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# The Scottish road network debris flow project: Contribution of the Geology and Landscape (Northern Britain) Programme

Information Products Programme

Internal Report IR/06/102

BRITISH GEOLOGICAL SURVEY

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INTERNAL REPORT IR/06/102

# The Scottish road network debris flow project: Contribution of the Geology and Landscape (Northern Britain) Programme

C A Auton



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Debris-flow Hazard Assessment, Scottish Road Network, NextMap.

*Bibliographical reference*

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# Foreword

This report outlines the methods applied by staff of the Geology and Landscape of Northern Britain (GNLB) Programme in contributing to the assessment of potential debris flow activity that may affect the Scottish trunk road network. This work was undertaken as part of an overall study by the British Geological Survey (BGS) commissioned by the Scottish Executive Transport Agency (Transport Scotland). The work was managed by Matthew Harrison of the Information Systems Programme. GeoSure50 and DigMap50 datasets formed the basis of the study, together with updates to the former provided by A Forster and A Gibson of the Physical Hazards Programme.

The work was undertaken in two phases. The first phase, completed by C A Auton in March 2006, involved modification of an assessment, provided by A Forster and C Foster, of categories of Bedrock, Superficial Deposits and Artificial Deposits indicating their susceptibility for debris-flow generation and also their properties as impermeable substrates upon which debris flows can develop in overlying strata. The second phase, completed in mid May 2006, involved the generation of new GIS layers for Superficial Deposits in areas of Scotland where existing DigMap50 data were known to be absent or inadequate. This work was undertaken by a team of GLNB staff (C A Auton, T Bradwell, S M Clarke, J Everest, N R Golledge, and J W Merritt) coordinated by N R Golledge and the outputs were approved by M Smith (GLNB Programme Manager).

The new GIS layers were generated in Arc9 by cartographic services staff at BGS Murchison House, under the direction of Stuart Horsburgh.

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# 1 Introduction

The British Geological Survey (BGS) was commissioned by Transport Scotland to provide an initial objective assessment of the causal and contributory factors in the generation of debris flows across the whole of Scotland These are listed in the Scottish Road Network Landslide Study (Winter *et al.*, 2005). All of the factors identified are valid inputs to an assessment of debris flow potential but many were not available for the whole of the country and were omitted from the assessment.

## 1.1 DATA SOURCES

Following a meeting of the steering committee of the Scottish debris flow hazard assessment project on Tuesday 14th February 2006, a version of the methodology produced by Harrison *et al.* (2006) was agreed as a basis for the first iteration of the assessment.

Five relevant data sources are available for the entire study area.

1. The BGS digital geological map (DigMap50 Bedrock, Superficial Deposits, Mass movement and Artificial Deposits).
2. NextMap (©Intermap Technologies)digital surface model
3. CEH land use data
4. GeoSure50 slope angle data
5. The Met. Office rainfall data.

A conclusion of the steering committee was that intense rainfall could occur anywhere in Scotland and it was not a factor that should be considered by BGS.

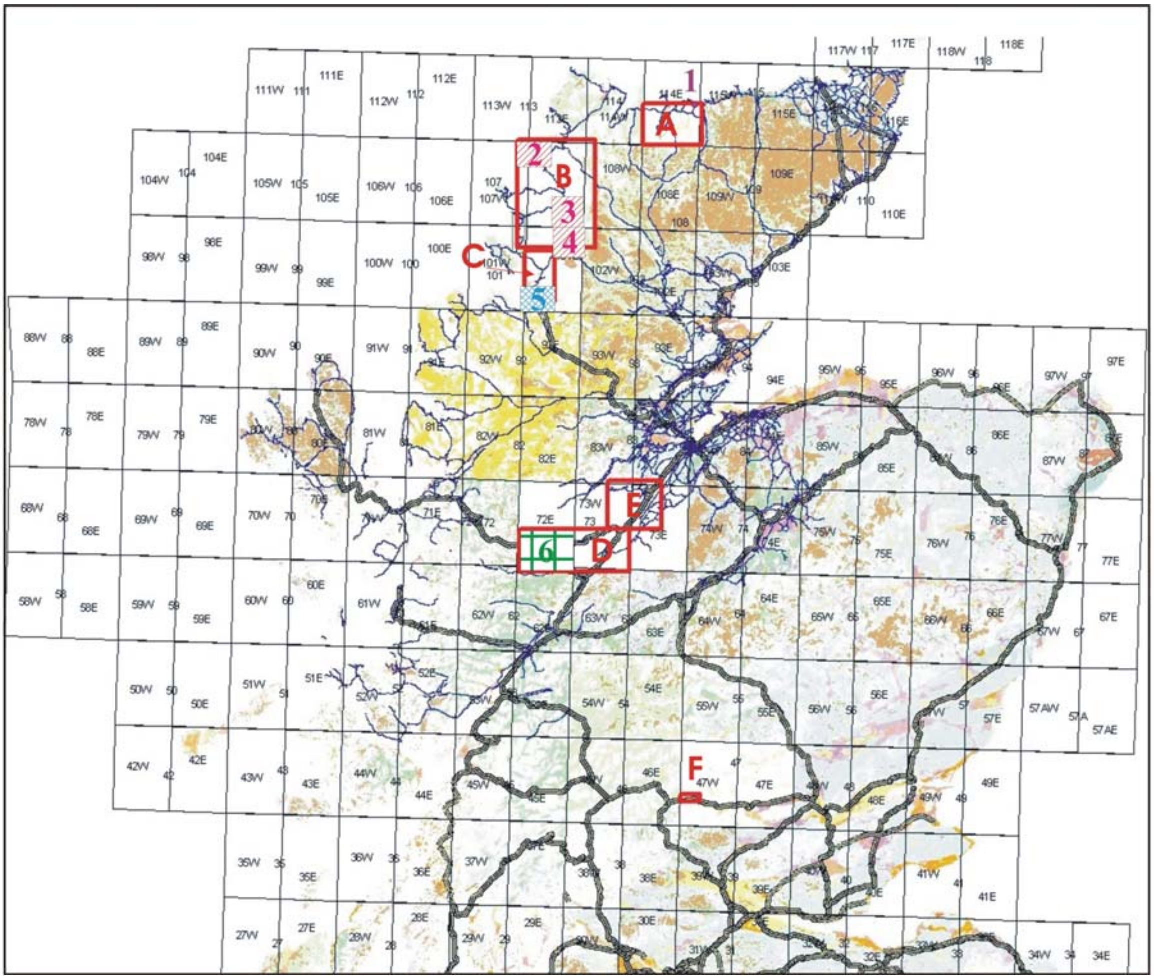
## 1.2 AIMS

The aim of Phase 1 of the study was to identify areas that are likely to have a significant potential for debris flow generation that could impact on the Scottish road network. Consequently, the areas under investigation (the ‘area of interest’) was trimmed to a buffered corridor along major roads. Using GeoSure50 data, slope angle was integrated with combined strength and permeability characteristics, of identified types of bedrock and superficial deposits, with the aim of indicating the likelihood of debris-flow development during a heavy rainfall event (for a given slope, on a given substrate).

### 1.2.1 Implications for the project aims, evident during the Phase 1 study

It was known that DigMap50 data, particularly for the Superficial (Quaternary) deposit cover in some parts of the Scottish Highlands was inadequate for characterising the distribution of surface lithologies. Therefore, establishing their propensity for the development of debris flows throughout this part of Scotland could only be achieved in some places. It also became clear, during the initial phase of work that several of the most notable sites of recent debris-flow activity fell within these areas of inadequate Quaternary data coverage.

A meeting held between Matthew Harrison and Transport Scotland staff in January 2006, agreed an extension to the original contract, with the aim of providing new geological data that could be added to fill in gaps (shown in the areas outlined in red on Figure 1) in the areas of ‘adequate’ Quaternary coverage. This Phase 2 study, would include desk-studies and compilation of other sources of data to cover the ‘debris flow catchment boundary’ that encompassed the major roads of interest. The data would, of necessity, be at quite a simple level of attribution, but above what was currently available in DigMap 50 Version 2.




## Figure 1. Areas of Interest for Phase 2 study.

Cross-hatched boxes show areas of detailed geological mapping digitized in Option1; red outlined boxes show areas containing NextMap interpretation, digitized as Option 2.

# 2 Methods and results

## 2.1 PHASE 1

The methodology used for Phase 1 of the study followed that outlined in Harrison *et al*. ( 2006) and Appendix 1, and involved assigning values (scores) to the various lithologies encountered within the debris-flow catchments affecting major roads identified by Scottish Transport. This was achieved by scoring LEX_D units from the BGS combined Lithostratigraphical/Rock Description database that crop out within the 'catchments' (as shown on DigMap50) for their susceptibility to debris flow generation and also their permeability (which influences their potential to act as a substrate upon which debris flows may develop in overlying lithological units) based on their ROCK_D (rock description) lithology. A first pass was made by Engineering Geology staff at Keyworth and the subsequent dataset passed to C A Auton for amendments that were based on local knowledge of Scottish rock types.

### 2.1.1 Results

Some 580 different lithostratigraphy/lithology types were assessed for both their rock/soil type and their permeability; during a first iteration, completed in March 2006, the lithology scores were modified by C A Auton for 97 of the units. The principal changes included: increasing the debris flow susceptibility values for granites that are known to be locally deeply decomposed; decreasing the values of silty and clayey rocks forming raised marine features, and lake sediments which are known to be prone to slump failures, and are more sandy than their general lithological description would indicate; changing values of pelites and slaty pelites that are known to have a tendency to form Head deposits and Colluvium, but which is often un-recorded in the Dig Map50 data set. No changes were made to the permeability hazard values during the first iteration.

A second iteration of the lithology and permeability data was examined by C A Auton in May 2006, comprising some 3,706 rows of data. This examination involved confirming lithology scores assigned to all of the units and assigning lithology scores to 22 units that had had no score assigned during the first and subsequent versions of the dataset. It also involved reviewing all permeability scores and making alterations where necessary; some 190 permeability values were amended. The main changes required were assigning a consistent permeability value to all un-metamorphosed limestones (score 7; see Appendix 1) and amending the values for less pure metalimestones and other calcareous rocks; minor adjustments were also made to the permeability values given to some intrusive igneous rocks.

## 2.2 PHASE 2

Costing, staffing and scheduling of Phase 2 of this study took place in March 2006. A review of the Quaternary geological mapping available for the areas of interest identified by Transport Scotland was made by C A Auton (areas outlined in red, labelled A-F on Figure 1). It showed that several types and vintages of digital geological data were available for parts of the areas of interest (labelled 1-5 on Figure 1). These shaded areas are where digital Quaternary data could be produced from existing data sets that were available, or could be quickly sent to the Murchison House drawing office, or that were concurrently being produced by them. (This is high quality surveyed data that was the best available at the time of the contract. It was identified, and costed as 'option 1' for the customer). This data was of the following types:

> Area A~ Locality 1 (NE Sutherland) small-scale new mapping of minor part of coastal zone.

Area B ~ Localities 2, 3 and 4 (NW Highlands; red cross-hatch). Digital 1: 25 000 scale clean copies of new mapping completed and approved (but data not entered onto DiGMap50).

Area C ~ Locality 5 (NW Highlands; blue cross-hatch). 1: 25 000 scale new mapping that was being complied as a 1:25 000 scale digital clean copy in the Murchison House drawing office (but not yet entered onto DigMap50). This was prioritized within the drawing office work-flow so that a DigMap25 tile would be available well before the scheduled completion date of this new phase of the contract (end May 2006).

Area D Locality 6 (Glen Affric; green hatch) hand drawn 1:50 000 scale map compilation by J D Peacock based on 1: 10 000 scale mapping, undertaken in the 1970's-80's. This compilation was passed to the drawing office for compilation as a DigMap50 tile for the southern half of Sheet 72E. The remainder of Sheet 72E is being complied as a full DigMap50 during FY06-07; the Area D compilation will be incorporated within it later in the year.

This option (1) was costed as c 5 man days (geologist) and 36 man days (cartographic services). The procedure for capturing this data involved cartographic services staff converting existing Quaternary data to ArcMap 9.1 (©ESRI, 2005) format, capable of integration with the stand-alone dataset generated from the existing DigMap50. This was essentially a conversion and integration exercise, involving geologists in two stages of data validation, and in the generation of LexRock forms, so that the new polygons could be attributed. This exercise produced polygons and polylines covering Superficial, Artificial and Mass movement deposits, for the whole of the area of the shaded boxes.

A second option (option 2) was offered for the remainder (unshaded portions) of the areas of interest. A very simplified preliminary interpretation of the distribution of the principal Quaternary units (eg peat, fluvial deposits, raised beaches till, moraines, and bedrock near surface) within buffered 'potential debris flow catchments' in the unshaded areas of boxes A-F, would be made by experienced field geologists, using NextMap data overprinted on large scale topographic base maps.

The procedure was as follows:

1. Digital OS topographic bases with contours were compiled by cartographic services staff, to cover the ground within the unshaded areas (with a marginal overlap of 2 km width, to enable edge-matching to the existing DigMap50 and the adjoining option1 data sets).
2. A NextMap digital elevation model (DEM) was used to produce shaded relief models, tailored to cover the areas of each topographic map. This was produced by J Everest. The original DSM data, stored on the BGS San, was generated from a low-level radar survey of the ground surface for the whole of the UK. The data, which forms the basis for the DEM, has been mapped at 1m vertical and 5m horizontal resolution. Using ArcMap 9.1 the DEM was reinterpreted to produce a photorealistic hillshade model for each map, showing landscape and landform features at very high resolution. The construction of the hillshade model differed for each area. The illumination and vertical exaggeration of the topography was altered to best highlight relevant features of the ground surface, for its interpretation by the geologists.
3. Paper copies of each topographic base were produced by cartographic services with a semi-transparent overprint of the NextMap model and provided to a team of experienced geologists. Each printout was interpreted by a geologist using techniques analogous to those used in geological aerial photographic interpretation.

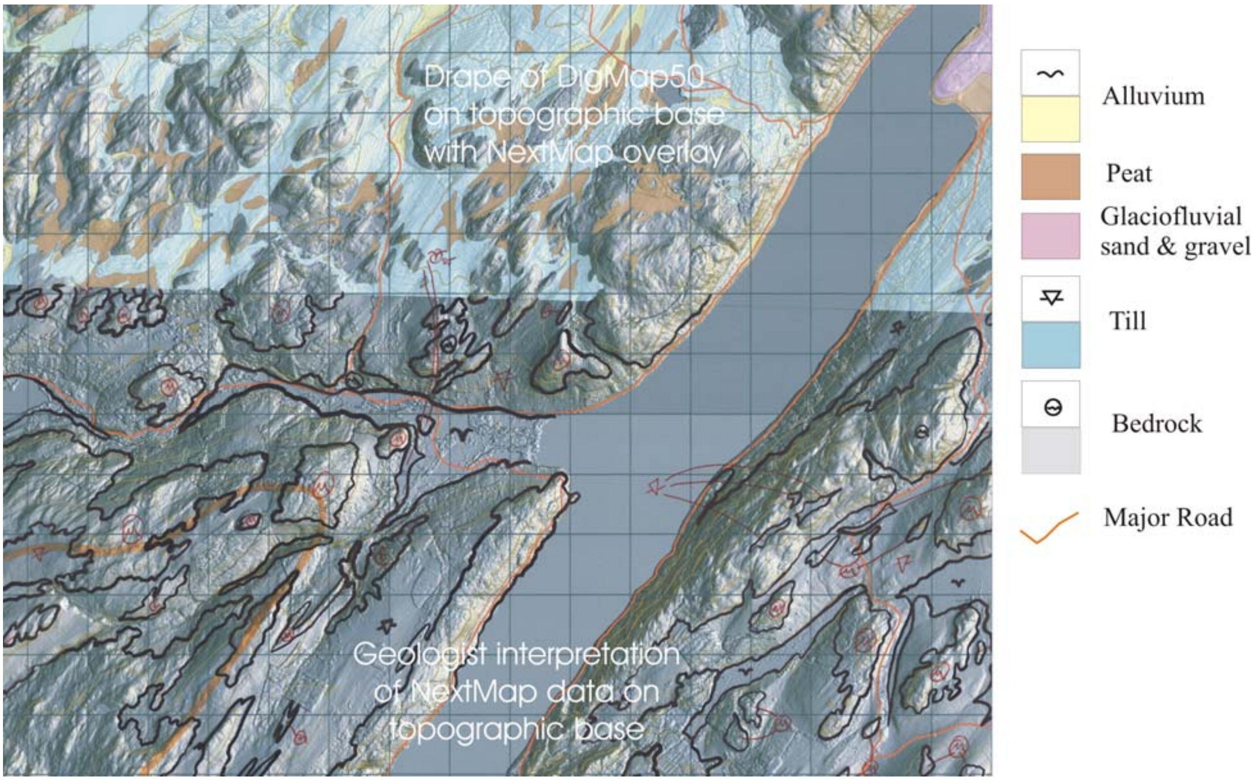



**Figure 2. Geologist interpretation of NextMap data; Foyers area.**

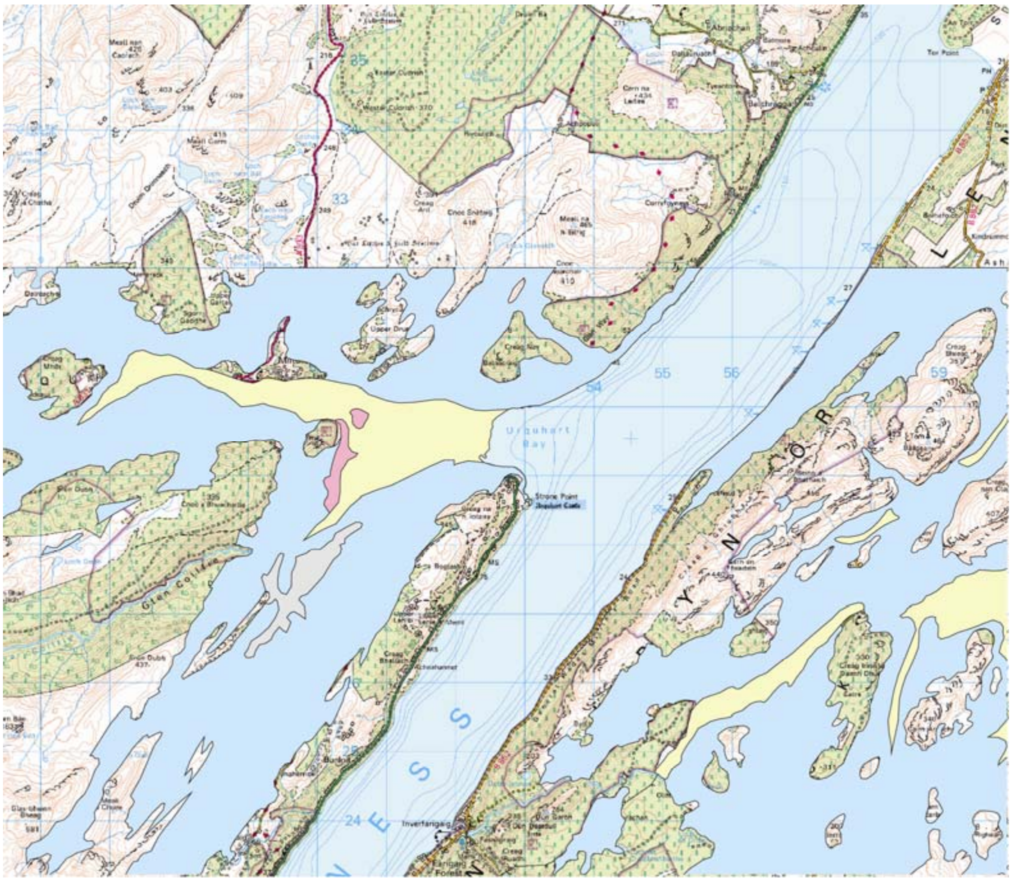


**Figure 3. Attributed polygons from Next Map interpretation, Foyers area.**

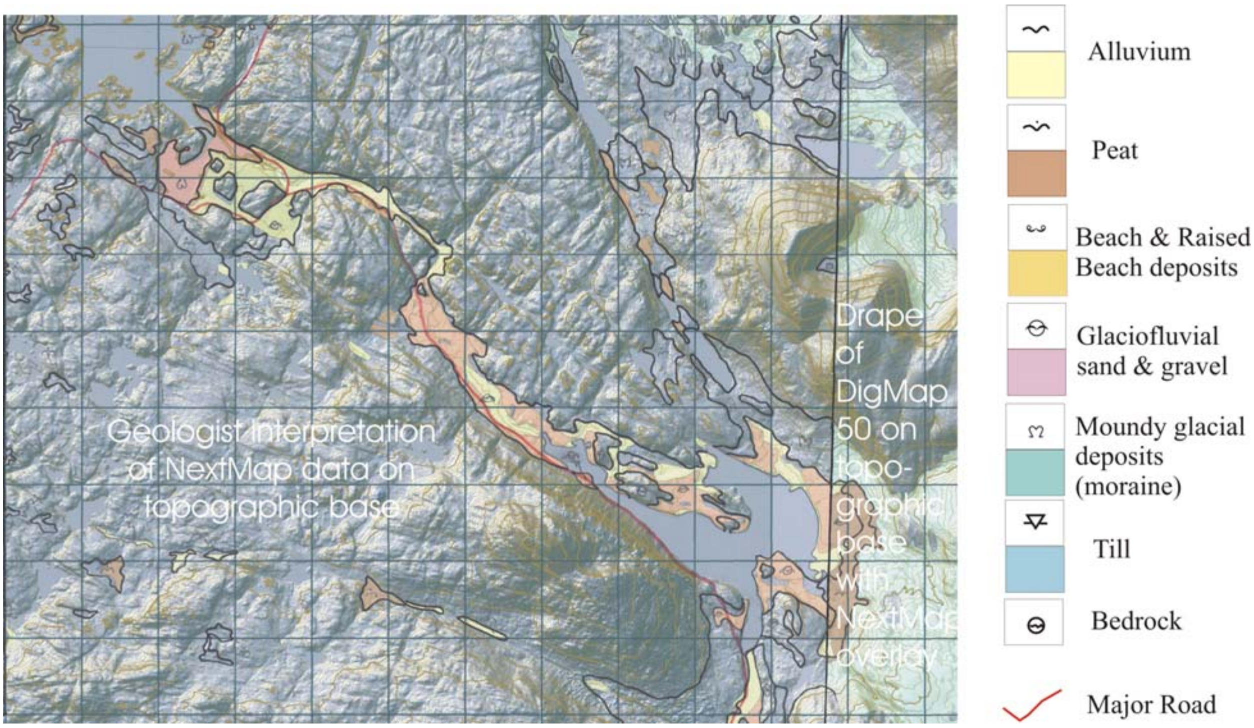



**Figure 4. Geologist interpretation of Next Map data, N W Highlands.**

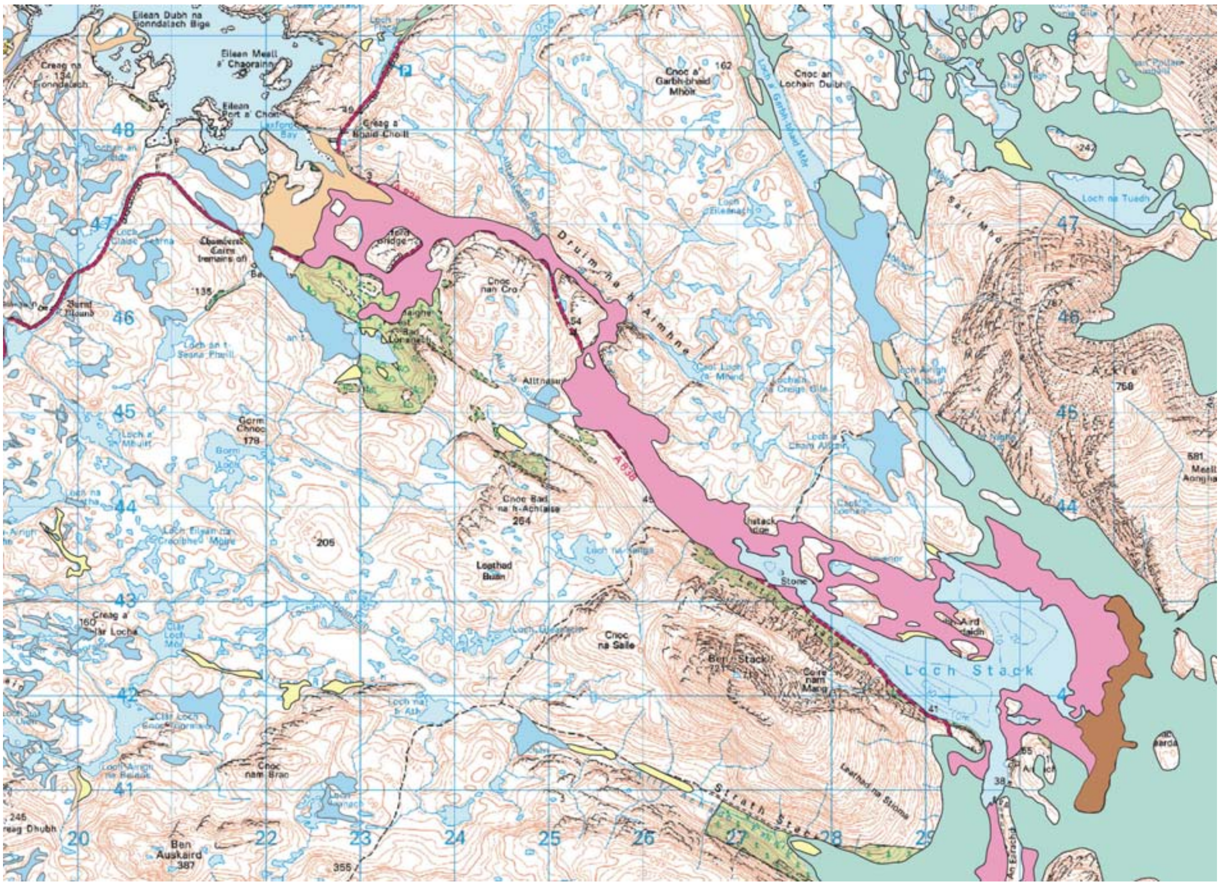



**Figure 5. Attributed polygons from Next Map interpretation, N W Highlands.**

4 Areas of similar featuring were delimited on the basis of their visual character; for example, where ground had an overall craggy or streamlined appearance, it was clear that bedrock was exposed at or near the surface, beaches and raised beaches occur as flat lying ground along the coast, prominent mounds and ridges transverse to glacial streamlining were generally interpreted moraines, or more generally moundy areas as either moraine or glaciofluvial sand and gravel. Flat-lying vegetated interfluve areas with abundant lochans suggested spreads of hill peat.

5 Interpretations were, in general, limited to the 'debris-flow catchments' for the major roads. These were designed to include the whole of each true potential catchment, together with an additional buffer zone, to enable seamless edge-matching of marginal polygons. The Superficial Deposits layer on adjoining DigMap50 tiles often provided a clear guide to the nature of the deposits on the un-mapped ground (see Figure 2).

6 All of the interpretation was done manually, and pen and ink line-work generated for digitization and conversion to polylines and attributed polygons by cartographic staff. This exercise produced polygons and polylines covering Superficial, Artificial and Mass movement deposits, converted to Arc9 format for the whole of the catchment areas.

7 Area F (east of Lochearnhead) was interpreted at 1:25 000 scale, as it was seen as the most critical for potential debris flow hazard, and the extent of the 'area of interest' was relatively small. All of the other interpretations were made at 1:50 000 scale.

This option (2) was costed as c 28 man days (geologist) and 32 man days (cartographic services).

### 2.2.1 Phase 2 outputs

Costed options for the phase 1 and 2 studies were submitted to Transport Scotland and, with the exception of Area A, NE Sutherland (which was omitted as being the area of lowest priority) all were accepted. The work, which was coordinated and managed by N R Golledge, began in early April 2006. It was completed on schedule by mid May, for inclusion in the final output to the client with a deadline of end May 2006.

Option 1 data for Areas B and C (NW Highlands; Figure 1, cross-hatched boxes 2-5) were compiled by T Bradwell.

Option 1 data for Area D (Glen Affric; Figure 1, cross-hatched box 6) were compiled by J W Merritt.

Option 2 data for unshaded Areas B and C were compiled by J Everest and N R Golledge.

Option 2 data for unshaded Areas D (Invermoriston) and F (east of Lochearnhead) were compiled by N R Golledge.

Option 2 data for unshaded Area E (Foyers) were compiled by S M Clarke.

Examples of geologist's interpretations of the Quaternary cover on ground in the NW Highlands and along the Great Glen, and the resulting attributed Arc9 polygons created during this Phase 2 work are given in Figures 2 to 5.

All of the geologist's outputs, which were completed by mid April, were assessed and standardised by N R Golledge. They were then passed to Murchison House cartographic services for digitizing. These digital outputs were returned to the geologists for correction. Final proofs of the digitized tiles and their edge-matching (both between Option 1 and Option 2 data sets, and between both of these new datasets and existing DigMap50 data) were completed by cartographic services in mid May.

All of the outputs were then submitted to M Smith (GLNB Programme Manager) for final approval in accordance with the rules for 'special approval of digital geological data for improving resolution of data included in derived information products'.

The attributed digital data, in ArcGIS format, was placed on the corporate server space at:

W:\PH\ScottishLandslides\Data\ScottishTrunkRoads\MH_Carto_data\arc\Landslide_scotland.shp

Pdfs of the all of the newly assessed areas were made available at:

W:\PH\ScottishLandslides\Data\ScottishTrunkRoads\MH_Carto_data\pdf

# 3 Summary and conclusions

This report describes the methods used by GLNB staff who contributed to the assessment of potential debris-flow hazard to Scottish trunk roads, as part of a study commissioned by Transport Scotland.

The first part of the report covers the first phase of the work, which involved verifying and amending the causal factor values for rock/sediment type shown on the amended GeoSure/DigMap 50 (LEX_D classification) for all of the units that crop out within the 'potential debris flow catchments' in Scotland, based on local knowledge. This resulted in amendments to 97 lithology values, and assigning lithology scores for 22 units that had had no values originally assigned to them It also involved reviewing all permeability scores and making alterations to some 190 permeability values (out of a total dataset of 3,706).

The second part of the report describes the methods adopted for rapidly providing new attributed polygons for Superfical Deposits in areas of interest identified by Transport Scotland, where existing DigMap50 data was absent or known to be inadequate. Some new Quaternary data was produced from existing large scale analogue data sets that could be quickly digitized and new digital 1:25 000 scale datasets which were concurrently being produced by cartographic services.

For the remainder of the areas of interest, a preliminary simplified interpretation of the distribution of the main Quaternary units (eg peat, fluvial deposits, raised beaches till, moraines, and bedrock near surface) was made by hand, using experienced field geologists to interpreted tailored NextMap data, overprinted on large-scale topographic base maps. This attributed line-work was then captured, in Arc9, by cartographic services staff and integrated with the adjacent DigMap50 tiles. This produced a seamless coverage of digital polygons for the Superficial Deposits within the potential debris flow catchments. The methods adopted produced the highest quality, most cost-effective and internally consistent interpretations which could be made, within the time-frame and costing constraints of the project.

# Appendix 1 Scottish debris flow scoring for lithology Version 2.

## SOURCE MATERIAL AVAILABILITY

In order to establish the availability of debris flow source material, the main question to be asked is:

Is this material capable of being mobilised by water into a debris flow either:

1. in its fresh unweathered state?
2. is it likely to have a weathered regolith or covering of head that could be mobilised by water to form a debris flow?

Each ROCK_D in the BGS rock description database has been assigned a number, on a scale of 1 to 10, to give an indication of its potential to supply the material, within its outcrop, that would be capable of generating a debris flow. The judgement is based on the indicated grain-size distribution or its assumed probable grain-size distribution (superficial material), or inferred likely 'block size' distribution of near-surface material/regolith (bedrock materials).

**Materials scoring 10**.

Granular superficial material – sand, gravel and boulders, and silt and clay, if they are minor components. Diamicton is assumed to be granular and capable of being mobilised.

Un-cemented or loose material, such as talus.

Material that might reasonably be assumed to be granular (in a worst-case scenario) such as made ground and fill.

If dense subglacial (lodgement or deformation) till can be distinguished from the above materials it could be assigned a lower rating, perhaps 5 may be appropriate (presuming that material in the near surface zone would be sufficiently weathered to become mobilised, in the same way that less dense melt out till or flow till would be mobilised).

**Materials scoring 9**

Materials at the finer grade of non-cohesive materials, containing some silt and clay, but not enough to stabilise the material if copious water were present.

**Materials scoring 8**

Materials with clay and silt listed as the major component. Probably sufficient fine material to stop debris flow mobilisation, unless the components are present as discrete bodies that could be mobilised and the finer components then incorporated. It is known that their potential for being mobilised may be overestimated at this score and subdivision and rescoring on geomorphological grounds may be considered to improve their ranking. For example, raised alluvial and marine deposits may be assigned a score of 7 or 6 and the flat lying deposits forming floodplains and beaches given a score of 1.

**Materials scoring 7**

Only landslip and worked ground are included in this group on the basis that they are probably loose and at residual strength but may be cohesive.

**Materials scoring 6**

Not used

### Materials scoring 5

This score has been assigned to bedrock lithologies that were considered the most likely to develop a significant regolith (roughly 1 to 2 m) that could be mobilised by flowing water. Thus the regolith would be predominantly a result of physical weathering and comprise non-cohesive particulate material, either through the induced fracturing along incipient discontinuities (pelites semipelite etc) under the influence of freeze/thaw activity or lesser thermal effects, or the break up of inter-mineral bonds by the alteration of some of the mineral components (coarse grained acid igneous and metamorphic rocks such as granites, migmatites etc). It has been assumed that coarse grained basic igneous rocks and basic igneous rocks are more likely to weather to form a greater proportion of clay minerals that will bind the regolith together, and would be less likely to form a regolith that could be mobilised.

The working party report noted that schistose pelites, semipelites and granitic rocks were known to be associated with debris flows; an observation that supports this classification.

### Materials scoring 4

This score was assigned to bedrock lithologies that appear less likely to generate a granular regolith because:

1. They comprise mixed sedimentary rock with lithologies that contain some clay rich components that may soften and bind the regolith together e.g. undivided cyclic sedimentary rocks, ‘sandstone, siltstone, mudstone’, greywacke.
2. Are mainly stronger and have a lesser propensity for breaking along discontinuities than the pelite/semipelite lithologies. These lithologies include some more gneissose semipelites.

### Materials scoring 3

This score was assigned to mainly extrusive volcanic rocks that are assumed to have large numbers of discontinuities due to cooling joints, or to posses a ‘rubbly’ fabric that would assist their weathering to a granular material, although their composition might be expected to favour chemical weathering that would generate sufficient clay material to bind the regolith together and limit its ability to be mobilised.

Sedimentary conglomerates are included on the basis that the individual clasts might weather out of a weaker matrix.

### Material scoring 2

These materials include sandstones, psammites, and minor igneous intrusions (both basic and acidic). They are assumed to have relatively few discontinuities that would allow them to form an extensive granular regolith and to be relatively resistant to chemical weathering. However, some of basic igneous intrusions would be more likely to form clay rich weathering products than the other lithologies in this group.

### Materials scoring 1

These materials are those which are considered unlikely to be mobilised as a debris flow because

- They are too silty or clayey
- They are limestones that would dissolve rather than form a regolith
- They are high-grade metamorphic psammite/quartzite/gneiss and would be unlikely to form a regolith due to their strength and chemical stability.

## INFLUENCE OF SUBSTRATE PERMEABILITY ON MOBILISATION

The permeability of a material will control three processes:

1. Saturation of surface material.

If a material is not easily permeable, water will not be able to infiltrate rapidly and mobilise it as a debris flow, particularly if it is sufficiently non-cohesive or uncemented. This property is taken into account in the assessment of lithology.

2. Elevation of pore water pressure.

If the material beneath a surface deposit that has a potential to be mobilised is impermeable, it will stop dissipation of pore water in the surficial material. This will facilitate the build up of pore-water pressure leading to a lowering of shear strength and triggering a debris flow in the surficial material. Most bedrock types may be expected to be relatively impermeable with regard to the timescale of a high intensity rainfall event and act in a similar manner at the time of the rainfall event. However, they may have significant differences regarding the under drainage of different bedrock types in the days or weeks before a rainstorm. These differences will influence the condition of the slope by the removal, or not, of pore-water derived from antecedent rainfall. Thus they may have different effects with respect to the amount of water from an event that is needed to initiate movement in that material or in overlying strata.

3. Stabilisation by under drainage.

If a debris flow moves over permeable ground it may be slowed by water draining from the moving mass into the substrate with a consequent increase in shear strength. It is unlikely that this mechanism will have a significant effect, except where the debris flow has flowed onto gentle very permeable slopes and has spread out to allow under drainage over a large area.

**Assessment of permeability and under drainage.**

The permeability of a formation will be a function of grain-size distribution for superficial materials and discontinuity spacing and dilation for bedrock materials. For superficial materials coarse clean gravels will be the most permeable and clay the least permeable. The permeability of the bedrock materials needs to be considered for the level above which any material (including regolith) that has the potential to be mobilised. Below this depth, discontinuities in the bedrock are likely to have been developed and dilated by thermal and chemical weathering but the rock mass is still interlocked and unlikely to be incorporated in a debris flow.

**Material scoring 10**

These formations include superficial deposits and bedrock comprising silt and clay with little permeability due to their fine particle size, as well as bedrock formations of gneissic or plutonic formations with low porosity and very widely spaced discontinuities.

**Material scoring 9**

These formations include metamorphic rocks that are expected to have very low porosity and widely spaced, tight discontinuity spacing.

**Material scoring 8**

These formations comprise fine-grained metamorphic rocks (pelites), uniform sandstones (metamorphic and sedimentary quartzites) and mixed sequences of mudstone/siltstone/sandstone that might be expected to have slightly more discontinuities than the previous class.

**Material scoring 7**

These formations comprise sandstones, minor igneous intrusions (i.e. not plutonic), limestone, conglomerate and lavas that are likely to have moderately spaced discontinuities which may be expected to form an interconnected three dimensional network pattern, rather than a predominantly planar disconnected pattern, and thus promote downward drainage.

**Material scoring 6**

These comprise clay- or silt-rich superficial deposits that may have a small under drainage capacity if they contain discrete units of coarse material (interbedded sands and gravels) and a small number of bedrock and other lithologies with properties that are not easily predicted, such as landslip, fault crush and worked ground.

### Material scoring 5 to 2

No materials are assigned to these scores.

### Material scoring 1

These materials are superficial deposits that are sandy or gravely, or may be expected to contain significant amounts of sand and/or gravel that would allow some under drainage of overlying material.

### Material scoring 0.1

These are superficial deposits that comprise primarily sand and gravel which would offer significant under drainage, possibly to the extent that passage of a debris flow on low slope-angles could be slowed and pore water from antecedent rainfall might be dissipated relatively quickly.

# References

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

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