# A reconnaissance of the superficial deposits of the Kale Water, Cheviot Hills, Roxburghshire

Geology and Landscape Northern Britain Programme

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View of Hownam Law from the Kale Water Near Hownam, Roxburghshire. P608621

Photograph by W A Mitchell, September 3003

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# Foreword

This report was prepared by Dr Wishart Mitchell, University of Durham on behalf of the British Geological Survey (BGS). It describes a brief study in the summer of 2003 to assess and characterise the superficial deposits and landforms of the district around the Kale Water, Hownam, Roxburghshire. The area mapped forms part of 1:63360 scale Sheet Scotland 18 (Morebattle) which was previously surveyed by James Geikie and published by the Geological Survey of Scotland in 1883. The present study took the form of a two-week field reconnaissance, preparation of two 1:10 000 scale field maps and a literature review. The report presents the results of the survey and describes the superficial deposits and weathered bedrock of the district with reference to logged natural and temporary sections. It also makes recommendations for future research and mapping.

# Acknowledgements

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The ready support of landowners and tenants during the course the field work is gratefully acknowledged. Dr W Mitchell drafted the report and provided all of the photographic images. Dr D Millward and Mr A A McMillan reviewed the report.

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# Summary

This report was prepared by Dr Wishart Mitchell, University of Durham on behalf of the British Geological Survey (BGS). It describes a brief study to assess and characterise the superficial deposits and landforms of the district around the Kale Water, Hownam, Roxburghshire. The area mapped forms part of 1:63360 scale Sheet Scotland 18 (Morebattle) which was previously surveyed by James Geikie and published by the Geological Survey of Scotland in 1883. No Survey memoir was prepared for this district although Geikie published a series of informal papers in 1886. The study took the form of a two-week field reconnaissance (August-September, 2003), preparation of two 1:10 000 scale field maps (NT71NE and NT71SE) and a literature review. The report presents the results of the survey and describes the superficial deposits and weathered bedrock of the district with reference to logged natural and temporary sections. It also makes recommendations for future research and mapping. The field maps and images including photographs of sections and landscapes have archived at BGS Murchison House Edinburgh.

Notable features of the district include the widespread distribution of weathered bedrock and periglacial deposits. Combined with the paucity of well-developed glacial landforms these features make it difficult to set out a regional glacial history. A modern regional synthesis and stratigraphical review could be achieved with a mapping exercise covering a larger area utilising detailed sedimentological analysis, sampling for dating and an assessment of published OSL dates.

# 1 Introduction

A reconnaissance field visit to the valley of the Kale Water in the Cheviot Hills was conducted over a two week period during 2003. This area forms part of the Morebattle sheet (GS Scotland 1inch, Sheet 18). Superficial deposits and landforms were mapped over an area of c. 30 km2 following definitions laid out in McMillan and Powell (1999). Little is known about the geology of this part of Scotland which was originally mapped by James Geikie of the Geological Survey in the mid-nineteenth century without publication of any memoirs although there is a series of short informal papers (Geikie, 1876). In comparison, there are a number of early memoirs associated with the English side of the border (e.g. Clough, 1888); this side of the border has also been the area of subsequent work, particularly with respect to the Quaternary evolution of the Cheviots.

The Cheviot Hills form the eastern part of the Southern Uplands culminating in the high ground of The Cheviot (815 m OD). The hills form a broad rolling plateau at about 400m incised by deep river valleys that form a general radial pattern around the high ground (massif) of The Cheviot and westward along the high ground of the Scottish-English border.

The upper tributaries of the Kale Water rises to the east of Carter Bar [NT 698 067] on the main divide which marks the border (Fig. 1) with the highest point in the catchment being reached at Hungry Law (501 m OD) [NT 747 081]. The Kale Water is formed at the confluence of the Long Burn and Hindhope Burn and flows northwards with few tributaries, the most notable being the Heatherhope Burn (Fig. 1). At Morebattle [NT 772 249] the Kale Water makes a dramatic westerly turn to join the Teviot ignoring a major abandoned valley that can be traced eastwards towards Town Yetholm. This has been variously interpreted as an exhumed valley cut during Devonian times, a pre-glacial river or associated with meltwater activity (Clark, 1974; Geikie, 1876).

Many of the hilltops within this part of the Cheviots are marked by impressive ramparts of Iron Age hillforts and earthworks whilst in the valley there are remains of a Roman camp on the major Roman road (Dere Street) at Tow Ford [NT 755 137]. The area is primarily agriculture with forest cover limited to the upper catchment of the Long Burn. Soils tend to reflect the underlying geology, particularly the superficial deposits (Muir, 1956). There are two villages; within the valley is the small settlement of Hownam [NT 779 192] whilst the larger village of Morebattle lies at the junction of the Jedburgh -Town Yetholm and valley roads. Jedburgh [NT 650 205] is the major settlement in this area located about 8 km to the west of the study area.

The bedrock geology of the area is known from original mapping by the Geological Survey during the mid-nineteenth century (Geikie, 1876). Although most papers refer specifically to the geology of the English side, a general map covering the Scottish part of the border has been published (Robson, 1976, 1980) (Fig. 2). Within the southern part of the catchment of the Kale Water, the oldest rocks are greywackes of Silurian age which forms an inlier south of the Thieves Fault between Carter Bar [NT 698 067] and Coquet Head [NT 779 082]. These are overlain unconformably in the east of the catchment at Gaisty Burn [NT 784 105] by volcaniclastic rocks that perhaps mark the beginning of volcanic activity in this area (Robson, 1980). The main rock types exposed across this part of the Cheviots are andesite and dacite lavas of the Cheviot Volcanic Formation of Devonian age (c. 396 Ma)(Thirwall, 1988). To the east, the high ground of The Cheviot is underlain by granite intruded into these volcanic rocks; the Cheviot Granite Pluton is also Devonian in age and is co-magmatic with the volcanic rocks. In the northern part of the Kale Water catchment, around Morebattle, exposed rocks of the Old Red Sandstone Supergroup are part of a more extensive outcrop to the west (Robson, 1992).

It is generally accepted that the area was glaciated by the last British Ice Sheet during the Dimlington Stadial of the Devensian Stage with the central Cheviot Hills acting as an independent ice centre (Clapperton, 1970; Harrison, 1992a; Lunn, 1980; 2004). Away from this small ice centre the area was covered by ice flowing generally eastwards across the Southern Uplands from an ice centre in the western Southern Uplands and diverted around the Cheviot Hills flowing northeast into the Tweed valley and east or southeast down Redesdale towards the Tyne.

# 2 Previous work on the Quaternary geology

As with the bedrock geology, recent work on Quaternary landscape evolution has concentrated on the main mass of The Cheviot and the easterly river valley systems within Northumberland, such as the Bowmont Water and the College Burn (Fig. 1). The earliest account of the area was by James Geikie in the latter part of his papers in ‘Good Words’ (Geikie, 1876). Geikie describes the main landforms and superficial deposits reaching the conclusion that the area had been completely covered by an ice sheet. There is also a detailed discussion of the river diversion associated with the lower Kale Water noting the existence of numerous mounds near Eckford [NT 709 262] and Morebattle [NT 772 249] as moraines, the formation of a lake in the area and the eventual abandonment of the large channel towards Town Yetholm [NT 820 280] which continues into England as the Bowmont Water.

There was a long debate in the literature about whether the Cheviots generated their own ice cover. In comparison to Geikie (1876), early mapping of the English side of the border proposed the former existence of a local ice centre over the higher parts of the Cheviot Hills based on the direction of striations and erratics (Clough, 1888). This idea was accepted by some later workers (Raistrick, 1931; Smythe, 1912) but questioned by others who proposed that the Cheviots had been overridden by external ice (Carruthers et al., 1932; Common, 1954). Present day interpretations, based on recent research have reviewed the evidence and on the basis on detailed field mapping of striations, erratics within the superficial deposits, drumlins and the pattern of meltwater channels have concluded that the Cheviots were a centre of ice dispersal during the last glaciation (Clapperton, 1968; 1970; Harrison, 1994a; Lunn, 2004). However, it was not thought to have been a major centre given the low precipitation which would have occurred in this easterly location during a glaciation, although the Rede, Coquet, Kale and Bowmont valleys were all thought to have generated local glaciers (Clapperton, 1971a).

The widespread cover of superficial deposits in the area means that bedrock outcrops are rare; no striations are reported from the igneous rocks of the massif but have been reported from the surrounding sedimentary rocks on many of the early geological maps indicating divergent flow from the higher ground where the ice met a major north-east ice flow down Teviotdale to the north and eastward flow to the south (Clapperton, 1970).

Erratics from the western Southern uplands are common around the western part of the massif up to an elevation of 300m but not within the central part around The Cheviot (Clapperton, 1970; Clough, 1888; Smythe, 1912). The earliest attempt to map the erratic distribution was by Smythe (1912) who was able to identify limits of local Cheviot rocks in comparison to Galloway granites and Lake District rocks. This pattern suggested the former existence of a local Cheviot ice centre which was confirmed by later work. For example, details presented by Clapperton (1970) for granite erratics at elevations of 580 m on Bloodybush Edge [NT 902 144] indicating southerly ice flow from the granite outcrop. However, there is a notable lack of granite erratics in the surrounding lowlands (Carruthers et al., 1932) in comparison to erratics of Cheviot andesite which forms an important indicator erratic throughout eastern England.

There are reports of drumlins and streamlined interfluves within some of the Cheviot valleys, notably the Bowmont and College valleys indicating northerly ice flow from the border towards Teviotdale (Clapperton, 1971a; Harrison, 1994a) and suggests that the ice divide over The Cheviot extended westwards to the high ground of Windy Gyle and Mozie Law (Fig. 1). Clapperton (1970) included a map showing north-east directed drumlins north of the lower Kale Water as part of the Tweed drumlin field but as noted by (Sissons, 1976) the map excluded a suite of well developed ice-moulded bedrock forms developed to the west of Kale Water. This would suggest that the ice divide included the Kale Water interfluve east of Carter Bar. Roche moutonnée and superficial deposits tails have also been reported from the Coquet valley associated with the deflection of western ice eastwards to south-eastwards around the southern flank of the Cheviots (Harrison, 1992a; 1994a). All of this clearly indicates an ice cover flowing from a source further west in the Southern Uplands and being diverted around the Cheviot massif.

The pattern and distribution of meltwater channels in the Cheviots has been the source of much discussion in the literature. As with other areas in northern England, early papers interpreted the channels within the paradigm of glacial lake outlet channels (Kendall and Muff, 1901; 1903; Raistrick, 1931) and this view remained prevalent for over fifty years until a series of papers reviewed the field evidence within the concept of ice sheet stagnation (Clapperton, 1968; 1971a; 1971b; Derbyshire, 1961). These papers re-mapped the distribution of meltwater channels, generally found below 360 m OD in the eastern Cheviots, and concluded that, rather than being formed as lake outlets, they had been formed in the subglacial environment associated with ice sheet deglaciation. The mechanism of channel formation was thought to be due to englacial drainage being imposed on the underlying topography due to glacier thinning (Clapperton, 1968; 1971a; 1971b). Distribution of these channels is of interest because whilst there are numerous examples within the eastern Cheviots in Northumberland, there are few channels to the west which was noted but has not been explained (Clapperton, 1971a).

In relationship to these meltwater erosional forms on the upland slopes are areas in the surrounding lowlands where glaciofluvial deposition has occurred in association to ice stagnation and the formation of glacial lakes (Clapperton, 1971a; 1971b). These have been mapped particularly around Wooler and towards the Tweed valley south of Coldstream; smaller glaciofluvial sediment bodies have also been reported from the Teviot valley and the abandoned channel to the east of Morebattle towards Town Yetholm. It is of note to record that eskers found in the Teviot valley near the Kale confluence appear to continue eastwards up the Kale valley towards the abandoned channel which suggests that this channel was active during deglaciation (Clapperton, 1971a; Geikie, 1876).

More recent research has been directed towards the periglacial landforms and sediments that are widespread throughout the upland area associated with ice sheet deglaciation and the subsequent cold Loch Lomond Stadial (Harrison, 1991; 1992a; 1992b; 1993; 1994a; 1994b; 1996; 2002). Two main processes are thought to have operated on these exposed hillslopes during deglaciation; firstly, they were subjected to mechanical weathering that led to the formation of either a *gelifractate* that was composed of large very angular clasts of the underlying bedrock or a finer grained *geliturbate* due to the presence of argillaceous bedrock forming a regolith layer on the hillslope (Ballantyne, 1998). A second process is associated with the slow downslope creep of hillslope material by solifluction under periglacial conditions (Ballantyne and Harris, 1996). This may act to move recently deposited glacigenic deposits, particularly till, downslope to be re-deposited at lower elevations. These periglacial slope deposits have been generally defined by the term 'head', which has been used to describe diamictons that have been moved by downslope movement of material in a periglacial environment (Ballantyne and Harris, 1996; Dines et al., 1940; McMillan and Powell, 1999).

Detailed study of these deposits has been specifically directed to the granite massif and the eastern stream valleys, particularly the Bowmont Water, College Burn and Coquet valleys where the overall geomorphology of the lower slopes is dominated by extensive solifluction sheets (Douglas and Harrison, 1985; 1987) although these landforms are also extensively developed on the volcanic outcrop. The overall model of these landforms is to create a slope catena with a number of landforms and deposits reflecting the solifluction (Fig. 3). The form of the solifluction sheet depends on the valley topography with wider valleys having wide (>300 m) treads with angles of the bluffs (risers) of between 3 – 10º. In incised valleys, treads are narrower (< 100 m) but at steeper angles (31º). Risers (bluffs) are less than 15 m and the result of fluvial incision (Harrison, 1994a). In many valleys, there is marked asymmetry with well developed solifluction sheets developed on only one side of valley (Harrison, 1992a; 1993; 1994a).

Exposures within these solifluction sheets shows that the simple morphology of solifluction sheet masks a complex internal stratigraphy with a number of lithofacies; some of these sections have been given the informal status of 'type sections' (Harrison, 2002). The lithological character of these main types of solifluction deposits are summarised in Table 1. The general stratigraphic situation appears to be of a lower diamicton that can be interpreted as an *in situ* till that is overlain by a number of sediments that reflect downslope movement of either the original till or disintegrated bedrock by solifluction and deposited with gravel layers associated with hillslope fluvial processes (Ballantyne and Harris, 1996). Spatial variability of the solifluction terraces within a valley has been noted from the Cheviots (Harrison, 1993) and elsewhere in Britain (Ballantyne and Harris, 1996) associated with valley floor breadth, aspect and the availability of sediment.

The Cheviots are one of the few upland areas of Britain where there is widespread evidence for deep weathering of the bedrock and the formation of summit tors (Awujoola et al., 1992; Ballantyne and Harris, 1996; Harrison, 1994a). Tors are particularly developed in England on the granite, for example at The Schill, Auchope Cairn, Braydon Cray (Harrison, 1994a). As with other tor areas, the origin of such landforms is contentious and the object of present research on other upland areas (e.g. Cairngorms) with respect to the use of cosmogenic isotopes to establish their age and resolve their relationship to ice cover during the last glaciation (Phillips et al., 2005).

The extensive presence of deep weathering (saprolite) profiles has been reported from many valleys below 450 m OD and interfluves (Awujoola et al., 1992; Clapperton, 1970; Harrison, 1994a). Within the granite outcrop, there are many exposures that show that the granite has been altered and mechanically weathered to form a sandy grus; depths of weathering of between 2-5 m are common with exceptional depths of 20 m and 50 m also reported (Awujoola et al., 1992; Harrison, 1994a). Deep weathering is also noted from the andesite (Harrison, 1994a) but no details have been published. Reports from the granite exposures show that the degree of weathering decreases with depth with many exposures showing the development of corestones and preservation of the original joint pattern but with only minimal chemical alteration (Awujoola et al., 1992). Whilst many primary minerals such as feldspars are found intact within the sand fraction, pyroxene and mica is altered to form an increased clay fraction, particularly kaolinite (Awujoola et al., 1992). These can be placed within weathering grades IV and V (British Standard, 1999) and defines much of the material as saprolite (McMillan and Powell, 1999).

The presence of deep weathering and tors raises the question of the age of these features and the implications for the development of a glacial chronology given that their presence questions the efficiency of glacier erosion (Godard, 1989). Deep weathering profiles in other areas of Scotland (Hall, 1986; Merritt et al., 2003) suggest that these profiles are much older and formed during warmer periods of the Neogene (including the Quaternary); this has also been proposed for the Cheviots (Awujoola et al., 1992). Recent research in the Cairngorms involving cosmogenic dating suggests that the tors may be much younger than previously thought and only (Phillips et al., 2005).

In the Cheviots the established chronology has been challenged by Optically Stimulated Luminescence (OSL) dates from the Linhope Spout type section (NT 958172] in the Breamish valley where dates of 28.8 ± 10.22 ka and 43.0 ± 12.21 ka have been obtained from soliflucted material above *in situ* till (Harrison, 2002). No discussion on these dates was included within the paper but, if these are correct and there is the problem of zeroing, they have implications for the glacial chronology of the Cheviots and the wider area with respect to Late Quaternary landscape evolution.

# 3 Geological Findings

This section reports on the findings from the field mapping within the Kale Water valley. Information from the field slips is summarised as two maps: superficial deposits (Fig. 3) and geomorphology (Fig. 4). This section of the report will be directed towards this information employing the standard morpho-lithostratigraphic definitions used by the Geological Survey (Ambrose, 2000; McMillan and Powell, 1999) However, before describing these deposits there must be some discussion of terminology used in this report.

With respect to this particular area, problems were encountered with some of the deposits that do not easily fit within this comprehensive scheme (McMillan and Powell, 1999). Extensive areas of the Kale Water catchment are covered by weathered rock which is often overlain by a sequence of stratified fine gravels composed of the more coherent small clasts from the weathered rock set within a matrix of the finer weathered material. These gravels have also been observed overlying weathered bedrock and coarse angular bedrock debris (head).

These deposits occur particularly on the upper parts of the slope; they cannot therefore be defined as colluvium (hillwash) which is specifically defined for hillfoot sediments (McMillan and Powell, 1999). Reference to the definitions in McMillan and Powell (1999) suggests that these deposits should probably be defined as head, that is as ‘clayey hillwash and soil creep’ associated with solifluction. However, head is only generally defined with the definition stipulating that the material should be poorly sorted and non-stratified. The definition also allows the inclusion of two distinct lithofacies: firstly, debris resulting from solifluction including re-sedimented till which tends to form a matrix-supported diamicton, and secondly, coarser angular debris associated with mechanical fracture of the bedrock which is often a clast supported diamicton. The latter facies appears to fall within the definition of regolith.

Regolith is another all encompassing term (McMillan and Powell, 1999) covering a range of deposits but with the implicit understanding that the material has not been moved or at least only small distances; however, the definition also allows regolith formation by distinctively different processes such that it can be formed by mechanical rock breakdown under periglacial conditions and by weathering of bedrock that is likely to occur under warmer non-periglacial processes. In the literature a more restricted use of this term is directed to the mechanical disintegration of bedrock by either macrogelivation or microgelivation to form a debris mantle (cf. (Ballantyne and Harris, 1996). This appears to overlap with what other research workers have termed head, although Ballantyne and Harris (1996) appear to restrict the use of head to lowland Britain. Within this report, regolith is assumed to refer to weathered bedrock.

The term regolith cannot therefore be used to deal with the stratified slope gravels because there has clearly been the operation of water driven process to transport the debris downslope and allow the development of stratification. This appears to be associated with hillwash and channel processes. They may be classified as stratified slope deposits and may actually fall within the term ‘grèze litée’ (DeWolf, 1988) except that the original definition makes no mention of weathered material, although Ballantyne and Harris (1996) have been reported that the bedded grown from Dartmoor may fit this definition. Such stratified slope deposits are assumed to relate to periglacial environments where there is abundant water available from snowmelt to allow reworking of slope materials (Ballantyne and Harris, 1996).

Furthermore, there is no specific symbol for outcrops of weathered rock; using the specific colour code for the original rock with an overlay of dots may be appropriate for the finished map but is unhelpful for the field mapping at 1:10,000. To resolve these difficulties while mapping, the abbreviations SFG for stratified fine gravels and WBR for weathered bedrock were marked on the field slips to describe these particular lithological units without implication of genesis and any future modification in definitions. These points will be exemplified with respect to specific field locations.

Specific attention will now be focussed on the 30 km$^2$ that has been mapped between Nether Hindhope [NT 765 104] and Hownam [NT 777 192]. Sections are referred to by a unique number and the lithostratigraphic information for each noted outcrop is summarised in Table 2. A separate section will deal with the landforms that have been mapped at the end of this chapter.

## 3.1 TILL

Given the general inference that the entire area was glaciated during the last glaciation, there is a notable lack of direct sedimentological evidence for glaciation to back up this statement. In the Kale Water catchment, diamicton that could be accepted as an *in situ* till is only exposed at a few locations in the valley as the basal lithofacies in a section.

Along the Kale Water, there are exposures that reveal a compact matrix-supported diamicton (Dmm) with numerous subrounded, striated boulder sized clasts. Clast lithology is dominated by the local andesite but there are also striated clasts of sandstones and other sedimentary rocks which have been brought from the south and west. This diamicton is overlain by either re-sedimented diamicton which can be defined as a solifluctate (head) or by gravel. This till is well exposed in the eastern bank of the Kale Water (WAM036) just south of Swanlaws [NT 7694 1561] where there is >3 m of highly compact diamicton with large sub-rounded to sub-angular erratic clasts of sandstone and fine grained igneous rock (Fig. 4; Fig. 5). Another exposure (WAM050) in the Kale Water just north of Towford [NT 755 135] shows about 5 m of a pinky-brown diamicton with isolated sub-angular striated clasts of greywacke. This appears to underlie sorted stratified gravels.

## 3.2 REGOLITH (WEATHERED BEDROCK)

There is a remarkable amount of weathered bedrock (WBR) to be found across this area and whilst the occurrence of such a deposit has been reported in detail for the granite outcrop (Awujoola et al., 1992), there has been only passing mention to the occurrence of such profiles in the area of the andesite outcrop. Most of the exposures are small and the depth of weathering is difficult to determine.

Bedrock exposures show that the andesite has a variety of colours but is commonly purple with well developed joints. Where this rock has been weathered, outcrops show intense physical disintegration and the formation of a sandy grus with little mineralogical alteration. One of the larger sections can be seen in a quarry near the foot of the western slope of Hangingshaw Hill [NT 765 142] (WAM029) where andesite has been weathered to distinct purple and cream grus (Fig. 8). This weathered material still retains the original structures, including the porphyritic texture and igneous lamination, over an exposure of c. 100m (Fig. 9) revealing weathering >5 m thick and overlain by up to 0.5 m of stratified gravel composed of granules of weathered rock.

Another interesting exposure (WAM027) occurs at the interfluve area at 290 m OD on Kippie Knowe [NT 778 160] where an excavation exposes deeply weathered volcaniclastic breccia within the Cheviot Volcanic Formation. The large angular to sub-rounded boulders of porphyritic andesite within a finer matrix composed of weathered rock fragments (Fig. 10). This fabric is an original depositional one which has been preserved despite the depth of weathering.

Good examples can also be seen in the backscarp of a landslide on Gaisty Law [NT 7804 1100] (WAM014) where weathered bedrock is overlain by stratified fine gravels. Further sections can be observed on the east side of the Gaisty Burn towards the border [NT 786 110] where purple – yellow weathered bedrock is overlain by stratified fine gravels about 0.5 m thick. This section is in pyroclastic rocks associated with early stages of volcanic activity before the emplacement of the lavas and is divided by a small igneous dyke which has remained unweathered. At Horseshoe Wood [NT 786 189], east of Hownam, an old quarry in the andesite shows weathering of the bedrock to about 5m with an overlying thin layer of stratified gravels (Fig. 11)

More intense alteration of bedrock can be observed within a large meltwater channel on the east side of Hangingshaw Hill towards Buchtrig [NT 7715 1396] where lateral excavation (WAM025) of > 60 m to form a pond has exposed > 3m of dark grey fine silty clay with pale cream clay partings (Fig. 12). This grades upwards into a clay rich matrix dominated diamicton with angular gravel clasts.

Exposures of weathered rock are distributed across the area and can be differentiated into those that indicate that the rock has been broken down into a coarse sandy grus; these form the majority of exposures with evidence of more chemical alteration to form clays of more restricted occurrence.

## 3.3 HEAD (SOLIFLUCTION DEPOSITS)

The smooth gentle slope profiles of the Cheviot Hills have been interpreted as the morphological response to a cover of soliflucted debris (Douglas and Harrison, 1987; Harrison, 1993). Along many parts of the Kale Water there is a prominent bluff defining the down valley limit of a solifluction sheet. The upper edge is more difficult to identify occurring as a thinning of the superficial deposits upslope and the increasing appearance of bedrock outcrops. The general model for solifluction features (Fig. 3) cannot be applied to the Cheviots without modification; there is a lack of upslope solifluction landforms whilst downslope there is often a break of slope prior to the bench defining a terrace of varying width (Fig. 13).

Many sections across the area expose a coarse diamicton that is poorly sorted including angular clasts of various sizes, shows no stratification and tends to form the surface layer on many hillslopes. Examples can be seen in the Hindhope Burn (WAM011) [NT 7720 1064] where 10 m of this material can be seen near the foot of the slope (Fig 13). The general thickness is however usually less than this (< 1 m) but it does form an extensive layer that can be followed across many hillslopes. Head is also found in a small quarry on Chatto Craig [NT 763 167] (WAM040) where it is seen resting on bedrock and overlain by stratified gravels (Fig. 15).

The lower hillslopes have few exposures except towards the stream where fluvial erosion exposes the valley infill. The Cheviot valleys are characterised by a exceptional amounts of superficial deposits that form solifluction sheets (Douglas and Harrison, 1987; Harrison, 1992b; 1993). As previously discussed, these exposures have been shown to include *in situ* till which underlies a diamicton that is composed of re-sedimented till that has been moved downslope by solifluction (solifluctate or head). These upper facies are physically similar except with respect to fabric which points to downslope movement.

## 3.4 STRATIFIED FINE GRAVELS

Exposures on many of hillslopes reveal the presence of a stratified fine gravel unit (Fig. 16). This particular lithofacies is usually thin and only c. 1m thick but is found in unusual locations for fluvial sediments. It is found resting on bedrock rock, weathered bedrock or head but there seems to be a link with weathered bedrock. The important point about this lithofacies is that the clasts, which are of granule size (2-4 mm), are composed of fragments of weathered rock. This can be more clearly appreciated where the underlying unit is the weathered bedrock. However, the fact that this unit is well stratified indicated the operation of fluvial hillslope processes that have reworked the weathered debris leading to this unit prograding downslope to overlie other superficial deposits, particularly head. The stratified gravels also appear to occupy channels eroded into underlying lithofacies.

The most commonly found combination is stratified gravels overlying weathered bedrock. At the large section at Hangingshaw Hill [NT 765 142] where weathered bedrock is exposed to good effect, there is a thin (>1 m) of pale brown stratified gravel at the top of the sequence. Similar sequences can be found, for example at Standard Knowe (WAM017) [NT 7832 1295] where bedrock is exposed that is weathered in places but also fractured elsewhere into angular head with overlying stratified gravels that inter-digitate with the head (Fig. 17). At Wideopen Cleugh [NT 7629 1585] (WAM039) a similar pale brown unit of bedrock fragments is overlain by stratified pale grey stratified gravels (Fig. 18). In many other locations, this stratified fine gravel layer is found to overlie head, as at Kielhope Law [NT 783 144] (WAM033) where there is lower coarse unit with large boulders under the gravels (Fig. 19).

At Horseshoe Wood quarries [NT 784 189] (WAM042) excavations in the andesite show a complex stratigraphy including weathered bedrock previously discussed. At one location, poorly sorted diamicton with large angular clasts (head) is exposed to the north of the larger quarry (WAM043). On the lower slopes of Lodden Hall toward Tod Burn [NT 7575 1095] (WAM054) there is a lower grey poorly sorted diamicton (head) overlain stratified gravels occupying a channel (Fig. 20).

## 3.5 PEAT

There is a widespread cover of peat over many of the gentle upper slopes of the hills and within some of the main valleys. On the upland plateau, a large peat bog is located north of Kippie Knowe [NT 780 168]. Peat has also been found within the floodplain of the Kale Water near Nether Hindhope [NT 763 105] and in an abandoned channel of the Kale water near the confluence with Butter Cleugh [NT 769 154]. There is also an extent of peat indicating a possible former lake in the Capehope Burn valley south of Moat Knowe near Buchtrig [NT 778 135].

## 3.6 ALLUVIUM

The Kale Water has a well developed floodplain through much of its length in the mapped area with lateral limits often defined by the bluff of the main terrace that is found developed within the valley.

## 3.7 GEOMORPHOLOGY

There are few distinctive landforms to be found in this area. Attention here is focussed on the few meltwater channels, terraces and landslides that have been identified across the area (Fig. 5).

There is one major meltwater channel eroded through the eastern side of Hangingshaw Hill towards Buchtrig Farm [NT 770 137]. This has an up and down profile (Fig. 21) and is continued northwards as small tributary of the Capehope Burn and may be excavated along a fault. There may be a second smaller channel on the slope to the east but this may be part of a possible landslide. Other possible meltwater channels include the following (Fig. 5). There is an interesting channel on the west side of the Kale Water on the slope south of the Towford Roman camp [NT 757 133] which begins at a number of small mounds before heading directly downslope (Fig. 22).

North of Batch Knowe towards White Knowe [NT 777 123] there is a dry channel which may be associated with a larger deeper channel to the west occupied by the small stream of Twise Hope [NT 772 124]. A small channel cutting through a spur on the east side of the Capehope Burn has also been observed [NT 788 158]. There is another possible channel that has been mapped at 435 m OD across the main interfluve east of Gaisty Law [NT 788112] into the catchment of the River Coquet.

There is a well developed terrace feature in the Kale Water associated with the formation of solifluction sheets and subsequent fluvial incision (Fig. 13). Two terraces have only been mapped along a short part of the confluence of the Ettles Cleugh and Capehope Burn [NT 782 155]. In the Kale Water the terrace surface can be mapped within the broad valley north of Lower Hindhope [NT 765 105]. The terrace achieves a maximum width north of Towford towards and beyond Pennymuir Bridge [NT 763 143] (Fig. 5) before becoming narrower near Chatto [NT 770 175] and towards the confluence of the Heatherhope Burn at Hownam [NT 779 191]. Bedrock has been observed in both these areas (Fig. 5).

Landslides are not widely distributed across the area (Fig. 5). However, there has been a major deep seated slope failure (Fig. 23) on the southern side of the valley of Scraesburgh Hope [NT 780 126] This extends from the top of the slope at Woolfa Crag at 375 m OD to the valley bottom at 300 m OD where it has diverted the stream. The disjointed ridges within the upper part of this landslide indicate deep seated rotational failure. Landslides have also been found on the southern side of Gaisty Law [NT 783108] where a series of lateral ridges and uneven topography mark the ground into the valley of the Gaisty Burn. This is defined as two different landslides; the presence of distinct lateral ridges suggests that there was a flow element within their failure mechanism. A similar landslide can be observed on the northern side of Saddler’s Knowe [NT 786 126].

There are also possible landslides developed to the east of the major meltwater channel at Hangingshaw Hill [NT 771 134] and on the line of the Roman road east of Tow Ford towards Old Streethouse [NT 768 128]. There are a few small rotational failures in the terrace riser but this seems to be quite stable due to the resistant nature of the clay diamicton.

Talus is also distributed throughout the mapped area in areas downslope of well exposed bedrock (Fig. 5; Fig. 24); good examples can be observed on the southern slopes of Blackhall Hill [NT 780 117], Woden Law [NT 765 124] and the western slopes of Stanshiel Hill [NT 779 132].

# 4 Interpretation

It is remarkable that so little is known of the Quaternary landscape evolution of this part of south-east Scotland both in terms of glacial events and subsequent landscape modification. Comparison of the superficial deposits and landforms can however be made to the English side of the border. However, this is not a simple task because a detailed level of correlation is difficult given the spatial separateness between the areas. So, whilst the overall pattern of events may be assessed and agreed, it is too early to attempt a detailed regional synthesis. Furthermore, this is a reconnaissance and has not involved any detailed sedimentological analysis of the superficial deposits which will be necessary to allow meaningful assessment. Thus while the geological evidence of till and meltwater channels in the Kale Water catchment does support that the area was covered by an ice sheet, it cannot be ascertained whether this is was associated with a local ice centre, because there is no map showing detailed limits (Clapperton, 1970) or as part of an ice divide that lay along the present border and extended westwards to the high ground at the head of Teviotdale. Also, it does not give any indication as to the timing of this event.

One of the key findings from this limited mapping exercise has been the extensive distribution of deep weathering of the andesite. Such decomposition has been reported from many former glaciated areas and been interpreted as reflecting formation under much warmer preglacial climates (Awujoola et al., 1992). However, the disintegration of a rock to a grus may well have occurred under cold non-glacial periods of the Pleistocene; there are also examples of a more pervasive weathering to silty clay that may require warmer conditions. The survival of these saprolites is thought to indicate the inefficiency of cold, thin passive ice in landscape modification (Godard, 1989).

The Cairngorm Mountains in north-eastern Scotland have a similar landscape of tors and deeply weathered bedrock to the Cheviots. Recent cosmogenic exposure ages from this area demonstrates a complex sequence of evolution during the Pleistocene (Phillips et al., 2006). Tor development and bedrock disintegration has been shown to date back to Middle Pleistocene associated with burial and development associated with different glacial events. A similar situation may have occurred in the Cheviots suggesting that the establishment of a chronology may be more complex than previously envisaged as suggested by the provisional OSL dates for the solifluction deposits in the Linhope valley (Harrison, 2002).

The periglacial modification of the landscape can easily be seen in the development of a blocky diamicton with angular gravel clasts on many slopes, although there may be a problem of definition with respect to the use of ‘head’ within an upland area and overlap with the terms ‘regolith’ or ‘debris mantle’ (Ballantyne and Harris, 1996; McMillan and Powell, 1999). This particular superficial deposit is seen to overlie both bedrock and weathered bedrock so is clearly younger than the weathering event.

More problematic is the occurrence of deposits of stratified fine gravels that are composed of the weathering products with the clasts being of an angular nature and formed from the more resistant parts of the weathered part of the profile with the matrix being composed of the grus. Stratigraphically this facies is seen to overlie bedrock, weathered rock and head and often appears to be the youngest deposit on the hillslopes. The fact that they are stratified and appear to occupy channels cut in underlying deposits suggests that they are the result of fluvial process operating on the hillslopes that re-mobiles and then deposits the saprolite. Although there are no dates to support this, it is suggested that this is not Holocene but earlier and associated with the melting of a snow cover (cf. Ballantyne and Harris, 1996)

Within the Kale Water catchment, the most obvious landform associated with this process is the development of solifluction sheets that have been reported from most of the other valleys within the Cheviots (Douglas and Harrison, 1987; Harrison, 1993; 1994b; 2002). In this matter, the Kale Water conforms to the geomorphological character identified in other parts of the Cheviots and therefore suggests that inferences can be made from these eastern areas. Of particular significance is the dates obtained from the solifluction deposits at Linhope Spout (Harrison, 2002) which give OSL dates of 28.8 ± 10.22 ka and 43.0 ± 12.21 ka that pre-date the last glaciation. A further date on the uppermost coarser unit (E) gives a date of 9.87 ± 1.64 ka showing that the dates are in the correct order. If these are correct and the minerals were properly zeroed prior to deposition (Harrison, 2002), then it suggests that solifluction ceased at the end of the Younger Dryas (Loch Lomond Stadial) and that the underlying till must relate to an earlier age on the glaciation. This would suggest that the main period of periglacial activity was during deglaciation and probably the Loch Lomond Stadial and imply a paraglacial input into the operation of the periglacial processes (Harrison, 1996). The Lateglacial age of the solifluction deposits is acceptable but the wider implications of this have not been considered in the literature and this really needs to wait until verification of the dates.

# 5 Recommendation for future work

The widespread distribution of weathered bedrock and periglacial deposits plus the paucity of glacial landforms and deposits makes this area problematic within a regional synthesis. This could be resolved by:

- Complete the mapping for a larger area of this part of Scotland to allow the completion of a modern regional synthesis
- Detailed sedimentological analysis of the weathered bedrock and associated stratified gravel deposits to allow comparison to previous geochemical study
- Assessing the reliability of the published OSL dates and taking further samples to establish a rigorous chronology for the Cheviot and Scottish Borders.

# Appendix 1 Archived Data Sources

Air photographs covering the Kale Water catchment

Field slips: NT 71NE, NT 71SE

Field images: Photos of sections and landscapes are held within the BGS Photographic Archive, photo numbers P608252-P608756.

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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.


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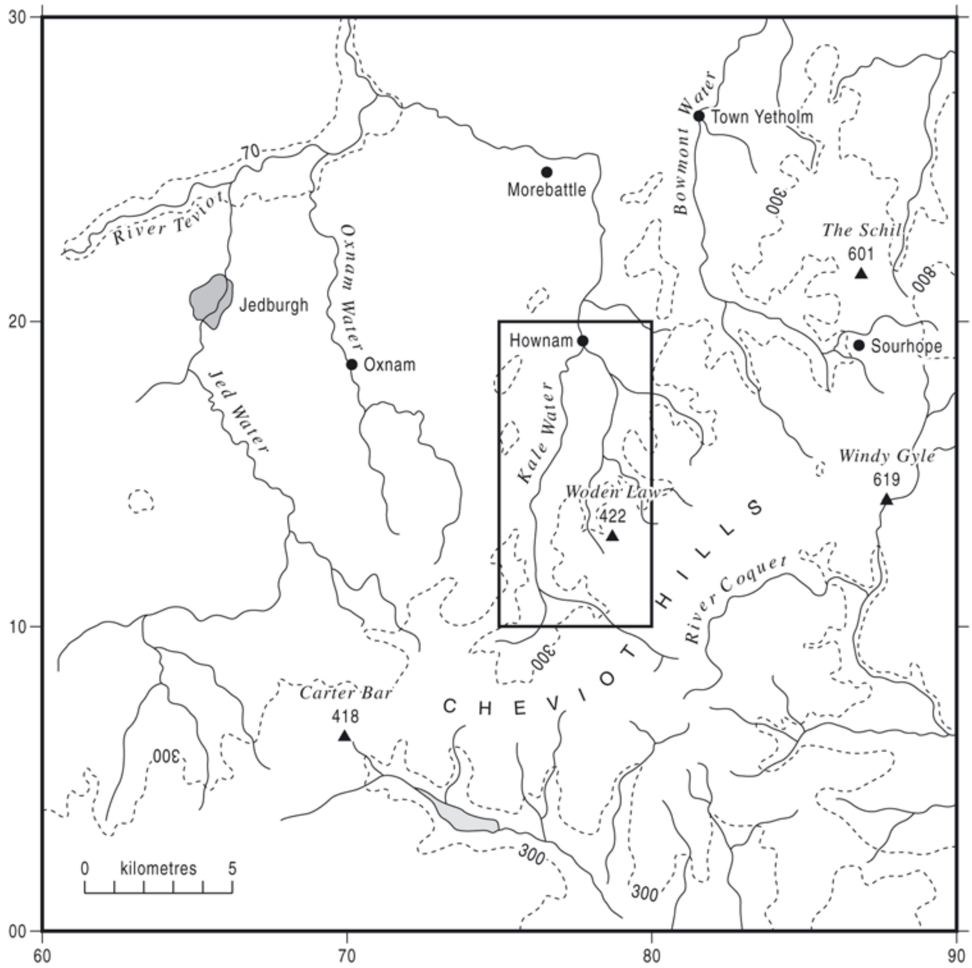


**Figure 1. Location Map of the Kale Water showing extent of mapped area. Scale and orientation given by National Grid coordinates (NT).**

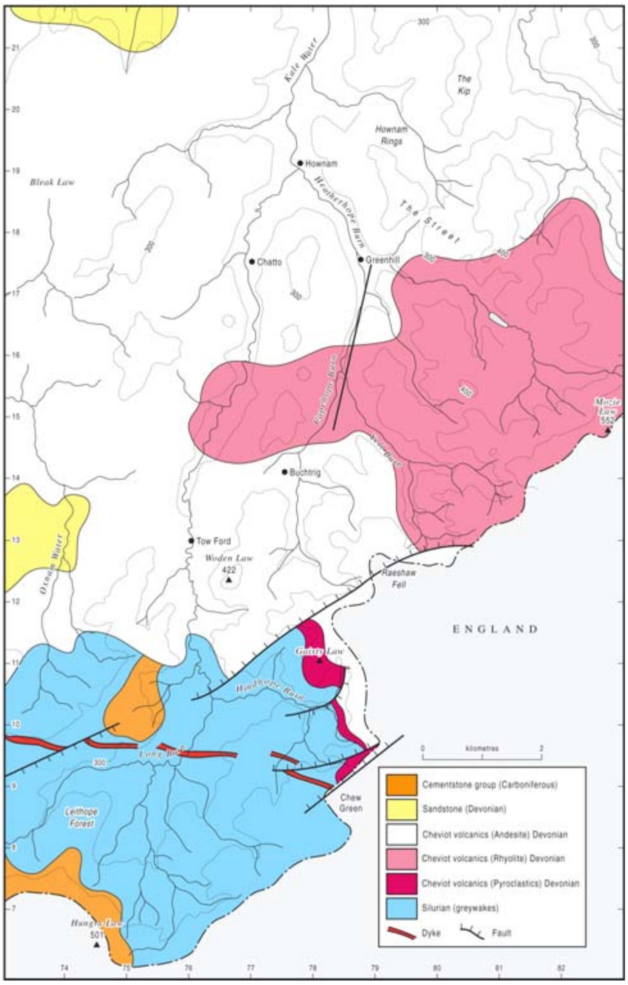


Figure 2. Summary geological map of the Kale Water catchment (after Robson, 1980). Scale and orientation given by National Grid coordinates (NT).

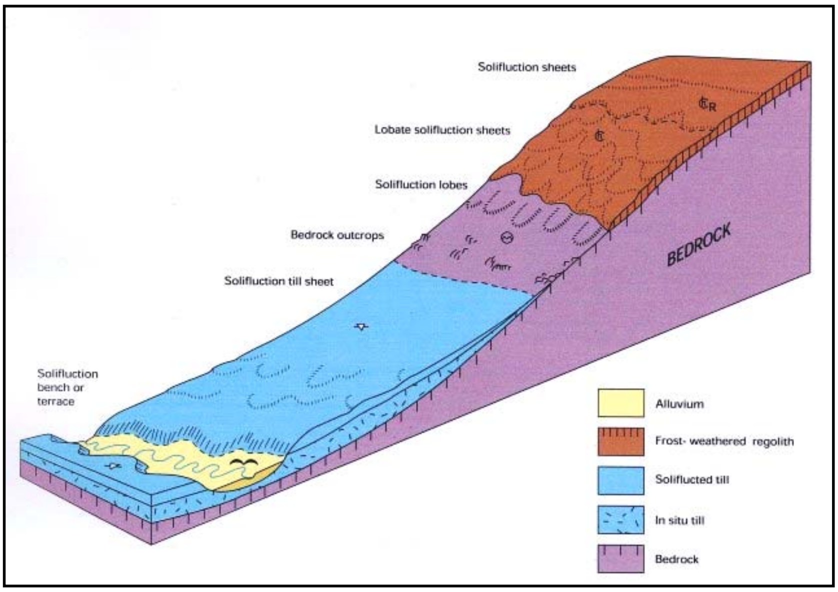


Figure 3. Schematic diagram of hillslope showing solifluction phenomena (from McMillan and Powell, 1999).

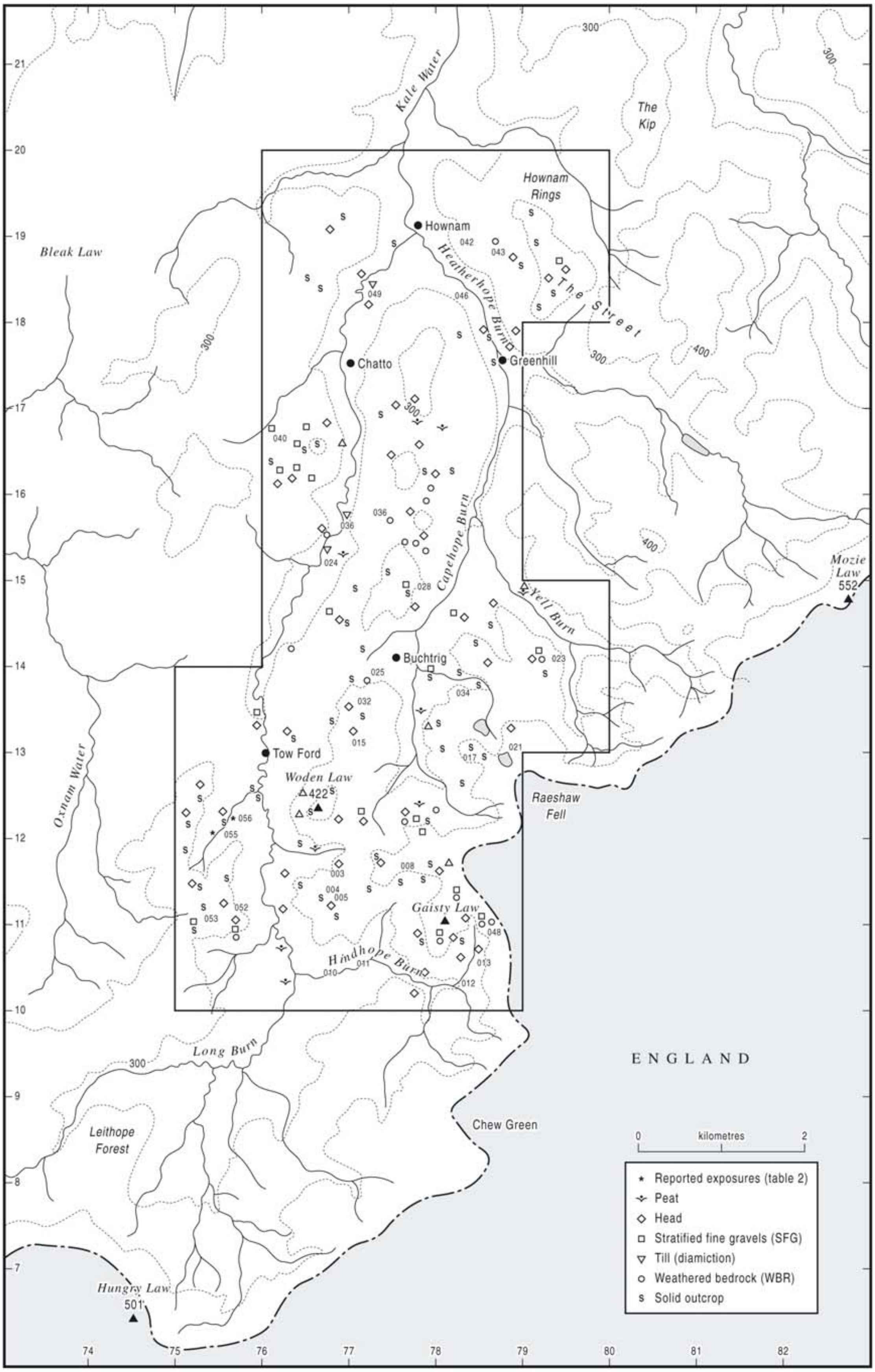


Figure 4. Summary map showing the location of exposures both within the bedrock and superficial deposits. Scale and orientation given by National Grid coordinates (NT).


Figure 5. Summary geomorphological map Scale and orientation given by National Grid coordinates (NT).

Figure 6. Kale Water near Swanlees [NT 7694 1561] showing general location of section WAM036. P608556

Figure 7. Detail of the diamicton (till) exposed at section WAM036 Kale Water. Scale length is 20 cm. P608558

Figure 8. Deeply weathered andesite west of Hangingshaw Hill (WAM029) [NT 765 142]. P608663. For general situation of the section see Figure 13.

Figure 9. Detail of section WAM029 showing grus formed from disintegrated bedrock that still preserves the internal structure of the original rock. Hammer length is 30 cm. P608661

Figure 10. Kippie Knowe [NT 778 160] showing weathered volcaniclastic breccia of the Cheviot Volcanic Formation exposed on the interfluve at 290 m OD. Hammer length is 30 cm. P608491

Figure 11. Deep weathering of andesite, Horseshow Wood quarry (WAM043) [NT 786 189]. Hammer length is 30 cm. P608599

Figure 12. Deeply weathered bedrock within the Hangingshaw meltwater channel, Buchtrig [NT 7715 1396]; section (WAM025) showing clay derived from deep weathering of andesite (?). Hammer length is 30 cm. P608484

Figure 13. Kale Water near Towford showing the extensive floodplain and well developed terrace and the basal break of slope at the hillfoot [taken looking northeast from NT 759 136]. The section showing deep weathering (WAM029) can be seen to the right of the image. P608297

Figure 14. Poorly sorted coarse diamicton (head) at Hindhope Burn (WAM011) [NT 7720 1064]. Scale length is 20 cm. P608284

Figure 15. Chatto Craig [NT 763 167] showing shattered bedrock and overlying stratified gravels (WAM040). Hammer length is 30 cm. P608584

Figure 16. Stratified fine gravels (SFG) overlying deeply weathered bedrock on Gaisty Law (WAM014) [NT 7804 1100]. Hammer length is 30 cm. P608378

Figure 17. Standard Knowe (WAM 017) [NT 7832 1295] Section showing weathered bedrock overlain by stratified gravels and coarser poorly sorted diamicton (head). In some places the stratified gravels and head are inter-digitated. Hammer length is 30 cm. P608432

Figure 18. Wideopen Cleugh – weathered rock fragments overlain by stratified fine gravels (WAM039) [NT 763 158]. Hammer length is 30 cm. P608580

Figure 19. Stratified fine gravel overlying head – Kielhope Law (WAM033) [NT 783 144]. Scale length is 20 cm. P608546

Figure 20. Loddan Hall showing poorly sorted diamicton (head) overlain by stratified gravels (WAM054) [NT 757 109]. Hammer length is 30 cm. P608740

Figure 21. Hangingshaw meltwater channel showing the up and down profile looking northwest from NT 770 136. P608414

Figure 22. Tow Ford meltwater channel looking eastwards from [NT 755 133]. P608715

Figure 23. Scraesburgh Hope landslide looking southwest from Standard Knowe [NT 784 130]. P608438.

Figure 24. Stanshiel Hill showing well developed talus around the hill; looking east from Langside Law [NT 775 132]. P608394

**Table 1 Summary description of the informal stratotype sections for different solifluction deposits in the Cheviot Hills (from Harrison, 2002).**

| Name | Location of Type Section (other sections) | Grid Reference Altitude | Thickness m | Stratigraphy | Sedimentology | Orientation | Underlying bedrock |
|---|---|---|---|---|---|---|---|
| **MOWHAUGH** | Mowhaugh School<br>(Bowmont Water College Burn Breamish) | NT 824203<br>183 m | 10 | B resedimented till (3 m)<br>A *in situ* till (7 m) | B - matrix supported diamicton; poorly sorted subangular – subrounded clasts<br>A – stiff massive silty-clay diamicton | Unit B downslope<br>Unit A down valley | Andesite |
| **LINHOPE** | Linhope Spout<br>(Upper Breamish) | NT 958172<br>300 m | 8 | B-E mass wasting of grus (weathered granite)<br>A *in situ* till | E – cemented stratified poorly sorted sand layers<br>B- D matrix supported granite clasts with high sand content<br>A – massive matrix supported sheared diamicton - striated clasts | Downslope | Granite (weathered?) |
| **MAKENDON** | Makendon Farm<br>(Upper Coquet) | NT 806097<br>330 m | 9 | C angular clast supported diamict (rhyolite)<br>B stratified matrix supported diamict<br>A *in situ* till (greywacke) | Matrix supported | Downslope | Greywacke |
| **LEECH BURN** | Leech Burn | NT 962229<br>210 m | 8 | Gelifractate –angular bedrock clasts over a shattered irregular bedrock surface | Clast supported with angular to very angular clasts | Downslope | Andesite |

**Table 2 Summary of descriptions and locations of the main outcrops recorded on field slips NT71NE and NT71SE (see also Figure 4)**

| SITE NUMBER | LOCATION | GRID REF | DESCRIPTION |
|---|---|---|---|
| **WAM 001** | Upper Hindhope Farm | 752 088 | Bedrock – fine grained fissile Mudstones |
| **WAM 002** | Loddon Hill | 762 111 | Head/gravel within river terrace section |
| **WAM 003** | Hindhope Hill | 7684 1143 | clast supported angular blocks of volcanics = head |
| **WAM 004** | Hindhope Hill | 7682 1121 | Thinly bedded gravels (SFG) overlain and underlain by head; bedrock rock also apparent |
| **WAM 005** | Hindhope Hill | 7686 1121 | 100 m east of 004 – bedrock with overlying head of very variable thickness and SFG |
| **WAM 006** | Hindhope Hill | 7660 1126 | SFG (20-30 cm) over rock |
| **WAM 007** | Hunthall Hill | 7734 1152 | Weathered bedrock (WBR) overlain by SFR infilling a small gully; bedrock weathered into hard angular clasts and subangular granules (smaller) |
| **WAM 008** | Hindhope Hill | 7736 1170 | 10m long section – head >1m thick; no structure Fining upwards? |
| **WAM 009** | Batch Knowe | 7778 1198 | Head of large valley – exposure in upper part of channel. Lower unit – diamict with angular clasts (till?). Upper unit - coarse grey poorly sorted clast-supported gravel with angular clasts of different lithologies |
| **WAM 010** | Nether Hindhope | 7687 1053 | Track to cottages – steeply dipping phyllites overlain by 20-30 cm of blocky head |
| **WAM 011** | Hindhope Burn | 7720 1064 | East of cottages – actively eroding stream section – 10 m of head (angular clasts in silty matrix) |
| **WAM 012** | Gaisty Burn | 7847 1078 | Small exposure of head |
| **WAM 013** | Gaisty Burn | 7849 1088 | Gorge section – bedrock exposed showing clear contact with overlying lead and SFG ( 50 cm) |
| **WAM 014** | Gaisty Law | 7804 1100 | Back scarp of large landslide – exposure of SFG over WBR – bedrock is pale brown and fractured into ‘nodules’ |
| **WAM 015** | Langside Law | 771 134 | Long ditch section >2m deep showing deeply weathered rock overlain by coarse angular blocky head |
| **WAM 016** | Stanshiel Hill | 7793 1310 | Talus exposed at base of slope |
| **WAM 017** | Standard Knowe | 7832 1295 | West face – small slip exposes SFG and WBR. Gravels are 25-30 cm in thickness on an uneven buried bedrock surface. |
| **WAM 018** | Saddlers Knowe | 787 127 | Small rotational failure – WBR overlain by 20 cm of SFG. Movement of bedrock blocks observed |
| **WAM 019** | Saddlers Knowe | 7865 1274 | 100m upslope from 018; slope 25$^{o}$ ; SFG formed in a former declivity in the hillside with angular head downslope. |

| SITE NUMBER | LOCATION | GRID REF | DESCRIPTION |
|---|---|---|---|
| **WAM 020** | Raeshaw Fell | 7873 1274 | Bedrock exposed – weathered in some places; exposure is in multiple small hollows near summit. overlain by SFG with possible palaeosols – organic layers within the gravels? |
| **WAM 021** | Raeshaw Fell | 788 129 | Section at eastern end of hillfort. Strong lateral variability across 30m of slope showing angular head and weathered bedrock overlain by peat. |
| **WAM 022** | Dormont Hope | 793 133 | End of earthwork; large angular open framework blocks overlain by SFG to north. To south and downslope there is a massive sand (brown-red) layer with occasional angular clasts. To north<br>There is WBR overlain by SFG but with head above 'good' rock |
| **WAM 023** | Peelinick | 7932 1409 | Cottage track shows within 10m- sound bedrock to fragmented WBR overlain by head and SFG. |
| **WAM 024** | Kale Water | 7671 1525 | Section east of meander – 2m of compact matrix supported diamict – clasts are angular to sub-angular overlain by thin stratified gravels (<u>not</u> the same as SFG on slopes); interpreted as till |
| **WAM 025** | Buchtrig | 7715 1396 | Hangingshaw meltwater channel – section is 60 m in length due to excavation; shows 3m of WBR – dark grey with pale cream clay partings. Matrix is clay with isolated angular clasts; grades into clay matrix dominated diamict with angular clasts. Bedrock is also apparent to the south. |
| **WAM 026** | Little Humblemoor | 7745 1562 to 7789 1592 | Long section (600 m) near new track; SFG overlain by laminated (?) pale brown sandy clay thin white gravel |
| **WAM 027** | Kippie Knowe | 7786 1600 | Mound excavated at eastern side of road giving an exposure of >100m length; >2m of WBR – rock is weathered to a white finish creating a diamict of weathered fine gravels and angular blocks (corestones). |
| **WAM 028** | Cooper Cleugh | 7785 1493 | Well exposed bedrock with small patches of SFG. |
| **WAM 029** | Hangingshaw | 765 142 | West of Kale Water – purple/white WBR overlain by granular weathered rock showing variable stratification – SFG but no angular clasts. |
| **WAM 030** | Kale Water | 7609 1386 | Section in river cliff – compact diamict |
| **WAM 031** | Kale Water | 7628 1439 | North along river – river section – compact pale silty diamict with numerous angular clasts (head/till?) |
| **WAM 032** | Buchtrig | 7703 1382 | Dam – further south along m/w channel - bedrock with complex gravel sequence – SFG? |
| **WAM 033** | Kielhope Law | 783 144 | Hillslope scars showing SFG with occasional diamict |
| **WAM 034** | Raeshaw | 7830 1392 | Very coarse diamict with large (>1m) blocks |
| **WAM 035** | Buchtrig | 7737 1376 | Hillslope to south; fragments of bedrock overlain by SFG and further coarse layer of clast supported angular gravels then SFG |

| SITE NUMBER | LOCATION | GRID REF | DESCRIPTION |
|---|---|---|---|
| **WAM 036** | Kale Water | 7694 1561 | 5-6m highly compact diamict with large sub-angular clasts (erratics – sst and fine grained igneous) exposed at river – till |
| **WAM 037** | High Chatto | 762161 | Wideopen Cleugh – numerous small scars – thin superficial deposits cover of brown sandy matrix supported diamict with angular clasts – head. Some SFG overlying head |
| **WAM 039** | Wideopen Cleugh | 7629 1585 | 1m of weathered bedrock overlain by SFG reworking the weathered rock |
| **WAM 040** | High Chatto | 763 167 | Quarry by track – bedrock overlain by coarse angular diamict (head) then overlain by SFG to infill hollows on head surface |
| **WAM 041** | Coldside Burn | 7634 1728 | Stream section – angular clast supported (?) diamict overlain by finer diamict |
| **WAM 042** | Hownam | 7841 1886 | Horseshoe Wood – quarries – bedrock overlain by head and SFG |
| **WAM 043** | Hownam | 7864 1890 | Horseshow Wood quarry – bedrock and purple/cream WBR overlain by thin (10 cm) head |
| **WAM 044** | Windy Law | 7923 1878 | Small scars in Hillslope showing stony head with some stratification (too coarse for SFG) |
| **WAM 045** | | 788 185 | Ditch – angular gravel clasts in clay matrix (grey) with thin weathered layer. |
| **WAM 046** | Heatherhope Burn | 784 185 | Complex section – showing WBR (purple-cream with ghost clasts)overlain by angular grey matrix supported diamict but traced laterally into SFG with underlying gravels at stream |
| **WAM 047** | Kale Water | 7715 1840 | Slope failure – weathered (?) diamict (till) exposed well stratified gravels (fluvial) with overlying angular diamict |
| **WAM 048** | Gaisty Law | 7852 1099 | Series of small exposures showing in situ physically broken bedrock overlain by SFG with the coarser clasts formed of granules of weathered rock. Presence of dyke cutting section |
| **WAM 049** | Towford | 7606 1347 | Stream section – lower diamict (Dmm with sst and andesite clasts) – till. Overlain by Dmm (solifluctate) and laterally by fluvial gravels |
| **WAM 050** | Towford | 755 135 | 5m of pinky-brown diamict (till) with isolated subangular to subrounded (some striated) boulders |
| **WAM 051** | Pennymuir Hill | 7532 1241 | Little exposure – strange ridge – small exposure shows dark grey igneous rock overlain by thin layer of SFG |
| **WAM 052** | Lodden Hill | 756 111 | Numerous small exposures of diamict with angular gravel clasts- matrix to clast supported - head |
| **WAM 053** | Lodden Hill | 755 111 | Angular diamict – head but also bedrock overlain by SFG |
| **WAM 054** | Lodden Hill | 7575 1095 | Tod Burn – WBR overlain by SFG/head |
| **WAM 055** | Hazelton Syke | 7535 1196 | West tributary of Kale W. WBR (dark grey with lighter mottles) overlain by pale grey clay with few small angular clasts |
| **WAM 056** | Hazelton Syke | 7546 1206 | Diamict with pale brown silty matrix with 1 very large subangular clast (erratic) till |