Geological notes to accompany 1:10k sheets SD58SE (Scout Hill) and SD68SW (Barbon) Part of 1:50,000 Sheet 49 (England & Wales), Kirkby Lonsdale.

Geology and Landscape Programme

Open Report OR/09/042

BRITISH GEOLOGICAL SURVEY

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Part of 1:50,000 Sheet 49 (England & Wales), Kirkby Lonsdale

P Stone

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Foreword

This report is the published product of a field study by Dr P. Stone carried out between 2006 and 2008. The report describes the geology of 1:10 000-scale Bedrock and Superficial Deposits Geology Series sheets SD 58 SE (Scout Hill) and SD 68 SW (Barbon), 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. The work was completed as part of the British Geological Survey's work in Northern England, a project led by Dr D. Millward who has also edited this report.

Acknowledgements

In addition to the BGS staff acknowledged in the Foreword Drs N. H. Woodcock and C. J. Thomas are thanked for their contributions to discussion of the Windermere Supergroup's stratigraphy and structure. Graptolites were examined and identified by Dr R. B. Rickards.

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Figure 2

Saetograptus soperi Rickards & Woodcock. An example from Grove Gill (LX994-B) drawn by Dr R B Rickards.

Figure 3

Equal-area stereogram plot of poles to bedding and cleavage from the Kirkby Moor Formation exposed in the Warth Hill and Scout Hill areas of SD58SE.

Figure 4

Equal-area stereogram plot of poles to bedding and cleavage from the Bannisdale Formation and Coniston Group exposed in the Middleton Fell area of SD68SW.

Figure 5

Equal-area stereogram plot of poles to bedding and cleavage from the Coniston Group exposed in the Barbon Fell and Casterton Fell areas of SD68SW.

Summary

The area described in this report, the adjacent 1:10 000 sheets SD58S and SD68SW, forms a central part of the eastern sector of the Kirkby Lonsdale 1:50 000 sheet, England and Wales 49. It lies in the south-east of the English Lake District. Geologically, the area forms part of the south-eastern extremity of both the Lake District Lower Palaeozoic inlier as a whole, and of the main outcrop of the Windermere Supergroup. Two outcrops of Upper Silurian (Ludlow-Pridoli) rock are described, separated by Devonian (Upper Old Red Sandstone) and Carboniferous strata, the latter linked to the Dinantian, platform limestone succession of South Cumbria. The geological boundaries between the Lower and Upper Palaeozoic strata are major faults trending broadly north-south. These define a graben structure, broadening southwards, which bisects SD68SW. The northern part of the graben is occupied by Upper Devonian strata of the Sedbergh Conglomerate Formation. Carboniferous rocks crop out in the southern part of the graben: the Great Scar Limestone Group and the Alston Formation of the Yoredale Group. To the west of the graben the Windermere Supergroup outcrop comprises rocks of the Kirkby Moor Formation. These strata have been folded into open, broadly symmetrical anticline-syncline systems with hinges plunging a few degrees to the east. To the east of the graben, the Bannisdale Formation occupies the hinge zone of a compound syncline that plunges gently westward. The hinge zone lies across the north-east part of SD68SW so that, in the southern limb of the syncline, sequentially older strata of the Coniston Group appear southwards. The graptolite fauna confirms a position high in the Ludlow for this part of the Coniston Group. The folding and cleavage development affecting the Windermere Supergroup strata are assigned to the Acadian Orogeny, of Emsian (latest Early Devonian) age. There is ample exposure of bedrock on the higher ground, but lower parts of the area are largely covered by a thick development of drumlinised till and the alluvial terraces of the River Lune, the river following a course defined by the Upper Palaeozoic graben.

1 Introduction

The area described in this report forms a central part of the eastern sector of the Kirkby Lonsdale 1:50 000 sheet, England and Wales 49 (Figure 1). It lies to the south-east of the English Lake District. In the western part of SD58SE and the eastern part of SD68SW, craggy hillsides rise, respectively, to about 280m and over 500 m above sea level. Between these areas of rocky upland, drumlins become the dominant landscape feature with rolling hills rising to about 270 m above sea level. Geologically, the area forms part of the south-eastern extremity of both the Lake District Lower Palaeozoic inlier as a whole, and of the main outcrop of the Windermere Supergroup. Two outcrops of Silurian rock are described, separated by Devonian and Carboniferous strata occupying a graben structure coincident, in this area, with the valley of the River Lune. The main geological boundaries are major faults trending broadly north to north-north-west, the most important of which contribute to the graben's boundaries: the Firbank and Casterton Hall faults in the west; the Barbon and Millhouse faults in the east.

The Silurian strata form parts of the Coniston Group and the Bannisdale and Kirkby Moor formations of the Kendal Group; these are the uppermost two groups of the Windermere Supergroup. The first two of these divisions, the Coniston Group and Bannisdale Formation crop out to the east of the graben; the last of the three, the Kirkby Moor Formation, crops out to the west. Within the graben, the Devonian strata are assigned to the Sedbergh Conglomerate Formation, whereas the Carboniferous rocks present are components of the Great Scar Limestone Group and the Alston Formation of the Yoredale Group.

Early work in the area, notably by Sedgwick, has been discussed and listed by Oldroyd (2002). The results of the primary Geological Survey mapping were reported in the original Kirkby Lonsdale memoir (Aveline et al., 1872). More recent academic studies of the area and its adjacent hinterland have developed the stratigraphy of the Lower Palaeozoic rocks (Furness, 1965a; Furness and others, 1967; Shaw, 1968, 1971; Rickards and Woodcock, 2005) and their sedimentology (Furness, 1965b; King, 1992, 1994). There has been little or no modern investigation of the Upper Palaeozoic strata in the area described here, wherein their exposure is very limited.

2 Coniston Group

Sandstone, siltstone and mudstone assigned to the Coniston Group crop out in the south-east part of SD68SW where they form the Casterton and Barbon fells, the former rising to 420 m at Brownthwaite Pike [648 805]. The lowermost strata are present in the south where, just beyond the south-east corner of SD68SW, the Coniston Group conformably overlies a very thin development of the Wray Castle Formation, the subjacent unit of the Windermere Supergroup. A regional, gentle to moderate dip to the north carries successively younger strata to outcrop until the top of the Coniston Group is conformably overlain by the lowermost sandstones of the Bannisdale Formation on the southern flank of Middleton Fell [648 834]; about 1400 m of Coniston Group strata are present (Furness, 1965a and b).

After a long history of traditional usage as the Coniston Grit, the Coniston Group was formally defined by Kneller et al. (1994) in the south-west of the Lake District where five constituent formations were recognised. Three of these are dominated by beds of turbidite, wacke-type sandstone: the Gawthwaite Formation (at the base), the Poolscar Formation, and the Yewbank Formation (at the top). Separating the three dominantly sandstone formations are two units wherein hemipelagic mudstone-siltstone is the principal lithology: the Latrigg Formation (between the Gawthwaite and Poolscar formations) and the Moorhowe Formation (between the Poolscar and Yewbank formations). The group's thickness is variable within the 1.5 to 2.5 km range, and deposition was mostly within a single Gorstian graptolite Biozone (*scanicus*, Early Ludlow).

Unfortunately, when followed eastward, this five-part division breaks down such that

in the southern Shap Fells and the Howgill Fells (to the north of the area described in this report), the lower formations thin, pinch out and merge with the underlying siltstones of the Wray Castle Formation. At the base of the group, the Gawthwaite Formation thins eastwards and finally fails, thus eliminating the means of distinguishing between the lithologically similar, hemipelagite formations above and below, respectively the Latrigg and Wray Castle formations. Higher in the succession, a similar problem is caused by the eastwards thinning and disappearance of the hemipelagic Moorhowe Formation, which accordingly allows the sandstone formations above and below to merge. As an additional complication, the turbidite sandstones marking the base of the Coniston Group in the Howgill Fells probably extend diachronously to a lower stratigraphic level than do their counterparts further west. In the Howgill Fells, and the Casterton Fells to the south, the base of the Coniston Group probably lies within the earliest Gorstian, *nilssoni* graptolite Biozone.

Across the Casterton and Barbon fells the Coniston Group is dominated by fine- to medium-grained sandstone beds with an assemblage of sedimentary features indicative of deposition from turbidity currents. In the south of the area, the thicknesses of individual beds are mostly in the 20 to 50 cm range, but rarely may exceed 1 m. Repetitive series of beds cumulatively up to about 15 m thick, alternate with thinner runs of silty, laminated hemipelagite, up to about 2 m thick, in which there are only sporadic sandstone interbeds. The sandstone beds are internally graded and show an upward increase in lamination, usually parallel to bedding but cross-laminated locally. A few bed bases were noted to carry bottom structures, mostly grooves, but this was not a widely observed phenomenon.

Northwards from the Casterton Fells onto the Barbon Fells (i.e. up sequence), there is a tendency for the sandstone beds to decrease in thickness and for their dominance over the hemipelagic intervals to become less pronounced, until both lithologies are equally represented. Based on these trends Furness (1965a) recognized distinct stratigraphical divisions: in his terminology these were designated the Lower and Middle Coniston Grits. Furness also recognized a reversal of the sedimentological pattern farther north (and up sequence) with the sandstone beds being thicker and more abundant on the northern flank of the Barbon Fells: he referred the strata in this area to the Upper Coniston Grits. Whilst the stratigraphical variation noted by Furness is real enough in a general sense, it is a progressive rather than an abrupt effect so that any geological boundary based on it is arbitrary. Further, since there are no unique sedimentary features within the succession that can be correlated between exposures, any such boundary defined cannot be mapped beyond the area of definition. Accordingly, in this account and on SD68SW, the Coniston Group is shown undivided.

Graptolite faunas collected by Furness at several localities proved an age for the Coniston Group within the *nilssoni-scanicus* biozones, Gorstian Stage, Early Ludlow. One new graptolite occurrence was discovered during the recent resurvey, in Grove Gill [6434 8126]. Fossils from here were identified by Dr. R. B. Rickards (University of Cambridge) as *Saetograptus soperi* (Figure 2), a taxon not defined at the time of the Furness survey, but regarded by Rickards and Woodcock (2005) as indicative of a position high in the Coniston Group or in the overlying Bannisdale Formation. In the Howgill Fells, to the north of SD68SW, Rickards and Woodcock erected a *soperi* Biozone at the top of the Coniston Group, with the graptolite's range extending into the overlying *leintwardinensis* Biozone, which they correlated with the lower part of the Bannisdale Formation. The absence of any accompanying fauna at Grove Gill encourages the association of the sequence there with the *soperi* Biozone and the upper part of the Coniston Group.

3 Bannisdale Formation, Kendal Group

The Bannisdale Formation was formally defined by Kneller et al. (1994), following a long history of traditional usage as the Bannisdale Slates. In total it is over 4 000 m thick but both the top and base are widely transitional, may be diachronous, and are not necessarily taken at a uniform level across the whole of the southern Lake District outcrop (Rickards and Woodcock, 2005; Woodcock and Rickards, 2006).

The regional northward dip seen across the Coniston Group outcrop on Casterton and Barbon fells introduces strata assigned to the overlying Bannisdale Formation on the Middleton Fells. At the eastern margin of SD68SW the Bannisdale Formation lies conformably above the Coniston Group, but farther west and across a subsidiary splay from the Millhouse Fault, the boundary is faulted-out across a structure cutting WNW-ESE through Barbon Beck [639 827].

The lowermost strata of the Bannisdale Formation that crop out on SD68SW are atypical of the formation as a whole in comprising fine-grained sandstone beds, commonly laminated throughout, interbedded with an approximately equal proportion of finely banded intervals of laminated siltstone/mudstone; the latter form the characteristic lithology of the formation. Graptolite faunas have been collected from the banded intervals at several localities (Furness, 1965a; Rickards and Woodcock, 2005) and from their evidence the base of the Bannisdale Formation has become associated with a position close to the boundary of two graptolite biozones. These were first defined by Rickards (1967) as a lower, *scanicus* Biozone (occupied by much of the Coniston Group) and an upper, *incipiens* Biozone (largely occupied by the Bannisdale Formation). Subsequent revision by Rickards and Woodcock (2005) defined an upper, *leintwardinensis* Biozone and a lower, *soperi* Biozone, with the boundary lying very close to the Coniston-Bannisdale lithostratigraphical boundary.

One effect of the biostratigraphical evidence in the Middleton Fells, and particularly in the area immediately to the north [SD68NW and SD68NE], has been to place sequences dominated by sandstone within the lowermost Bannisdale Formation despite their similarity to the underlying Coniston Group. These 'Bannisdale' sandstone units are local developments and demonstrate the diachroneity of the lithofacies change from the mainly turbidite sandstone of the Coniston Group to the more distal, ‘banded’ strata of the Bannisdale Formation. The interpretation adopted on SD68SW follows Furness (1965a) and the criteria established by Woodcock and Rickards (2006) when mapping the 1:10 000 sheets immediately to the north [SD68NW and SD68NE].

The sandstone-rich facies – designated sa(Bnd) on SD68SW – forms a sequence about 600 m thick. This comprises up to 75% sandstone beds, typically 20-50 cm thick but approaching 1 m in thickness locally, and generally showing a weak parallel lamination throughout. The sandstone is most commonly medium grained, but coarsens locally. Grading is abrupt from a sharp bed base so that the larger part of each bed is texturally uniform. To the north of the Middleton Fells, Woodcock and Rickards (2006) described the Bannisdale Formation sandstone facies interfingering with a more fine-grained, thinly bedded lithofacies, but this effect is not seen on SD68SW. There, to the south of Eskholme Pike [6385 8330], Bannisdale Formation sandstone facies shows a transition over a few tens of metres into a sequence wherein beds of fine-grained sandstone grading up to siltstone, and between about 50 cm and 1 m thick, form the bulk of the outcrop, but are interbedded with thinner units of banded siltstone and mudstone. The proportion of the latter may be underestimated since it is the thicker beds that provide much of the obvious, craggy exposure on the west-facing slopes of Middleton Fell. The banded siltstone intervals may be calcareous and are commonly picked out by bedding-parallel zones of weathered-out hollows. Overall, siltstone-grade rock dominates, and whilst sporadic, thicker and coarser sandstone beds do occur, they are not mappable over any great distance. This is the Bannisdale “mixed” facies as described by Soper (1993). Mudstone forms a thin top layer to most of the graded beds but is only rarely developed to a thickness of more than a few centimetres; bioturbation is rare and usually bed-parallel where seen. Internally, the beds are variously parallel or ripple cross-laminated. Their bases are generally sharp and may be loaded or carry current-induced grooves. Deposition was from repeated, low-density turbidity flows into relatively deep water (King, 1994).

On SD68SW the Bannisdale Formation ‘banded’ lithofacies crops out in the hinge zone of an open syncline that plunges gently to the west. The outcrop is terminated by faults to the west and the east and the stratigraphical top of the formation is not seen; about 300 m of ‘banded’ strata are present. The southern limb of the syncline forms a local culmination to the regional northward dip seen over the southern part of the lower Palaeozoic outcrop in Middleton-Barbon-Casterton fells. The northern limb of the syncline, with southward dips, lies along the northern margin of SD68SW and, accordingly, the sandstone-dominated lower part of the Bannisdale Formation reappears there on the northern flank of Middleton Fell.

4 Kirkby Moor Formation, Kendal Group

All of the Lower Palaeozoic strata (dominantly sandstone) at outcrop across 1:10,000 sheet SD58SE, to the west of the ‘Lune valley graben’, are assigned to the Kirkby Moor Formation. This unit was formally adopted by Kneller et al. (1994) following descriptions by Lawrence et al. (1986), but was recognised in all earlier stratigraphical schemes as the Kirkby Moor Flags. Traditionally, the type area has been taken at “Kirkby Moor” but this is a poorly defined area, perhaps intended to be near Kirkby Lonsdale and not to be confused with the “Kirkby Moor” in Furness [SD 260 845] where the sequence exposed ranges no higher than the Bannisdale Formation. However, this distinction is not clear from the early literature, as also noted by

Oldroyd (2002, footnote to p 181). Curiously, within the area described in this report, abandoned buildings at [5909 8087] are named ‘Kirkby Moor’ on 1:10k sheet SD58SE, but whilst the locality does indeed lie on the outcrop of the Kirkby Moor Formation, there is no exposure of bedrock in the vicinity. Instead, representative exposure of the Kirkby Moor Formation can be seen across the craggy hillsides of Warth Hill [5675 8445] and Scout Hill [5645 8260]. In total the formation may exceed 1000 m in thickness but only approximately half this thickness, towards the top of the formation, is seen in the area described here.

Over much of the outcrop of the Kirkby Moor Formation on SD58SE the sandstone has suffered secondary weathering and this feature, coupled with fossil distribution, led Shaw (1971) to assign the strata to his *Scout Hill Flags*, which were thought to succeed the Kirkby Moor Formation. Palaeontological variation is now thought to be controlled by changes in facies and in their formalization of the lithostratigraphy Kneller and others (1994) recommended that the term *Scout Hill Flags* should be regarded as redundant, with all of the sequence subsumed into the Kirkby Moor Formation.

The Kirkby Moor Formation is characterised by medium- to thickly bedded, generally fine-grained micaceous sandstone grading up into thin layers of mudstone or siltstone at the top of the beds. These commonly range up to about 75 cm thick and more rarely to more than 1.5 m, although many of the thicker beds may be amalgamated. The thickness of many individual beds seems to be variable on a “pinch and swell” pattern. Convolute lamination and disruption of bedding by de-watering are common and characteristic features, whereas hummocky cross-stratification is widespread. Some beds have strongly loaded bases; others have wave-rippled tops. The fine-grained tops to the beds may be bioturbated, with trace fossils occurring both as bed-parallel trails and as penetrative burrows, of which U-shaped examples were noted in several places. Secondary reddening is a conspicuous feature across almost all the outcrop on SD68SW and also affects the very few exposures of the Kirkby Moor Formation on the western side of SD68SW.

Lenticular accumulations of shell debris are a widespread, though never common feature of the Kirkby Moor Formation: examples occur on SD58SE in the vicinity of Scout Hill [5633 8265 and 5659 8244]. These shell accumulations occur at the bases of beds as a lag deposit, with small snails and brachiopods the most common components of the fauna. Shaw (1971) described a more extensive regional assemblage that includes brachiopods, ostracods and trilobites. A biostratigraphic range for the Kirkby Moor Formation is likely to span the late Ludlow and the Přídolí, with the sequence on SD58SE lying in the younger part of that range.

The Kirkby Moor Formation has all the characteristics of deposition in a shallow marine environment (King, 1994). The bed thickness and internal structures suggest deposition from relatively high-energy turbidite flows sourced from an abundant sediment supply. The typical bed-form has, in upward sequence, a locally erosive base, a shelly lag accumulation, hummocky cross-stratification, large-scale convolution, ripple cross-lamination, and bioturbation. Overall, this would seem to indicate a brief erosive phase with subsequent deposition from the waning flow before a quiescent interval preceded the next flow. The presence of hummocky cross-stratification is indicative of deposition from storm-generated waves in relatively shallow water. The large-scale and widespread convolution, caused largely by de-watering, suggests rapid deposition.

A variation from the typical Kirkby Moor Formation lithofacies is seen in a series of small and very overgrown quarries to the north-west of Old Town [5915 8333], where at least 30 m of reddened strata are seen to be finer grained and more thinly bedded than usual. This occurrence was correlated by King (1994) with a proposed Helm Member of the Kirkby Moor Formation that cropped out to the north, on SD58NW, near Kendal. The Helm Member comprises finely bedded to laminated siltstone and mudstone, with the individual sediment layers ranging from 2 mm up to about 10 mm. The bedding is irregular and some of the siltstone layers appear as lenticular, cross-laminated ripples. Fine-grained sandstone interbeds range up to about 50 cm thick and increase in abundance towards the base of the sequence, where they carry tabular cross-bedding. Bioturbation is widespread in the mudstone and siltstone, though is by no means pervasive. The alternation of silt and mud laminae, with variable ripple cross-lamination, suggests deposition in a shallow-water environment subject to irregular wave action. King (1994) suggested that the member originated as tidal mudflats in estuaries or lagoons, or behind barrier islands or sand bars. The limited exposure near Old Town shows the strata there to have some similarity with the Helm Member lithofacies, but they are by no means identical. Further, the Old Town occurrence is likely to lie at a higher stratigraphical level within the Kirkby Moor Formation than does the Helm Member *sensu stricto* (Stone, 2006), where it may represent a second phase of shallowing during evolution of the Kirkby Moor Formations' depositional regime.

5 Upper Palaeozoic rocks

Upper Palaeozoic strata are contained within the graben structure defined by the Firbank and Casterton Hall faults, to the west, and the Barbon Fault, to the east. The faults trend approximately north-south and the graben occupies the central zone of SD68SW; the western margin of the graben, at the Firbank Fault, coincides with the current valley of the River Lune.

The oldest strata to crop out within the graben are the red sandstone and conglomerate beds of the Sedbergh Conglomerate Formation, which is thought to be an Upper Devonian deposit. There is good exposure of the conglomerate in Barbon Beck, at [6315 8250], and particularly for about 150 m downstream from the road bridge on the north side of Barbon village [6275 8268]. There, the sandstone is generally coarse grained, whereas the conglomerate is clast-supported with sub-angular to rounded clasts ranging in size up to 50 cm across. Most of the clasts are composed of sandstone or siltstone that appears to match those lithologies in the Coniston Group and Bannisdale and Kirkby Moor formations, as exposed nearby. A few clasts of fine grained, felsic igneous rock are also present. Farther to the west, the Sedbergh Conglomerate crops out in two structural settings exposed in the banks of the River Lune. The northernmost outcrop, between Holme House and Treasonfield [6140 8345] is an isolated segment contained within the fault zone of the Firbank Fault, which otherwise in this area has Kirkby Moor Formation strata to each side. The southern exposures in the River Lune are in the vicinity of St Michael's College [615 803]. They lie at the western edge of the main graben outcrop of conglomerate, which in the southern part of SD68SW is extended westward to the Firbank Fault by an east-west transfer fault that links it to the Casterton Hall Fault.

In its type area to the north, the Sedbergh Conglomerate Formation is up to 270 m thick in the Rawthey valley, to the east of Sedbergh (Woodcock and Rickards, 1999).

The thickness present in the SD68SW graben structure is unknown. The observed dips are relatively low and it is possible that only a thin sequence is represented.

The southern part of the SD68SW graben structure is occupied by Carboniferous strata, probably faulted against the Sedbergh Conglomerate by cross faults linking its north-south boundary faults. There is hardly any exposure of the Carboniferous rocks, but massive limestone, loosely assigned to the Great Scar Limestone Group, is seen at the southern margin of the sheet south-east of The Grange [625 800]. The presence of limestone is otherwise indicated by swallow holes, as for example to the south-east of Fell Garth [6335 8055]. Elsewhere, a small outlier of limestone is caught-up in the Barbon Fault zone and exposed in Barbon Beck, to the east of Barbon village [6323 8245]. It is tentatively assigned to the Great Scar Limestone Group.

The outcrop of Alston Formation strata in the southern part of SD68SW is extrapolated from the area to the south. There is no exposure of the Alston Formation on SD68SW, and so the position and nature of the formation's contact with the Great Scar Limestone Group is entirely conjectural.

6 Structure

All of the folding and cleavage development affecting the Windermere Supergroup is now regarded as Emsian (latest Early Devonian) in age, produced during the Acadian Orogeny. A recent review of the pertinent regional evidence is provided by Soper and Woodcock (2003). However, despite the single phase of deformation, the resulting structures in the two outcrops of Lower Palaeozoic strata, on either side of the north-south graben of Upper Palaeozoic rocks, have rather different structural characteristics.

To the west, across SD58SE and the western margin of SD68SW, bedding strike in the Kirkby Moor Formation is approximately ESE-WNW, and the strata are locally folded about hinges that plunge only a few degrees eastward (Figure 3). The folds are open and broadly symmetrical but cleavage is rare and only weakly developed, where present, as a slaty fabric in the finer grained rocks, and a more irregular and spaced, pressure solution fabric in sandstone. Cleavage is generally steeply inclined but its strike suggests a substantial clockwise transection of the fold hinges (Figure 3). This is similar to the situation described from the adjacent ground to the north (Stone, 2006) and north-east (Woodcock and Rickards, 2006) although the wide variation in cleavage attitude seen, particularly across the northern half of SD58, makes it unlikely that the degree of transection is consistent.

To the east of the graben, on the eastern side of SD68SW, the overall structure is broadly synclinal about a hinge zone plunging very gently to the WNW across Middleton Fell (Figure 4). Bannisdale Formation strata crop out in the hinge of the regional syncline, which in detail is a compound arrangement of several separate syncline-anticline-syncline sequences. Cleavage is very weak in the Middleton Fell area, but the limited evidence of sporadic bedding-cleavage intersection lineations (Figure 4) suggests that, unlike the situation farther west, there is no cleavage transaction of the fold hinge.

The southern limb of the Middleton Fell syncline extends southwards such that, across Barbon and Casterton fells, Coniston Group strata dips consistently to the NNE with gentle to moderate inclination (Figure 5). Slaty cleavage is sporadically developed in the finer grained rocks and approximates to an axial planar relationship with the local, minor folding of the bedding, albeit this appears to plunge more steeply, and in a slightly more north-eastward direction, than the main Middleton Fell syncline (Figure 5). Again, unlike the situation farther west but in keeping with Middleton Fell, there is no evidence that cleavage transacts the fold hinges. One additional structural feature of the Barbon and Casterton fells that is not seen elsewhere is a steeply dipping and rather irregular fracture that strikes approximately NW-SE, becoming more N-S close to the Barbon Fault (Figure 5); it is best developed, with the NW-SE trend, on the south side of Barbon Low Fell [649 816].

The major faults on SD68SW that define the graben structure occupied by Upper Palaeozoic strata are orientated approximately north-south: the Firbank and Casterton Hall faults in the west, the Barbon and Millhouse faults in the east. Farther west, on SD58SE, the major faults have a more variable trend, NE-SW in the north and swinging towards the south or SE in the south, but they all form part of a widespread, regional pattern. The most immediately striking effect of the faults is the production of the graben structure, which was most probably an end-Carboniferous extensional (or transtansional) effect contemporaneous with Variscan deformation farther south. However, the partitioning of Acadian structure on either side of the graben suggests that its boundary faults had an earlier, Acadian history and were then subsequently reactivated.

7 Quaternary geology

Bedrock is exposed across the highest hills of both SD58SE and SD68SW: Warth and Scout hills in the former and the Middleton, Barbon and Casterton fells in the latter. In these areas glacial till is restricted to hollows and hillside veneers, with scree and head developed in places. Elsewhere, bedrock exposure is rare, a thick blanket of glacial till covers much of the area, and the dominant landscape feature is a drumlin swarm. The drumlins in the north-west of SD58SE have a general NE–SW orientation but this becomes more north-south towards the south-east of that sheet and farther east, on either side of the Lune valley, on SD68SW. The result is a smooth, rounded topography with the largest individual drumlins rising 100 m above their surroundings. There is no evidence to suggest that any of the drumlins have bedrock cores, but this possibility cannot be ruled out. Till sections of up to 2 m are widespread in the west of the area and reveal a coarse rubbly mixture of mostly sub-angular, local sandstone blocks closely packed in a brown, sandy-clay matrix.

Bisecting SD68SW is the north-south valley of the River Lune, the river itself following a course along the west side of the valley which coincides, approximately, with the westernmost boundary faults of the underlying structural graben. Extensive alluvial terraces are somewhat degraded, and in the south merge with higher, rather more moundy terraces that are interpreted as spreads of glaciofluvial, outwash sand and gravel: 2 m of course, cross-bedded sand was reported above the banks of the River Lune at Hyning Wood [608 488].

Small peat-filled hollows are widespread across the area, and some larger spreads of peat have developed on the high ground in the east, particularly in the Barbon and Casterton fells.

8 Archived material

Specimens:

- LX 994-A. Fine-grained, laminated sandstone from the Coniston Group containing graptolites. These have been examined by Dr. R. B. Rickards (University of Cambridge) and tentatively identified as *Saetograptus incipiens* (Wood) s.l. But, in view of the fauna present in LX994B, these graptolites might well be *Saetograptus soperi*. The sample comprises several rock fragments collected in situ from cliffs above Grove Gill [SD 6434 8126].
- LX994-B. Fine-grained, laminated sandstone from the Coniston Group containing graptolites. These have been examined by Dr. R. B. Rickards (University of Cambridge) and identified as *Saetograptus soperi* (e.g. Figure 2). The sample comprises several rock fragments collected from loose debris at the foot of the cliffs above Grove Gill [SD 6434 8126], beneath the locality represented by LX994A. Rickards and Woodcock (2005) propose *Saetograptus soperi* as a biozonal indicator for the top of the Gorstian Stage (Ludlow). As such it would be expected to have an association with a high level in the Coniston Group.

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British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk

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Figure Captions

Figure 1

Outline geology of the Kirkby Lonsdale 1:50 000 Sheet 49 (England and Wales) showing the location of the area described in this report.

Figure 2

Saetograptus soperi Rickards & Woodcock. An example from Grove Gill (LX994 B) drawn by Dr R B Rickards.

Figure 3

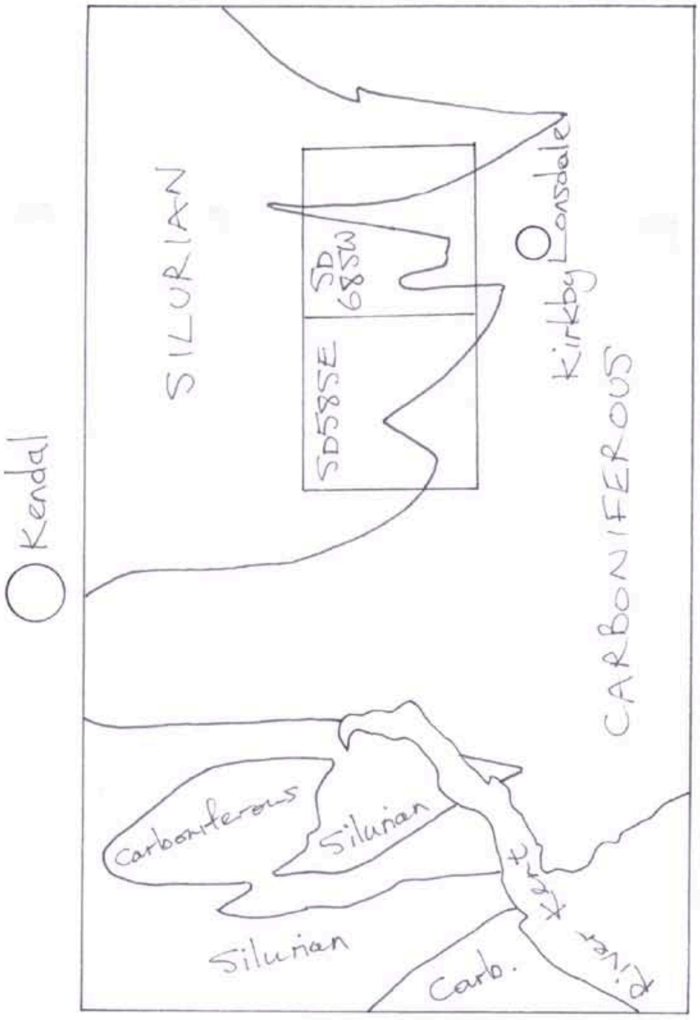
Equal-area stereogram plot of poles to bedding and cleavage from the Kirkby Moor Formation exposed in the Warth Hill and Scout Hill areas of SD58SE.

Figure 4

Equal-area stereogram plot of poles to bedding and cleavage from the Bannisdale Formation and Coniston Group exposed in the Middleton Fell area of SD68SW.

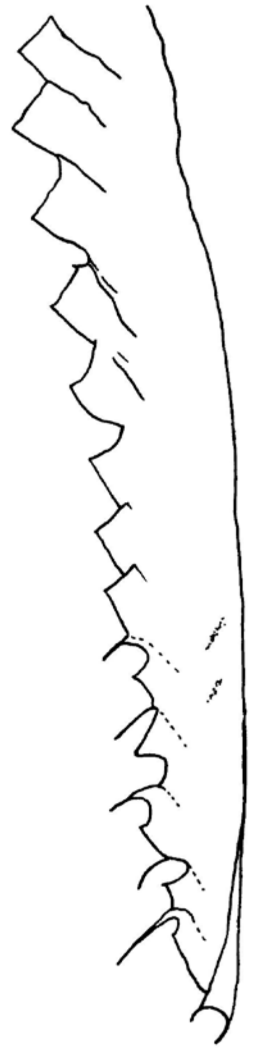
Figure 5

Equal-area stereogram plot of poles to bedding and cleavage from the Coniston Group exposed in the Barbon Fell and Casterton Fell areas of SD68SW.



1:50K SHEET 49 Kirkby Lonsdale

Figure 1



X 20

Figure 2

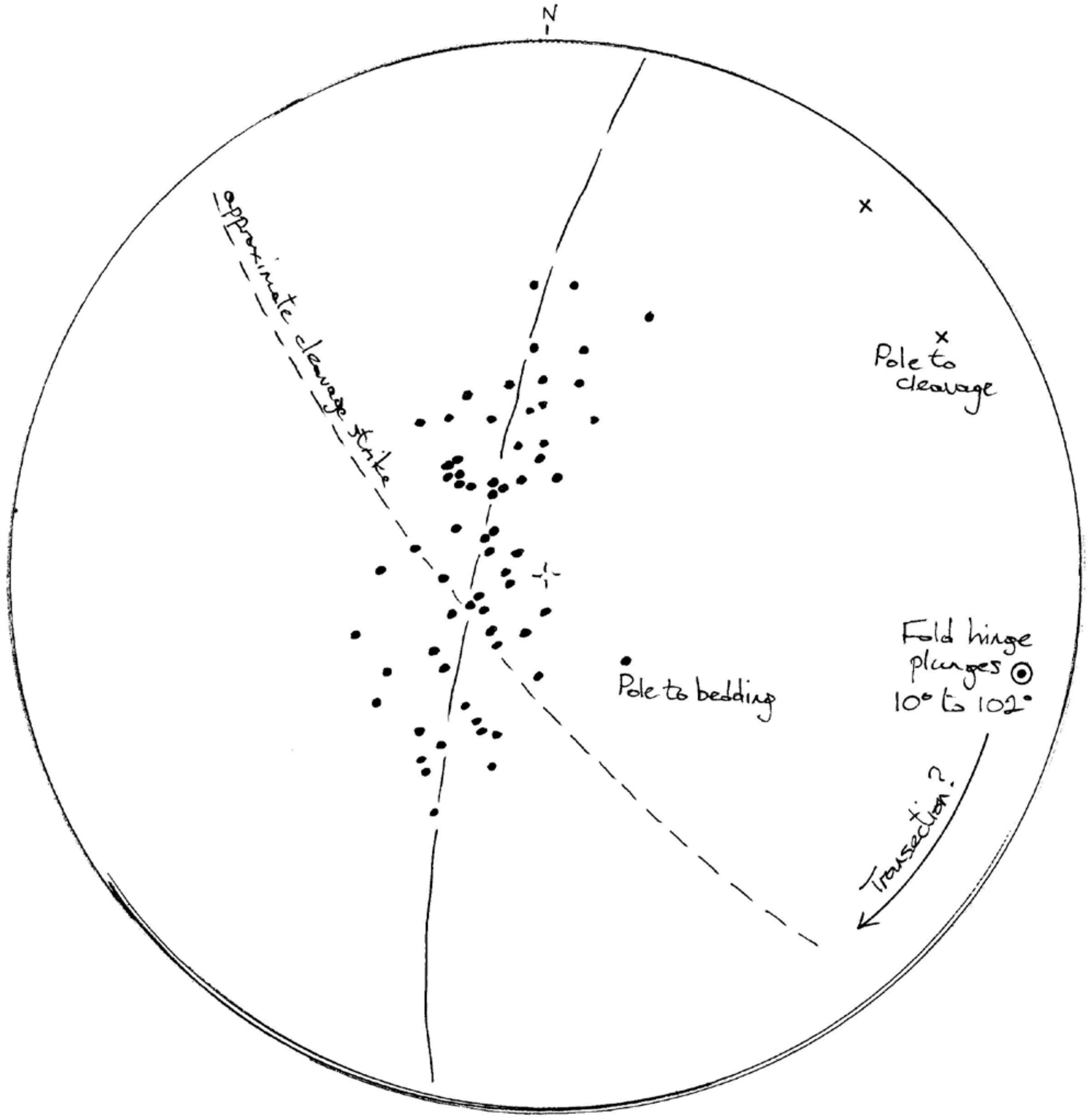

N
approximate cleavage strike
Pole to cleavage
Pole to bedding
Fold hinge plunges 10° to 102°
Transection?

Figure 3

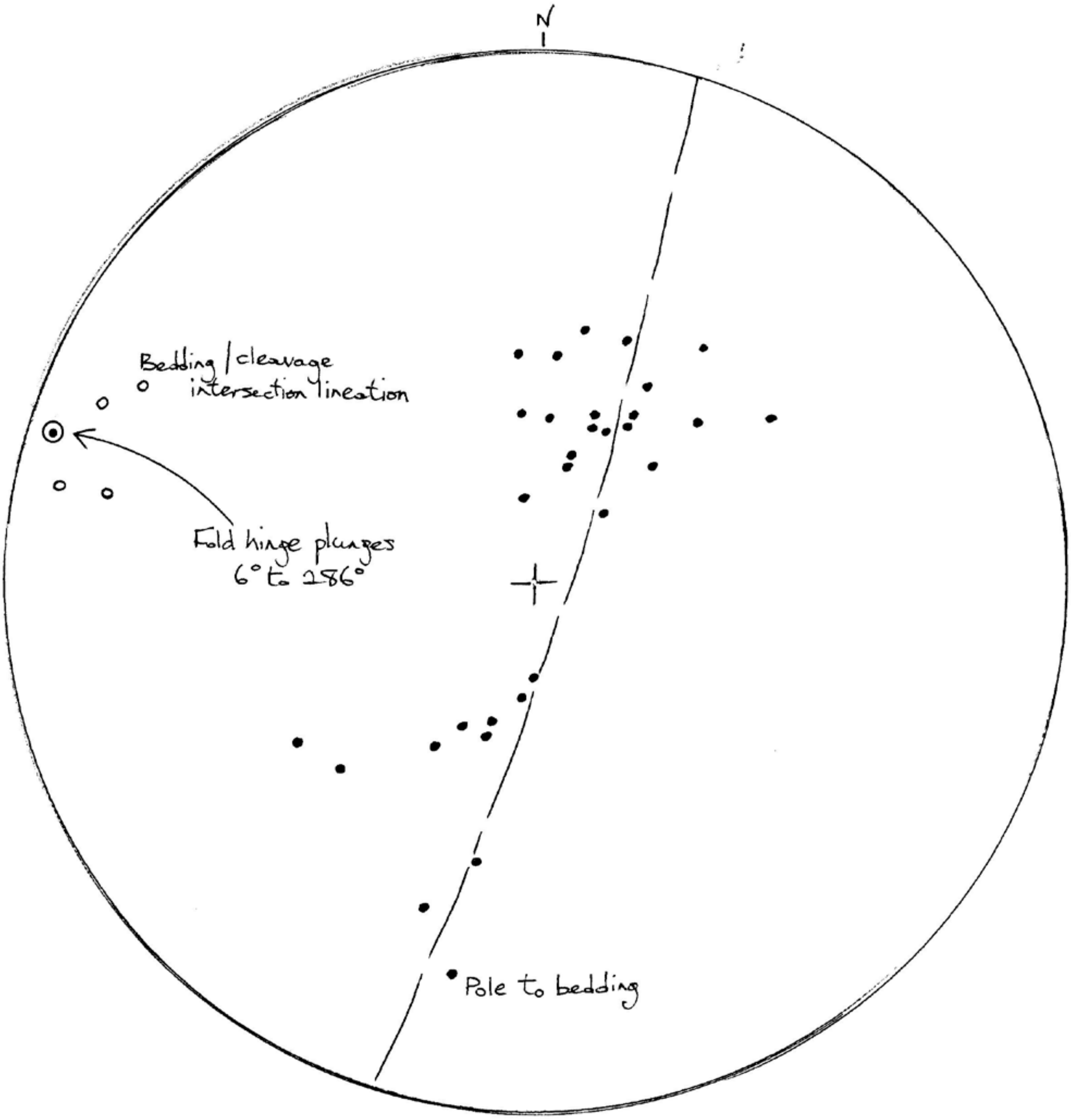

N
Bedding / cleavage intersection lineation
Fold hinge plunges 6° to 286°
Pole to bedding

Figure 4

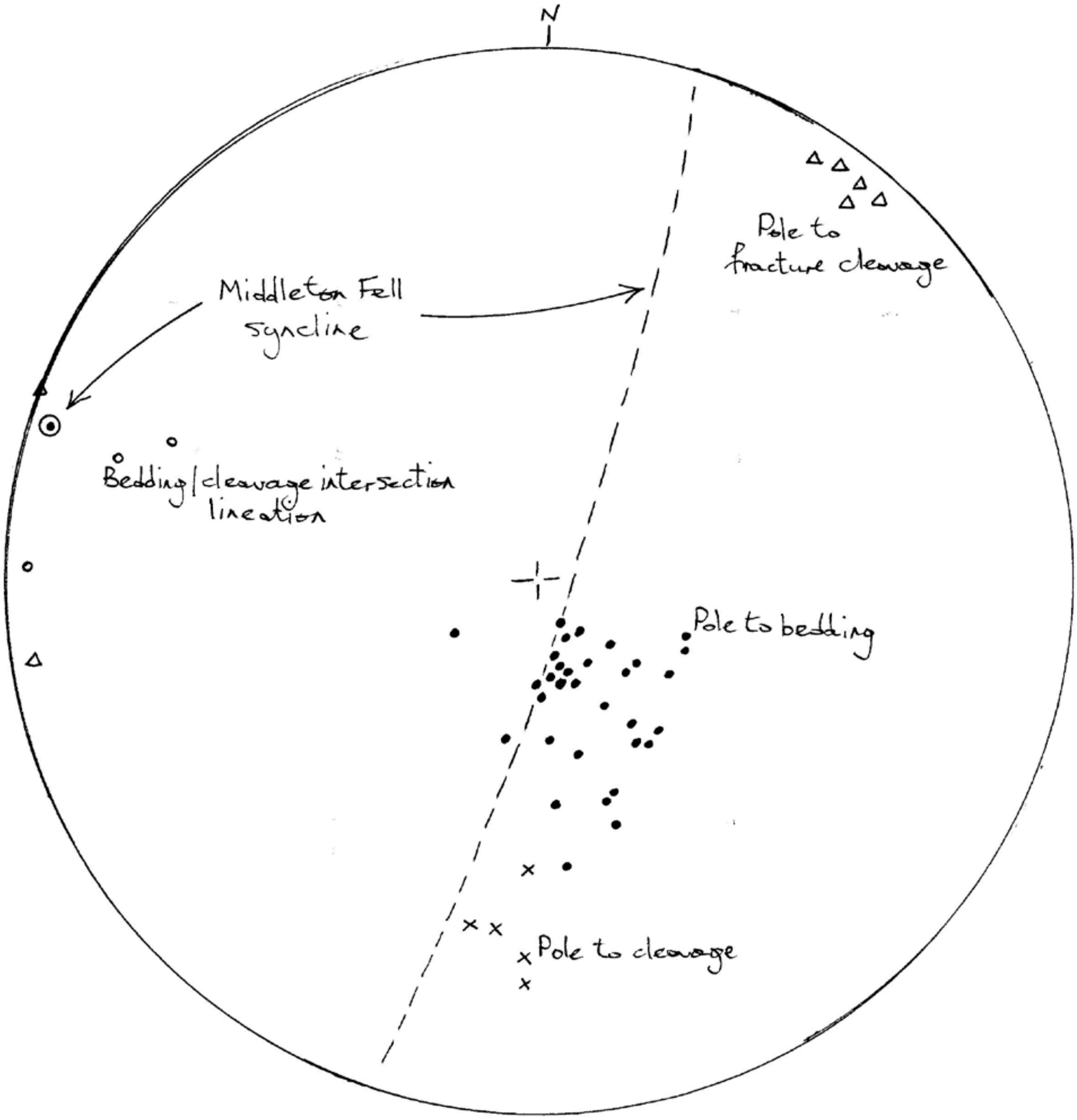

N
Pole to fracture cleavage
Middleton Fell syncline
Bedding/cleavage intersection lineation
Pole to bedding
Pole to cleavage

Figure 5