorded landslides were identified, verified and accurate grid references were recorded. Landslide records in the BGS National Landslide Database that were duplicates or could not be verified by this survey were removed from the database.

The distribution of landslides is concentrated in the west of the survey area, within the outcrop of the Millstone Grit Group (Figure 8). The Millstone Grit Group contains around 60% of the previously recorded landslides within the Sheffield Sheet (Figure 9). The landslide in the Cadeby Formation is within a railway cutting and as such the slope has been artificially steepened (Location A, Figure 8). Over 35% of the landslides occurred in the Pennine Coal measures, with most occurring within the Lower Coal Measures in the west of the sheet (Figure 9).

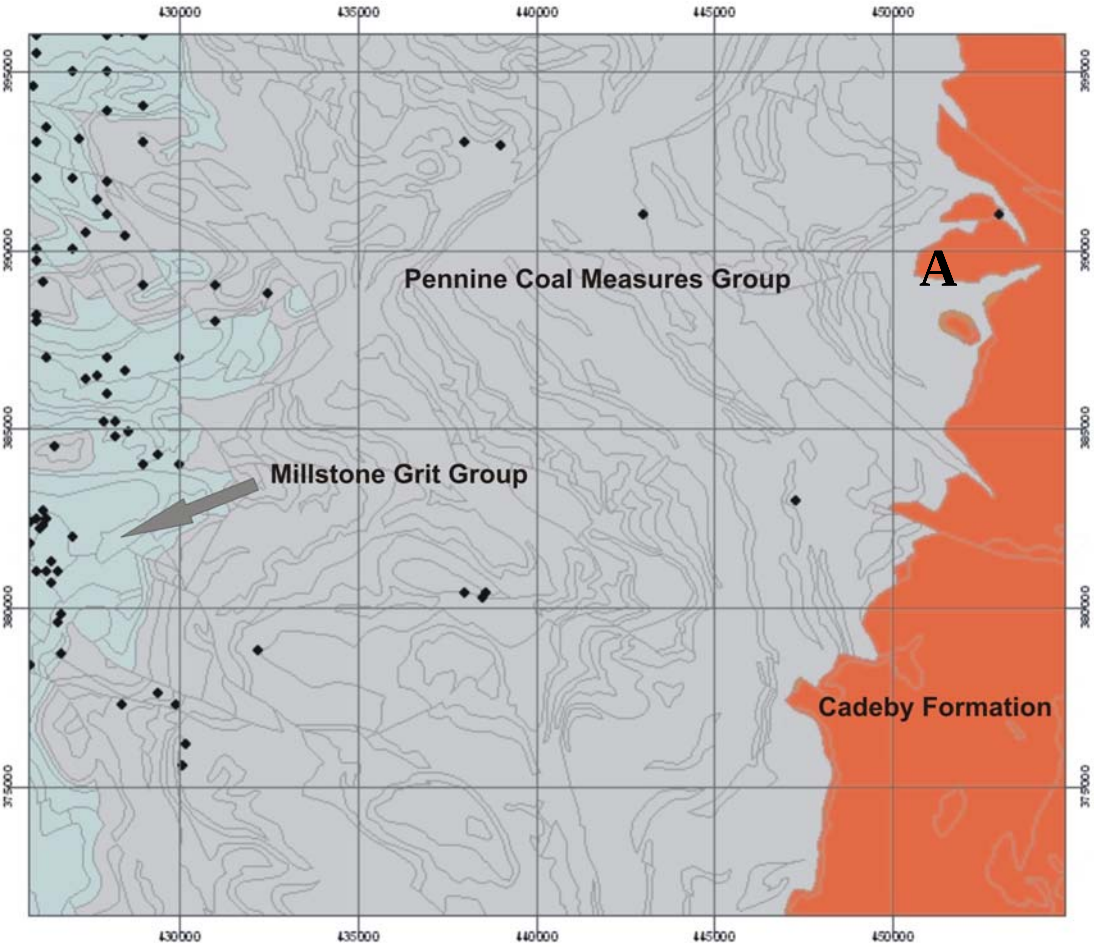

Figure 8: Distribution of known landslides in Sheffield as recorded in the BGS National Landslide Database.

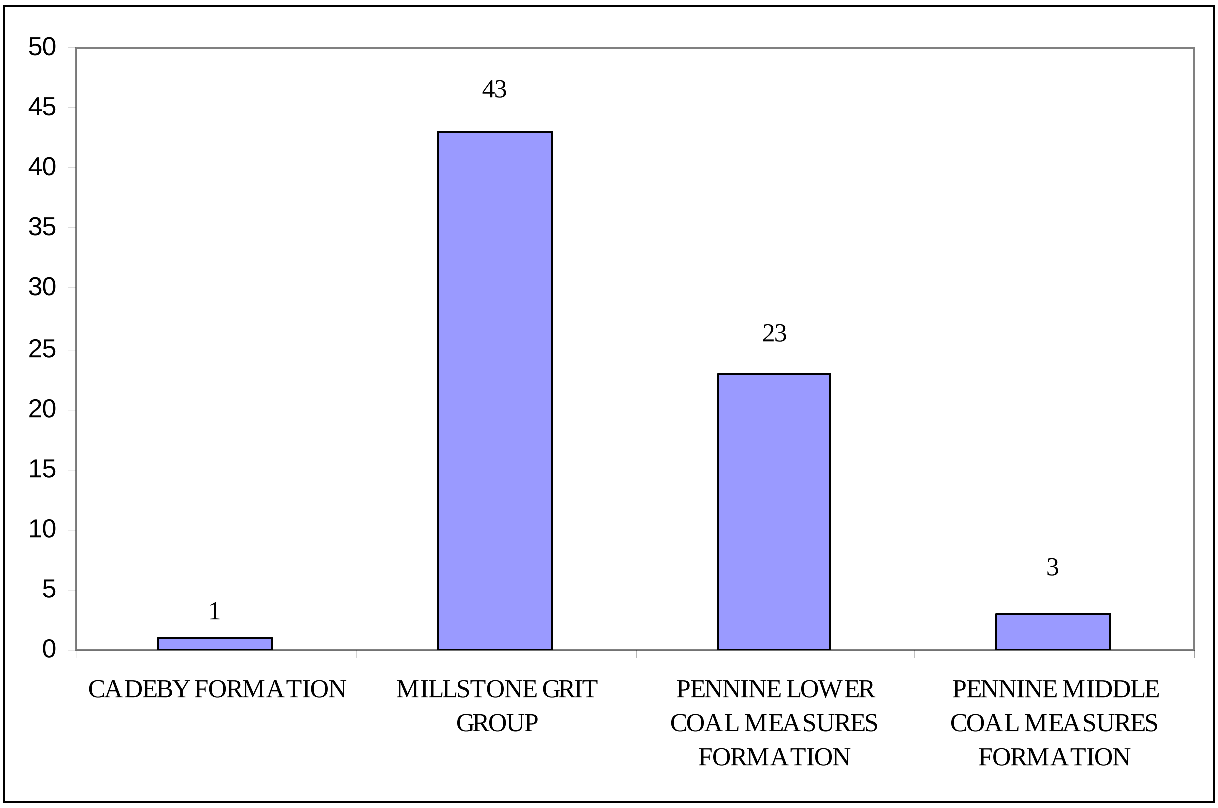

Figure 9: Graph representing the number of landslides occurring in geological formations and groups on the Sheffield Sheet.

4.2 LANDSLIDE MAPPING

Difficulties arose during the mapping of landslide deposits in the Sheffield area due to the extensive cover of mass movement deposits including Head and talus. As defined by McMillan and Powell (1999) there are four types of mass movement deposit: Landslip, Talus, Head and Dry valley deposits. Head deposits commonly form hummocky ground and lobate features and are most extensive outside of the Devensian glacial limits. The formation of Head deposits is through solifluction of material downslope by a process of freeze-thaw and gelifluction. Head deposits are not recorded as landslides under the WLI convention or BGS Mapping Guidelines. In agreement with the BGS team responsible for mapping the geology of this area, it was agreed that only those landslides, with a discernable back scar and a zone of deposition should be considered as mappable units. In other words, only those landforms that an experienced member of staff could, with reasonable confidence attribute to the process of landsliding should be termed landslide. Mass movement deposits where the origin of the feature or deposit could not be attributed to landslide processes were not termed landslides (this is likely to include some areas where landslides have taken place but where the deposit and landform have been significantly reworked). Bouldery deposits on low angled slopes within Chatsworth House were defined as Head (Figure 10). Lobes were distinguishable in some areas of the bouldery head, which proved to be extensive in some areas of the Millstone Grit ‘edges’. As well as mapping new landslides work was carried out to ensure all the database points on the Sheffield corresponded to the appropriate mapped landslide deposit. In some instances this involved checking references, using aerial photographs as well as field checking. An example of previously mapped landslide deposits and database entries is shown in Figure 12.

Figure 9: Solifluction lobes (mass movement) and blocks below Millstone Edge (SK248380).

Figure 10: Bouldery Head deposits on a low angle slope (SK 270718)

Figure 11: Aerial photograph (37 97 281) showing an area just west of Sheffield. The squares indicate the areas shown in 12.

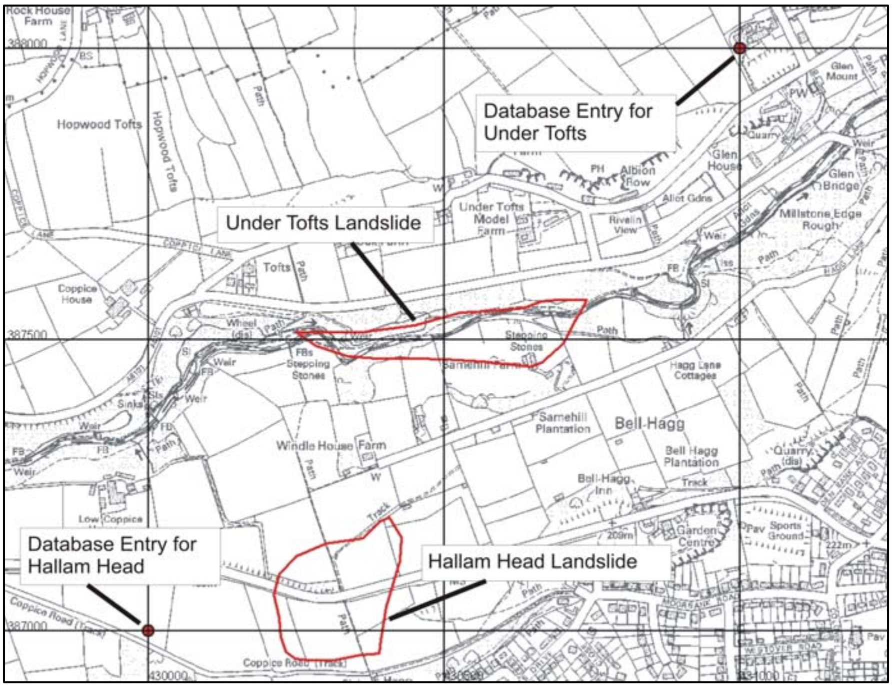

Figure 12: A section of 1:10,000 map showing areas of landsliding and wrongly positioned data points from the National Landslide Database. The black polygons are previously mapped landslides.

5 Results

Large-scale landslides, which were known to exist in the area around Baslow and Chatsworth House, were difficult to delineate using aerial photographs due to the presence of thick vegetation and superficial deposits. These failures occurred in the far west of the sheet on the Millstone Grit sequence. It was decided that the best way to delineate the back scar and extent of the landslide deposits was by means of a walk over survey. The results of the walkover survey are present separately along with an analysis of the data collected.

Areas of small-scale landsliding were compared to field slips provided by the field mappers. Approximately 15 new landslides were mapped as part of the aerial photograph interpretation of the Sheffield Sheet whilst 24 of the previously recorded landslides were removed.

6 Conclusions

Large-scale landslides are common where strong competent rocks, such as the Millstone Grit, are underlain by less competent rocks. Landslides also commonly occurried on the boundary between mudstones and sandstones of the Pennine Lower Coal Measures. There was also evidence of shallow translational movements within these two formations. Conclusions

The Sheffield sheet is characterised by low relief Permo-Triassic Limestone areas with limited numbers of landslides. Landsliding becomes more widespread further west on the sheet. Large scale deep seated landslides are common on the Millstone Grit Group, which fits the national trend as the Millstone Grit has a high density of landsliding within the UK. Figures from the National Landslide Database report a density of 26.6 landslides per 100 km^2 for the Namurian Millstone Grit. In this study a density of 79 landslides per 100 km^2 was calculated. This increased density was a result of a large number of landslides concentrated in a small area of Millstone Grit. The Pennine Coal Measures have less incidence of landsliding, although figures from the National Landslide Database suggests that the Upper sections of the Pennine Coal Measures Group can have a higher density of landsliding than the Millstone Grit at 31.1 landslides per 100 km^2. The figure for Sheffield was much less because of the more subdued topography of the Pennine Coal Measures, although shallow rotational and translational landslides were more common on the Pennine Coal Measures than other formations.

7 Recommendations for Survey

Field surveys will take place in order to check landslides identified within this study as well as to validate some landslides from the National Landslide Database. In particular work will be focussed on the Millstone Grit Edges in the west of the sheet in the Curbar and Chatsworth areas.

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.

AITKENHEAD, N, BARCLAY. W. J., BRANDON, A., CHADWICK, R. A., CHISHOLM, J. I., COOPER, A. H. AND JOHNSON, E. W. 2002. British Regional Geology: *The Pennines and adjacent areas* (Fourth Edition). British Geological Survey. Nottingham.

BRITISH STANDARDS BS5930:1999. *Code of practice for site investigations*. British Standards Institute.

CROZIER, M. J. 1986. *Landslides: causes, consequences and environment*. Routledge, London-New York.

CRUDEN, D.M. 1991. A simple definition of a landslide. Bulletin International Association of Engineering Geology, 43: 27–29.

CRUDEN D.M., VARNES, D. J. (1996) - Landslide types and processes. In: Turner A.K.; Shuster R.L. (eds) *Landslides: Investigation and Mitigation*. Transport Research Board, Special Report 247, pp 36-75.

DEPARTMENT OF THE ENVIRONMENT (DOE). 1990. *Development on unstable land*. Planning Policy Guidance Note 14, Department of the Environment. London. HMSO.

EDEN, R. A., STEPHENSON, I. P. & EDWARDS, W. 1957. *Geology of the country around Sheffield*. Memoir of the Geological Survey of Great Britain Sheet 100.

GRIFFITHS J S, 2005. Landslides, (Chapter 8) In P G Fookes, G Milligan & E M Lee (eds.). *Handbook of Engineering Geomorphology.* Whittles; Caithness, 173-217

HUTCHINSON, J.N. 1968. Mass movement. In: *Encyclopaedia of Geomorphology Series III*. Reinhold. New York.

LAWRANCE, C., BYARD, R. AND BEAVEN, P. 1993. *Terrain evaluation manual*. HMSO, London, 285 pp

MANTOVANI, F., SOETERS, R. AND VAN WESTEN, C.J. 1996. Remote sensing techniques for landslide studies and hazard zonation in Europe. *Geomorphology*, 15: 213-225.

MASON, P AND ROSENBAUM, MS. (2002) Geohazard mapping for predicting landslides the Langhe Hills in Piemonte, NW Italy. *Quarterly Journal of Engineering Geology & Hydrology*, 35 (4), 317-326.

MCMILLAN, A.A. AND POWELL, J.P. 1999. BGS Rock Classification Scheme Volume 4. *Classification of artificial (man made) ground and natural superficial deposits- applications to geological maps and datasets in the UK.* British Geological Survey Research Report RR 99-04.

TRIBE, S. AND LEIR, M. 2004. The role of aerial photograph interpretation in natural hazard and risk assessment. *Proceedings of the International Pipeline Conference*, October 2004, Calgary, Alberta, Canada.

VARNES, D.J. 1978. Slope movements types and processes, Chapter 2 . In: Schuster, R.L. and Turner, R.J. (eds). *Landslides: Analysis and Control*. Transportation Research Board, National Academy of Sciences, Washington D.C., Special Report, No. 176.