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Geology and Landscapes Northern Britain Programme

Internal Report IR/06/101

BRITISH GEOLOGICAL SURVEY

GEOLOGY AND LANDSCAPES NORTHERN BRITAIN PROGRAMME

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Geological notes and local details for 1:10 000 scale Sheet SD 68 NW (Middleton) and part of Sheet SD 68 NE (Gawthrop)

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Foreword

This report is the published product of a study by Dr N H Woodcock and Professor B Rickards of the Department of Earth Sciences in the University of Cambridge, commissioned by the British Geological Survey (BGS) and completed under Contract 2K02E024. The report describes the geology of 1:10 000-scale Bedrock and Superficial Deposits Geology Series sheets SD 68 NW and NE, which constitute part of the England and Wales 1:50 000 series sheet 49, Kirkby Lonsdale. This report should be read in conjunction with the 1:10 000-scale maps.

Acknowledgements

The authors extend their thanks to all the local landowners and tenant farmers for access to their land, but particularly to Dr Helga Frankland and Dr Juliet Frankland for access to their land in Dentdale and for valuable advice on other access issues. They are grateful to Dr Jack Soper and Dr David Millward for field discussions on the geology.

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Summary

The mapped area of Cumbria represented on Sheets SD 68 NW and NE includes the settlements of Killington, Middleton and Gawthrop. Larger settlements border the area: Sedbergh 2 km to the north, Dent 0.5 km to the east and Barbon 2.5 km to the south. The area is bounded to the east by the Dent Fault, and is completely traversed by two other major faults, the Barbon Fault and the Firbank Fault. These faults divide the solid geology into three major sectors and one minor sector, the stratigraphical continuity of which can only be inferred outside the area.

The oldest rocks at outcrop occur as a small sliver along the Dent Fault, comprising Dent Group calcareous mudstones and volcanic rocks and Tranearth Group laminated mudstones; the two groups are also separated by a fault. The major outcrop sector between the Dent and Barbon fault zones comprises turbidite sandstones and subordinate mudstones of the uppermost Coniston Group and a lower division of the Bannisdale Formation, passing up into a mudstone-rich upper Bannisdale Formation. The distinction between the Coniston and lower Bannisdale units is difficult, and based mainly on the lamination characteristics of the their hemipelagic mudstone.

The outcrop between the Barbon and Firbank faults comprises mudstones with thin sandstones assigned to the upper part of the Bannisdale Formation. This lithology is also present at the base of the succession west of the Firbank Fault, though most of the outcrop here comprises the overlying sandstone-rich Kirkby Moor Formation. Reddening of the upper parts of this formation also affects part of the upper Bannisdale Formation across the Firbank Fault: the reddening is therefore interpreted as secondary, and not diagnostic of a ‘Scout Hill Formation”.

The Lower Palaeozoic rocks are deformed by a weak Acadian cleavage striking generally ESE, and by open kilometric-scale folds. These structures are cut by the major north-south Variscan faults.

Till occurs in upland valleys and in the major valleys of the Lune and Dee, where it is moulded into drumlins. The River Lune has extensive spreads of post-glacial alluvium.

1 Introduction

This report describes the bedrock and superficial deposits geology of the area of Cumbria that includes the settlements of Killington, Middleton and Gawthrop. Larger settlements border the area: Sedbergh 2 km to the north, Dent 0.5 km to the east and Barbon 2.5 km to the south. Kirkby Lonsdale, the eponymous town of the 1:50,000 geological sheet containing the area, lies 6.5 km to the south. Topographically, the area mapped is bisected by the broad north–south trending valley of the River Lune at about 65-80 m above mean sea level. To the east of the Lune are the Middleton Fells, rising to 609 m at Calf Top and bordered to the north-east by lower Dentdale – the valley of the River Dee – and to the south-east by Barbondale. To the west of the Lune Valley are lower hills rising to 246 m at Green Park Hill.

Geologically, the area lies near the south-eastern extremity of the Lower Palaeozoic inlier of the Lake District (Figure 1). Here, the major Dent Fault zone juxtaposes Carboniferous rocks, more typical of the Yorkshire Dales, and cropping out in the east and south-east of Sheet SD 68 NE (Figure 2). These rocks are only briefly described here, having been documented in other BGS publications, for instance by Dunham and Wilson (1985).

The outcrop pattern of Lower Palaeozoic rocks within the study area is also determined by two other major faults, the Barbon Fault and the Firbank Fault, which throw down progressively younger units towards the west (Figure 2). East-trending Acadian folds and cleavage exert a subsidiary control on the outcrop pattern but the open geometry and gentle plunge of the folds means that local bedding strikes are variable.

The mapped area preserves a range of Quaternary deposits, mostly till and alluvium within the valleys.

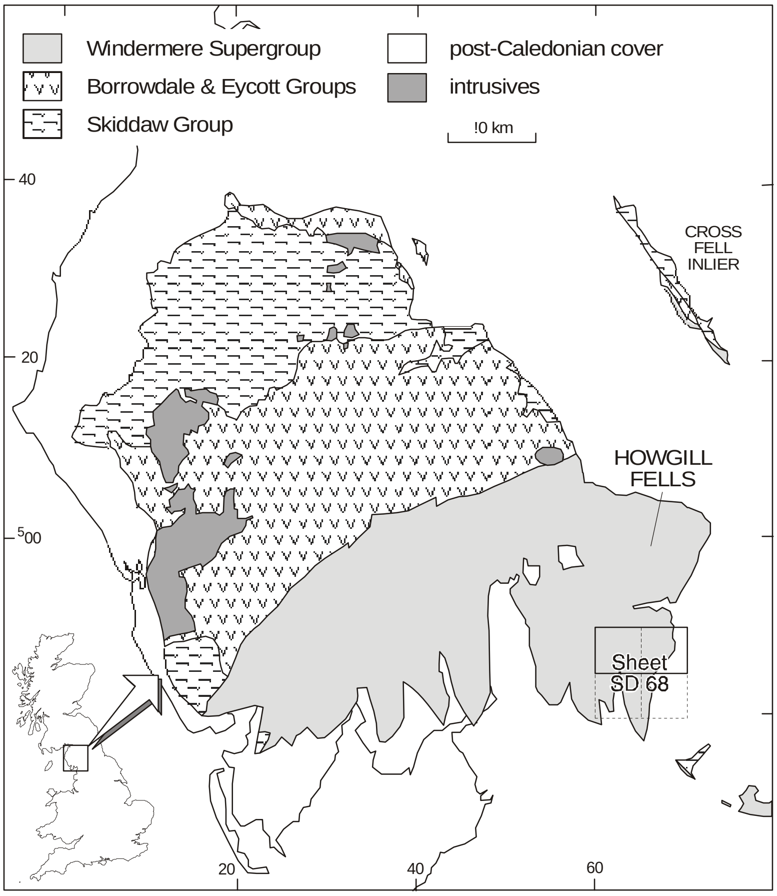

Figure 1. Map of the Lower Palaeozoic geology of north-west England, showing the location of Sheet SD 68 and of Figure 2.

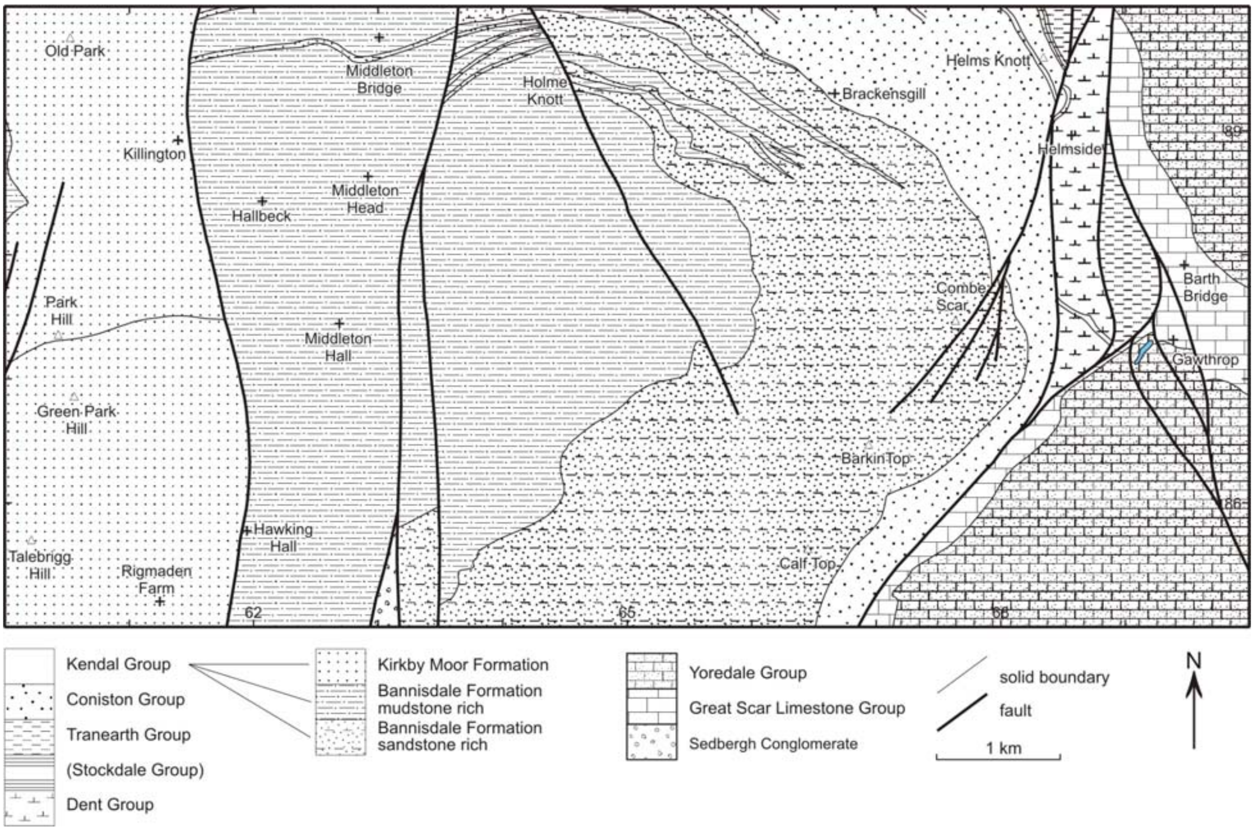

Figure 2. Simplified geological map of the northern half of Sheet SD 68. Location shown on Figure 1.

2 Previous Work

2.1 BEDROCK GEOLOGY

The history of geological research in the English Lake District *sensu lato* (that is, including peripheral areas such as the Howgill and Middleton fells) has been comprehensively reviewed by Oldroyd (2002), and this regional perspective will not be repeated here. Woodcock and Rickards (1999, 2006), and Rickards and Woodcock (2005) have also provided recent reviews of the history of research in the Howgill Fells, much of which is generally relevant to the present study area. Furness (1965a) gave the most recent review of investigations in the Middleton Fells, and Shaw (1971a) briefly listed work from the west side of the Lune valley.

The earliest phase of work in the study area was concerned with broad-scale delimitation of major units only. Both Smith (1815) and Otley (1820a, b) contributed to this mapping, though certainly not collaboratively (Oldroyd, 2002). William Smith several times based himself at Kirkby Lonsdale in the early 1820s, meeting there with his nephew John Phillips and once (in 1822) with Adam Sedgwick (Oldroyd, 2002). These two men made more detailed traverses across the area, Sedgwick (1831, 1836b, 1836a) from an interest in the Lower Palaeozoic rocks and Phillips (1828, 1829, 1836) for his study of the geology of Yorkshire. Both men contributed to the mapping of the Craven and Dent faults (then both named as the Craven Fault) and to understanding the role of the Dent Fault in separating the rocks of the Yorkshire Dales from those of the Lake District. Marshall (1840) noted the similarity of strata across the southern part of the Lake District and into the Barbon Fells, and Sharpe (1842) made early attempts to subdivide the sequence. However, it was Sedgwick (1845, 1846, 1847, 1852a, 1852b) who made the most conspicuous progress in erecting a Lower Palaeozoic lithostratigraphy (Figure 3), and in correlating it more widely, notably with Wales.

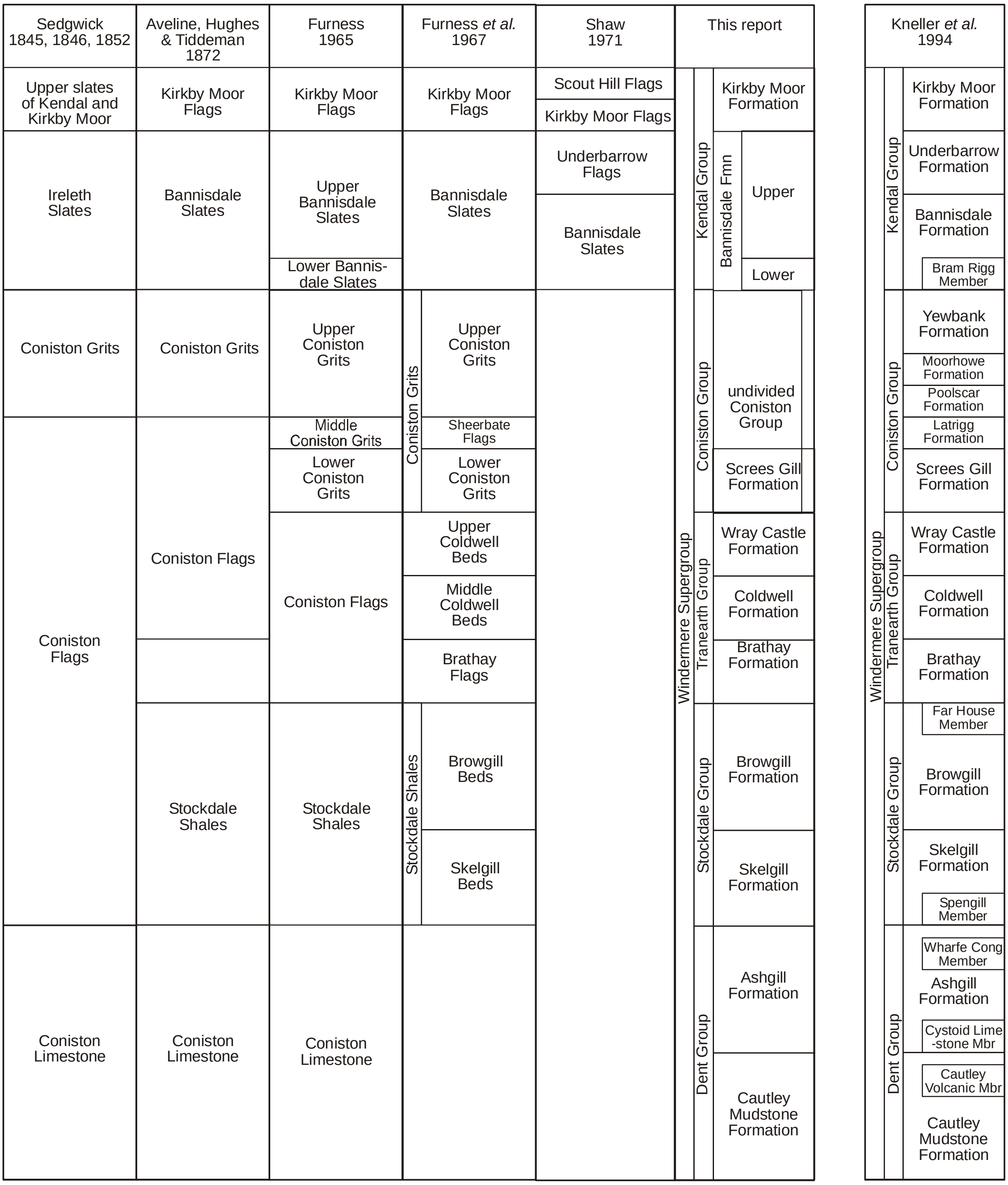

Figure 3 History of the lithostratigraphical nomenclature of the Windermere Supergroup in the Middleton Fells and Killington area. The columns follow Sedgwick (1845, 1846, 1852b); Aveline et al. (1872); Furness (1965a); Furness et al. (1967) and Shaw (1971a). The standard Lake District stratigraphy of Kneller et al. (1994) is shown for comparison.

The next phase of work in the study area was more locally specific, connected as it was with the Geological Survey remapping. Hughes (1866, 1867) made further stratigraphical advances, recognising the inlier or inliers of Ordovician (then 'Lower Silurian') rocks in Dentdale. His view of this part of the sequence, which envisaged an unconformity between Silurian and Ordovician rocks was much influenced by a meeting with Sedgwick in 1866. Publishing these views at all, and particularly outside of the Survey publications, made Hughes unpopular with the then director, Sir Roderick Murchison, and with supporters in the Survey of Murchison's stratigraphical ideas (Oldroyd, 2002, p.42). The dispute eventually led to Hughes leaving the Survey to take up the Woodwardian chair in Cambridge vacated by Sedgwick's death in 1873.

The Survey memoir (Aveline et al., 1872) avoided most controversy, because contacts of Ordovician rocks in the study area are faulted, in contrast to those flanking the Howgill Fells to the north (Figure 3). The memoir also gave the first detailed description of the structure of the area, recognising that the Lower Palaeozoic rocks are folded on approximately east–west axes, then cut by later faults striking about north–south.

After the publication of the Kirkby Lonsdale memoir (Aveline et al., 1872) and those on related areas to the north (Aveline and Hughes 1872, 1888; Dakyns et al., 1891), stratigraphical effort concentrated on the Howgill Fells, where the sequence is more complete. Notable contributions with regional significance were by Marr (Marr, 1878; Marr and Nicholson, 1888; Marr 1892a, b, 1913, 1927) and by Watney and Welsh (1910, 1911). Only in the 1960s was the study area remapped, the Middleton and Barbon Fells by Furness (Furness, 1965a, b) and the area to the west of the Lune by Shaw (1969, 1971a) (Figure 3). Furness' work was part of a wider resurgence of sedimentological interest (e.g. Furness, 1965b; Furness, et al., 1967). Shaw's work by contrast was primarily biostratigraphical (see also Shaw, 1971b). Valuable biostratigraphical revisions of adjacent areas were also completed about this time: Ingham (1962, 1966) worked on the Ordovician sections, including those in the mapping area, whilst Rickards (1963, 1967, 1969) concentrated on the Silurian sequence of the Howgill Fells.

No primary mapping of the Middleton Fells or Killington area has been carried out since the 1960s. King (1992, 1994a, b) included data from the area in a regional sedimentological study and Kneller et al. (1994) made an important attempt to standardise the stratigraphy of the Windermere Supergroup across the southern Lake District (Figure 3). New mapping in the Howgill Fells and Firbank Fells, on contract to BGS, (Soper, 1999, 2006; Woodcock and Rickards 1999, 2006; Rickards and Woodcock, 2005); puts new constraints on the geology of the study area. Structural work on the Dent Fault by Woodcock and co-workers (Woodcock and Rickards, 2003; Tarasewicz et al., 2005; Woodcock et al., in press) has mainly focused north of the study area, but has implications for it.

2.2 QUATERNARY GEOLOGY

The history of investigations on the Quaternary geology of the Lake District has been described by Oldroyd (2002) and more detail relating to the Howgill Fells is provided by Woodcock and Rickards (1999). Three Geological Survey mappers were instrumental in documenting the evidence for the glacial hypothesis of the 'Drift' in the Lake District. Tiddeman (1872) assembled the evidence for the area from Sedbergh southwards through Lancashire to beyond Preston. Ward (1873, 1875) for the Lake District, and Goodchild (1875) for the eastern flanks of the Lake District and the Yorkshire Dales. Goodchild showed, from striation and erratic evidence, how west-flowing ice from Garsdale and Dentdale was diverted southward into the Lune ice-stream around the now strongly sculptured north end of the Middleton Fells. In a new phase of work, Marr and Fearnsides (1909) also recognised the strong influence of ice shed from Baugh Fell, to the east of the Howgills, in restricting the radial outflow of the Howgills ice on its east side, a conclusion reinforced by Raistrick (1926) from work in the Yorkshire Dales.

New Geological Survey mapping in the Solway Plain, Eden Valley and Yorkshire Dales allowed Hollingworth (1931) to compile a major new synthesis of the regional glaciation, particularly utilising an extensive record of drumlin orientations. Hollingworth (e.g. 1938) was also a proponent of the burgeoning study of denudation chronology. McConnell (1940) applied this methodology to the Howgill Fells, identifying seven planation surfaces; the lowest including the Lune/Rawthey flood plain in the northern part of the study area.

3 Dent Group

3.1 DISTRIBUTION AND DEFINITION

Strata assigned to the Dent Group are exposed in the north-east of the area, close to the Dent Fault. There are two main groups of exposures, one north and one south of the alluvium of the River Dee. The northern group – termed the Helmside Inlier by Ingham (1966) – occurs around the hamlet of Helmside [SD 6863 8904] and in Helmside Gill (also known as Helm Gill) to the north. It is bounded by the Helm Gill Fault to the west and by the Dent Fault to the east. The southern group of exposures – the Gawthrop Inlier of Ingham (1966) – occurs in Wilsey Beck [SD 6886 8767], south of Bower Bank [SD 6864 8786] and in Intake Gutter [SD 6850 8709]. This inlier is also bounded on the west by the Helm Gill Fault, but to the east it is faulted against poorly exposed Brathay Formation along the Underwood Fault of Aveline et al. (1872). In the present work, the Underwood Fault is shown as splayed at either end from the Dent Fault rather than striking north-westward between the Dent and Helm Gill Faults (Furness, 1965a; British Geological Survey, 1997a). The Dent Group rocks are thereby allowed to form one continuous outcrop joining the two 'inliers'.

The Dent Group is named after this combined inlier (Kneller et al., 1994), though its constituent formations have type sections in other, better exposed, areas. The exposed thickness is estimated as about 165 m in the Helmside inlier and 145 m in the Gawthrop inlier, although biostratigraphical work shows that there are significant gaps in the section (Ingham, 1966). The full Dent Group section in the Cautley inliers to the north reaches 630 m.

3.2 CAUTLEY MUDSTONE FORMATION

The Dent Group rocks on Sheet SD 68 are assigned to the Cautley Mudstone Formation, first defined as a unit by Ingham (1966), and as a formation by Ingham et al. (1978). A representative section was chosen by Kneller et al. (1994) in Backside Beck [SD 6983 9864 to 6976 9965] in the Cautley district to the north. The predominant lithology is massive or burrow-mottled blue-grey calcareous mudstone. This lithology is interbedded with light grey calcareous nodules, commonly amalgamating into more or less continuous beds, 10-30 cm thick. This micritic limestone weathers to a rusty or olive-brown colour. Benthic shelly fossils are abundant in the limestone, particularly trilobites, brachiopods, bryozoans and corals, but can usually be collected only from weathered rock. Calcareous sandstone in the lowest part of the Wilsey Beck section [SD 6868 8748] is assigned member status (see below). Intermixed volcanic ash gives a splintery texture to the mudstone in the upper part of the Helmside Gill section [SD 6861 8920], culminating in the discrete Cautley Volcanic Member (see below).

Regionally, the Cautley Mudstone Formation ranges from Onnian (Caradoc), through the Pusgillian and the seven Cautleyan and Rawtheyan shelly biozones of Ingham (1966). However, no faunas representative of zones 1, 4 and 7 have been found in the inliers on SD 68(N), the assumption (Ingham, 1966) being that these are unexposed or faulted out. Biozones 1-7 have been referred to the *anceps* graptolite Biozone (Ingham, 1966; Fortey et al., 2000). However, recent work (Rickards, 2002, 2004) indicates that Ingham's zone 6 is referable to the *linearis* Biozone, that is much earlier than previously supposed. It is possible that part of zone 7 might be of *complanatus* Biozone age, although a *linearis* Biozone is still possible. It is almost certain that zone 5 is *linearis* too, but the graptolitic ages of zones 1-4 are doubtful. No new faunas from the Dent Group have been collected during the present work.

3.2.1 Wilsey Beck Sandstone Member

The member was identified as a unit by Ingham (1966) and assigned member status by Kneller et al. (1994). The only exposure of the member is near the source of Wilsey Beck [SD 6868 8748]. Here, it comprises about 7 m of calcareous sandstone, passing up section and downstream into the typical Cautley Mudstone lithology. Faunas collected by Ingham (1966) place the member in Cautleyan Zone 2. The member has a possible correlative at this level in the Taythes Inlier to the north, 100 m east of Taythes Farm [SD 7057 9586] and south of Taythes Beck Wood [SD 7064 9545].

3.2.2 Cautley Volcanic Member

The Cautley Volcanic 'Group' was defined by Ingham (1966) and assigned member status by Kneller et al. (1994). In its type section on Sheet SD 69 (in Backside Beck, SD 6943 9888 to 6937 9891) the member comprises bedded rhyolitic vitric or lithic tuffs, buff or pink in colour. One small exposure of vitric tuff occurs on Sheet SD 68(N), on the south-east ridge of Helms Knott [SD 6853 8932]. Here it is underlain, in barely accessible crags [SD 6862 8920], by ashy mudstones of the Cautley Mudstone Formation from which Ingham (1966) obtained a Rawtheyan Zone 6 fauna. Exposures in Helmside Gill where it reaches the road [SD 6845 8903] also contain Zone 6 faunas, restricting the outcrop of the Cautley Volcanic Member to a small area east of the Helm Gill Fault.

3.3 ASHGILL FORMATION?

No unequivocal exposures of the Ashgill Formation occur on Sheet SD 68(N). Brecciated mudstones, lacking carbonate nodules, occur close to the Helm Gill Fault [SD 6842 8940] and have been speculatively assigned to the Ashgill Formation by Ingham (1966).

3.4 DEPOSITIONAL ENVIRONMENT OF THE DENT GROUP

The facies and faunas of the Dent Group are consistent with deposition on a shallow marine shelf. The Cautley Mudstone Formation shows continuous deposition in oxygenated marine water. It is debatable whether the nodular limestones in this interval reflect some primary variation in carbonate input or are mainly diagenetic. The Wilsey Beck Sandstone presumably represents a period of increased clastic input during Cautleyan Zone 2, perhaps due to low relative sea level. However, though it coincides with a non-sequence in the Craven inliers further south-east, it correlates with a depositional episode in the main Lake District outcrop (Kneller et al., 1994). The Cautley Volcanic Member, where better exposed, shows no sign of subaerial accumulation, and is presumed also to have been deposited in shallow marine conditions.

4 Tranearth Group

4.1 DISTRIBUTION AND DEFINITION

No outcrops of the Stockdale Group occur on Sheet SD 68(N), and the next exposed strata belong to the Tranearth Group. Regionally, this group is characterised by a distinctively laminated hemipelagic silt-mudstone. Two formations composed almost entirely of this lithology, the Brathay and Wray Castle formations, are separated by a thin calcareous unit, the Coldwell Formation, in which most of the primary lamination has been destroyed by bioturbation. The three units lie between the Stockdale and Coniston Groups, but were not themselves awarded group status in the scheme of Kneller et al. (1994). The term Tranearth Subgroup was used to include the Brathay and Coldwell formations in an earlier version of

Kneller's scheme, and appeared in the Geological Society's Silurian correlation chart (Cocks et al., 1992). An updated Tranearth Group, including the Wray Castle Formation, was used by King (1992, 1994b) and Soper (1999) and is formally defined by Rickards and Woodcock (2005).

Two poorly exposed inliers of the Tranearth Group have been located on Sheet SD 68(N). One occurs around Helms Moss [SD 6847 8994], west of the Helm Gill Fault. The Tranearth Group passes stratigraphically up here into the Coniston Group to the west. The other inlier is centred on the River Dee [SD 6900 8800] and is bounded by the Dent Fault to the east and the Underwood Fault to the west.

4.2 BRATHAY FORMATION

The Brathay Formation is essentially the Brathay Flags defined by Marr (1878) at Brathay Quarry in the Lake District. This unit became the Brathay Flags Formation of Moseley (1984) and the Brathay Formation of Kneller et al. (1994). Two exposures only occur on Sheet SD 68(N), one in the River Dee [SD 6925 8795] 230 m west of Barth Bridge and the other in Wilsey Beck [SD 6887 8766] 80 m south of Underwood. These exposures are the only evidence for the nature of the inlier between the Dent and Helm Gill faults. The Brathay Formation is unexposed at Holms Moss, but is exposed 500 m further north in Hole Beck on Sheet SD 69 (Woodcock and Rickards, 1999).

The Brathay Formation is composed of very thinly laminated siltstone. The lamination is defined by alternating layers rich in either quartz silt or organic carbon. The silt–carbon couplets have a spacing of about 0.2 mm in the compacted rock. A new find of *Monograptus flemingii warreni* (Figure 4a) places the River Dee exposure in the *lundgreni* Biozone. Further biostratigraphical resolution has not been possible, nor is an estimate of the thickness of the unit. On Sheet SD 69 the Brathay Formation is about 240 m thick (Woodcock and Rickards, 1999).

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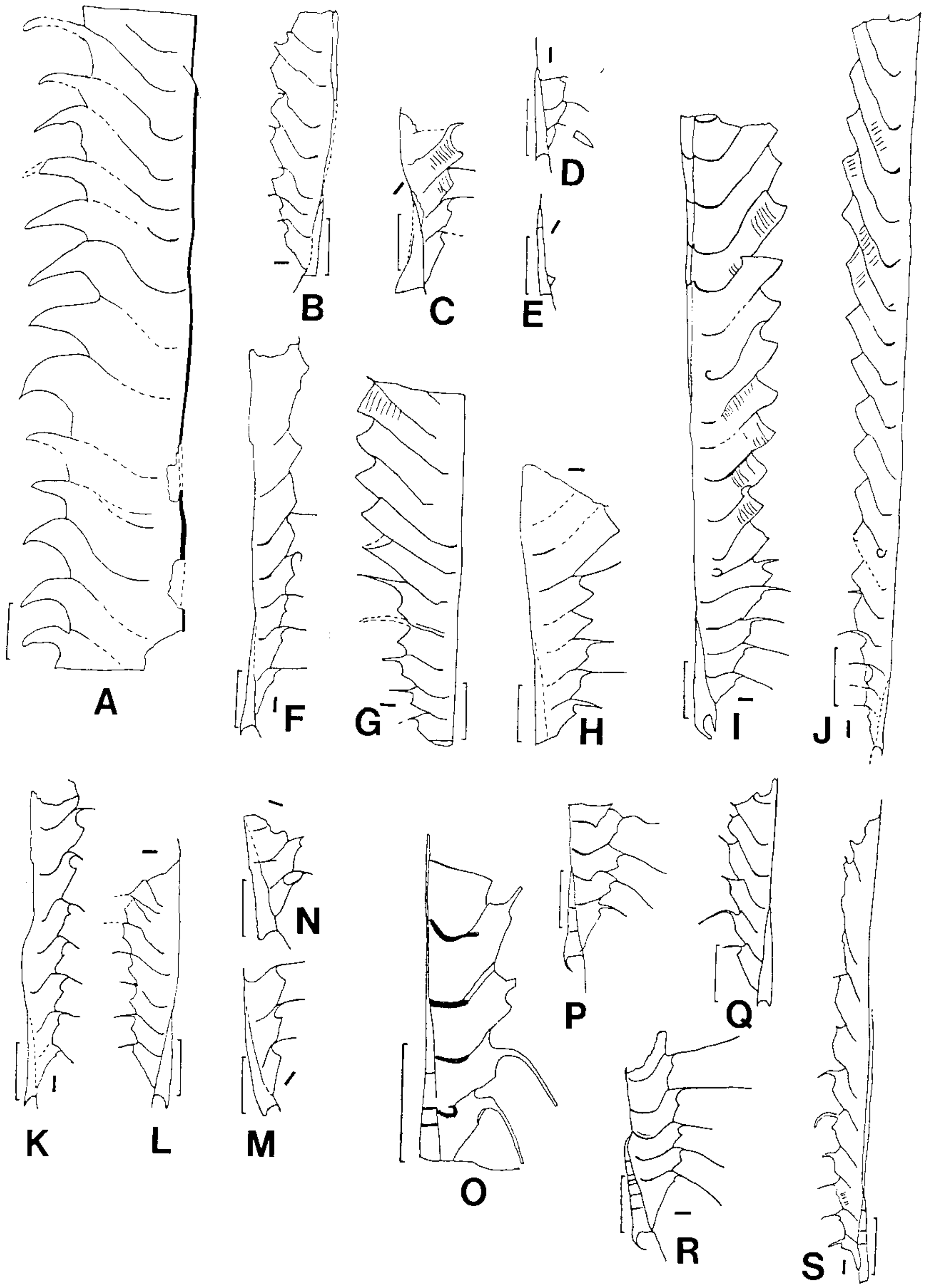
Figure 4. Representative graptolites collected during the present study

A) from the Brathay Formation; *Monograptus flemingii warreni* Burns and Rickards, X.41704, from west of Barth Bridge, Dentdale [SD 6925 8795]. B-E) from the Coniston Group; *Saetograptus incipiens* (Wood) respectively X.41724, X.41723, X.41727 and early growth stage with prosicula preserved X.41728, all from Thorny Hills [SD 6801 8998]. F-J) from the lower Bannisdale Group, *Saetograptus soperi* Rickards and Woodcock, respectively X.41606, X.41609, X.41607, X.41637, X.41608, all from Brackens Gill [SD 6650 8902]. K-N) from the lower Bannisdale Formation, *Saetograptus leintwardinensis* (Hopkinson) respectively X.41691 from Brackens Gill [SD 6615 8948], X.41690 from the northern tributary of Riding Beck [SD 6446 8920]. O-S) from the Coniston Group; *Saetograptus chimaera salweyi* (Hopkinson), respectively X.41591, showing annular bands on sicula, thickened bases to interthecal septae and spine bases, X.41589 showing pronounced dorsal sucular process, X.41600, X.41605, X.41590, all from Haw Gill [SD 6827 8817]. Scale bars are 1 mm long; short heavy bars indicate the stretching direction where appropriate.



4.3 COLDWELL FORMATION

The Coldwell Formation is characterised by calcareous silty mudstone with sporadic lenses and nodules of fossiliferous silty limestone. The unit was termed the Coldwell Beds by Aveline and Hughes (1872). Confusingly, Marr (e.g. 1878) added lower and upper units to the Coldwell Beds, with little lithological affinity to the 'Middle Coldwell Beds'. Kneller et al. (1994) reverted to Aveline and Hughes' original definition for their Coldwell Formation. Two exposures of the Coldwell Formation have been identified on the northern slope of Helms Knott [SD 6842 8972 and SD 8938 8992]. The exposures define an outcrop cut off to the south-east by the Helm Gill Fault and continuing northward onto Sheet SD 69, with minor modification to the outcrop on that map.

The exposures just referred to are not good. However, just south of the mapped area, on Leck Beck [SD 6560 7930], there is a continuously exposed sequence, in the right bank of the river, from the higher levels of the Brathay Formation into the sandstones of the Screes Gill Formation. This section was first described by Furness (1965a), who recognised increasingly calcareous Brathay Formation as the contact of the two formations was approached. This calcareous interval culminated in two thin impure limestone units just below hemipelagic mudstones yielding a Ludlow graptolite fauna. Our preliminary re-examination of this section has concluded that Furness' impure limestones, 30 cm and 60 cm thick, are very difficult to recognise. His first Ludlow graptolite fauna occurred between the two calcareous units: he naturally made a comparison with the Howgill Fells, where a similar situation obtains, although with thicker and purer limestones.

Furness' Wenlock fauna below the lower of his limestones was referable to the *lundgreni* Biozone: he did not identify a *ludensis* Biozone as occurs in the Howgill Fells. We feel that, given the continuous deposition of hemipelagic mudstone, albeit slightly calcareous in places, and the clear presence of graptolitic material throughout, there is probably a full biozonal suite present. Further work is necessary, but possible contrasts with the Howgill Fells are evident: the sequence about the boundary is thinner, the highest Brathay Formation lacks calcareous nodules, and the sequence as a whole is less calcareous. It may represent a slightly deeper water facies.

4.4 WRAY CASTLE FORMATION

The Wray Castle Formation comprises a similar very thinly laminated siltstone lithology as the Brathay Formation, although with a higher proportion of silt and a greater lamination spacing of about 0.3 mm. The formation is equivalent to the Upper Coldwell Beds of Marr (1878), and was named by Kneller et al. (1994) from a Lake District locality. There are no exposures of the formation on Sheet SD 68(N), but its postulated outcrop runs across the north-east side of Helms Knott and on to Sheet SD 69.

4.5 DEPOSITIONAL ENVIRONMENT OF THE TRANEARTH GROUP

The laminated mudstone and siltstone of most of this unit has been interpreted to record sedimentation in anaerobic bottom water (e.g. Rickards, 1964) consistent with the lack of bioturbation and the preservation only of pelagic graptolites and nektonic shelly faunas. The origin of the lamination has been widely discussed (e.g. Rickards, 1964; Dimberline et al., 1990; Kemp, 1991; King, 1992); whether it records a periodic fluctuation in silt and organic supply, and whether the sediment was supplied entirely from hemipelagic fallout or partly by dilute turbidity flows. The Coldwell Formation is thought to record a period of aerobic conditions that allowed the establishment of a shelly benthos, including bioturbating organisms (e.g. Ingham and Rickards, 1974; King, 1992). This aeration was probably due to a eustatic fall in sea level (e.g. Furness et al., 1967; Kemp, 1991; Kneller et al., 1994), because similar facies occur in other distant basins at this time.

5 Coniston Group

5.1 DISTRIBUTION AND DEFINITION

The base of the Coniston Group in the Howgill and Middleton Fells is marked by the first substantial appearance of sandstone in the Windermere Supergroup. In the Howgill Fells there follow 800-1300 m of section dominated by the thin to thick-bedded sandstone units characteristic of the Coniston Group, before a transition to the generally thinner bedded sandstone and mudstone of the overlying Bannisdale Formation. South of the Howgills, and particularly in the Middleton Fells, the thickness and proportion of sandstone in the lower part of the Bannisdale Formation increases markedly, such that distinction between that unit and the Coniston Group is problematic. The correlation of the base of the Bannisdale Formation into the Middleton Fells will be discussed further in a later section.

The Coniston Group crops out in Dentdale, with the upper contact of the unit running at a low level along the southern slope of the valley. This contact then swings southward below Combe Scar and runs along the north-west side of Barbondale. A strip of Coniston Group strata, mostly unexposed, therefore separates the Bannisdale Formation from the Dent and Helm Gill faults. Both the Survey (Aveline et al., 1872) and Furness (1965a) have postulated that the Bannisdale/Coniston contact in Dentdale might be faulted. No support was found for this hypothesis in this study. The thickness of the Coniston Group across Dentdale is certainly very low, about 550 m, but not much thinner than the 750 m estimated in better exposed ground in the Frostrow Fells on the north side of the dale (Rickards and Woodcock, 2005; Woodcock and Rickards, 1999, 2006).

The Coniston Group derives its name from the Coniston Grits of Sedgwick (1845). However, the current definition of the Coniston Group (Kneller et al., 1994) conforms to the usage of Furness et al. (1967). The base of the Coniston Grits formerly chosen in the Howgill Fells by the Geological Survey (Aveline and Hughes, 1872; Dakyns et al., 1891) was apparently below the Wray Castle Formation, and that of Sedgwick (1845) and Marr (e.g. 1913) was apparently above both the Screes Gill Formation and the overlying siltstone unit (Figure 3).

5.2 SCREES GILL FORMATION

The Screes Gill Formation was defined by King (1992), and formalised by Kneller et al. (1994). In its type area in the Howgill Fells it comprises the lowest 250-280 m of the Coniston Group, but the unit has thinned to about 100 m in the Frostrow Fells, and on to Helms Knott where it crops out on Sheet SD 68(N). The formation base is taken at the incoming of the first sandstone beds above the Wray Castle Formation, presumably on the unexposed north-east slope of Helms Knott. The formation top is defined by the base of a hemipelagite-rich unit, the ‘Wotey Gill unit’ in the Howgill Fells (Woodcock and Rickards, 1999). A presumed correlative of this unit has been mapped on to Sheet SD 68(N) north-west of Helms Knott [SD 6802 8998] and is assumed to run along the saddle over its summit [SD 6830 8956].

The only exposures of the Screes Gill Formation on Sheet SD 68(N), on the summit of Helms Knott [SD 6833 8960] are too limited to fully characterise the unit. It is predominantly composed of thin, medium or thick beds, each of fine sandstone grading rapidly to a mudstone cap forming the top third of the bed. In the Howgill Fells, intervals of these sandstone–mudstone beds are intercalated with packets of thin-bedded siltstone–mudstone couplets, the ‘Banded Unit’ facies of Rickards (1964), making up about 30% of the formation, but the presence of this facies cannot be verified in the study area.

As defined above, the Screes Gill Formation corresponds to the Lower Coniston Grits of Furness et al. (1967) and Rickards (1967).

5.3 UNDIVIDED CONISTON GROUP

The upper part of the Coniston Group, which is between 1030 and 1085 m thick in the Howgill Fells, thins to about 650 m in the Frostrow Fells, on the south side of Sheet SD 69, and again to about 450 m in Dentdale on Sheet SD 68(N). Like the Screes Gill Formation, the rest of the Coniston Group is composed of packets of beds rich in fine sandstone, alternating with 'Banded Unit' packets comprising very thin-bedded siltstone–mudstone couplets. Three mappable siltstone-rich units were distinguished within the undivided Coniston Group in the Howgill Fells, and tentatively also in Frostrow Fells (Woodcock and Rickards, 1999, 2006), though without mapping continuity between the two areas. Each of these units comprises very thin-bedded siltstone–mudstone couplets and thinly to thickly laminated silty mudstone. Only the lowest of these three units has been identified on Sheet SD 68(N), north-west of Helms Knott [SD 6802 8998]. The possible outcrop of the upper two units is shown at the northern edge of the sheet, based on evidence on Sheet SD 69, but lack of exposure makes it impossible to map these farther east and south.

Apart from the exposure of the lower siltstone unit mentioned above, all other limited exposures of the undivided Coniston Group are of the sandstone-rich facies. They occur a) on the south-western ridge of Helms Knott [SD 6826 8954] and intermittently on its continuation to the north-west to Burton Hill Wood; b) in the bed of the River Dee at Rash Bridge [SD 6589 8991]; and c) in Haw Gill and Combe Gill south and west of Dillicar Farm [SD 6825 8837]. A typical log through the sandstone-rich facies is provided (Figure 5a) from a fourth locality, on the north slope of Holme Fell, just on Sheet SD 69. The comparison with the range of Bannisdale Formation facies (Figure 5b-d) is conveniently made.

The 'undivided Coniston Group' of this report closely approximates the Upper Coniston Grits of Rickards (1967), and the Latrigg, Poolscar, Moorhowe and Yewbank Formations of King (1992).

5.4 BIOSTRATIGRAPHY OF THE CONISTON GROUP

The Coniston Group was assigned to the broad *nilssoni-scanicus* Biozone of Rickards (1967), which ranges from the top of the Coldwell Formation just into the bottom of the Bannisdale Formation. A more refined bistratigraphic subdivision of the Coniston Group was made possible by new collections on Sheet SD 69 (Rickards and Woodcock, 2005; Woodcock and Rickards, 1999). The main conclusions were that a) the lower half of the Screes Gill Formation is referable to the *nilssoni* Biozone, b) the upper half of the Screes Gill Formation is probably referable to the *progenitor* Biozone, and c) the undivided Coniston Group above the Screes Gill Formation is probably *scanicus* Biozone. Some of the relevant specimens collected on Sheet SD 68(N) are shown in Figure 4B-4E, all from the basal siltstone unit of the undivided Coniston Group.

There are few fossiliferous sites in the Coniston Group of the study area, although Furness (1965a, p. 37) recorded a *nilssoni* Biozone fauna from Helms Knott [SD 684 896]. As it happens, they were identified by one of us (RBR) and the following fauna is recorded with up-to-date names (old names in brackets where appropriate): *Saetograptus (Saetograptus)* c.f. *wandalensis* (Watney and Welch) (*P.* c.f. *wandalensis*); *Saetograptus (Saetograptus) chimaera chimaera* (Barrande) (*M. chimaera chimaera*); *Bohemograptus bohemicus bohemicus* (Barrande) (*P. bohemicaus*); *Pristiograptus dubius* (Suess); *Neodiversograptus nilssoni* (Barrande) (*P. nilssoni*); *Saetograptus (Colonograptus) colonus* (Barrande) (*M. colonus*); *Saetograptus (Colonograptus) roemeri* (Barrande) (*M. roemeri*); and *Monograptus haupti* (Kühne) (*Monoclimacis haupti*). Similar faunas have been collected by Furness (1965a, pp.33-34) from south of the study area (Leck Beck [SD 640 790]), from strata correlatable with the Screes Gill Formation.

From rocks correlatable with the undivided Coniston Group herein, Furness (1965a, pp.34-36) recorded faunas broadly comparable to those in the Howgill Fells (Rickards and Woodcock, 2005), and also referred there to an undivided Coniston Group. These faunas are as follows: *Saetograptus (Saetograptus) incipiens incipiens* (Wood) (*M. leintwardinensis incipiens*); *Saetograptus (Saetograptus) varians pumilis* (Wood) (*M. varians pumilis*); *Saetograptus (Saetograptus) chimaera salweyi* (Hopkinson) (*M. chimaera salweyi*); *Pristiograptus dubius* (Suess) (*P. vicinus*); *Bohemograptus bohemicus bohemicus* (Barrande) (?*Pristiograptus nilssoni*).

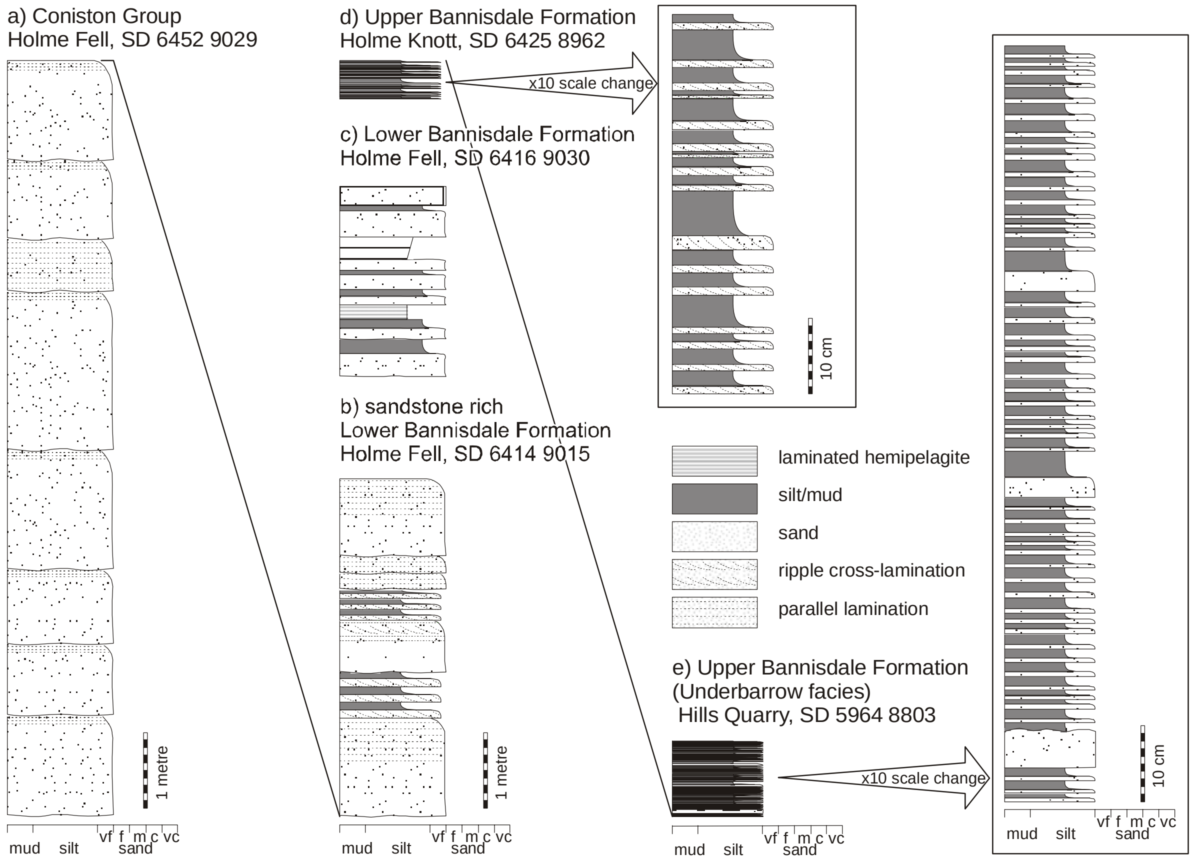


Figure 5. Lithological logs of representative facies from the Coniston Group and Bannisdale Formation

5.5 DEPOSITIONAL ENVIRONMENT OF THE CONISTON GROUP

Since the phase of work summarised by Furness et al. (1967), the Coniston Group has been interpreted predominantly as the deposits of turbidity currents. The sandstone–mudstone couplets were deposited from medium to high concentration flows, and the siltstone–mudstone couplets from low-concentration flows. The laminated siltstone facies, which forms a subordinate but persistent component of the group, is interpreted as a hemipelagic deposit that continued between turbidite events. This facies, the presence only of pelagic or nektonic faunas, and the rarity of bioturbation, all indicate that anaerobic bottom waters persisted into Ludlow from Wenlock time.

The major sandstone-dominated units in the Coniston Group are interpreted as episodes of turbidite fan growth, separated by periods of slower sediment supply represented by the siltstone units (King 1992, 1994b). The thinning of the Coniston Group units in Dentdale may represent their more distal position with respect to the Howgill Fells, although the data of Furness (1965a) suggest that the group thickens again southwards to over 1300 m in the Barbon Fells.

6 Kendal Group: Bannisdale Formation

6.1 DEFINITION

As intimated in the section on the Coniston Group, the definition of the Bannisdale Formation on Sheet SD 69 is not straightforward, there being transitional or intermediate facies both at the base and at the top.

The Bannisdale Formation as formalised in the Howgill Fells and eastern Lake District (Moseley, 1984; Kneller et al., 1994) follows the definition of Aveline and Hughes (1872) of a finer grained and thinner bedded unit above the Coniston Group. However, the contact between the two units is typically transitional, and the mapped boundary has varied between different authors and areas. The base of the Bannisdale Formation picked on Sheet SD 69 (Woodcock and Rickards, 1999) was deliberately close to that mapped by Soper (1999) in the northern Howgill Fells. As such, it was at least 300 m higher in the succession than that chosen by Rickards (1967), but close to that picked by Aveline and Hughes (1872). Thick-bedded sandstone packets occur in the lower part of the Bannisdale Formation in the Howgill Fells (SD 69) and increase in frequency and thickness southward (Woodcock and Rickards, 1999). The same lower boundary has been mapped southward on to Sheet SD 68(N), with a further increase in the proportion of sandstone in the lower Bannisdale Formation.

Four main criteria have been used in this study to discriminate the Bannisdale Formation from the Coniston Group. These criteria are a) the presence in the Coniston Group of discrete units, some metres to tens of metres thick, rich in hemipelagic mudstone in contrast to only very thin hemipelagite units persisting in the Bannisdale Formation; b) the expanded lamination spacing in the hemipelagite of the Bannisdale Formation, about 1 mm compared with 0.3 mm in the Coniston Group; c) the more pronounced sedimentary structures within Bannisdale Formation sandstone beds, probably due to slightly higher mud content, and d) the more prominent mudstone tops to even the thick Bannisdale sandstone beds. These lithological criteria have been augmented by new fossil collections, described below, which suggest that the chosen lithostratigraphical base to the Bannisdale Formation is the same biostratigraphical age as in the Howgill Fells.

Using these criteria, the base of the Bannisdale Formation has been reliably located on the north slopes of Holme Fell, just north of the study area. Here [e.g. SD 6415 9030] the base is marked by a prominent packet of thin-bedded sandstones and mudstones which can be mapped eastward and on to Sheet SD 69 south-east of Rash Bridge [SD 6586 8981]. This unit is then obscured by superficial deposits, but is presumed to run under the lower, south-eastern slope of Dentdale. All the exposed units in the streams draining this slope – Ruddles Gill, Brackens Gill and Corn Close Gill – are assigned here to the Bannisdale Formation, whereas Furness (1965a) placed the lowest strata in these gills in the Coniston Group. On both interpretations, the contact rises through unexposed ground beneath Combe Scar, before being exposed again at the head of Barbondale, north–west of Stone Rigg [SD 6818 8697]. From here it probably runs close below the exposures of Bannisdale sandstones on the north-west slope of Barbondale.

The sandstone-rich lower division of the Bannisdale Formation on Sheet SD 68(N) is stratigraphically overlain by a sandstone-poor upper division (Furness, 1965a). However, this upper unit is cut by the major Barbon and Firbank faults, so that no unbroken transect through to its upper contact is available. A gradational facies change in the upper part of the upper division was the basis for the recognition by Shaw (1969, 1971a) of an Underbarrow Formation, roughly equivalent to the Passage Beds of Aveline and Hughes (1872, 1888). However, a boundary between this Underbarrow facies and the typical Bannisdale facies has not proved mappable either on Sheet SD 68(N), or on sheets SD 59 or SD 69 to the north. The Underbarrow facies is therefore treated here as a variant within the upper division of the Bannisdale Formation. The upper contact of the Bannisdale Formation is taken where thick-bedded sandstones, here of shallow marine character, reappear in the sequence, marking the lower boundary of the Kirkby Moor Formation.

The Underbarrow and Kirkby Moor flags have previously been grouped, together with the Scout Hill Flags (now subsumed in the Kirkby Moor Formation, see below), into a Kendal Formation (Moseley, 1984), and the Bannisdale, Underbarrow and Kirkby Moor Formations into a Kendal Group (King, 1992, 1994b). The Kendal Group was not adopted by Kneller et al. (1994), but has been formally defined by Rickards and Woodcock (2005).

6.2 DISTRIBUTION

Rocks of the Bannisdale Formation crop out over most, about 29 km^2, of the northern half of Sheet SD 58.

Between the Barbon and Dent faults the lower division of the Bannisdale Formation passes up into the upper division in the core of the gently west-plunging Luge Syncline. Numerous small hill crags expose the lower division rocks around their arcuate outcrop, particularly in the areas around Holme Knott [SD 6460 8953], Long Bank [SD 6672 8780] and Combe Scar [SD 6766 8748]. Well exposed stream sections include – on the north limb of the syncline – Ruddles Gill [SD 6615 8949] and Brackens Gill [SD 6657 8918], and – on its south limb – Red Gills [SD 6741 8630] and Millhouse Gill [SD 6397 8538]. The upper division is well exposed west of Holme Knott [SD 6442 8945], and in Ridding Beck [SD 6430 8893], Raismoor Beck [SD 6418 8860] and Luge Gill [SD 6438 8773].

Between the Barbon Fault and the Firbank Fault to the west, the lower division in the north is succeeded by generally southward younging upper division rocks further south. The possibility cannot be excluded that the upper contact of the Bannisdale Formation occurs within this fault block in the south of the study area. The valley ground between the Barbon and Firbank faults is covered by a thick cover of superficial deposits, but good exposures of lower division rocks occur in the bed of the River Rawthey near Middleton Bridge [SD 6300 8976], and in the Lune between Blea Wheel [SD 6250 8964] and Waters Meeting [SD 6289 8953]. The upper division rocks are adequately exposed in the Lune below Park Wood [SD 6290 8943], east of Hallbeck [SD 6230 8848], south-west of Low Waterside [SD 6242 8880] and north of Hawking Hall [SD 6200 8594].

West of the Firbank Fault, upper Bannisdale rocks only crop out on Sheet SD 68(N) in the far west, near the Old Scotch Road. The only extensive exposure is just west of the study area at Hills Quarry [SD 5964 8803].

6.3 LOWER DIVISION OF THE BANNISDALE FORMATION

Two facies have been distinguished in the northern part of the main, lower Bannisdale outcrop, for instance east of Holme Knott [SD 6462 8953]. The finer grained of these two facies (coded Bnd on the 1:10,000 standards) contains about equal proportions of sandstone and mudstone (Figure 5c). The sandstone is mostly in sharp-based beds, typically 10-50 cm thick, grading from very fine sand to a mud top forming less that 25% of the bed. The sandstones are mostly massive or parallel laminated. These medium to thick beds are intercalated with intervals, also 10-50 cm thick, comprising very thin graded beds with cross-laminated very fine sand bases and mud tops forming over 50% of the bed. This very thin bedded lithology is similar to that typical of the upper Bannisdale Formation. It contains sporadic, very thin intervals of laminated hemipelagite.

The coarser grained facies (coded sa on the 1:10,000 standards) has at least 75% sandstone, due to the presence of thick or very thick sandstone beds, massive or weakly parallel laminated

(Figure 5b). The very thin-bedded lithology is rare, and thin to medium graded beds dominate the intervals between thick-bedded sandstones.

Around Holme Knott, the two lower Bannisdale facies are interbedded in about equal proportions, forming mappable units each about 50 m thick. Followed south-eastward, however, the finer grained units seem to thin and interfinger laterally with the coarser grained facies. Two kilometres from Holme Knott, the fine-grained facies makes up only 25% of the section and, in a further kilometre, no mappable fine-grained units persist. From this point southwards into Barbondale and over Middleton Fell, the lower Bannisdale Formation is mapped as entirely sandstone-dominated. Any finer grained intervals are too thin to map, that is less than about 20 m, and form perhaps less than 10% of the section. The lateral replacement of mudstone by sandstone is accompanied by only a modest southward increase in the thickness of the lower division of the Bannisdale Formation from about 500 m on Holme Knott to nearer 600 m from Middleton Fell over to Barbondale.

A small but important outcrop area of lower Bannisdale Formation has been delimited between the Barbon and Firbank faults, north of the confluence of the rivers Rawthey and Lune [SD 6286 8957]. Both the finer and coarser grained components of the sequence here are finer and thinner-bedded than east of the Barbon Fault. Indeed, the sandstone-poor facies, exposed for instance at Low Craigles [SD 6220 8990], might reasonably be assigned to the upper Bannisdale Formation, with its lower contact above a sandstone unit at SD 6213 8999. However, mapping on Sheet SD 69 (Woodcock and Rickards, 1999) suggests that the higher unit of thin-bedded sandstone exposed at Stangerthwaite [SD 6238 8970] and Waters Meeting [SD 6283 8960] thickens and coarsens northward, over an intervening anticline, and correlates with the sandstone unit at Crowder's Leaps [SD 6286 8957] that forms a mappable top to the lower Bannisdale Formation in the Howgill Fells.

6.4 UPPER DIVISION OF THE BANNISDALE FORMATION

The upper division of the Bannisdale Formation is dominated by a mudstone-rich facies comprising beds 1–10 cm thick, each with a sharp base and grading from very fine sandstone up to mudstone (Figure 5d). Mudstone forms at least 50% of each bed, and includes sporadic intervals or laminae of laminated hemipelagite. The basal sandstone units typically show ripple cross-lamination. Medium-bedded (10-30 cm), graded sandstone beds are intercalated in the thin-bedded facies sporadically, but rarely form organised packets.

The upper part of the upper Bannisdale Formation, particularly below the Kirkby Moor Formation in the west of the study area, may contain a greater number of medium- or thick-bedded sandstones, in places forming up to 40% of the section (Figure 5e). The sandstone beds are calcareous and some contain low-dipping swaley cross-bedding. Others have sharp tops showing symmetric to weakly asymmetric ripple forms. The very thin-bedded facies that still dominates the succession shows more evidence of bioturbation than in the typical upper Bannisdale facies. The best exposure of the upper facies of the upper Bannisdale Formation, at Hills Quarry [SD 5964 8803] just west of the study area, was a locality cited by Shaw (1971a) as typical of his Underbarrow Formation and taken as the formal type locality by Kneller et al. (1994). However, this unit has proved elusive to map in the ground to the north of the study area (sheets SD 59 and SD 69), and has not therefore been adopted in this study.

Because the base and top of the upper Bannisdale Formation are not present in any one major fault block within the study area, the total thickness of the unit is poorly constrained. East of the Barbon Fault, the maximum thickness in the core of the Luge Syncline is 570 m. Between the Barbon and Firbank faults, the calculated minimum thickness is at least 1130 m.

6.5 BIOSTRATIGRAPHY OF THE BANNISDALE FORMATION

A marked feature of the Bannisdale Formation in the Middleton Fells is that graptolites referable to the genus *Saetograptus* are more abundant and better preserved than specimens from the same level in the Howgill Fells (Figures 4, 6). Graptolites from the lower division of the Bannisdale Formation have been found at numerous localities, and comprise the following species: *Saetograptus* (*Saeotograptus*) *soperi* Rickards and Woodcock (=*M. leintwardinensis incipiens* when recorded from the Bannisdale slates by Furness (1965a)); *Saetograptus* (*Saeotograptus*) *leintwardinensis leintwardinensis* (Hopkinson); ?*Saetograptus* (*Saeotograptus*) *chimaera salweyi* (Hopkinson); *Monograptus* s.l. indet. The first two species are almost always in association, the former being more common. The last two occur low in the section on Brackensgill [SD 6666 8920], the former rarely, the latter only as a single specimen [SD 6650 8905].

The upper division of the Bannisdale Formation is also typified by *S.* (*S.*) *soperi* and *S.* (*S.*) *leintwardinensis* at numerous localities, the former becoming less common up the section than the latter. Thus the whole of the Bannisdale Formation, can reasonably be referred to the *leintwardinensis* Biozone, and the base of the Biozone coincides closely with the base of the lower Bannisdale Formation. The correlation with the base of the *leintwardinensis* Biozone in the Howgill Fells is clear, where it also coincides with the base of the Bannisdale Formation

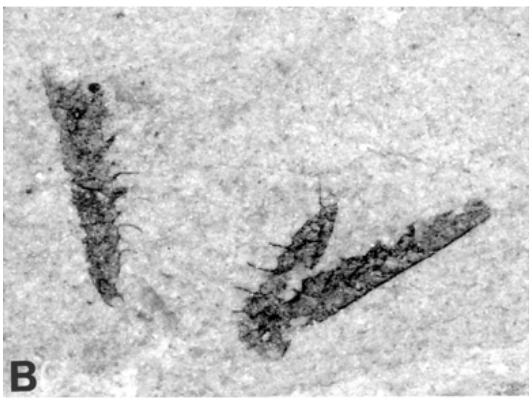


Figure 6 Photographs of slabs of *Saetograptus soperi* Rickards and Woodcock, from the Howgill Fells:

A) X.41876-85 from Stranger Gill [SD 9760 6581] and B) X.41895 from Middle Gill [SD 9745 6668].

6.6 DEPOSITIONAL ENVIRONMENT OF THE BANNISDALE FORMATION

Most of the Bannisdale Formation lithologies can be interpreted in terms of deposition from turbidity currents. The very thin-bedded facies, predominant in the upper Bannisdale Formation, was deposited from low-concentration turbidity flows, and the associated laminated siltstone facies from hemipelagic fallout in the intervals between turbidite events. The rate of supply of silt to the laminated facies was greater than in the Coniston Group by a factor of two or three, resulting in a larger spacing between successive organic carbon laminae. The medium- to thick-bedded sandstone beds typical of the lower Bannisdale Formation were deposited from medium to high concentration flows. The volume of such flows clearly decreased up the Bannisdale succession. The sparse but present graptolitic faunas and the rarity of bioturbation indicate anaerobic bottom waters persisting from Wenlock time well into the Ludlow.

The ‘Underbarrow facies’ at the top of the Bannisdale Formation has several features indicating a shallow marine origin: increased bioturbation and carbonate content; swaley cross-lamination and possible wave-influenced ripples. The upward transition to a storm-influenced marine shelf is entirely consistent with this interpretation of the overlying Kirkby Moor Formation.

7 Kendal Group: Kirkby Moor Formation

7.1 DEFINITION AND DISTRIBUTION

The Kirkby Moor Formation has been recognised in all lithostratigraphical schemes since those of Sedgwick (1845, 1846, 1852a) and was formally defined by Kneller et al. (1994), with a type section at Black Crag, Staveley [SD 4647 9933], (Lawrence et al., 1986). Its base is marked by the incoming of medium-bedded (10-30 cm thick) greenish grey sandstone beds above the upper Bannisdale lithology. This base to the Kirkby Moor Formation is closely mappable, though not exposed, at the extreme western edge of the study area [SD 6000 8832]. Here the formation overlies the Underbarrow facies of the upper Bannisdale Formation, exposed for instance at Hills Quarry [SD 5964 8803]. The contact can be mapped northward and relocated by the Old Scotch Road, north of Three Mile House [SD 6005 8900].

The Kirkby Moor Formation crops out over most of the ground in the study area west of the Firbank Fault. Extensive hill crag exposures occur from south of Aikrigg [SD 6092 8848] over Park Hill [SD 6048 8727] to Green Park Hill [SD 6057 8686]. There are also stream sections in Hall Beck around Killington [SD 6142 8892], in Springs Gill [SD 6062 8900], Aikrigg Beck [above SD 6158 8800] and at [SD 6145 8727].

In the south of the area, the Kirkby Moor facies is reddened, either pervasively or locally along joints and cleavage, for instance west of Gill Foot [SD 6138 8631], on the track to High Rigg Brown [SD 6084 8566], and in the stream draining Kitmere [SD 6080 8542]. Shaw (1971a) distinguished this reddened unit as a separate formation, the Scout Hill Flags. Kneller et al. (1994) recommended that this unit be abandoned, a recommendation which is followed here. The secondary nature of the reddening is emphasised by the observation that it also affects upper Bannisdale Formation mudstone units in this area, across the Firbank Fault near Hawking Hall [SD 6204 8596]. Reddening therefore occurred after Devonian displacement on the Firbank Fault and presumably at a Devonian or Early Carboniferous land surface preserved beneath the unconformity below the Carboniferous strata.

As mapped, outcrop of the Kirkby Moor Formation on Sheet SD 68(N) is restricted to the area west of the Firbank Fault. However, the formation is exposed, apparently east of the fault, north of Treasonfield [SD 6172 8382] just over a kilometre into the southern half of the sheet.

Exposures of Kirkby Moor Formation under Rigmaden Bridge [SD 6170 8483], only 150 m south of the study area, are assumed to lie west of the Firbank Fault. If this assumption is incorrect, then the basal beds of the Kirkby Moor Formation may lie below drift cover south of Millbeck [SD 6265 8527].

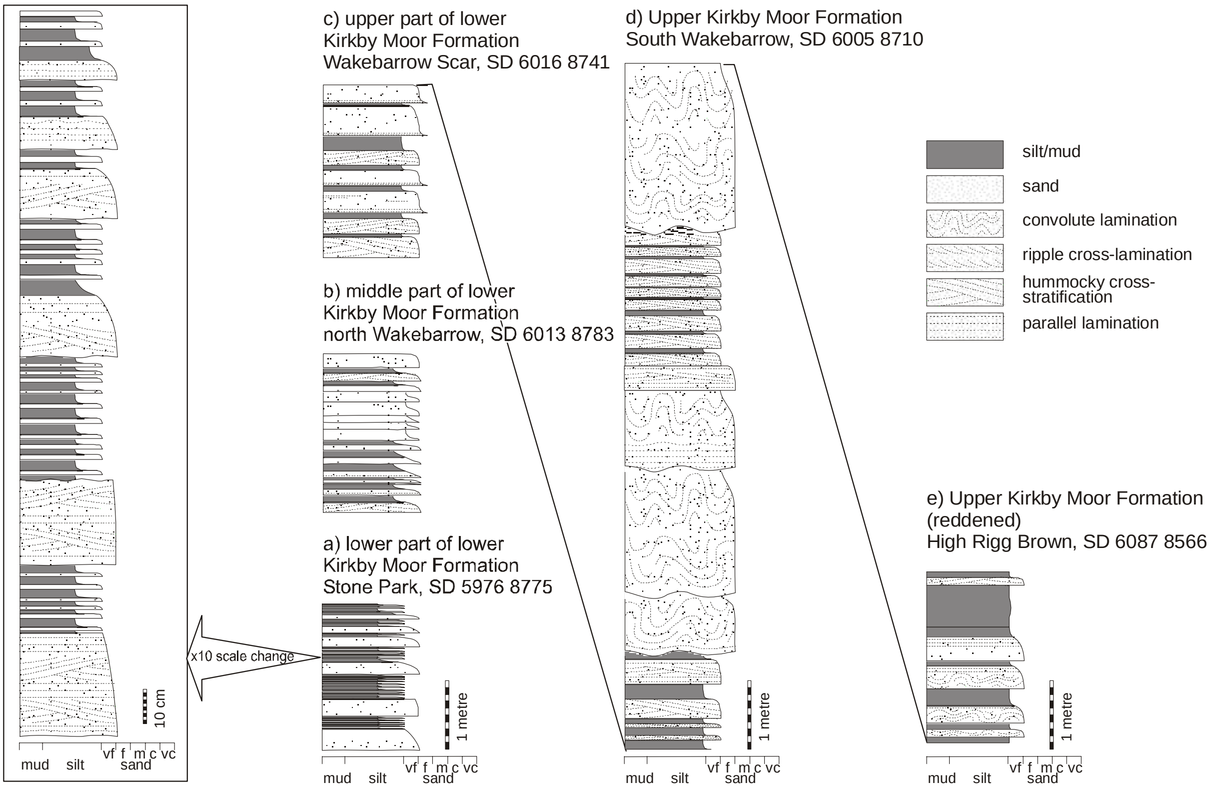


Figure 7 Lithological logs of representative facies from the Kirkby Moor Formation.

7.2 LOWER DIVISION OF THE KIRKBY MOOR FORMATION

Two informal divisions of the Kirkby Moor Formation have been recognised in this study. The lower unit is about 350 m thick on a transect across Wakebarrow Moss [SD 6012 8812] to Park Hill [SD 6048 8727]. The basal 50 m of the lower Kirkby Moor Formation is transitional from the underlying ‘Underbarrow facies’ of the upper Bannisdale Formation. The very-thinly bedded silt–mud couplets of this facies are increasingly interbedded with medium-bedded (10-30 cm) units with sharp bases, grading up from very fine sandstone to thin silty mudstone tops (Figure 7a). The sandstone beds, which, even at the formation base, dominate this transitional facies, may be massive or more commonly show parallel or hummocky bedding. Calcareous shelly debris occurs at the base of some of these beds, and some have wave-rippled tops. The very thin-bedded component is lost above the basal 50 m of the formation, though some thin-bedded graded units persist (Figure 7b). However, the thickening-up trend within the formation continues, and near the top (Figure 7c) graded beds average 15-50 cm thick. These beds now grade from fine sand up to silt.

7.3 UPPER DIVISION OF THE KIRKBY MOOR FORMATION

The thickening and coarsening trend seen in the lower Kirkby Moor Formations continues into the upper part of the unit. Its gradational base has been mapped striking east-north-east across Park Hill [SD 6048 8727]. A typical log (Figure 7d) through the upper Kirkby Moor Formation shows packets of the medium-bedded graded units intercalated with thickly- to very thickly-bedded (50-250 cm) fine sandstone units. Although these very thick beds may retain some parallel or hummocky bedding, their defining characteristics are large-scale convolute lamination and strongly loaded basal contacts.

The convolute-laminated upper Kirkby Moor facies persists up-section as far as the south edge of the study area though, as far as can be judged from the the limited exposure, not with increasing bed thickness. A short log (Figure 7e) through reddened Kirkby Moor facies on High Rigg Brown [SD 6084 8566] shows sandstone beds up to 60 cm thick, not all convolute-laminated. The thickness of the upper Kirkby Moor Formation between Park Hill and the southern edge of the study area near Rigmaden is estimated at 600 m [SD 6100 8500]. A further 400 m of the unit, all secondarily reddened, probably occurs south of the study area, before it is overlain by the basal Carboniferous Sedbergh Conglomerate around Holme House [SD 6128 8383].

7.4 BIOSTRATIGRAPHY OF THE KIRKBY MOOR FORMATION

We have found only rare and fragmentary shells in the Kirkby Moor Formation of the study area. The best biostratigraphical dating available is by Shaw (1971a, b), although almost all of the data are from west of the study area, especially around Underbarrow. The most common of Shaw's (1971a, B) fossils are gastropods, bivalves, brachiopods and ostracods. Of his figured ostracods (Shaw, 1971b), only three specimens are from our study area, from the region of Park Hill and Killington [SD 6051 8688, 6030 8902, 6027 7958]: *Neobeyrichia lauensis* (Kiesov) from his Upper Underbarrow Flags, *Neobeyrichia confluens* Shaw from the Kirkby Moor Flags, and *Frostiella groenvalliana* Martinsson from his Scout Hill Flags.

Shaw's research was based upon locally quite rich and diverse assemblages in thin coquinas. He dated his Upper Underbarrow Flags and Kirkby Moor Flags as Whitcliffian, which is Ludlow (Ludfordian, post *bohemicus* Biozone) and his Scout Hill Flags as Downtonian, that is Přídolí, based largely on crucial ostracods. In this study we place the Underbarrow Flags in the upper part of our upper division of the Bannisdale Formation, and the Scout Hill Flags in the upper part of our upper division of the Kirkby Moor Formation (Figure 8).

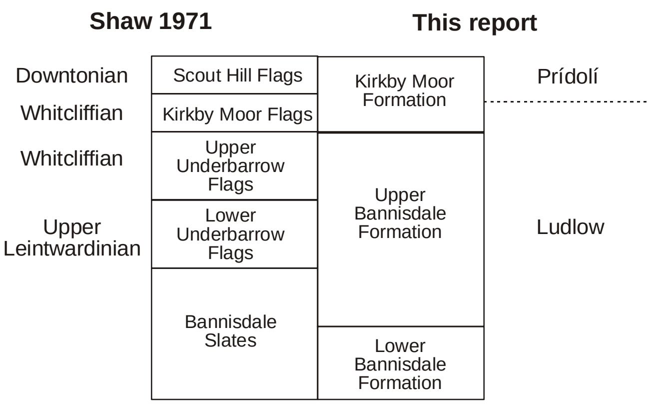


Figure 8 Comparison of the stratigraphical schemes of Shaw (1971a) and this study.

7.5 DEPOSITIONAL ENVIRONMENT OF THE KIRKBY MOOR FORMATION

A number of features suggest that the Kirkby Moor Formation records storm deposition at shallow marine shelf depths. The graded units imply episodic deposition from waning flows. The hummocky cross-stratification suggests a component of combined wave and unidirectional flow typical of storms. The sporadic wave ripples imply depths above storm wave base. The diverse if sparse shelly fauna, probably mostly resedimented, implies a source of storm sediment in the photic zone. The transition upwards from the presumed deep-water turbidites of the Bannisdale

Formation implies a shallowing-upward trend that probably continued through into the coarser, thicker bedded facies of the upper division of the Kirkby Moor Formation. The convolute-lamination in this unit probably reflects syn-depositional triggering of soft-sediment deformation by the impact of the storm waves, though seismic triggering cannot be discounted. If the reddening in the upper part of the section is secondary, no depositional significance can be attached to it, though it is likely that shallowing continued upwards. An intertidal reddened facies of the Kirkby Moor Formation, The Helm Member, has been recognised near Oxenholme, 7 km to the west of the study area (King, 1994b).

8 Igneous intrusions

Compared with the Howgill Fells and Cautley area to the north (Sheet SD 69), igneous intrusions are rare on Sheet SD 68(N). This is in part due to the generally higher stratigraphical levels at outcrop in the study area, the intrusions in the Howgills being markedly more common in lower levels of the succession.

Lamprophyre intrusions, presumably though not always demonstrably dykes, have been reported only from the Ordovician rocks of the Dentdale inlier (Aveline et al., 1872; Ingham, 1966). Two dykes, apparently striking north-westward, have been located in the present study in the northern part of Helmside Gill [SD 6867 8956 and SD 6872 8967]. Two similar dykes, recorded by both Aveline et al. (1872) and by Ingham (1966) were not exposed during the present survey, but are shown on the standard map in the gully south of Bower Bank [SD 6858 8767 and SD 6863 8775]. Elsewhere in the region, lamprophyre dykes intrude as high as the Bannisdale Formation. K-Ar dates from micas in lamprophyre dykes from the Howgill Fells by Nixon et al. (1984) have a weighted average of 413±7 Ma of suggesting an Early Devonian (Pragian or late Lochkovian) intrusion age. The implication is that both lamprophyres and felsites predate the climax of regional deformation at about 400 Ma, although neither group of intrusions is conspicuously cleaved.

A vertical sheet of brecciated felsite is exposed in Wilsey Beck [SD 6886 8764], at the fault contact with the Brathay Formation. This sheet is interpreted as a felsite intrusion, probably into the Dent Group, which has locally influenced the course of the Underwood Fault.

9 Carboniferous strata

Carboniferous rocks crop out, on Sheet SD 68(N), east of the Dent Fault and, more speculatively, in a wedge between the Barbon and Casterton Hall faults. Although detailed description of the Carboniferous succession is outside the remit of the present report, a brief comment on observations made during the present study is relevant to the location and nature of the mapped faults.

9.1 SEDBERGH CONGLOMERATE FORMATION

The basal unit to the Carboniferous succession comprises reddish brown conglomerate and sandstone. The name Sedbergh Conglomerate(s) was proposed by Burgess (Dunham and Wilson 1985; Burgess, 1986), and appeared, without designated formational status, as the Sedbergh Conglomerate on the Hawes 1:50,000 sheet (British Geological Survey, 1997a) and as the Sedbergh and Garsdale Conglomerates on the Kirkby Stephen 1: 50,000 sheet (British Geological Survey, 1997b). Older names include the Upper Old Red Conglomerate (Aveline and Hughes, 1872; Aveline et al., 1872), the Carboniferous Basement Beds (Aveline and Hughes, 1888; Dakyns et al., 1891) and the Basement Conglomerate Series (Butterfield, 1920). On Sheet SD 69, the base of the unit is an angular unconformity above Silurian rocks (Woodcock and Rickards, 1999), though this relationship is nowhere exposed on Sheet SD 68(N). There are no exposures of the Sedbergh Conglomerate in the study area, but two exposures in the ground to the south influence the location of faults on Sheet SD 68(N).

The exposure in Barbon Beck, near Barbon Church, [SD 6310 8255] occurs just west of a sliver of Great Scar Limestone Group caught along the Barbon Fault. It suggests that there is a fault-bounded wedge of conglomerate between the Barbon Fault and the Casterton Hall Fault to the west. This hypothesis is reinforced by the record by Aveline and Hughes (1872) of an exposure of conglomerate, no longer visible in 2004, about a kilometre further north, west of Barwick Hall [SD 6271 8352]. On this evidence, we have followed previous workers (Aveline et al., 1872; Furness, 1965a) in showing this fault wedge encroaching on to Sheet SD 68(N), with its tip close to Ellers [SD 6316 8596].

The second relevant exposure is on the bank of the River Lune, south of Holme House [SD 6138 8354]. The moderate easterly dip of this conglomerate unit allows it to be unconformable on reddened beds of the Kirkby Moor Formation 500 m to the north-north-west [SD 6123 8412]. However, this dip seems to preclude unconformity on the reddened Kirkby Moor Formation 250 m to the east [SD 6167 8365]. A fault is postulated between these two exposures. This fault strikes northwards, just east of exposures of Kirkby Moor Formation at Rigmaden Bridge [SD 6170 8483], and onto Sheet SD 68(N) as the Firbank Fault.

9.2 GREAT SCAR LIMESTONE AND YOREDALE GROUPS

Units of these two groups crop out east of the Dent Fault as far as the eastern edge of the study area. The present mapping has essentially confirmed the outcrop pattern shown on the Hawes 1:50,000 sheet (British Geological Survey, 1997a) and the six-inch surveys on which it is based. In particular, the unit immediately east of the Dent Fault is probably the Danny Bridge Limestone. The Hawes Limestone, forming the base of the Yoredale Group, is not cut by the Dent Fault at the present erosion level. Both groups are involved in the abrupt monoclinal upfold adjacent to the Dent Fault, in which between 100 m and 300 m of beds are bent vertically during the west-up displacement on the Dent Fault.

10 Structure

The study area of Sheet SD 68(N) is affected by two main generations of structures, with trends almost at right angles to each other. These structures are summarised in map view on Figure 9. First, the Acadian deformation produced approximately east-south-east-trending folds (shown in cross-section on Figure 10) and sub-parallel cleavage and minor faults. These structures developed between late Silurian and earliest Carboniferous time, and probably mainly during the Early Devonian. Secondly, the Variscan deformation produced major north or north-east striking faults and a sub-parallel monocline (shown in cross-section on Figure 12). This phase was probably Late Carboniferous to Early Permian on regional evidence. There is the possibility that the Variscan faults reactivated earlier structures, of Acadian or even pre-Acadian age.

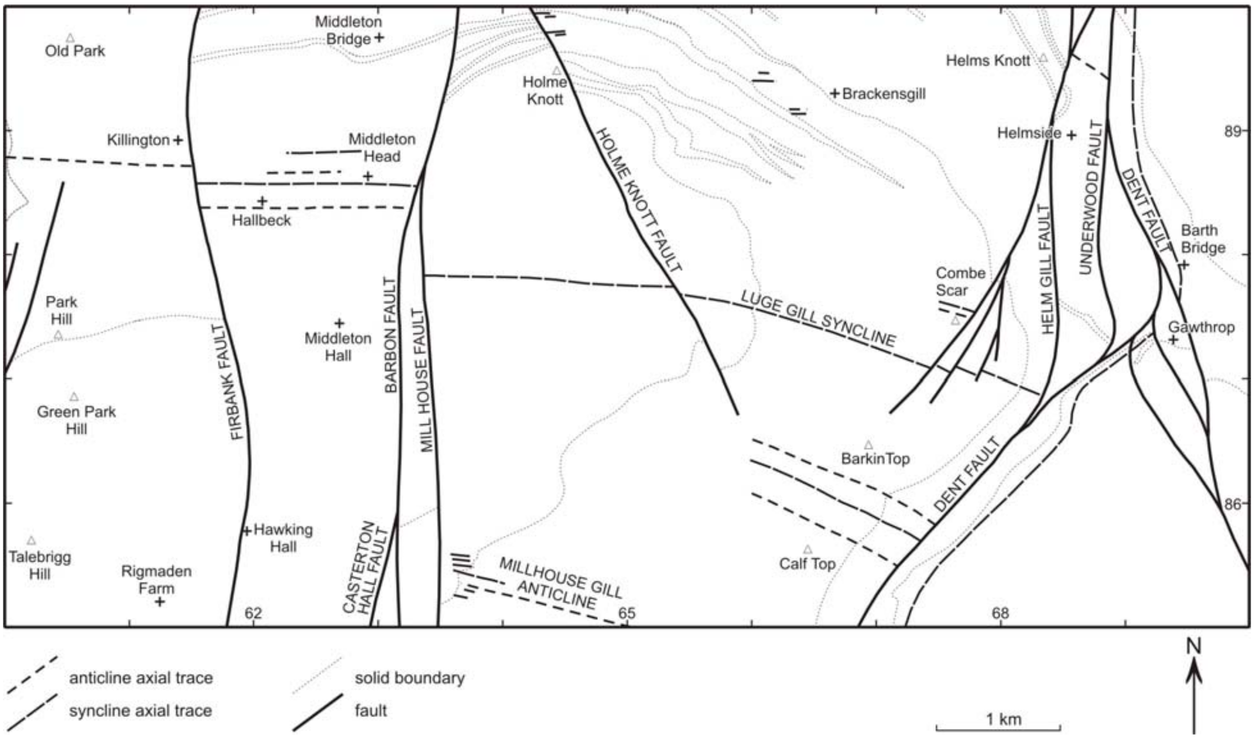


Figure 9 Summary map of the main structures on Sheet SD 68(N).

10.1 ACADIAN FOLDS

The Acadian folds in the study area mostly have an open to gentle geometry and a wavelength in the order of some kilometres. Shorter wavelength folds, on a scale of several hundred metres or – less commonly – tens of metres, only occur in localised zones.

The dominant fold in the area is a broad syncline, named here the *Luge Gill Syncline*, occupying most of the area between the Millhouse/Barbon and Dent/Helm Gill faults (Figure 10). The imprecisely defined axial trace runs almost west to east, nearly coincident with Luge Gill, then heads east-south-eastward over Combe Top to be truncated by the Helm Gill Fault north of Stone Rigg [SD 6834 8686]. The fold axis plunges between 5° and 10° westward, based on stereographic analysis of bedding data, except close to the Helm Gill Fault, where it plunges about 5° eastward. Erosion into the west-plunging syncline has produced the west-facing crescent of the Middleton Fells, defined by the resistant lower division of the Bannisdale Formation, and preserving the less resistant upper Bannisdale rocks in the syncline core.

Minor syncline – anticline pairs have been mapped in five places on the northern limb of the Luge Gill Syncline. In each case, the folds trend east or east-south-east and the distances between the axial traces of the anticline and syncline are in the range 40-60 m. However, the asymmetry of the fold pairs is not consistent. In two fold pairs at Brigflatts Moss [SD 6834 8686 and SD 6458 8979] and one in Combe Scar [SD 6262 8756], the vergence is northward, the expected up-dip sense for parasitic folds on this major fold limb. However, the folds pairs crossing Ruddles Gill [SD 6610 8942] and the stream north of Brackensgill [SD 6636 8915] verge southward, that is down the sheet dip of the major fold limb.

Subsidiary folds on the southern limb of the Luge Gill Syncline comprise two gentle anticlines and an intervening syncline trending east-south-east from the head of Wrestle Gill [SD 6638 8618] over to Barbondale [SD 6727 8572]. These folds have a wavelength of about 400 m.

The flanking east-trending anticlines to the Luge Gill Syncline are the *Riggs Anticline*, about 500 m north of the sheet boundary (Woodcock and Rickards, 1999), and the newly named *Millhouse*

Gill Anticline. The anticline hinge zone comprises a belt of closely spaced folds, either side of Millhouse Gill [SD 6375 8545], a few hundred metres north of the southern edge of the study area (Figure 9). The folds have wavelengths of about 70 m and together define a hinge zone about 350 m wide trending east-north-east.

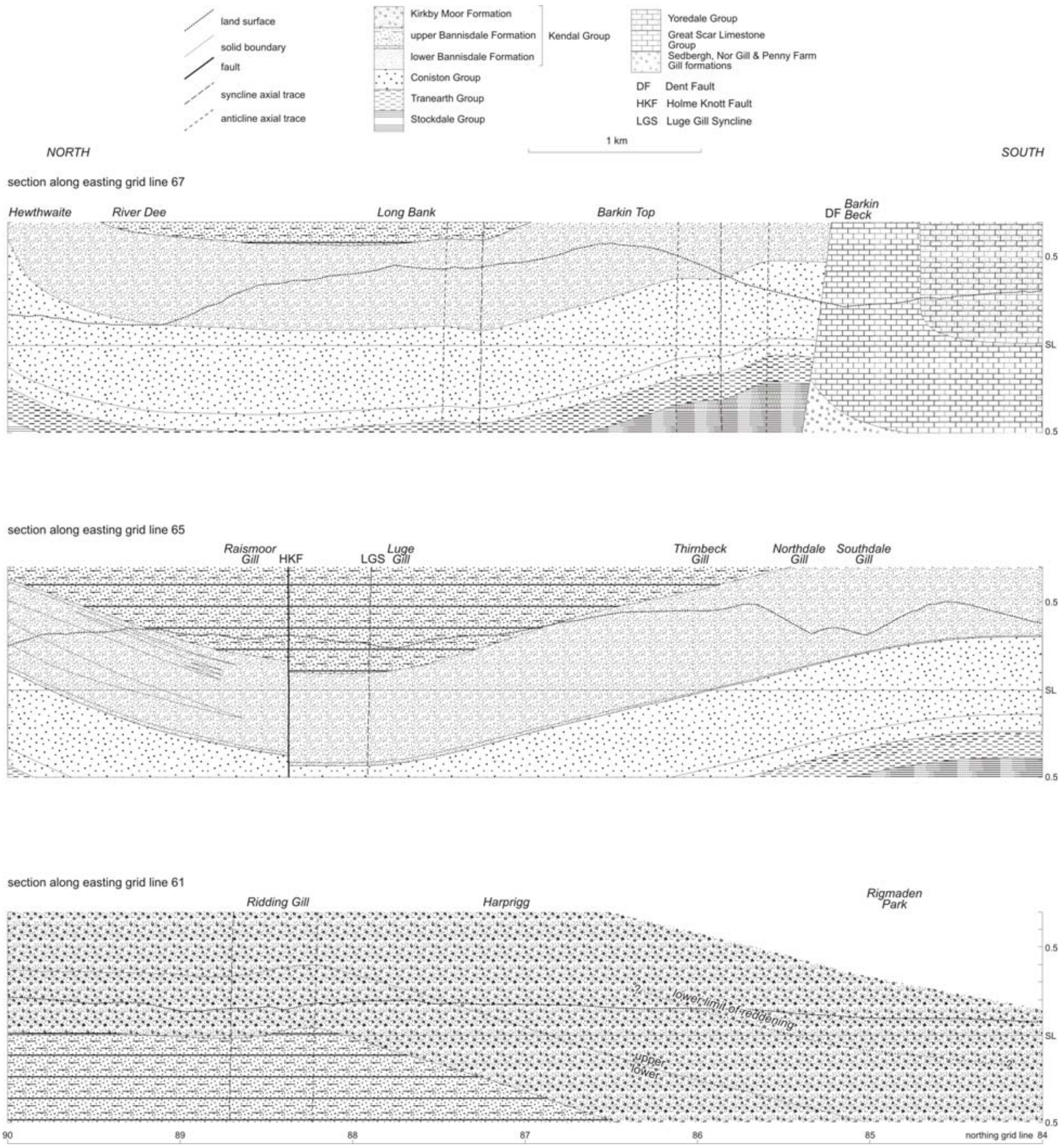


Figure 10 North-south cross-sections across Sheet SD 68(N).

Between the Barbon Fault and the Firbank Fault, the Bannisdale Formation is entirely part of a major south-dipping fold limb, with dips typically between 5° and 20°, interrupted only by two north-verging anticline-syncline pairs near Hallbeck [SD 6230 8856]. These pairs have an open geometry, a wavelength of 300 m, and plunge eastward at about 10°. The anticlinal hinge to the major limb occurs 1.5 km north of the northern edge of the study area, at Farthing Hole Dub [SD 6250 9150]. The synclinal hinge to the south might occur north of Treasonfield [SD 6170 8379], 1.2 km south of the study area. This estimate would give a total width of the major south-dipping fold limb of 7.7 km.

West of the Firbank Fault, the Kirkby Moor Formation is also mainly part of a major south-dipping fold limb, with dips typically between 10° and 30° (Figure 10). A major, though very broad, anticline hinge zone borders this limb to the north, with its axial trace running east–west just south of Killington [SD 6143 8872]. The synclinal hinge at the south of the major fold limb has not been identified: it lies at least 1 km south of the study area.

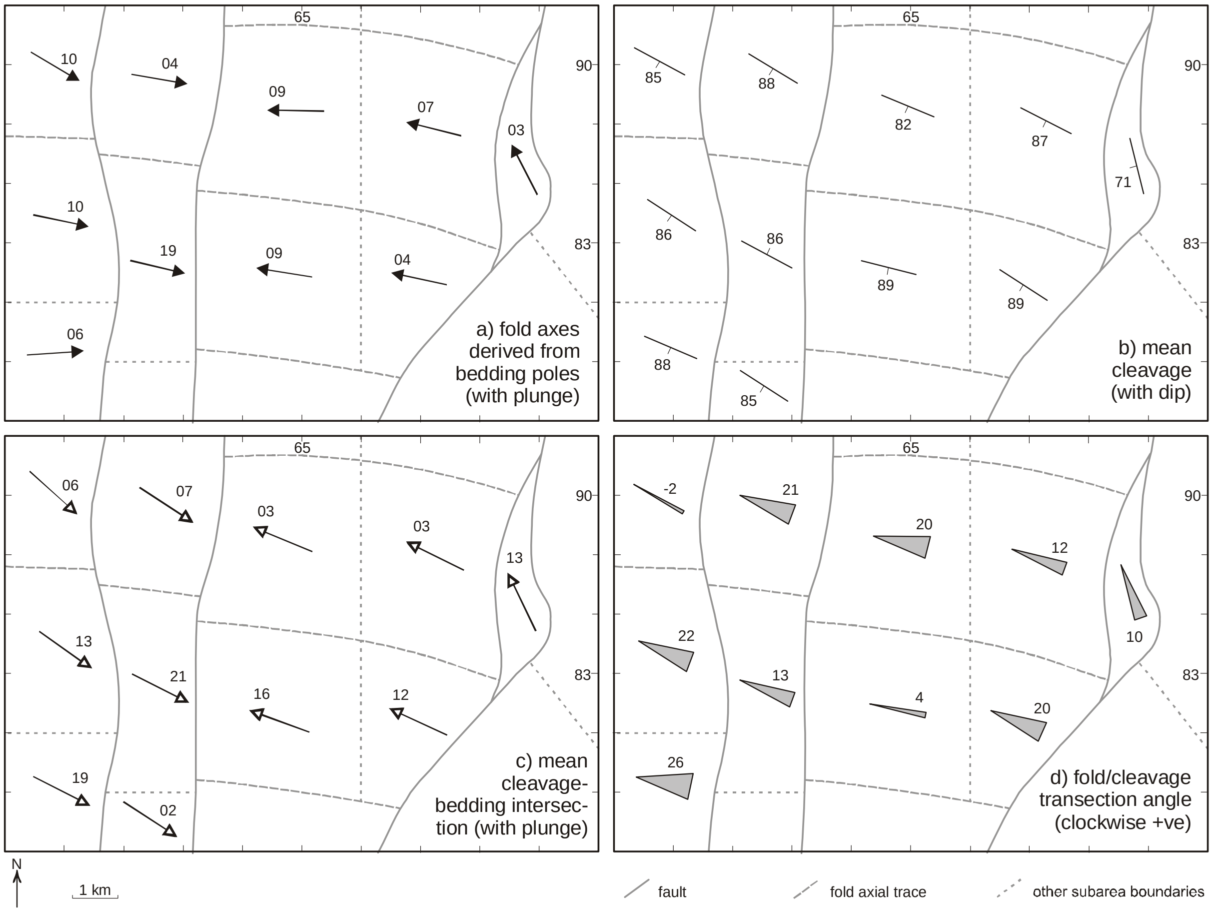


Figure 11 Structural data from the pre-Acadian rocks on Sheet SD 68(N).

a) Fold axis direction estimated from bedding-pole girdle. b) Mean cleavage. c) Mean cleavage–bedding intersection. d) Transection angle between fold axis and cleavage (positive = cleavage clockwise of fold axis).

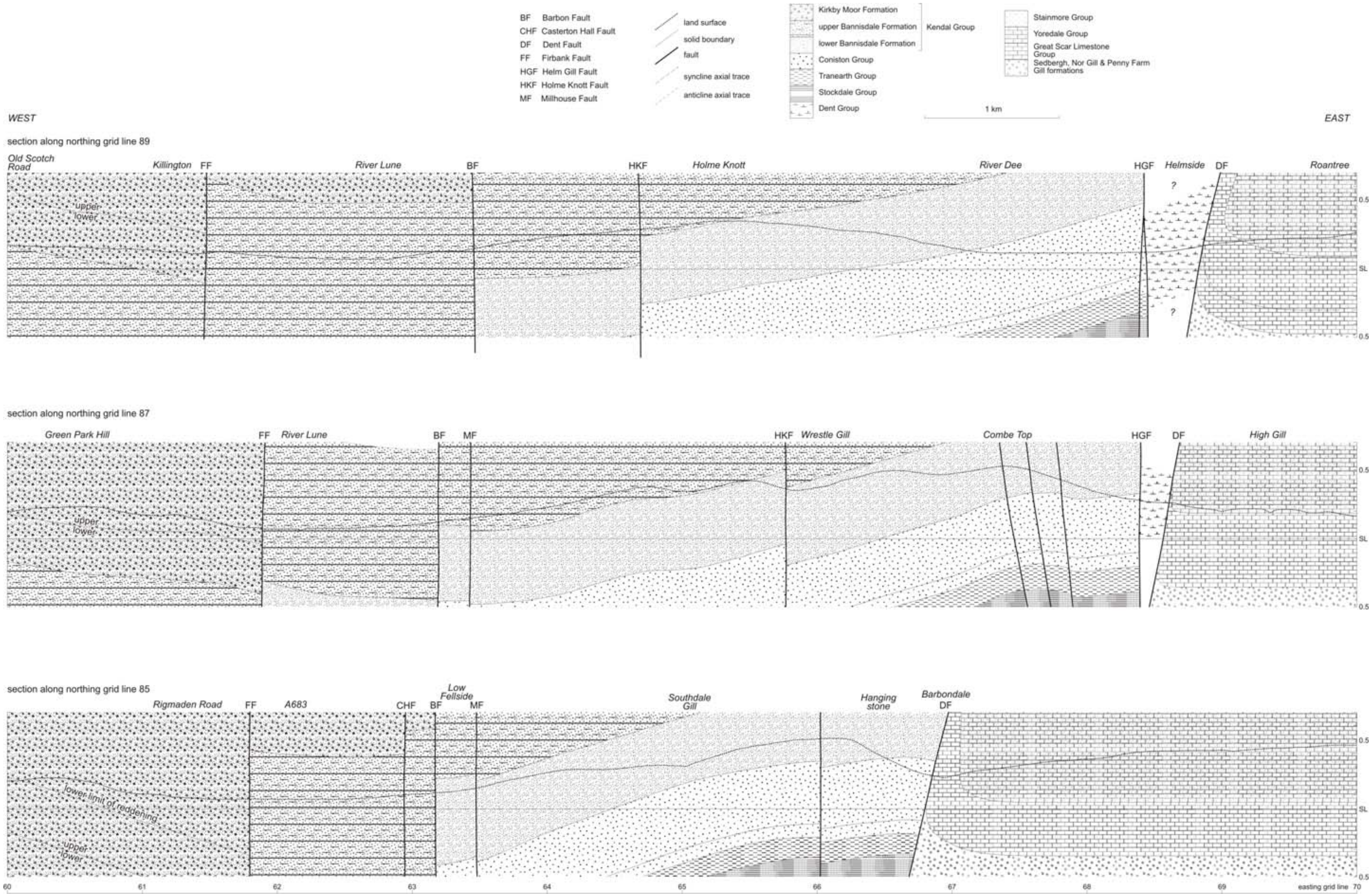


Figure 12 Structural cross-sections along three E-W lines through the Middleton Fells area

10.2 ACADIAN CLEAVAGE

The Acadian folds are associated with a cleavage that appears in the field to be crudely axial planar, though paucity of minor folds makes this relationship difficult to assess. The cleavage is strongly developed as a penetrative grain-alignment fabric in mudstone units and more weakly displayed as a spaced pressure-solution fabric in sandstone units. The cleavage refracts through the sandstone–mudstone couplets of the Coniston Group and Bannisdale Formation, but is near-vertical on average throughout the area (Figure 11). Stereographic analysis of cleavage and bedding data shows that the cleavage strikes east-south-east or south-east, and is typically clockwise of the calculated fold hinges. The modal transection angle is about 20°, but there is a wide variation (Figure 11). Three small areas of anti-clockwise transection show no particular distribution. Soper et al., (1987) showed that the transecting cleavage is also part of a regional pattern throughout north-west England, though, on their model, the east-north-east-trending folds in the Middleton Fells would be expected to show anti-clockwise transection.

The intersection of cleavage with bedding gives a prominent lineation throughout the Lower Palaeozoic rocks of the sheet. The trend of the cleavage-bedding intersection closely follows the strike of cleavage (Figure 11) and therefore also tends to transect fold hinges in a clockwise sense.

10.3 MAJOR FAULTS

10.3.1 Overview

A major component of the structure of Sheet SD 68(N) is the series of large, steep faults striking between north and north-east. Most of these faults cut the Carboniferous succession or its basal conglomerate, and can therefore be assigned a 'Variscan' age, at least in part. None of the faults is well exposed, and they have been mapped variously by their brecciated damage zones or by the stratigraphical contrasts across them. Most of the faults are well known from previous work (Sedgwick, 1836b; Aveline et al., 1872; Furness, 1965a), though the mapped course of some of them has been adjusted during the present study.

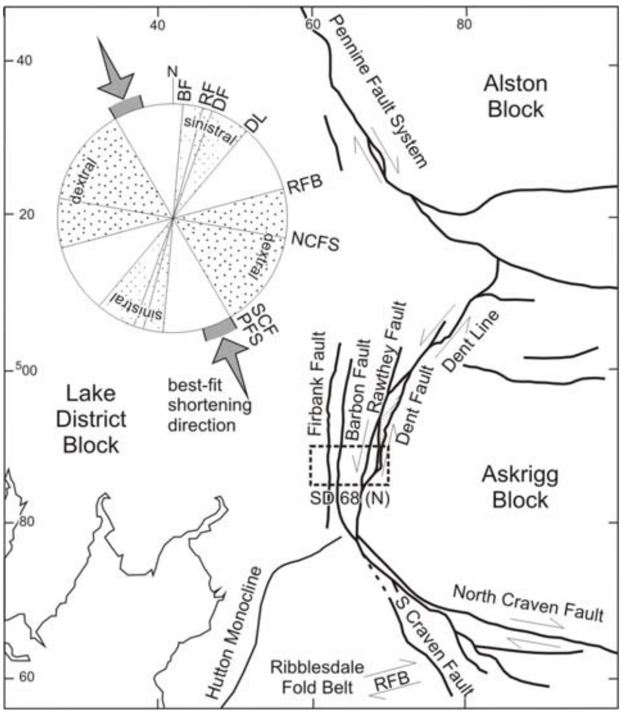


Figure 13 Outline map of some major faults in NW England, particularly those bordering the Askrigg Block.

The estimated Variscan shortening direction is derived from senses of strike-slip displacement of the fault belts (Woodcock and Rickards, 2003).

The faults on Sheet SD 68(N) form part of the boundary between the Lake District Massif to the west and the Askrigg Block to the east (Figure 13). The 30 km-long Dent Fault is the most important of these. At its southern end, the Dent Fault joins the Craven Fault System, which strikes first south-eastward, then eastward along the south edge of the Askrigg Block. The Dent Fault is continued to the north-east by a more complex deformation zone, the Dent Line (Underhill et al., 1988). This zone links, in turn, with the NW-SE and E-W orientated faults that bound the Alston Block (Figure 12). The Barbon and Firbank faults have less regional continuity, both losing displacement northwards. The Barbon Fault tip is apparently within the southern half of Sheet NY60 (Soper, 1999). The Firbank Fault apparently passes under the sub-Carboniferous unconformity on this sheet, suggesting that its small displacement here is mainly Acadian (Soper, 1999).

10.3.2 Dent Fault zone

The *Dent Fault* is the structure in the study area with the largest displacement. It strikes north-eastward then northward across the eastern half of the study area, always with a large throw down to the east. Its course is well constrained by exposures of contrasting Silurian and Carboniferous lithologies in the damage zone in Barbondale, particularly near the lime kiln [SD 6667 8452] just south of the study area and north–west of Stone Rigg [SD 6821 8638]. Here, the Helm Gill Fault then the Underwood Fault are deduced to splay northward from the Dent Fault, so that the upthrown wall comprises first Cautley Mudstone Formation then Brathay Formation, all poorly exposed. The course of the Dent Fault is still adequately constrained to the south-east by Carboniferous exposures. North of Gawthrop village the fault takes a remarkable 80° bend, and can be closely located, separating Brathay Formation and Carboniferous in the bed of the River Dee west of Barth Bridge [SD 6927 8798]. The fault then swings north again, and can be fixed within 25 m north of Dan's Croft [SD 6886 8909]. Here the Underwood and Dent faults are thought to rejoin, so that the Dent Fault separates Carboniferous rocks from Cautley Mudstone Formation as far as the north edge of the study area. The wedge of Cautley Formation terminates where the Helm Gill Fault rejoins the Dent Fault 500 m farther north. The Dent Fault can next be seen at outcrop in the River Clough, 1.5 km into Sheet SD 69 (Woodcock and Rickards, 1999).

The Dent Fault is thought to be steep throughout its length. The veeing of its trace in Dentdale is a true bend in the fault and not an indication of eastward hade. Observations further north (Woodcock and Rickards, 2003) suggest that generally the Dent Fault dips, if anything, north-westward and has a component of sinistral strike-slip during Variscan movement. The Gawthrop bend (Figure 2) would have been a neutral bend in this kinematic interpretation, but the north-east-striking Barbondale segment a strongly transpressive segment. The kinematic constraints at this bend were accommodated in the Carboniferous partly by south-south-east-striking splays from the Dent Fault, mapped in the original surveys and shown on the Hawes 1:50,000 sheet (British Geological Survey, 1997a).

In the upthrown wall to the Dent Fault, the bend was accommodated by the incorporation of fault-bounded slivers of Dent and Tranearth group rocks. The bounding faults to these slivers, both named by Aveline et al., (1872), are poorly exposed. The *Underwood Fault*, throwing down to the east, is closely located only in Wilsey Beck [SD 6886 8762]. The *Helm Gill Fault*, throwing down to the west, is constrained to within about 250 m on the eastern slope of Helm Knott [SD 6848 8936]. Just north of here, the *Branthwaite Fault*, throwing down to the west, is extrapolated into the area from the north, where it forms a major splay from the Rawthey Fault. A set of splay faults from the Helm Gill Fault are seen in Combe Scar [SD 6776 8747], where they seem to be steeply east-south-east-dipping, with normal, down to the east, sense of displacement. These might conceivably rejoin the Dent Fault in Barbondale, but exposure is too poor to verify this hypothesis.

10.3.3 Barbon Fault zone

The *Barbon Fault* (Aveline et al., 1872) runs nearly north–south across Sheet SD 68(N), throwing down to the east and apparently almost vertical. The fault is not well constrained on the southern half of Sheet SD 69, the nearest direct evidence being major fault breccias in Crosdale Beck [SD 6395 9363], 3.7 km to the north. Brecciation at Beckside Hall [SD 6333 8852] is the only direct fix on the fault on Sheet SD 68(N), and the next fix to the south is in Barbon Beck [SD 6318 8250] 2.2 km south of the study area, where Silurian rocks to the east are separated from the Sedbergh Conglomerate to the west by a 75 m thick sliver of brecciated Carboniferous limestone (Aveline et al., 1872; Furness, 1965a). Horizontal slickensides in this zone confirmed to Furness (1965b) that the Barbon Fault had strike-slip displacement. Different authors have suggested both dextral (Turner, 1935) and sinistral (Wager, 1931) components of displacements on the Barbon Fault. The study area offers no new evidence. A sinistral offset of fold hinges of a few hundred metres was identified about 6 km to the north by Woodcock and Rickards (1999).

The Barbon Fault has two splays with branch points on Sheet SD 68(N). The *Millhouse Fault* (Aveline et al., 1872) is evidenced by brecciation near Mill House [SD 6358 8547] and veining in Brow Gill [SD 6345 8680]. The fault probably throws down to the west, and branches from the Barbon Fault near Beckside Hall [SD 6335 8868] in the north and near Barbon [SD 6325 8214] in the south. The second splay is the *Casterton Hall Fault* (Aveline et al., 1872), the evidence for which has been discussed in the section on the Sedbergh Conglomerate. A further splay, the *Holme Knott Fault*, probably branches from the Barbon Fault near Holme [SD 6373 9080]. It runs south-eastwards across Holme Knott, where it is well constrained topographically and by the dextral offset of the base of the upper Bannisdale Formation. The fault is evidenced again by veining about 3 km to the south-east in Luge Gill [SD 6562 8728]. The apparent dextral offset of the same contact, here on the opposing limb of the Luge Gill Syncline, suggests dextral strike-slip rather than dip-slip displacement on the Holme Knott Fault. The fault cannot be traced further, though it is possible that it continues to meet the Dent Fault in Barbondale.

10.3.4 Firbank Fault

The *Firbank Fault* runs north–south across all of Sheet SD 68, throwing Kirkby Moor Formation down to the west against Bannisdale Formation rocks on the east. This lithological distinction is strong enough to map the fault confidently despite poor exposure. The fault is directly seen cutting Bannisdale Formation rocks near Ghyllhouse Style [SD 6188 9167], about 1.7 km north of the study area. It crosses Hall Beck [SD 6152 8860] at exposed fault breccias and must run close to fractured Kirkby Moor Formation in Aikrigg Beck near Beckside [SD 6163 8800]. It is then taken to separate reddened Kirkby Moor Formation in the River Lune east of Gill Foot [SD 6193 8651 and SD 6168 8566] from reddened upper Bannisdale Formation north of Hawking Hall [SD 6200 8593].

No splays to the Firbank Fault have been identified, though it should be noted that fracturing in reddened Kirkby Moor Formation west of Gill Foot [SD 6141 8630] was taken by Aveline et al., (1872) to indicate the course of the main fault, and a splay through this point cannot be discounted.

10.3.5 Summary of faulting

In summary, the three major faults of Sheet SD 69 are steeply dipping and strike between north-east and north. The Dent Fault throws down to the east, and the Barbon and Firbank faults to the west, leaving the Middleton/Barbon Fells block as an uplifted horst in the centre of the area. This is very similar to relations across the Howgill Fells and Cautley inliers to the north (Woodcock and Rickards, 2003).

Variscan displacement on the major faults is suggested directly by cross-cutting of Carboniferous rocks by all three faults. However, Acadian or earlier components on the Barbon and Firbank faults are suggested by the mismatching of Acadian fold axial traces across them. A similar mismatch was noted in the Shap Fells (Moseley, 1968), in the northern Howgill Fells (Soper, 1999) and in the southern Howgills (Woodcock and Rickards, 1999) and has been interpreted as partitioning of Acadian deformation by faults propagating up from pre-Acadian basement. Faults of the same orientation have been implicated in controlling fluvial sedimentation in Early Devonian extensional basins (Soper and Woodcock, 2003). The fact that reddening occurs at different stratigraphical levels on either side of the Firbank Fault, is evidence for pre-Early Carboniferous, though not necessarily pre-Acadian, faulting.

10.4 VARISCAN FOLDS

The only evidence for strong Variscan folding is the zone of steep or overturned Carboniferous beds that borders the Dent Fault, with Carboniferous rocks younging east or south-east. The steep zone flattens abruptly eastward or south-eastwards through a synformal monocline, into flat-lying Carboniferous strata between 100 m and 300 m from the fault. The anticlinal part of the monocline is barely preserved on the west side of the Dent Fault. The plunge of Acadian folds – normally westwards in the Middleton Fells – shallows or gently flips to eastward close to the Dent Fault. However, there is no major refolding of Acadian structures as seen further north along the Dent zone (Woodcock and Rickards, 2003). The structures in east–west section across the Dent zone on Sheet SD 68(N) (Figure 12) are but variants on a common pattern along the zone over much of its 45 km extent (Underhill et al., 1988).

11 Quaternary geology

The superficial deposits were mapped at 1:10,000 scale, primarily by ground traverses aided by aerial photograph interpretation. They are summarised on Figure 14. Areas marked as bedrock are, in the valleys, mostly exposed rock. On the hills, there is normally a thin cover of regolith and soil above rockhead, and no attempt has been made in these areas to distinguish head from scree or other lithologies. The bounding line of this hill-top bedrock is the upper feather edge of the valley-bottom till sheet.

11.1 TILL OR SOLIFLUCTED TILL

Unstratified, poorly sorted, matrix-supported diamicton forms sheets in the lower parts of most of the main valleys of the area. In the Middleton Fells the upper limit of this till sheet has been variously mapped using a break in slope, a vegetation change, a spring line, or the upper limit of gullying. On Holme Fell and the hills bordering the south side of Dentdale, small patches of till are preserved in ice-scoured hollows above the main upper till limit. Ice-scratched bedrock surfaces are prominent below till in places here. On the west side of the Lune, till itself forms substantial hills, for instance in the areas of Old Park and Talebrigg Hill. Solifluction has affected the till slopes to some degree, but no attempt has been made to distinguish soliflucted till from primary till. In the Howgill Fells the main tills are thought by Harvey (e.g.1974) to be Devensian and deposited between 20 and 13 ka BP.

The till sheet has been moulded into drumlins in Dentdale, the Lune Valley, and the hills to the west of the Lune. Mapped drumlins vary in length from 100 to 750 m and in width from 50 to 400 m. The drumlin axes approximately follow the present valley trend of the Lune, and the drumlins forming the western hills confirm that this Lune ice-stream took the same south-westward to southward course where it spilled out of the valley over these hills. The drumlins in eastern Dentdale have the same west-north-west trend as the present valley. However, towards the western end of the valley, the drumlins indicate that the Dentdale ice-stream turned westward then west-south-westward as it merged with the Rawthey ice. The dramatically scoured northern slopes of Holme Fell record this same swing in ice flow.

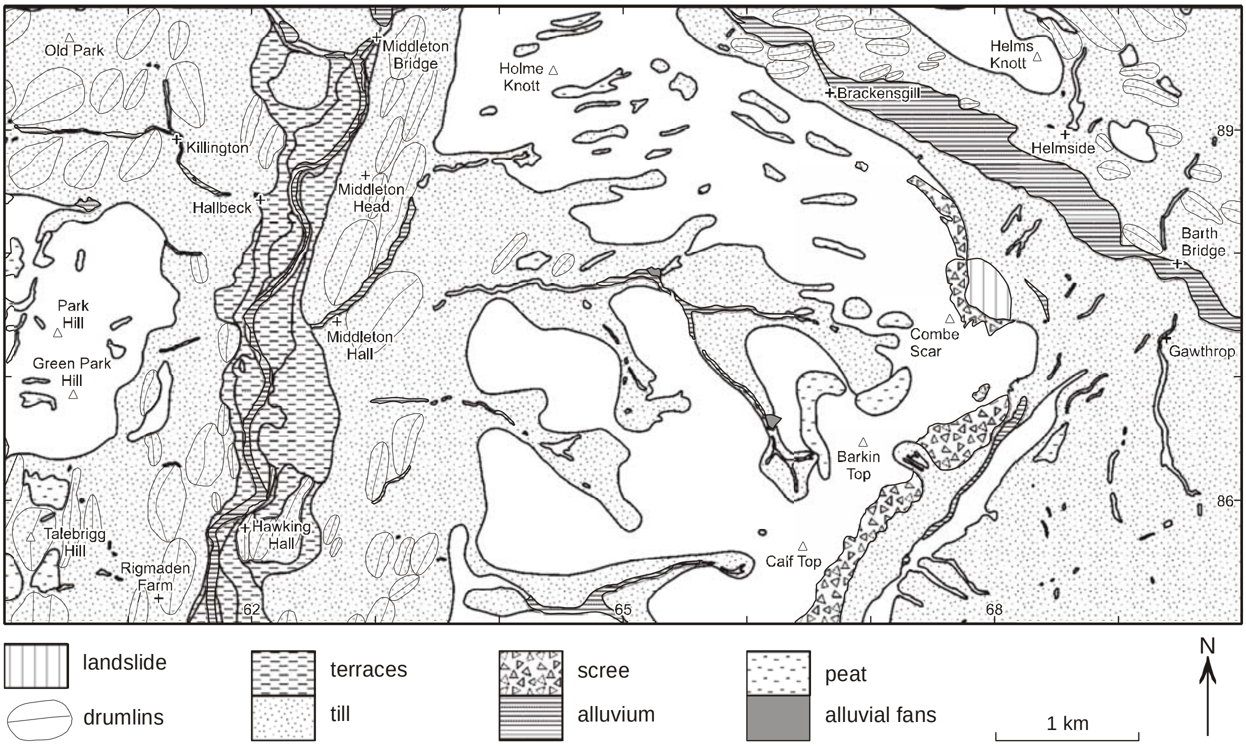


Figure 14 Summary map of superficial deposit type and distribution on Sheet SD 68(N).

11.1.1 Alluvium and river terrace deposits

Stratified, moderately well-sorted, clast-supported cobble gravel forms the present river flood-plains of the Lune and Dee, and of a number of the upland streams. A succession of older river terraces with a veneer of similar alluvium have been mapped along the Lune valley.

11.1.2 Scree and landslide deposits

Weakly stratified, angular, clast-supported gravel has been mapped below upland crags from north of Combe Scar [SD 6735 8860], round into the north-west slope of Barbondale [SD 6660 8500]. Combe Scar itself is a landslide scar fronted to the north-east by an arcuate ridge marking the toe of the landslide deposit.

11.1.3 Peat

Blanket peat occurs sporadically over some of the flatter upland areas, but only thicker and more extensive spreads have been mapped as such on Naughtberry Moor [SD 6658 8692]. Such peat in the Howgill Fells is said to date from 7000-5000 years BP (Harvey, 1985) and is now eroding. Small patches of peat have also been mapped in elongate hollows, probably lined by till, on the uplands south-west of Dentdale.

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.

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