British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Geological notes and local details for 1:10 000 sheet SD69NE (Westerdale), and parts of sheets SD69NW (Howgill), SD69SW (Firbank) and SD69SE (Sedbergh)

Part of 1: 50 000 sheets 39 (Kendal) and 40 (Kirkby Stephen)

Geology and Landscape Northern Britain Programme

Internal Report IR/03/090

BRITISH GEOLOGICAL SURVEY

GEOLOGY AND LANDSCAPE NORTHERN BRITAIN PROGRAMME

INTERNAL REPORT IR/03/090

Geological notes and local details for 1:10 000 sheet SD69NE (Westerdale), and parts of sheets SD69NW (Howgill), SD69SW (Firbank) and SD69SE (Sedbergh)

Part of 1: 50 000 sheets 39 (Kendal) and 40 (Kirkby Stephen)

N H Woodcock, R B Rickards

Keywords

Report; Howgill Fells, stratigraphy, Ordovician, Silurian.

Front cover

Howgill Fells from the Midddleton Fells.
(Photograph N H Woodcock)

Bibliographical reference

WOODCOCK, N H, RICKARDS, R B. 2006. Geological notes and local details for 1:10 000 sheet SD69NE (Westerdale), and parts of sheets SD69NW (Howgill), SD69SW (Firbank) and SD69SE (Sedbergh). *British Geological Survey Internal Report*, IR/03/090. 61pp.

Keyworth, Nottingham British Geological Survey 2006

BRITISH GEOLOGICAL SURVEY

The full range of Survey publications is available from the BGS Sales Desks at Nottingham, Edinburgh and London; see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications including maps for consultation.

The Survey publishes an annual catalogue of its maps and other publications; this catalogue is available from any of the BGS Sales Desks.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as its basic research projects. It also undertakes programmes of British technical aid in geology in developing countries as arranged by the Department for International Development and other agencies.

The British Geological Survey is a component body of the Natural Environment Research Council.

British Geological Survey offices

Keyworth, Nottingham NG12 5GG

☎ 0115-936 3241 Fax 0115-936 3488
e-mail: sales@bgs.ac.uk
www.bgs.ac.uk
Shop online at: www.geologyshop.com

Murchison House, West Mains Road, Edinburgh EH9 3LA

☎ 0131-667 1000 Fax 0131-668 2683
e-mail: scotsales@bgs.ac.uk

London Information Office at the Natural History Museum (Earth Galleries), Exhibition Road, South Kensington, London SW7 2DE

☎ 020-7589 4090 Fax 020-7584 8270
☎ 020-7942 5344/45 email: bgslondon@bgs.ac.uk

Forde House, Park Five Business Centre, Harrier Way, Sowton, Exeter, Devon EX2 7HU

☎ 01392-445271 Fax 01392-445371

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF

☎ 028-9038 8462 Fax 028-9038 8461

Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB

☎ 01491-838800 Fax 01491-692345

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff, CF15 7NE

☎ 029–2052 1962 Fax 029–2052 1963

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU

☎ 01793-411500 Fax 01793-411501
www.nerc.ac.uk

Foreword

This report is the published product of a study by Dr N H Woodcock and Professor R B Rickards of the Department of Earth Sciences in the University of Cambridge, commissioned by the British Geological Survey (BGS) and completed under Contract and GA/98E/44 between 1999 and 2003. The report describes the geology of 1:10 000-scale Bedrock and Superficial Deposits Geology Series sheets SD 69 NE (Westerdale) and parts of SD 69 NW (Howgill), SD 69 SW (Firbank) and SD 69 SE (Sedbergh), which constitute part of the England and Wales 1:50 000 series sheet 39, Kendal. This report should be read in conjunction with the 1:10 000-scale maps. Dr P Stone acted as BGS liaison. This work was completed in conjunction with the BGS Lake District Project led by Dr Stone. This report has been edited by Dr D Millward.

Acknowledgements

The authors thank all the local landowners and tenant farmers for access to their land. They are grateful to Dr Jack Soper and Dr Phil Stone for field discussion on the geology.

Notes

The numbers enclosed in square brackets are National Grid references. Unless otherwise stated the references lie within the 100 km square SD.

Contents

FIGURES

TABLES

Summary

This report describes the bedrock and superficial deposits geology of the southern parts of Howgill Fells, a picturesque upland area located at the easterly extent of the Lake District Lower Palaeozoic inlier in Cumbria. The bedrock geology consists mainly of a thick succession of mudstone and sandstone assigned to the upper Ordovician and Silurian Windermere Supergroup. These rocks are partially overlain by a variable thickness of glacial and post-glacial deposits. This description and an earlier one by the same authors (Woodcock and Rickards, 1999) accompanies, and should be read in conjunction with, the 1:10 000 scale geological sheets SD 69 NW, NE, SW, SE. These maps are components of the 1:50 000 Geological Series sheets 39 (Kendal) and 40 (Kirkby Stephen).

The first part of the report provides an extensive review of previous research into the Quaternary geology of the area, which complements a similar review of research into the bedrock geology of the area presented in Woodcock and Rickards (1999). Each of the Lower Palaeozoic bedrock units identified within the area are then described, along with the biostratigraphy and an outline of the depositional history. An account of the various dolerite, felsite and lamprophyre minor intrusions follows. The ?Upper Devonian and Carboniferous rocks around the margin of the area are described briefly for completeness. A description of the structures present and an analysis of the deformation history forms a major section. The final section describes the Quaternary deposits.

The Howgill Fells lies immediately to the west of the Dent Fault, a major zone of east-north-east-trending faults which has the form of a positive flower-structure in cross-section and a contractional strike-slip duplex in map view. Associated with the fault zone, structural domes cored by Ordovician rocks were the result of westerly plunging Early Devonian, Acadian folds affected by interference from Late Carboniferous (‘Variscan’) east-north-east-trending folds. The Ordovician Dent Group here is represented by the Cautley Mudstone and Ashgill formations. The Silurian succession is similar to that found in the Lake District, though significant variations in thickness are recorded for some of the units. The lower part of the Bannisdale Formation comprises the youngest strata represented. The Windermere Supergroup here is up to 3400 m thick.

Extensive till deposits overlie the bedrock in many of the upland valleys and alongside the River Lune. Alluvium and River Terrace deposits occupy most of the main streams. Peat blankets the flatter upland areas.

1 Introduction

This report describes the bedrock geology and superficial deposits of the area of Cumbria lying east of the River Lune and within 10 km grid square SD 69. This area is dominated by the southern part of the Howgill Fells. It also includes, to their south, the Frostrow Fells and the northern flank of the Middleton Fells and, to the east, the western flank of Baugh Fell. The ground within grid square SD 69 to the west of the Lune is not covered in this report or on the accompanying maps: it has been mapped on contract to BGS by Prof. N.J. Soper (Soper, 2006). The northern edge of square SD 69 roughly bisects the Howgill Fells, which continue northward as far as the east-trending part of the Lune Valley between Tebay and Ravenstonedale (Soper, 1999).

The mapped area is now entirely included within the administrative county of Cumbria, although most of it formerly lay within the West Riding of Yorkshire. A vestige of the former subdivision is the inclusion of most of the southern Howgill Fells in the Yorkshire Dales National Park. Geologically, however, the Howgill Fells are the eastern extremity of the Lower Palaeozoic inlier of the Lake District (Figure 1). Carboniferous rocks, more typical of the Yorkshire Dales, unconformably overlie the Lower Palaeozoic rocks on the northern and southern margins of the Howgill Fells, and are juxtaposed to the east across the major Dent Fault Zone. Accordingly, Carboniferous rocks crop out in the south and south-east of square SD 69 (Figure 2). These rocks are only briefly described here, having been fully documented in other BGS publications, particularly by Dunham and Wilson (1985).

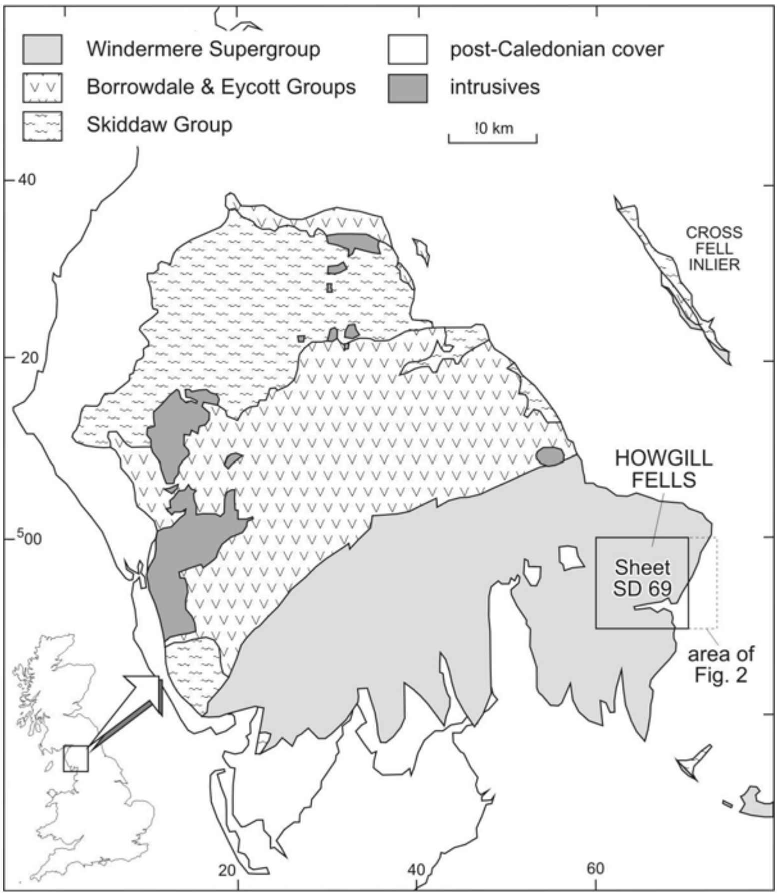


Figure 1 Map of the Lower Palaeozoic geology of north-west England, showing the location of Sheet SD 69 and of Figure 2.

The outcrop pattern of Lower Palaeozoic rocks within the southern Howgill Fells is determined by two structural controls (Figure 2). First, gently west-plunging Caledonian folds ensure that Ordovician rocks in the east pass up into progressively younger Silurian rocks to the west. Second, in the east of the area, later north-north-east trending Variscan folds within the Dent

Fault Zone, interfere with the Caledonian folds to form structural domes, cored by Ordovician rocks.

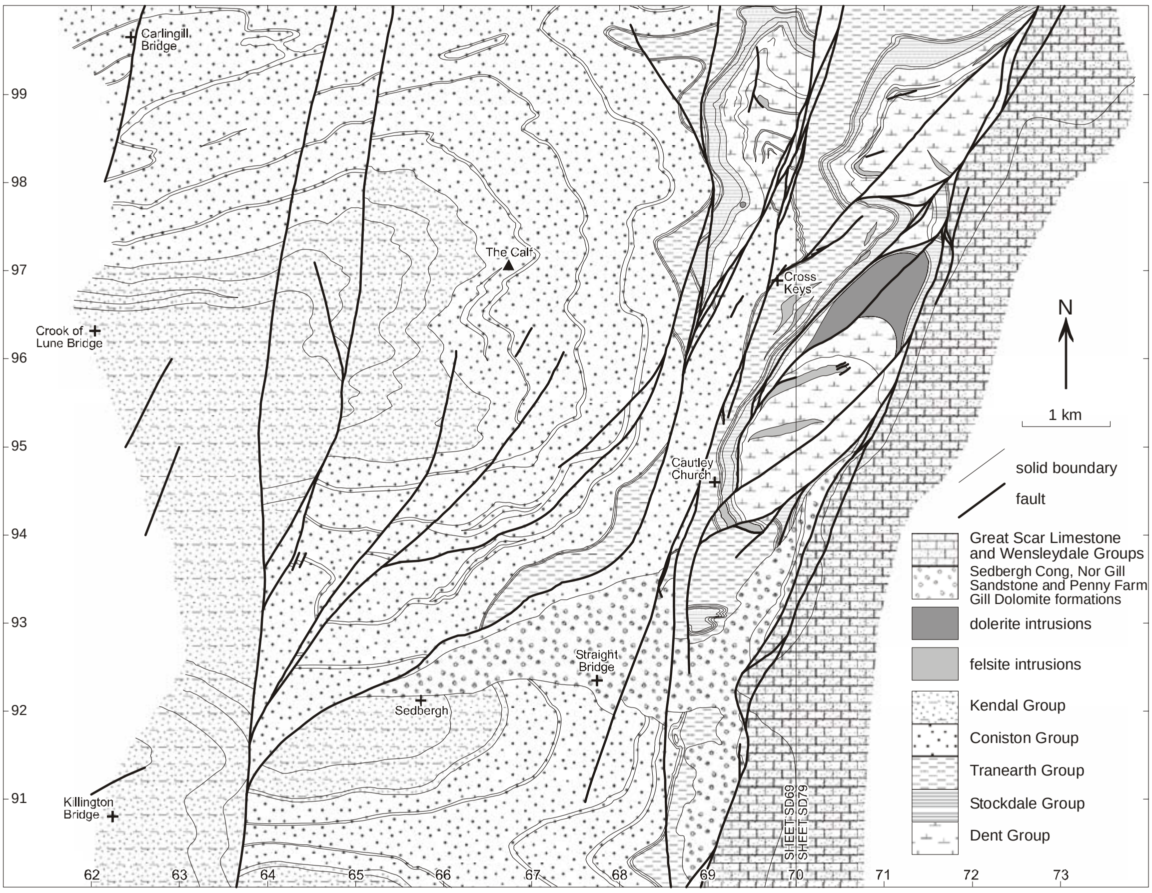


Figure 2 Simplified geological map of Sheet SD 69 and the area to the east as far as the Dent Fault Zone.

For location see Figure 1

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

2 Historical context

2.1 BEDROCK GEOLOGY

This report complements a previous BGS Technical Report (Woodcock and Rickards 1999), which accompanied preliminary bedrock-only standard maps of the southern Howgill Fells. A full history of research into the solid rocks of this area was provided in that report and is not repeated here. However, one summary chart from that report is reproduced for reference as Figure 3, giving the development of stratigraphical nomenclature in the Windermere Supergroup of the Howgill Fells. The main additions to the literature since the previous review have been the Technical Report on the geology of the northern Howgill Fells (Soper, 1999), which used essentially the same stratigraphy as in the present report, and new biostratigraphical results on the Ashgill Series (Rickards, 2002). The results from the northern Howgill Fells will be referred to in appropriate later parts of the present report.

2.2 QUATERNARY GEOLOGY

The history of research in the preliminary report (Woodcock and Rickards, 1999) did not cover Quaternary geology, and a brief review of this aspect of the geology of sheet SD 69 is therefore given here.

North-west England played a pivotal role in the development of Quaternary studies in Britain. The Superficial Deposits here contain a number of distinctive lithologies, such as the Shap Granite, now dispersed from their original source. In the early 19th Century, these dispersion

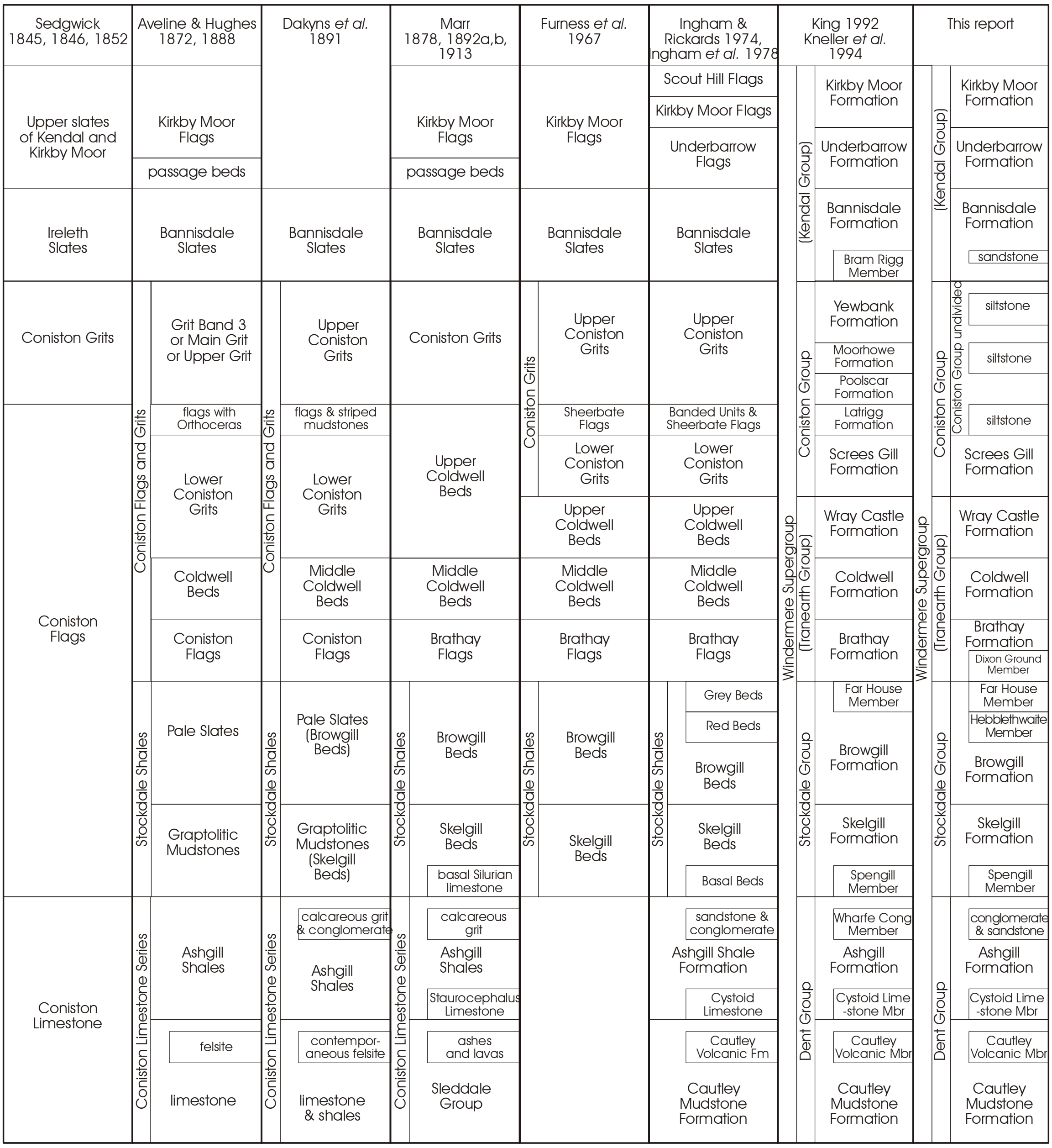


Figure 3 History of the lithostratigraphical nomenclature of the Windermere Supergroup in the Howgill Fells. The columns follow Sedgwick (1845, 1846, 1852), Aveline and Hughes (1872, 1888), Dakyns *et al.* (1891), Marr (1878, 1892a, 1892b, 1913), Furness *et al.* (1967), Ingham and Rickards (1974), Ingham and McNamara (1978), King (1992) and Kneller *et al.* (1994)

patterns were used as important evidence in the debate about the origin of the 'Drift' as a marine deposit or as a product of the Noachian Deluge (e.g. Phillips, 1837). More important, evidence from the region contributed to Buckland's (1840) proposal (inspired by field work with Louis Agassiz) that the 'Drift' was formed not by water but by glacial processes. Key evidence was the dispersion of the Shap clasts around the northern flanks of the Howgill Fells, at a level higher than any conceivable flood action and in a direction opposite to the present slope of the Lune and upper Eden river valleys.

Detailed documentation of the evidence for glacial action awaited the work of a trio of Geological Survey mappers published in the 1870s. Tiddeman (1872) assembled the evidence for the area from Sedbergh southwards through Lancashire to beyond Preston. He showed from measuring ice striations that the area was covered by a large ice-sheet, which was only constrained to flow parallel to the deeper valleys and converged with a major south-flowing ice stream in the Irish Sea. Tiddeman was convinced of the glacial origin of all the till. By contrast, his Geological Survey colleague Ward, after a similarly thorough survey of the Lake District (Ward, 1873, 1875), still appealed to water action or floating ice to disperse some of the erratic boulders and deposit the more sandy tills. However, Ward correctly showed that ice flow in this upland terrain tended to be more confined by deep valleys than in the lowlands. Crucially, he showed that ice flowed northwards as well as southwards off the Lake District mountains, impeding and diverting the southward flow of the Scottish ice that Tiddeman had envisaged supplying the Irish Sea ice stream. Ward also perceptively identified the erosional and depositional evidence for a late-stage valley and corrie glaciation – the Loch Lomond Advance of modern terminology.

The work of the third member of the Geological Survey trio (Goodchild, 1875), was the most relevant to the present report, covering an area centred on the Howgill Fells and extending over the upper Eden Valley and the western Yorkshire Dales. Goodchild was, like Tiddeman, a convinced glacialist. He demonstrated that the Howgill Fells effectively provided the eastern continuation of the Lake District ice-shed – the dividing line between north and south-flowing ice. He also showed, from striation and erratic evidence, how the north-flowing ice from the Howgill Fells and Lake District was rapidly diverted eastward up the upper Eden Valley and over the Stainmoor Gap into North Yorkshire. The Carboniferous hills immediately east of the Howgill Fells shed their own ice, first flowing westwards towards the Howgills, then diverting northward or southward either side of the main ice-shed.

Some local details of the glacial geology of sheet SD 69 were provided by Goodchild (1875), particularly striation data that showed 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. Further details were added in the Geological Survey Memoirs and accompanying maps. Aveline and Hughes (1888) mentioned the tongues of till that run up most valleys in the Howgill Fells, and the thicker, more sandy, mounded till at the confluence of the Lune and the Rawthey near Sedbergh. They distinguished alluvium superimposed on these till sheets in the main valleys, and made passing reference to the storm-induced debris cones that are a feature of the Howgill Fells slopes. In the memoir covering the eastern part of sheet SD 69, Dakyns et al. (1891) recognised the swarm of drumlins forming the Longstone and Frostrow Fells, and recorded the heights reached by till in major valleys such as Westerdale. However, these details added little to Goodchild's regional synthesis.

In the early part of the twentieth century, a new phase of interpretation of regional Quaternary events was led by John Marr. One of his primary interests was in the origin of the Lake District-Howgill Fells uplift that hosted both the regional drainage divide and the Quaternary ice-shed. He persuasively argued (Marr, 1906, 1916) that this uplift was dominantly of Cainozoic age, contemporaneous with the Thulean igneous province. Still plausible is his hypothesis that the Lake District 'dome' is underlain by a Tertiary intrusive sheet, though one deep in the crust rather than at a high level as envisaged by Marr. The uplift of the Howgill Fells was recognised by Marr and Fearnsides (1909) to be asymmetric, with a gentle north-dipping slope and an abrupt southern escarpment defined by the Sedbergh Faults. They showed how this asymmetry is reflected in the southerly position of the drainage divide in the Howgill Fells and by the way in which the high-gradient south-flowing streams have captured the headwaters of the north-flowing streams. Marr and Fearnsides also produced a much clearer synthesis of the glaciation of the Howgill Fells, emphasising the supply of local debris-laden ice down the Howgill Fells valleys, but the strong encroachment of the more regional ice-streams across the lower reaches of these valleys. One such ice-stream was shown to have flowed down the Lune Valley and over Grayrigg Forest on the west side of the Howgill Fells, thereby overtopping the regional ice-shed and feeding a limited supply of Shap Granite clasts towards the Lancashire coastal plain. Marr and Fearnsides also recognised the strong influence of ice shed from Baugh Fell 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.

A new phase of 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. His main conclusion was that basal ice-flow directions deduced from drumlins were sometimes oblique or opposite to the regional flow direction deduced from the dispersal of exotic clasts. He deduced that basal ice could be constrained by topography or even flow up the local topographic slope whilst upper levels of the same ice-stream would flow down the gradient of the ice surface. Two cited examples of this phenomenon occurred where basal ice flowed northward away from the Grayrigg – Howgills ice-shed, whilst upper ice flowed either southwards towards and over the Lune – Grayrigg depression or eastward up Ravenstonedale towards the Stainmoor gap. As Hollingworth noted, the topographic effect of the Howgill Fells on even the upper ice is greater than their modest height might suggest.

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 below Sedbergh and the highest comprising the ‘2000 foot’ summit plateau. The imprecise correlation and lack of dating that have dogged such studies mean that the significance of McConnell’s surfaces still awaits assessment.

Until the 1970s, there was little further work on the Quaternary geology of Sheet SD 69, except for Manley’s (1959) unequivocal assignment of corries at Cautley Crags and Yarlside to the Loch Lomond Readvance. Then Letzer (1981), working on the northern fringe of the Howgill Fells, disputed Hollingworth’s interpretation of divergent flow between different levels of an ice stream. Letzer preferred instead the effects of superimposed pulses of differently directed ice combined with the lateral migration of a linear ice-shed.

A substantial body of work on the Howgill Fells has arisen during the past three decades, from the studies of A.M. Harvey and colleagues of late Pleistocene and Holocene landforms and sedimentation. An important early observation was that much of the till in the Howgill Fells’ valleys shows signs of redistribution by downslope solifluction (Harvey, 1974). This till, assumed to be Devensian and probably deposited between 20 and 13 ka BP, is succeeded by two stages of alluvial terrace formation, then by a suite of gully-supplied debris cones or fans, and finally by the active meandering stream deposits (Harvey et al., 1984, 1986). Dating of some of these later events has proved possible by using radiocarbon methods (Harvey et al., 1981, 1996) and lichenometry (Harvey et al., 1984). The lower terrace deposits date from 2500–1000 years BP, and are post-dated by the main phase of gully and fan formation in the tenth century A.D – probably triggered by the start of upland sheep-grazing. Some of these gully and fan systems are currently kept active by approximately annual valley-bottom erosion of the fan toes (Harvey, 1977, 1979). However, the lichen dating suggests that most parts of the Howgill Fells landscape enjoys decadal or century-long periods of stability, interrupted by short periods of reactivation of the gully, fan and valley systems. A heavy storm in the central Howgill Fells on 6th June 1982 allowed the consequences of such a catastrophic event to be studied (Harvey, 1986; Wells and Harvey, 1987). Significant numbers of the tenth century gullies were re-opened and debris transferred to the fans below by a combination of debris flow and stream flow. Transient braided streams were established in the main valleys, so that the courses of the post-storm meandering channels were altered (Harvey, 1991). Recent attention has turned to analysis of the inactive gully system dating from the tenth century, suggesting a time-scale of about 150 years from gully initiation to restabilization (Harvey, 1992, 1996). The Howgill Fells are seen as a system operating close to its geomorphic threshold, so that future external events such as the 1982 storm can be expected to trigger new landscape changes.

3 Dent Group

The Dent Group is up to 630 m thick in the Howgill Fells, predominantly comprising massive or bioturbated dark grey mudstones. This lithology contrasts with the black graptolitic mudstones that comprise the base of the overlying Stockdale Group. The Dent Group also contains grey impure, muddy limestones, admixtures of ash, quartz silt and sand, and minor conglomeratic material. The group was defined by Kneller et al. (1994), who fully reviewed its terminological history. The description here is taken from Woodcock and Rickards (1999), with only minor amendments.

3.1 CAUTLEY MUDSTONE FORMATION

The Cautley Mudstone Formation makes up most of the Dent Group, although the maximum thickness on sheet SD 69 is about 370 m. 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 rusty or olive-brown. Benthic shelly fossils are abundant in the limestone, particularly trilobites, brachiopods, bryozoans and corals, but can usually be collected only from weathered rock. Intermixed volcanic ash gives a splintery texture to the mudstone in places, culminating in the discrete Cautley Volcanic Member. The Cautley Mudstone Formation ranges from Onnian (Caradoc), through the Pusgillian and the seven Cautleyan and Rawtheyan shelly biozones of Ingham (1966). Biozones 1-7 have been referred to the *anceps* graptolite Biozone. However, recent work (Rickards, 2002) 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. There is no evidence of an *anceps* fauna in the type Ashgill section of Backside Beck (Westerdale).

The Cautley Mudstones were defined 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 [6983 9864 to 6976 9965]. The base of the formation is not seen in the mapping area, but Ingham (1966) suggested that the base is exposed in the Murthwaite Inlier, east of the mapping area, in a gill 400 m north-north-east of Foggygill Farm [7220 9880]. There, mudstones are underlain by poorly exposed purple andesite, assigned to the Borrowdale Volcanic Group. The top of the Cautley Mudstone Formation is marked by the abrupt loss of carbonate nodules into the Ashgill Shale Formation. Representative exposures of the Cautley Mudstone Formation are listed in Table 1. A further outcrop of the formation is inferred in a fault-bounded sliver east of Long Moor Moss [6885 9005], in the south-east of Sheet SD 69, on the basis of exposure in Helmside Gill [6870 8960], beyond the southern edge of the sheet.

3.1.1 Cautley Volcanic Member

The member comprises bedded rhyolitic vitric or lithic tuffs, buff or pink in colour. The volcanic member reaches a maximum thickness of about 25 m in the Westerdale Inlier, but thins eastwards into the Murthwaite Inlier beyond the map area, and southwards to zero thickness in the Taythes Inlier. The member occurs in the top part of the Cautley Mudstone Formation, within

25 m of its upper contact. Ingham (1966) placed the volcanic rocks at the top of Rawtheyan biozone 6.

The Cautley Volcanic ‘Group’ was defined by Ingham (1966), and a representative section picked by Kneller et al. (1994) in Backside Beck [6943 9888 to 6937 9891]. Other exposures are listed in Table 1.

3.2 ASHGILL FORMATION

About 60 m of grey mudstones comprise the Ashgill Formation. The unit tends to be burrow-mottled and weakly calcareous in its lower part, and non-calcareous, more silty and better laminated in its upper part. This lamination is defined by silt-mud couplets about 5-10 mm thick, commonly sharp based and graded. The discrete Cystoid Limestone Member occurs at the base of the formation, and an horizon of sandstone with lensoid conglomerate units is present in its upper part. The Ashgill Shales are locally fossiliferous, with a distinctive low diversity shelly fauna of brachiopods, bryozoans and a trilobite. On this basis, Ingham (1966) assigned the unit a Hirnantian (latest Ashgill) age, except for the Cystoid Limestone Member, which is of highest Rawtheyan age (Ingham and Wright, 1972).

The Ashgill Shales were defined by Salter (1873) after Ash Gill Beck in the Lake District, extended downwards as the Ashgill Shale Formation by McNamara (1979) to include the *Phacops mucronatus* Beds of Marr (1916), and shortened to the Ashgill Formation by Kneller et al. (1994). There is a close lithological similarity between the formation in the Lake District and Howgill Fells. The base of the formation in the mapping area is marked by the Cystoid Limestone Member, above which the Ashgill Formation lacks the nodular limestones characteristic of the underlying Cautley Mudstone Formation. The top of the formation is taken at the base of a further thin limestone bed, above which appear the typical black mudstones of the Skelgill Formation. The Ashgill Formation broadly corresponds to the *complanatus* and *anceps* Bizones. However, this age is based on underlying and overlying faunas, no graptolites having been recorded in the Ashgill Formation.

Representative exposures of the Ashgill Formation are listed in Table 2.

3.2.1 Cystoid Limestone Member

The member is composed of between 1.5 m and 3 m of pale grey, argillaceous, fossiliferous limestone. The abundant fauna includes diploporitan and rhombiferan cystoids, trilobites and brachiopods, assigned a high Rawtheyan age by Ingham and Wright (1972).

The unit was known to Marr (1892a) as the *Staurocephalus* Limestone. It was renamed the Cystoid Limestone by Ingham (1966), and given member status by Kneller et al. (1994) with a representative section in Odd Gill [7146 9912] just east of the mapping area. The member overlies the Rawtheyan Biozone 7 of the Cautley Mudstone Formation in the north of the mapping area (e.g. Backside Beck), but overlies the older Biozone 5 further south (e.g. Ecker Secker Beck), implying some disconformity at this level (Ingham, 1966).

Known exposures of the Cystoid Limestone Member are listed in Table 2.

3.2.2 Conglomerate and sandstone

A unit of conglomerate or sandstone varying from 0.3 m to 9 m thick occurs consistently near the top of the Ashgill Formation, between 3 m and 15 m below the base of the overlying Stockdale Group. In different localities, the lithology is sandy mudstone, calcareous sandstone or a limestone conglomerate. Turner (1961) reported that the conglomerate clasts were mostly derived from the underlying Cautley Mudstone Formation. Rickards (1970b) deduced transport from the south-east on the basis of cross-bedding and shell imbrication. The unit has yielded shelly fossils, and lies within mudstones of Hirnantian (Biozone 8) age (Ingham, 1966).

The conglomerate and sandstone unit awaits formal definition in the Howgill Fells area. It was termed the Ashgill Shale Grit by Rickards (1970b), and has been correlated with the Wharfe Conglomerate Member of the Craven Inliers (Ingham and Rickards, 1974) and with the Rebecca Member of Furness (Kneller et al. 1994). Map continuity with the Wharfe Member is not demonstrable, but petrographical evidence that the Howgill Fells' conglomerate and sandstone is part of the same depositional body would be reassuring.

All known exposures of the conglomerate and sandstone unit are listed in Table 2. Spengill, Ecker Secker Beck and Birksfield Beck were known to Dakyns et al. (1891), and most of the rest were recorded by Ingham (1966) or Rickards (1970b). The exposures in Taythes Gill and the tributary of Backside Beck were discovered by Rickards more recently.

3.3 DEPOSITIONAL ENVIRONMENT OF THE DENT GROUP

The facies and faunas of the Dent Group are consistent with deposition on a shallow marine shelf. In the Lake District outcrop, four depositional cycles are separated by periods of emergence, non-sequence and erosion (Kneller et al., 1994). In the Howgill Fells' inliers, the first three of these cycles are not apparent. This interval, corresponding to 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 Cautley Volcanic Member shows no sign of subaerial accumulation. However, the biostratigraphical gap in the upper part of the Cautley Mudstone Formation suggests lowstand erosion, again not conclusively subaerial, before deposition of the Ashgill Formation. The basal Cystoid Limestone Member may record a period of reduced clastic supply during the succeeding transgression. Upward decrease in carbonate content and bioturbation in the Ashgill Formation may be interpreted in terms of increasing clastic supply, or cooling sea-water into the late Ashgill (Hirnantian) ice age. The conglomerate and sandstone unit presumably represents the lowstand during this event, with some erosion and redeposition by shallow marine processes.

4 Stockdale Group

The Stockdale Group comprises up to 120 m of mudstone and siltstone. The group is distinguished from the underlying Dent Group by its content of black graptolitic mudstone, which dominates the lower part (Skelgill Formation) and persists, interbedded with pale green siltstone beds, in the upper part (Browgill Formation). The lithological and faunal contrast at the base of the Stockdale Group is so abrupt that it was formerly thought to mark an unconformity in the Lake District succession (e.g. Aveline and Hughes, 1888). The Stockdale Group was formalised by Kneller et al. (1994) in the sense of the long-established Stockdale Shales of Aveline and Hughes (1872). The description here is taken from Woodcock and Rickards (1999), with only minor amendments.

4.1 SKELGILL FORMATION

The Skelgill Formation is up to 40 m thick, and mostly composed of black mudstone. The lower part (Biozones *acuminatus* to *magnus*) is almost entirely of this lithology and contains a rich graptolite fauna. The upper part also contains blue-grey mudstones and thin nodular limestone beds, yielding a sparse brachiopod and trilobite fauna, intercalated with the graptolitic mudstones. A distinctive nodular limestone unit, the Spengill Member, occurs at the base of the formation. The Skelgill Formation ranges from the *acuminatus* Biozone (basal Llandovery) and possibly the *persculptus* Biozone (topmost Ashgill) up to the *sedgwickii* Biozone of the Llandovery (Rickards, 1970b).

The Skelgill Beds were defined by Marr and Nicholson (1888) and designated as a formation by Kneller et al. (1994). The base of the formation was taken by Marr and Nicholson below the basal limestone. The top of the formation is taken where an increasing proportion of green oxic siltstone beds mark the transition into the overlying Browgill Formation. Representative exposures of the Skelgill Formation are listed in Table 3.

4.1.1 Spengill Member

The member comprises nodular limestone and pale grey pyritic mudstone. It varies in thickness from 0.4 m in the north of the area to 1.8 m in the south. The limestone is generally between 0.15 m and 0.50 m thick but, in Pickering Gill, exceptionally comprises six beds totalling 1.6 m (Rickards, 1970b). A thin (20 mm) bentonitic clay occurs at the contact between the Spengill Member and the overlying graptolitic shales in most sections.

The Spengill Member was formally named by Kneller et al. (1994), to include the Basal Beds of Rickards (e.g. 1970a, 1988) and earlier authors. The known exposures of the Spengill Member are listed in Table 3. The basal beds were first described by Marr and Nicholson (1888) from Spengill, which is now the chosen type locality. Dakyns et al. (1891) added exposures in Birks (Wood) Beck and Watley Gill. The unit was studied by Wilson (1954), and a further eight localities were identified by Rickards (1970b): Crosshaw Beck, Birksfield Beck, Pickering Gill, Rawthey Bridge, Wards Intake, Stockless Gill and two at Five Gills. Four further localities have been discovered by Rickards: Mountain View, Marsh Lane**,** Wandale Hill; and Whinny Gill.

4.1.2 The 'Green Streak'

One of the thin green-grey mudstone beds in the Skelgill Formation has received particular attention because its well defined stratigraphical position allows it to be traced across the Lake District. Moreover, it is represented at the same horizon in the Welsh Basin (e.g. Rheidol Gorge) and probably in the Dob's Linn section of the Scottish Southern Uplands (Spencer, 1966). This

2-8 mm thick 'Green Streak' occurs within the 0.3 m unit of black graptolitic mudstone assigned to the *argenteus* Biozone. It was traced in the Lake District by Marr and Nicholson (1888) and recognised by Marr (1913) in Watley Gill in the Howgill Fells. It was said to be absent in Spengill, but was later located there, within a fault slice, by Rickards (see Rickards, 1970b, fig. 12). All the localities at which it occurs in the Howgill Fells are listed in Table 3. The 'Green Streak' has not been given formal lithostratigraphical status.

The thin mudstone band weathers green-grey, hence its name, but in fresh rock is pale grey. Geochemical study by Spencer (1966) showed that the unit is not of volcanic origin. Rickards (1964) showed that such green-grey mudstone units have a lower organic carbon content than the enclosing black mudstone but are mineralogically identical to the mudstone, apart from lack of graptolites and pyrite.

4.2 BROWGILL FORMATION

The Browgill Formation comprises up to 80 m thickness, mostly of pale green-grey siltstone, weathered buff. Siltstone units appear either massive or thickly laminated to very thinly bedded on clean exposures, but weather to hard 'beds' between 0.1 m and 1 m thick. Such 'beds' are commonly defined by the intercalated thin graptolitic mudstone bands that persist through most of the Browgill Formation or by bentonitic clay horizons. Wilson (1954) identified 65 black mudstone bands within the main succession and Rickards (1973) a further 5 bands within the laterally discontinuous red siltstones of the Hebblethwaite Member that overlie it. Graptolitic mudstones bands are absent from the distinctive Far House Member at the top of the Browgill Formation. The graptolite fauna allows the Browgill Formation to be assigned to the *turriculatus* to *crenulata* Biozones (Upper Llandovery) (e.g. Rickards, 1970b).

Marr and Nicholson (1888) defined the Browgill Beds, based on the sequence in Browgill, in the Lake District. The formation status was assigned by Kneller et al. (1994). The base of the formation is taken where the hard green-grey siltstones come to dominate over the black mudstones of the Skelgill Formation. Thin, very fine sandstone beds are associated with this transition (Ingham et al., 1978). The top of the formation is marked by the first incoming of the very thinly laminated blue-grey siltstone of the Brathay Formation. Representative exposures of the Browgill Formation are listed in Table 4.

4.2.1 Hebblethwaite Member

The 'Red Beds' of the Browgill Formation comprise up to 20 m of red-brown mudstone, typically massive, but containing sporadic thin horizons of paler calcareous nodules. Wilson (1954) and Rickards (1964, 1970b, 1973) showed that the red mudstone units are discontinuous, missing from presumed rises and thickening into postulated shallow troughs (see Rickards, 1989, figs 89, 91). The thinner units of red mudstone are more calcareous and yield rare trilobites (phacopids) and brachiopods, proving their marine environment. Wilson (1954) showed conclusively that the red beds are underlain by the *griestoniensis* Biozone (Llandovery) and overlain by the *centrifugus* Biozone of the basal Wenlock. They were therefore assigned a *crenulata* Biozone age (latest Llandovery). This age matched that of the red beds at Cross Fell (Burgess et al., 1970). Later, thin black shales in new exposures of red beds in Hebblethwaite Hall Gill yielded a *crenulata* Biozone fauna to Rickards (1973). The evidence is, therefore, that the red mudstone units of the Browgill Formation are of similar age throughout the Howgills, Cross Fell and the main Lake District outcrop (Rickards, 1969; Hutt, 1974).

The 'Red Beds' were regarded by Kneller et al. (1994) as too variable in the main Lake District outcrop to warrant member status. In the Howgill Fells, however, they form a useful and coherent, if lenticular, mapping unit. They are therefore designated the Hebblethwaite Member of the Browgill Formation, with a type section in Hebblethwaite Hall Gill [6910 9317 to 6910

9318]. The upper and lower boundaries are marked by the abrupt change in colour from red-brown to grey mudstone. Known exposures of the member are listed in Table 4.

4.2.2 Far House Member

The Far House Member comprises 8 m of pale grey mudstone, lacking any black graptolitic mudstone bands. The member is present throughout the Howgills and Lake District outcrop, whether or not the Hebblethwaite Member is preserved beneath. The unit has yielded only rare ostracods (*Kloedinella* sp.) and its age is therefore in doubt. It is underlain in places by the Hebblethwaite Member (*crenulata* Biozone, Llandovery) and overlain by the first graptolitic mudstones of the Brathay Flags (*centrifugus* Biozone, Wenlock).

Wilson (1954) and Rickards (1964) recognised the member as the 'grey beds' and distinguished the unit from the blue-grey mudstones of the overlying Brathay Flags. Rickards (1969) and Hutt (1974) showed that the grey beds could be mapped throughout the Howgills and Lake District outcrop. Kneller et al. (1994) formally defined the Far House Member at a type section near Coniston. Representative exposures of the member in the Howgill Fells are listed in Table 4.

4.3 DEPOSITIONAL ENVIRONMENT OF THE STOCKDALE GROUP

The evidence is that the Stockdale Group was deposited in a marine environment, which lacked input of clastic debris coarser than silt or, rarely, very fine sand grade. The silt and clay were deposited either by hemipelagic fallout or low concentration turbidity flows.

The basal Spengill Member represents a condensed carbonate sediment with a low-diversity deep-water shelly benthos (Scott and Kneller, 1990). However, its deposition in the Howgill Fells and eastern Lake District was contemporaneous with thicker black mudstone deposition further west. Rickards (in Ingham and Rickards, 1974) suggested that the carbonate was deposited on or behind a fault-bounded outer shelf rise, and the contemporaneous black mudstones in a deeper slope basin. However, by late *atavus* time, black mudstones blanketed the whole area.

The black carbonaceous, pyritic mudstone of the Skelgill Formation has been widely interpreted as deposits in anaerobic bottom waters (e.g. Rickards, 1964). These sediments are consequently finely laminated, lacking a benthos or bioturbation, and preserving abundant graptolite zooplankton. The prevalence of anoxic mudstones at this time is probably a result of high plankton productivity during the marine transgression after the Hirnantian ice age (Leggett, 1980). The contrasting grey bioturbated mudstones are interpreted as deposition in dysaerobic conditions, allowing a sparse benthos to be established and more of the organic carbon to be oxidised before burial (e.g. Scott and Kneller, 1990). The alternation of more and less well-ventilated bottom waters may record Llandovery sea-level changes of the sort well-documented in other basins.

The transition into the Browgill Formation records a greater input of fine clastic debris into the area. Increased energy of the depositional environment is evidenced by thin sandstone beds within the *sedgwickii* Biozone and penecontempoaneous scour, yielding mud clasts, within the *maximus* Biozone. This evidence points to tractional flows, probably low concentration turbidity flows (e.g. Rickards, 1964). Dakyns et al. (1891) speculated that the Browgill Beds may contain a high proportion of primary or secondary quartzo-feldspathic ash. A possible volcanic sediment component cannot be discounted, given the direct evidence from bentonitic clays of contemporaneous volcanism.

Anaerobic conditions persisted intermittently into late Llandovery time, but oxygenated environments came to dominate, culminating in the haematite-rich Hebblethwaite Member, and the black-mudstone-free Far House Member. Rickards (1978) proposed that the red mudstones accumulated preferentially in topographic hollows, with thinner, carbonate-rich facies deposited on the flanks of intervening highs. Ziegler and McKerrow (1975) suggested that the widespread marine red beds at this level were due to an abundant supply of oxidised sediment washed off the arid Silurian land surface during the Llandovery transgressions.

5 Tranearth Group

Above the Stockdale Group lie about 260 m of strata dominated 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, 1994) and Soper (1999) and is adopted here.

5.1 BRATHAY FORMATION

The Brathay Formation is about 240 m thick and predominantly composed of very thinly laminated mudstone or 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. The carbon-rich laminae appear laterally continuous on smooth exposures, but are more wispy and discontinuous in thin section, especially within calcareous nodules where the original character of the lamination is better preserved.

The Brathay Formation ranges from the basal *centrifugus* Biozone up to the *lundgreni* Biozone of the Wenlock. Subtle changes in the lithology are evident up the succession. Immediately above the basal Dixon Ground Member, the hemipelagites are pyritic and yield pyritised three-dimensional graptolites. By the middle of the *murchisoni* Biozone, all graptolites are diagenetically flattened. Current orientation of the rhabdosomes appears at this level, becoming common in the succeeding biozone (*riccartonensis).* Small calcareous nodules appear in the middle and upper *riccartonensis* Biozone. These nodules become gradually larger up the sequence, reaching up to 1 m long in the uppermost part of the *lundgreni* Biozone. The hemipelagite laminations pass through the calcareous nodules, but at about twice their compacted spacing (King, 1992). The grain size also increases from mud grade in the base of the *murchisoni* Biozone to silt grade in the *lundgreni* Biozone. Very thin bedded sandstone turbidites occur in the *riccartonensis* Biozone, as they do at this level in the Lake District.

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). The base of the unit has been described above. The top is at the base of the calcareous mudstones of the Coldwell Formation. Representative exposures of the Brathay Formation are listed in Table 5, but numerous supplementary exposures of the unit occur, particularly in small hillside crags.

5.2 DIXON GROUND MEMBER

The basal 10-30 m of the Brathay Formation comprise a facies transitional from the homogeneous grey mudstones of the Far House Member (Browgill Formation). Wilson (1954) and Rickards (1964) recognised that, at the base of the Brathay Formation, the homogeneous mudstones take on a more blue-grey colour and the first laminated hemipelagite beds appear.

The blue-grey mudstones tend to be burrow-mottled. Critically, the first hemipelagites contain a *centrifugus* Biozone fauna (Rickards, 1967), marking the base of the Wenlock Series. The proportion of hemipelagite to burrow-mottled mudstone increases upwards through the *centrifugus* Biozone, so that its top is entirely composed of hemipelagite.

The basal lithology of the Brathay Formation was mapped by Rickards throughout the Howgill Fells (1967) and across the Lake District (1970a). It was named as the Dixon Ground Member in the Lake District by Kneller (1990). Within the top metre of the member there occurs a 10 cm thick, slightly calcareous mudstone with carious weathering. This bed occurs in all sections through the top of the Dixon Ground Member in the Howgill Fells and the Lake District (Rickards, 1970a) and has also been found at exactly the same level in the Builth district of Wales. This unit forms a distinctive marker horizon, recording an event perhaps worthy of further scrutiny.

Representative exposures of the Dixon Ground Member are listed in Table 5.

5.3 COLDWELL FORMATION

The Coldwell Formation is characterised by calcareous silty mudstone with sporadic lenses and nodules of fossiliferous silty limestone. The formation is typically up to 10 m thick, comprising two calcareous units separated by several metres of laminated hemipelagic mudstone. However, there is some lateral variation between the sections in the Howgills, charted by Rickards (1967, fig. 9). In particular, slumped calcareous mudstones, up to 30 m thick, represent the formation at the mouth of Backside Beck and Crosshaw Beck (Table 6). Conglomeratic units with limestone clasts and shells in a laminated hemipelagite matrix occur in Gais Gill and Screes Gill (King, 1992). Recent work has shown that, on the western side of Wandale Hill, the calcareous facies gives way to hemipelagite and to non-calcareous but burrow-mottled mudstone.

The Coldwell Formation contains a shelly fauna, particularly trilobites, in the carbonate horizons, and graptolites in intercalated hemipelagic mudstones. Rickards (1967, 1970a) showed that the lower part of the Coldwell Formation contains graptolites of the *ludensis* Biozone (Wenlock) but that *nilssoni* Biozone (Ludlow) faunas occur in its upper part.

The calcareous unit at this level 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’ (Marr’s Lower Coldwell Beds crop out only west of the Howgill Fells, and do not appear on Figure 3). Kneller et al. (1994) reverted to Aveline and Hughes’ original definition for their Coldwell Formation. The known exposures of the Coldwell Formation in the Howgill Fells are listed in Table 6.

5.4 WRAY CASTLE FORMATION

The Wray Castle Formation comprises the same 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 varies between 3 m and 15 m thick in the Howgill Fells, although it thickens westward to some hundreds of metres in the Lake District. The siltstones yield a *nilssoni* Biozone (low Ludlow) graptolite assemblage.

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. Exposures of the formation in the Howgill Fells are listed in Table 7.

5.5 DEPOSITIONAL ENVIRONMENT OF THE TRANEARTH GROUP

The laminated mudstone and siltstone of this unit has been interpreted in terms of sedimentation in anaerobic bottom water (e.g. Rickards, 1964). This environment is consistent with the lack of bioturbation from a normal benthos, and with 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). At issue is whether the lamination represents a periodic, possibly annual, fluctuation in silt and organic supply, and whether the sediment was supplied entirely from hemipelagic fallout or partly by dilute turbidity flows. The volumetric supply of silt-grade particles increased gradually through the succession.

The Coldwell Formation is thought to record aerobic conditions at the sediment surface, allowing the establishment of a rich shelly benthos, including bioturbating organisms (e.g. Ingham and Rickards, 1974; King, 1992). This aeration was probably due to an eustatic fall in sea level (e.g. Furness et al., 1967; Kemp, 1991; Kneller et al., 1994), since similar facies occur in other distant basins at this time. The calcareous nodules in the Brathay Formation are more likely to represent times of slower sedimentation than discrete changes in sea level (King, 1992).

6 Coniston Group

The base of the Coniston Group is marked by the first substantial appearance of sandstone in the Windermere Supergroup of the Howgill Fells. Above this horizon occurs 800-1300 m of succession dominated by thin to thick bedded sandstone. This Coniston Group succession is divided on the basis of the thickness of the component sandstone beds and particularly on the proportion of laminated hemipelagic siltstone that persists in the sequence. Three mapped units rich in hemipelagite serve to divide the Coniston Group into four sandstone-rich packets. However, only the lowest of these packets, the Screes Gill Formation, has been named. The top of the Coniston Group is marked by a transition to the generally thinner bedded Bannisdale Formation. This unit also contains sandstone, but typically in very thin beds, and it lacks the thick discrete units of hemipelagic mudstone that are intercalated in the Coniston Group.

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 Howgills 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). Judging by the westward increase in the thickness of the underlying Wray Castle Formation from a few metres in the Howgills to 450 m in the western Lake District, the base of the Coniston Group is diachronous, and earlier in the east than the west.

6.1 SCREES GILL FORMATION

The formation typically comprises the lowest 250-280 m of the Coniston Group in the Howgill Fells, but thins to about 100 m in the south of the area, in Garsdale and on the Frostrow Fells. The Screes Gill Formation 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. The modal thickness of these beds is about 0.3 m. 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. The mudstone is in part the laminated hemipelagite and in part homogeneous mudstone. The lamination spacing is about 0.3 mm, slightly greater than in the Brathay Formation. The laminated facies contains crinoids, orthocone cephalopods, phyllopods, the pelagic bivalve *Slava interrupta*, and graptolites diagnostic of the *nilssoni* Biozone of the early Ludlow.

Most of the sandstone in the Coniston Group is fine grained. The ‘Winder Grit Band’ of Aveline and Hughes (1888) is unusual in reaching granule grade (3 mm maximum) and having an associated mud-clast conglomerate unit. The Winder Grit is exposed on the south side of Winder [6590 9287] and analogous horizons have been identified by King (1992) in Settlebeck Gill [6604 9300; 6602 9316], within the Screes Gill Formation of the present study. However, other known examples of coarse units in the Coniston Group occur above the Screes Gill Formation, for instance at Cautley Crags [6810 9760] (King, 1992) and on the River Lune [6207 9953]. As King concluded, there are probably a number of localised coarse-grained units through the Coniston Group, rather than a unique Winder Grit Band (Llewellyn, 1960).

The Screes Gill Formation was defined by King (1992), and formalised by Kneller et al. (1994). Its type section is in Screes Gill (Table 8), and it precisely corresponds to the Lower Coniston Grits of Furness et al. (1967) and Rickards (1967). The formation base is taken at the incoming of the first sandstone beds above the Wray Castle Formation. The formation top is defined by the base of the 30-80 m hemipelagite-rich Wotey Gill unit, at the base of the ‘undivided Coniston Group’. Possible correlation of the Screes Gill Formation with the Gawthwaite Formation at the base of the Coniston Group of the Lake District has been suggested (King, 1992; Kneller et al., 1994). However, this possibility remains unproven due to the difficulty of mapping a coherent overlying hemipelagite-rich unit through the northern Howgill Fells (Soper, 1999). Representative exposures of the Screes Gill Formation are listed in Table 8.

6.2 UNDIVIDED CONISTON GROUP

6.2.1 Sandstone-rich units

The upper part of the Coniston Group is between 1030 and 1085 m thick in the Howgill Fells, but as little as 650 m in the Frostrow Fells to the south. Like the Screes Gill Formation, it is composed of packets of beds rich in fine sandstone, alternating with ‘Banded Unit’ packets comprising very thin-bedded siltstone–mudstone couplets. The modal thickness of the sandstone-rich beds is about 0.25 m, about the same as in the Screes Gill Formation. However, the mudstone tops to these beds are thinner, comprising about 20% rather than 35% of the bed, so that the succession appears more sandstone-dominated than the Screes Gill Formation. This impression is enhanced by the lower proportion of graptolitic mudstone than in the Screes Gill Formation.

Representative exposures in the ‘undivided Coniston Group’ sandstones are listed in Table 9. However, there are numerous small exposures of this unit, mostly in valley bottoms or in small hill crags.

6.2.2 Siltstone units

Three main mappable siltstone-rich units have been distinguished within the undivided Coniston Group. Each of these units comprises very thin-bedded siltstone–mudstone couplets and thinly to thickly laminated silty mudstone. The laminated lithology predominates in the lower two mapped units (informally named the Wotey Gill and East Grain units), and the thin-bedded facies in the upper unit (informally named the West Grain unit). Representative exposures of each siltstone unit are listed in Table 10. Correlations between the Howgill Fells and the poorly exposed siltstone units south of Sedbergh and on the Frostrow Fells are very tentative.

The lowest siltstone, the Wotey Gill unit – named by Soper (1999) from a gill at NY 6820 0004 – varies between 20-80 m thick. It locally divides into two discrete leaves separated by sandstone-rich units in Ashbeck Gill and Settlebeck Gill. Furness et al. (1967) correlated this horizon with the Sheerbate Flags of the Lake District, and King (1992) and Kneller et al. (1994) agreed with this equivalence to the renamed Latrigg Formation. However, the mapping continuity of this unit through the intervening ground cannot be proved (Soper, 1999), and it is therefore left without a formal name in the Howgill Fells.

The succeeding siltstone unit, the East Grain unit (see Table 10), is generally between 25-60 m thick, but apparently reaches 120 m thick around Hobdale Scar. The East Grain unit is separated from the top of the Wotey Gill unit by between 240-320 m of sandstone-rich strata in the Howgill Fells, but only 140 m in the Frostrow Fells. King (1992) tentatively correlated this sandstone-rich unit with the Moorhowe Formation of the Lake District succession, but this correlation cannot be proved (Soper, 1999).

The upper siltstone unit, the West Grain unit (see Table 10), is 30-40 m thick and is separated from the top of the East Grain unit by between 320-390 m of sandstone-rich strata in the Howgill Fells and 290 m in the Frostrow Fells. A further 250-280 m of sandstone-rich succession lies between the top of the East Grain unit and the base of the overlying Bannisdale Formation in the Howgill Fells and 160 m in the Frostrow Fells. This interval locally contains another 30 m thick siltstone unit around Calf Beck.

6.3 CORRELATION AND BIOSTRATIGRAPHY OF THE CONISTON GROUP

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). Through the southern Howgills the base of this informal unit is the base of the prominent Wotey Gill siltstone unit. The top of the Coniston Group is taken where sandstone-dominated sequences give way to the very thin-bedded sandstone-mudstone couplets of the Bannisdale Formation.

The Coniston Group can be 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. However, extensive new graptolite faunas collected during this project (Figure 4) allow more refined biostratigraphical division of the Coniston Group. Preliminary conclusions are 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 recently collected forms are illustrated (Figures 5, 6), particularly the spinose monograptids (broadly *Saetograptus*).

6.4 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 the 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 from Wenlock time well into the Ludlow.

The major sandstone-dominated packets are interpreted as episodes of turbidite fan growth. These episodes were separated by periods of finer grained sedimentation recorded in the siltstone units, perhaps induced by sea-level rise (King, 1992). King (1992, 1994) showed that the palaeocurrent pattern in the Coniston Group of the Howgill Fells is more complex than that in the Lake District, where an east-north-east-striking basin slope seems to have been the main influence on turbidity flow paths. In the Howgills, east-south-east-directed flutes and grooves and south-south-west-directed flows generating ripple cross lamination have been taken to indicate a transverse west-north-west-striking structural control on basin geometry.

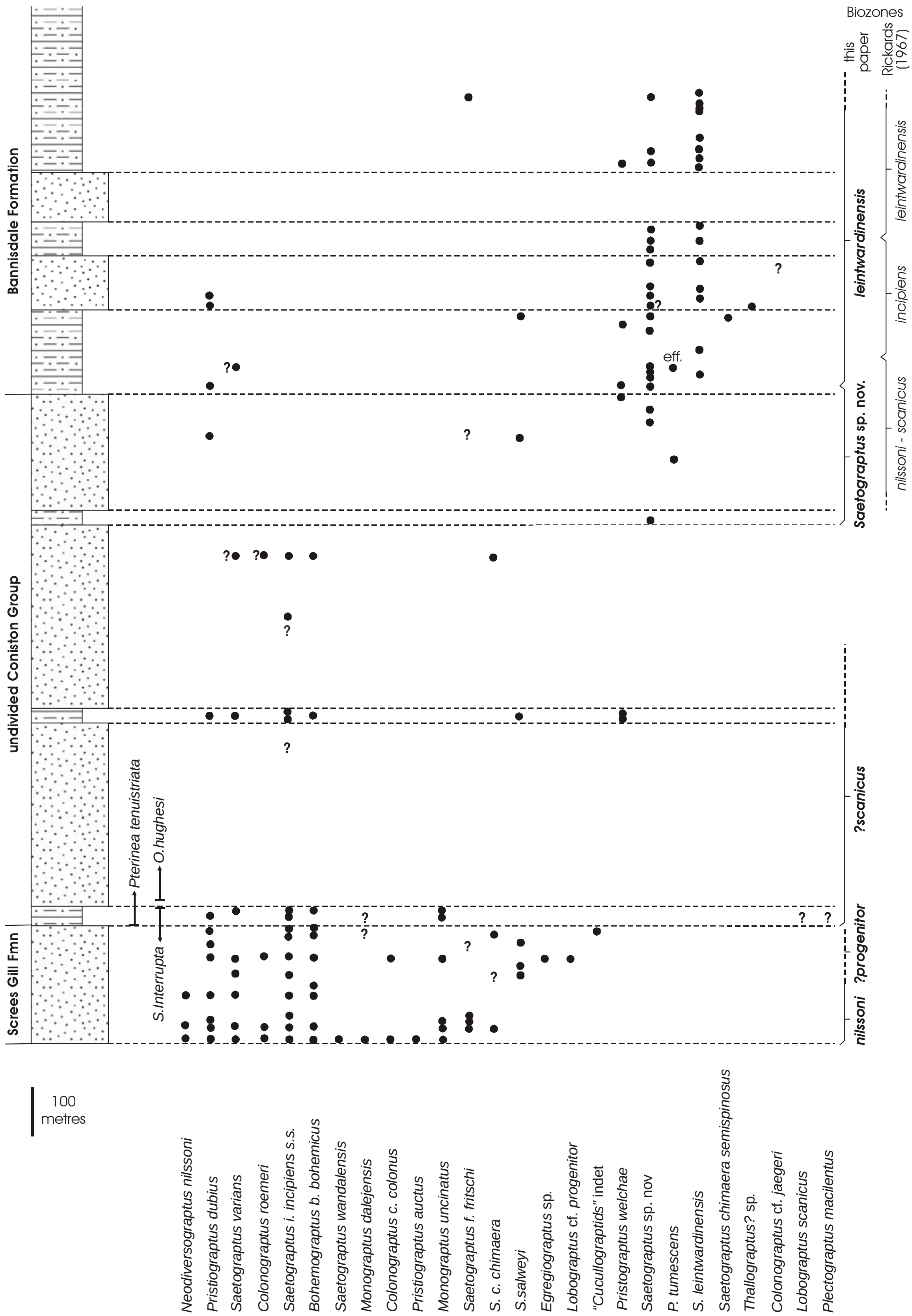


Figure 4 Ranges of Ludlow graptolites plotted against a generalised lithostratigraphic column for the Howgill Fells.

The chart incorporates the revised Ph.D. records of Rickards (1963), all his published records (Rickards 1967), as well as all new recordings of the present study.

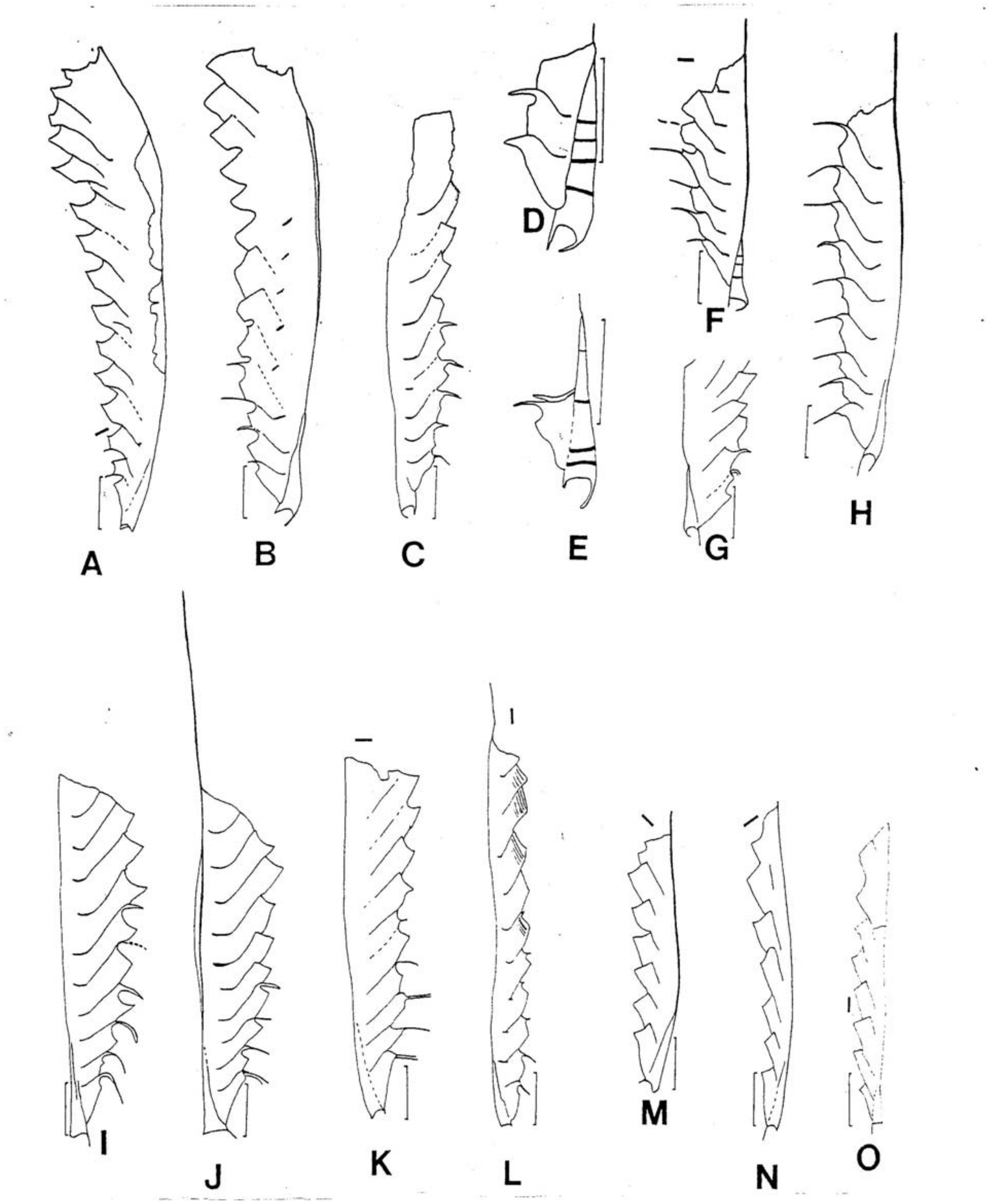


Figure 5 Graptolites from the Coniston Group and Bannisdale Formation.

A-H, *Saetograptus* sp. nov., a species typical of the upper part of the Ludlow Series; I-L, *Saetograptus incipiens* (Wood), a species typical of the lower part of the Ludlow Series and distinguishable from *S.*sp. nov. in that it lacks the pronounced dorsal sicular process of that species (see Fig. 6D, E); M-O, *Pristiograptus welchae* Rickards, a diminutive rare species. Scale bars 1 mm; heavy bar indicates tectonic stretching direction.

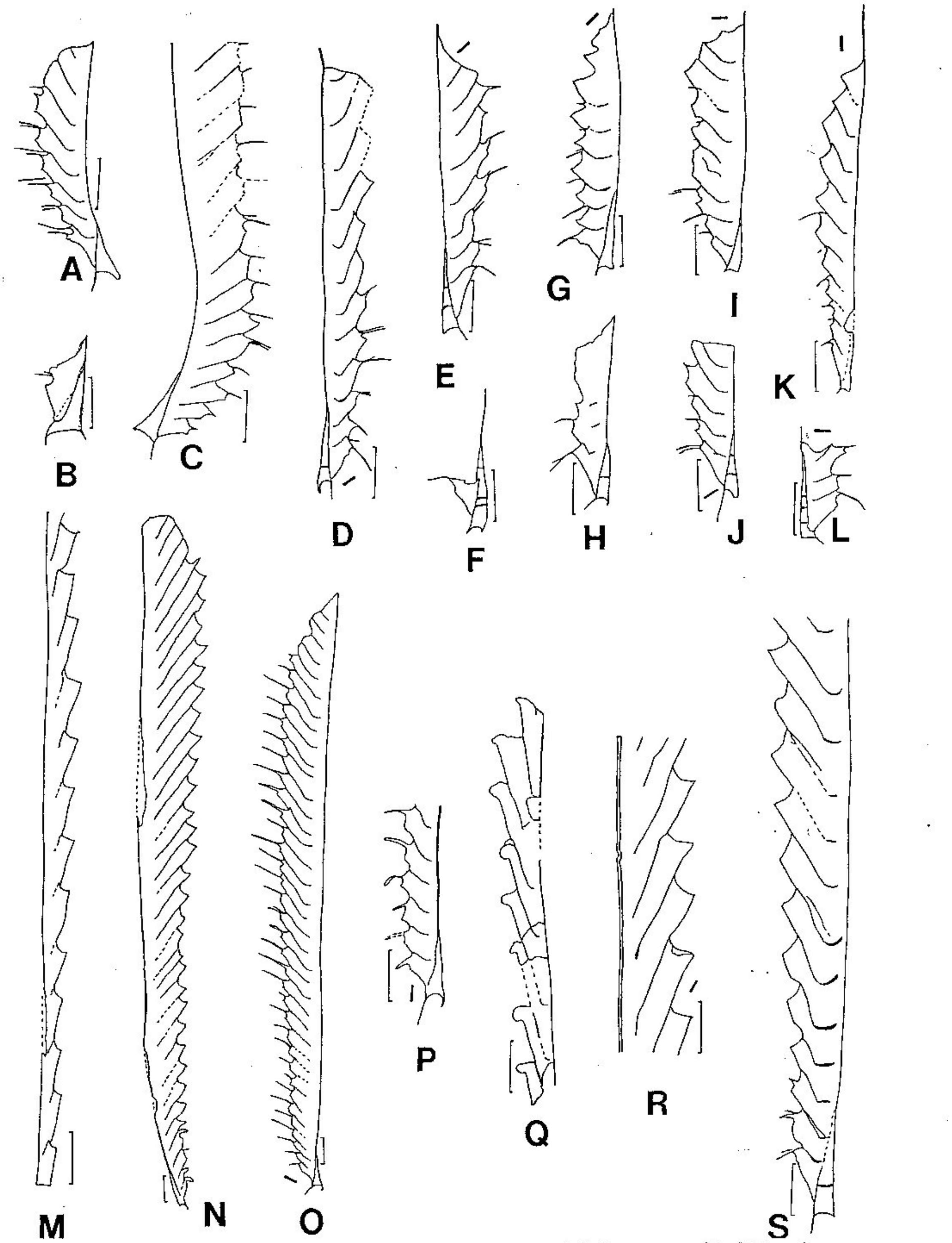


Figure 6 Graptolites from the Coniston Group and Bannisdale Formation.

A-C, *Saetograptus fritschi* Boucek, a species only recorded in the Howgill Fells; D-L, *Saetograptus leintwardinensis* (Lapworth), eponymous species of the highest biozone in the Silurian of the north of England; M, *Neodiversograptus nilssoni* (Barrande), zone fossil of the earliest Ludlow biozone; N, *Colonograptus colonus* (Barrande), a typical early Ludlow species; O, P, *Saetograptus chimaera salweyi* (Hopkinson); Q, *Lobograptus scanicus* (Tullberg), characteristic species of the *scanicus* Biozone; R, *Bohemograptus bohemicus* (Barrande), distal thecae of a large rhabdosome; S, *Saetograptus varians* (Wood). Scale bars 1 mm; heavy bar indicates tectonic stretching direction.

7 Bannisdale Formation

In the Howgill Fells, the Bannisdale Formation is dominated by very thin or thin beds, grading from siltstone to mudstone or, less commonly, fine sandstone to mudstone. There are sporadic medium or thick beds of sandstone. These amalgamate into substantial mappable packets in the lower part of the formation, and are described below. The proportion of sandstone in the Bannisdale Formation decreases upwards. A minor but persistent component of the sequence is laminated hemipelagite, defined by alternating laminae of silt and organic carbon. The lamination spacing is higher than in the Coniston Group, averaging 0.8 mm in the lower part of the formation and over 1 mm in the upper part. Convolute lamination in sandstone beds becomes increasingly common up-sequence in the Bannisdale Formation, and small calcareous and phosphatic nodules are present in mudstones.

The formalised Bannisdale Formation (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 transitional, and the mapped boundary has varied between different authors and areas. The base of the Bannisdale Formation picked on the accompanying 1:10,000 standard maps is deliberately close to that mapped by Soper (1999) in the northern Howgill Fells. The base is at least 300 m higher in the succession than that chosen by Rickards (1967), but close to that picked by Aveline and Hughes (1872).

Representative exposures of the Bannisdale Formation are listed in Table 11.

7.1.1 Sandstone units

The lower part of the Bannisdale Formation contains a number of mappable sandstone packets, representative exposures of which are listed in Table 11.

On the north limb of the Castley Knotts Syncline, two sandstone packets are exposed in the Lune section. The first is 80 m thick, with its base about 90 m above the base of the Bannisdale Formation. A further 30 m of thin-bedded Bannisdale facies separates the lower sandstone from the upper unit, which is 100 m thick here. Traced eastward, these two packets apparently amalgamate into one, and attain a combined thickness of several hundred metres in Long Rigg Beck, between the Barbon and Swang Head fault. East of the Swang Head Fault, the sandstone packet is about 150 m thick as it wraps around the hinge of the Castley Knotts Syncline. This outcrop was included in a Bram Rigg Member of the Bannisdale Formation by King (1992). The member was adopted by Kneller et al. (1994) and correlated with the Rusland Member of the Bannisdale Formation in the western Lake District. However, this Bram Rigg Member was said to be 600 m to 650 m thick (King, 1992), and to include a number of sandstone packets. It was probably intended to include the two lower sandstone packets in Calf Beck and Bram Rigg Beck included in the Coniston Group in this study. The Bram Rigg Member is therefore not recognised as such here.

Sandstone packets are also present in the lower part of the Bannisdale Formation on the southern limb of the Castley Knott Syncline, but correlation with the northern limb is problematic. There are three main packets exposed in the River Lune sections, to the west of the Barbon Fault. The upper two packets, about 130 m and 100 m thick and separated by 90 m of thin bedded facies, seem to thin and fine both into the syncline to the north and over the next anticline to the south. The lowest packet, separated from the other two by 240 m of fine-grained facies, is therefore more likely to correlate with the main sandstone packet on the north limb of the Castley Knotts Syncline, but its thickness and its distance above the base of the Bannisdale Formation is unknown.

To the east of the Barbon Fault, sandstone-rich successions occur only about 30 m above the identified base of the Bannisdale Formation, and persist upwards for at least 250 m. Indeed, so sand-rich is this part of the formation that only the intercalation of thin-bedded silt–mud couplets and of hemipelagite with a distinctively wide lamination spacing distinguishes it from the Coniston Group. The basal part of the Bannisdale Formation can be correlated across the Riggs Anticline, but is separated by the Sedbergh Faults from correlative successions in the Castley Knotts Syncline.

7.2 BIOSTRATIGRAPHY OF THE BANNISDALE FORMATION

The new graptolite collections allow the preliminary conclusion that the *Saetograptus* sp. nov. Biozone extends up just into the bottom of the Bannisdale Formation (Figure 4). The *leintwardinensis* Biozone then ranges up at least above the second sandstone unit in the Lune section. Some forms illustrated (Figures 5, 6) include a new recording of *Colonograptus* from the *leintwardinensis* Biozone, and large semi-spinose saetograptids typical of the upper *scanicus* and *incipiens/tumescens* biozones. Several species are new records for the UK, including forms previously only known from central Europe and Sardinia.

7.3 DEPOSITIONAL ENVIRONMENT OF THE BANNISDALE FORMATION

The individual facies of the Bannisdale Formation are interpreted in the same way as in the underlying Coniston Group. The predominant siltstone–mudstone couplets were probably 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 sandstone–mudstone couplets were deposited from medium to high concentration flows. The volume of such flows decreased up the Bannisdale succession, but intermittently larger flows early in its deposition produced the packets of thick-bedded sandstone low in the succession. The sparse graptolitic faunas and the rarity of bioturbation indicate anaerobic bottom waters persisting from Wenlock time well into the Ludlow. Bioturbation increases in the higher part of the Bannisdale Formation, west of the mapping area, and marks the change to the more oxygenated depositional environment of the ‘Underbarrow Formation’.

8 Igneous intrusions

Three discrete compositions of intrusion cut the Ordovician and Silurian rocks of the Howgill Fells; dolerite, felsite and lamprophyre. None of these intrusions cuts the Carboniferous succession. Dolerite intrusions seem restricted to the Skelgill Formation (Llandovery). Felsite sills intrude as high as the Brathay Formation (Wenlock) and felsite dykes penetrate up into the Coniston Group. Lamprophyre dykes consistently cut felsite sills and dykes (Dakyns et al., 1891), and intrude as high as the youngest Silurian rocks of Sheet SD 69 (Bannisdale Formation, Ludlow). K-Ar dates from lamprophyre micas by Nixon et al. (1984) with a weighted average of 413±7 Ma suggest 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.

8.1 DOLERITE INTRUSIONS

Small exposures of dolerite occur on Sheet SD 69, notably on Ben End, and in Ecker Secker and Crosshaw Becks (Table 12). However, these last two exposures are the southern tip of a substantial outcrop of dolerite, capping the hill of Bluecaster, just east of Sheet SD 69. The dolerite is usually intensely altered, being composed predominantly of chlorite and calcite with a relict texture suggesting ophitic augite penetrated by lath-shaped feldspar.

Where the country rock can be verified, the dolerite is intruded solely into the Skelgill Formation, implying a concordant sill geometry. The characteristic level of intrusion may have resulted either from the mechnical weakness of the Skelgill mudstones or, more likely, from its impermeability and the consequent ease of hydraulic fracturing. On Crosshaw Beck and Bluecaster Side (Table 12) dolerite is seen in situ and in contact with mudstone immediately underlying the *argenteus* Biozone and the ‘Green Streak’. The intrusion therefore occurs between the *magnus* and *argenteus* biozones, but the lower contact is not seen. The *magnus* Biozone in the Howgill Fells is characterised by particularly soft black mudstone and it seems likely that this lithology preferentially allowed ingress of the basic magma. The horizon of intrusion is, incidentally, the same as that of the “Stockdale Thrust”, which occurs throughout most of the Lake District (Marr and Nicholson, 1888), but which does not occur in the Howgill Fells. The intrusion of the sill apparently predates the Acadian folding, although any Caledonian cleavage in it is too weak to verify this age unequivocally.

There are no outcrops of the dolerite sill in the Skelgill Formation on Harter Fell, Spengill, Stockless Gill and Watley Gill, implying that it thins out to the north. To the west, on Ben End (Table 12), the dolerite forms a subcircular topographical feature marked by old workings. A plug geometry might be suspected were it not that, in a gully 100 m to the south, dolerite occurs conformably in Skelgill Formation mudstones just above a *magnus* Biozone fauna. Farther south still, dolerite is absent in the Skelgill Formation in Pickering Gill, Birks Wood Beck and Birks Beck. The pre-folding extent of the sill is estimated to be about 15 km^2, with a maximum thickness on Bluecaster of at least 15 m. The closeness of the Taythes Gill outcrops to the Dent Fault, as well as those on Bluecaster and Ward’s Intake, suggest that the dolerite sill abuts against and is cut by the fault.

8.2 FELSITE SILLS AND DYKES

The felsite intrusions are typically light grey, weathering to orange, the lithology dominated by quartz with white orthoclase feldspar crystals. The feldspar is more or less kaolinised. Sills of such felsite occur in the east of the area, particularly in the Cautley Mudstone Formation of the Westerdale Inlier (Backside Beck, Table 13), and in the Cautley Mudstone and Brathay formations fringing the Taythes Inlier (West Gill to Crosshaw Beck, Table 13). Felsite dykes are particularly common in the lower units of the succession but occur sporadically in the Silurian of the Howgill Fells. The felsite intrusions predate the Caledonian folding, and their margins sometimes bear the Acadian cleavage.

8.3 LAMPROPHYRE DYKES AND SILLS

Lamprophyre intrusions occur sporadically throughout the Ordovician and Silurian succession. They are typically irregular in form but, where their margins can be seen, are more often discordant than concordant to the bedding in the country rock. The lamprophyres are grey, dark green or red-brown, with conspicuous euhedral brown mica phenocrysts. The intrusions occasionally contain xenoliths of quartz sandstone and mudstone, rimmed with hematite. The lamprophyres are strongly altered to chlorite and calcite (Bonney and Houghton, 1878). Nixon et al. (1984) reported co-existing orthoclase and albite, but only relict evidence of pyroxene or olivine. These authors recorded inclusions in the micas of rutile, zircon and apatite. The intrusions are classified as calc-alkaline minette. They are part of a much wider suite of such rocks in the Caledonides intruded during late Silurian or Early Devonian time (e.g. Rock, 1988; Vaughan, 1996). It is rarely possible to verify unequivocally the pre-cleavage age of the lamprophyre intrusions in the Howgill Fells. However, they consistently cut and post-date the felsites.

The mean orientation of the discordant lamprophyres is about 169° (Figure 7). This orientation is about 35° anticlockwise of the mean fault orientation, and only a very few intrusions can be shown to be directly associated with faults. The hypothesis will be later argued that the lamprophyres were intruded during sinistral transtension on a precursor to the Dent Fault Zone.

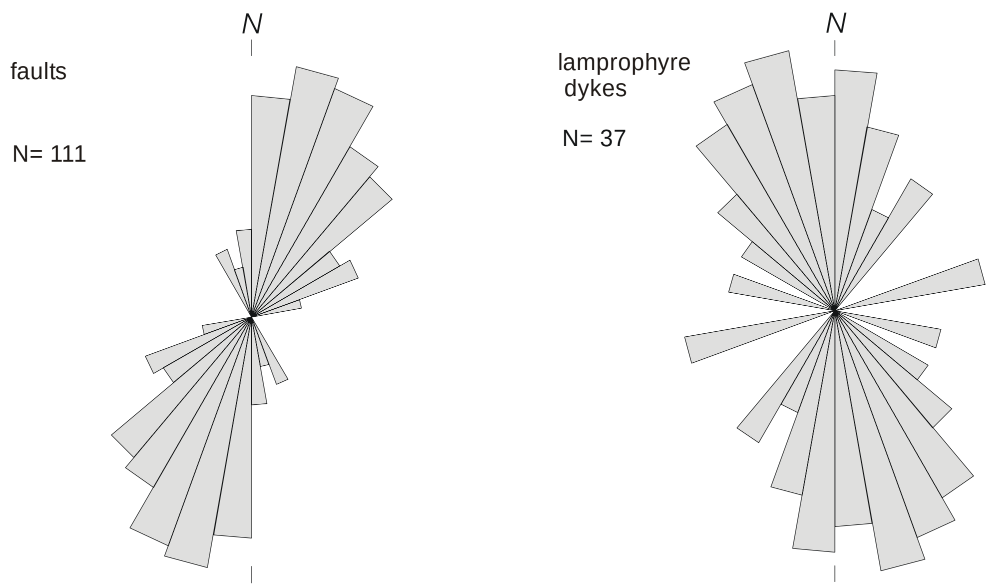


Figure 7 Rose diagram of the strikes of discordant lamprophyre dykes on sheet SD 69 and SD 79 compared with the strikes of faults.

9 Upper Devonian (?) and Carboniferous strata

Lower Carboniferous rocks crop out in the south-eastern corner of Sheet SD 69, and the basal conglomeratic unit to this succession forms a westward tapering outcrop in the southern part of the sheet. This conglomerate is undated, and could be of Upper Devonian or, more probably, of Lower Carboniferous age.

Detailed mapping and stratigraphical studies by Burgess (Dunham and Wilson, 1985; Burgess, 1986) in connection with the revision of the Kirkby Stephen 1: 50,000 sheet (British Geological Survey, 1997), preclude the need for full description here of the Carboniferous succession.

9.1 SEDBERGH CONGLOMERATE

The basal unit to the Carboniferous succession comprises reddish brown conglomerate and sandstone. Its thickness varies markedly across the area and is difficult to estimate. The unit may be as much as 270 m thick in the Rawthey valley around and east of Sedbergh, but it thins to about 75 m at the eastern edge of Sheet SD 69 and to zero in a further 250 m along its crop to the northeast (beyond Whinny Gill, Table 15). The conglomerate is clast-supported, with subangular to well rounded clasts varying in size up to 0.5 m or more. Clast compositions are dominated by the resistant sandstone and laminated siltstone of the Coniston Group and Brathay Formation, but micritic limestone (from the Cautley Mudstone Formation?), felsite and lamprophyre are not uncommon. The sedimentary rocks are unfossiliferous, compatible with their sedimentary facies interpretation as alluvial deposits, infilling a palaeovalley in eroded Silurian rocks (Burgess, 1986; Underhill et al., 1988). Representative exposures of the unit are listed in Table 15.

The name Sedbergh Conglomerate(s) was proposed by Burgess (Dunham and Wilson, 1985; Burgess, 1986), but appeared, without designated formational status, as the Sedbergh and Garsdale Conglomerates on the Kirkby Stephen 1: 50,000 sheet (British Geological Survey, 1997). Older names include the Basement Conglomerate Series (Butterfield, 1920) and the Carboniferous Basement Beds (Aveline and Hughes, 1888; Dakyns et al., 1891). The base of the unit is an angular unconformity above Silurian rocks. This unconformity is exposed, or nearly so, at the base of seven sections indicated in Table 15. The Silurian rocks below the conglomerate, varying from Brathay Formation to undivided Coniston Group, are typically haematite stained for some metres below the contact. Similar reddening in exposures near the present Howgill Fells' summits (e.g. Stockless Gill, Wandale Hill) suggests that an analogous basal conglomerate unit formerly extended over this area.

The top of the Sedbergh Conglomerate is an abrupt transition to the Nor Gill Sandstone Formation. This transition is signalled by a 3 m thick sandstone unit intercalated in conglomerates 5 m below the top of the unit. The transition is exposed in Penny Farm Gill and Nor Gill.

9.2 NOR GILL SANDSTONE FORMATION

The Nor Gill Sandstone Formation is dominated by units of pebbly sandstone and siltstone. The upper part of the Formation contains pedogenic carbonate (calcrete) horizons. The unit is about 10 m thick in Nor Gill (Table 16), but appears to thicken southward. The only other significant exposure is in Penny Farm Gill (Table 16). The unit was defined by Burgess (Dunham and Wilson, 1985; Burgess, 1986), and appeared on the Kirkby Stephen 1: 50,000 sheet (British Geological Survey, 1997) as the basal formation of the Ravenstonedale Group. Burgess took the base of the formation in Nor Gill [6983 9332] below a 0.5 m thick bed of pebbly sandstone overlain by a conspicuous 1 m thick bed of carbonate-cemented pebble conglomerate. The top of the formation is taken above the last calcrete horizon. The formation is unfossiliferous.

The Nor Gill Formation is interpreted as an alluvial deposit that included periods of very slow deposition, allowing pedogenic carbonates to form on arid flood plains. This postulated environment is transitional between the rapid alluvial accumulation of the Sedbergh Conglomerate and the marginal marine deposits of the Penny Farm Gill Dolomite Formation.

9.3 PENNY FARM GILL DOLOMITE FORMATION

This unit is about 50 m thick, and comprises interbedded limestone, dolomite and sandstone. Detailed logs of its exposures in Penny Farm Gill and Nor Gill (Table 16) are provided by Burgess (Dunham and Wilson, 1985; Burgess, 1986) who formally defined the unit.

The base of the formation is a medium-grained pebbly sandstone that rests on the eroded top of the calcrete units of the Nor Gill Formation [6987 9333]. The top of the formation is marked by a 0.4 m dolostone bed with a pseudonodular rhizolitic texture, before the incoming of the normal marine limestone of the Tom Croft Limestone Formation. The depositional environment of the Penny Farm Gill Dolomite Formation is interpreted as shallow marine, intertidal and supratidal, transitional from the alluvial environments of the Nor Gill Sandstone (Burgess, 1986).

9.4 GREAT SCAR LIMESTONE GROUP

The Great Scar Limestone Group comprises mainly limestone, with thin intercalations of siltstone and mudstone, and a 21 m thick unit dominated by sandstone and sandy limestone (Ashfell Sandstone Formation). The Great Scar Limestone Group has not been further divided on the accompanying standard maps, except to recognise that the section in Penny Farm Gill (Table 16) can be assigned to the Tom Croft Limestone Formation. Detailed logs of this section and that in the Clough River (Table 16) are provided by Burgess (Dunham and Wilson, 1985; Burgess, 1986).

The Great Scar Limestone Group contains an abundant marine fauna, dating it as Arundian to early Asbian. Shallow marine carbonate deposition was interrupted only by the regressive marine sandstone sheet of the Ashfell Sandstone.

9.5 YOREDALE GROUP

The Yoredale (formerly Wensleydale) Group comprises cyclic repetitions of limestone, mudstone and sandstone, together with thin coals; the ‘Yoredale Facies’. This facies is interpreted as the influence of pro-deltaic and deltaic lobes prograding over a marine carbonate shelf. The group ranges from Asbian through Brigantian in age. The boundary below the undivided Yoredale Group on the standard maps is that with the top of the Great Scar Limestone. However, it should be noted that the basal boundary of the ‘Alston Group’ with the ‘Orton Group’ in Ravenstonedale and the Stainmore Trough is taken within the Great Scar Limestone (British Geological Survey, 1997). The Yoredale Group is best exposed in the Clough River, for which detailed logs are provided by Burgess (Dunham and Wilson, 1985; Burgess, 1986).

10 Structure

The Howgill Fells are affected by two main generations of structures, with trends approximately orthogonal to each other. These structures are summarised in map view on Figure 8. First, the late Caledonian deformation produced approximately E–W folds (shown in cross-section on Figure 9) and subparallel 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-north-east-striking faults and subparallel folds (shown in cross-section on Figure 11), but only localised cleavage. This phase was demonstrably post-Dinantian in the report area, and probably Late Carboniferous to Early Permian on regional evidence.

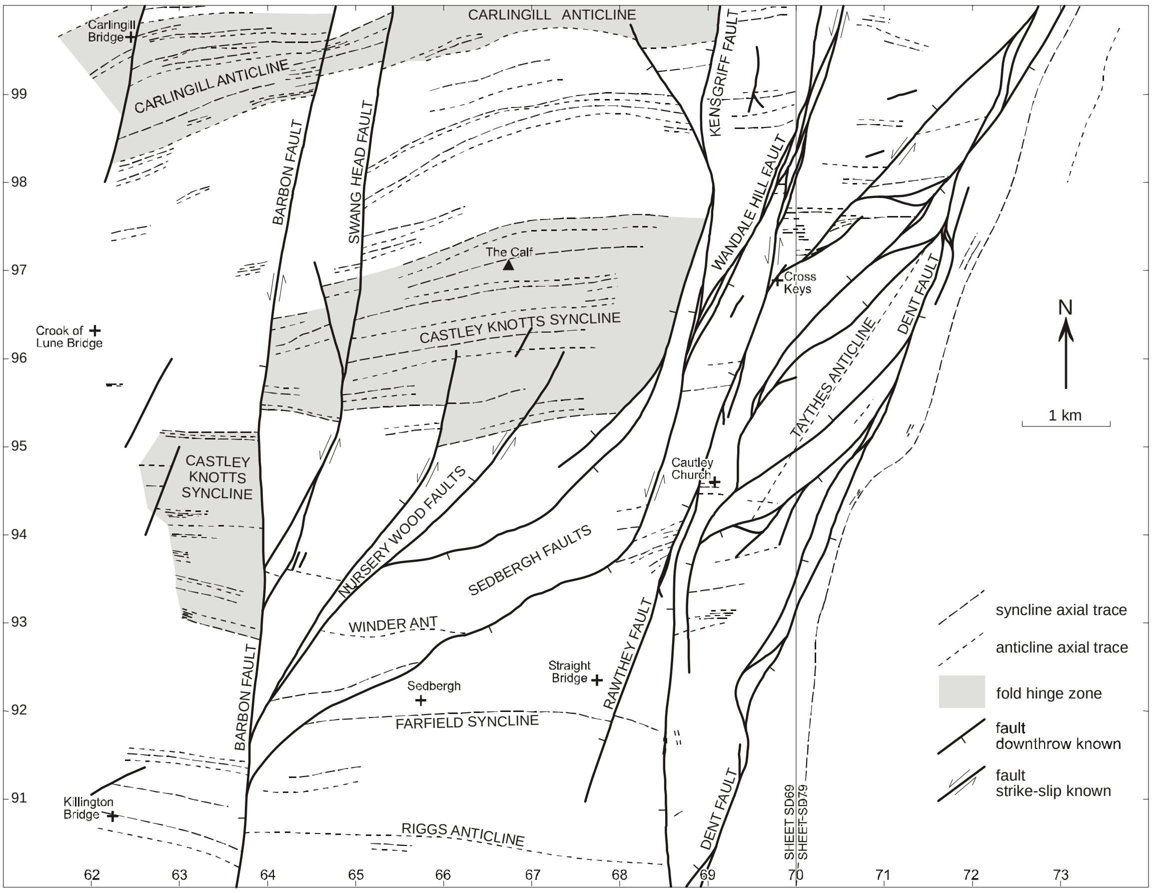
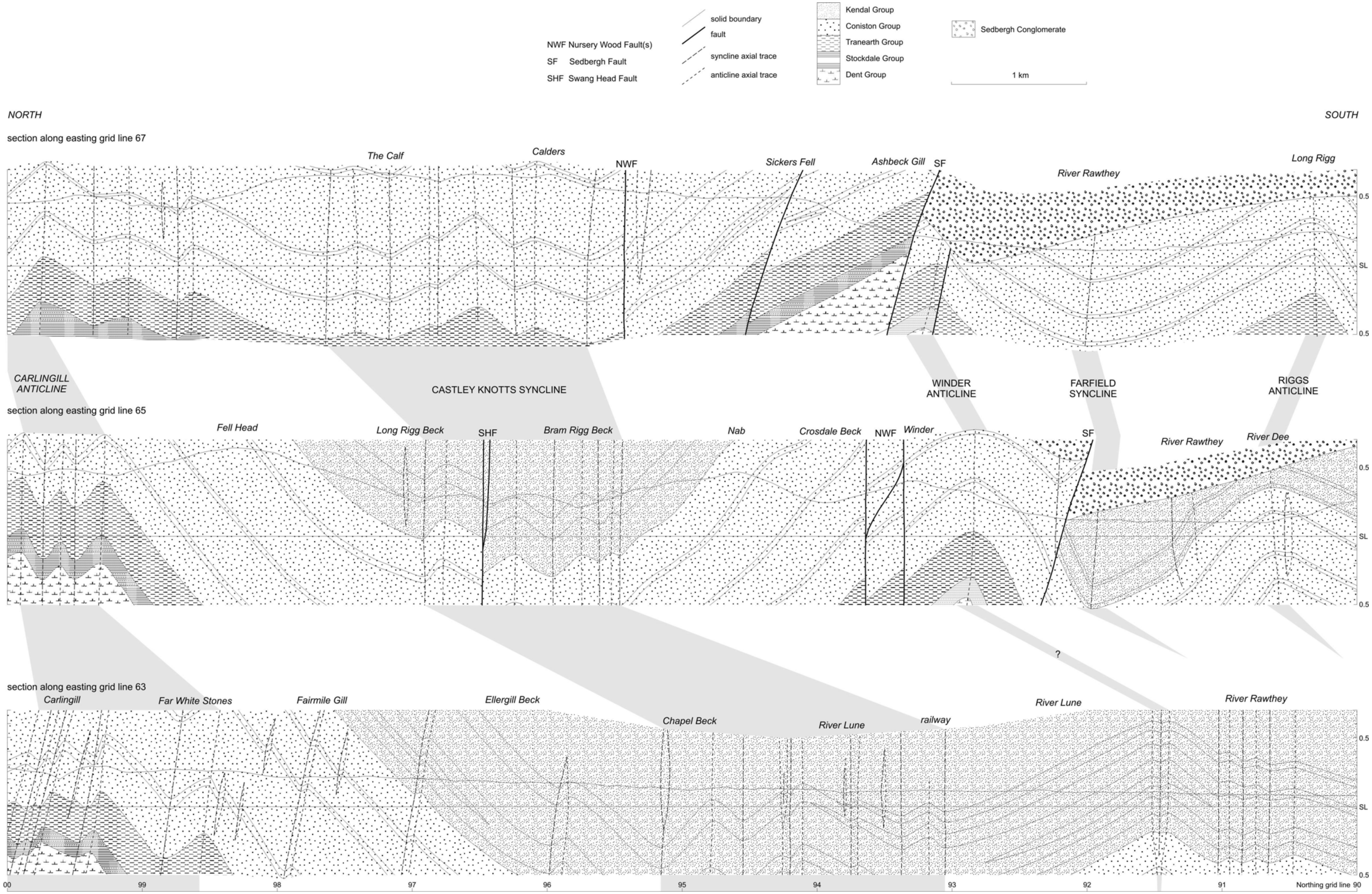


Figure 8 Structural map of sheet SD 69 and the area immediately to the east.

There is considerable interaction between the earlier Caledonian structures and the later Variscan structures. In the three sections that follow, Caledonian structures are described first. Next the major north-north-east-striking faults are described separately, and the evidence discussed for their age – Caledonian, Variscan or both. Finally, the Variscan folds and minor cleavage are described, including refolding of Caledonian structures.

In the preliminary version of this report (Woodcock and Rickards, 1999), the area was divided into three zones: a Caledonian zone, a Variscan zone, and an intervening Caledonian–Variscan interference zone. Although the 'interference zone' contains the prominent refolding of Caledonian by Variscan structures, more recent mapping has shown that major Variscan faulting affects rocks well to its west. The concept of a discrete zone of interference is therefore unhelpful.

Figure 9 Structural cross sections along three north - south lines through the Howgill Fells.



10.1 CALEDONIAN STRUCTURES

10.1.1 Major folds

Three major folds, originally identified by Sedgwick (1846) and named by the Geological Survey (Aveline and Hughes, 1872), dominate the Caledonian structure. In places, these folds have broad, complex hinge zones, which are difficult to specify precisely (Figures 8, 9).

The northernmost fold, the Carlingill Anticline, trends east-north-east or east. It comprises a zone of near horizontal or very gently east-plunging hinges and steep axial planes. In Carlingill Beck itself, the hinge zone is multiple and at least 1000 m wide, exposed between Black Force [6450 9897] and Weasel Gill [6278 9974]. To the west, in the River Lune, the hinge is similarly wide. Further east, across the Barbon Fault, it continues across Great Ulgill Beck [6493 9927 to 6478 9958]. East again across the Swang Head Fault, the southern part of the hinge zone has en echelon segments, right stepping near West Grain [6624 9947], and a faulted hinge is seen in Langdale Beck [6662 9960]. This hinge can be traced across Bowderdale and up Great Randy Gill [6882 9957]. The anticline is cut to the east by the Kensgriff Fault [6908 9960], east of which any continuation is conjectural.

The Castley Knotts Syncline trends east or east-north-east. It has a near horizontal hinge zone in the west, becoming moderately west-plunging further east, always with steep axial planes. The syncline has a 1100 m wide multiple hinge zone in its type area, exposed from north of Castley Knotts [6436 9649] to Seat Knott [6446 9537]. To the west, beyond the Barbon Fault, the hinge zone is taken to be at least 2 km wide, crossing the River Lune between Ullswheel [6292 9517] and the Lune Viaduct [6307 9302]. The hinge zone is apparently offset sinistrally across the Barbon Fault and its eastern splay, the Swang Head Fault. East of this Swang Head Fault, the syncline hinge zone is about 1600 m wide, with as many as six separate syncline hinges. Further east still, and down-section, the hinge zone loses its identity in the western slopes of The Calf.

The southern-most major fold, the Riggs Anticline, trends east or east-south-east. It typically has a single hinge, plunging gently west within a sub-vertical axial plane. The hinge is exposed on the western end of the Riggs [6600 9056], and can be located closely in the River Dee [65419058] where the fold has a subsidiary hinge to the south [6554 9041]. To both the east and west of this type area, the axial trace can be located to within ±200 m by opposing dips. At its eastern end, the Riggs Anticline is presumably cut out by the Dent Fault, in unexposed ground west of Helms Moss [6871 8993]. At its western end, the anticline must abut the Barbon Fault near Holme [6372 9063]. It is conjectural whether its westward continuation might be the double-hinged anticline exposed in the River Lune north of Farthing Holme Dub [6247 9143] or whether this might continue the Winder Anticline (see below).

10.1.2 Subsidiary folds

The hinge zones of the major folds are about 4-5 km apart and contain homoclinal panels as much as 2 km in cross-strike width. However, more commonly, these limbs are affected by subsidiary folds with wavelengths between about 200 m and 500 m in the Coniston Group and lower Bannisdale Formation, but decreasing to 100 m in the higher Bannisdale Formation. There are localised zones of intense short-wavelength (~100 m) folding in the Coniston Group around Black Force [6449 9898 to 6468 9962] and at its base at the Lune Viaduct [6307 9308]. Two particularly large subsidiary folds are a west plunging Farfield Syncline poorly exposed from Farfield Mills [6781 9191] through Sedbergh, and a west plunging Winder Anticline on the south flank of Winder [e.g. 6544 9288]. The axial planes of all the Caledonian folds are near vertical.

Direct mapping and stereographic analysis (Figure 10) show that the subsidiary folds are everywhere parallel to the major folds. Their trends are most commonly east-west, though tending to east-north-east in the north-west of the area and to east-south-east in the south of the area. Fold plunges are near horizontal or gently eastward in the west, but reverse to moderate (up to 30°) westward plunges in the east (Figure 10). Axial planes are uniformly steep.

10.1.3 Cleavage

The Caledonian folds are associated with a cleavage that appears in the field to be crudely axial planar. 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. The cleavage strike shows the same generally east–west pattern as the fold axial traces. However, the cleavage weakly but significantly transects the folds, so that it typically lies clockwise of the fold axial traces (Figure 10d). The modal transection angle is 10°-15°, but there is a wide variation up to 35°. 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.

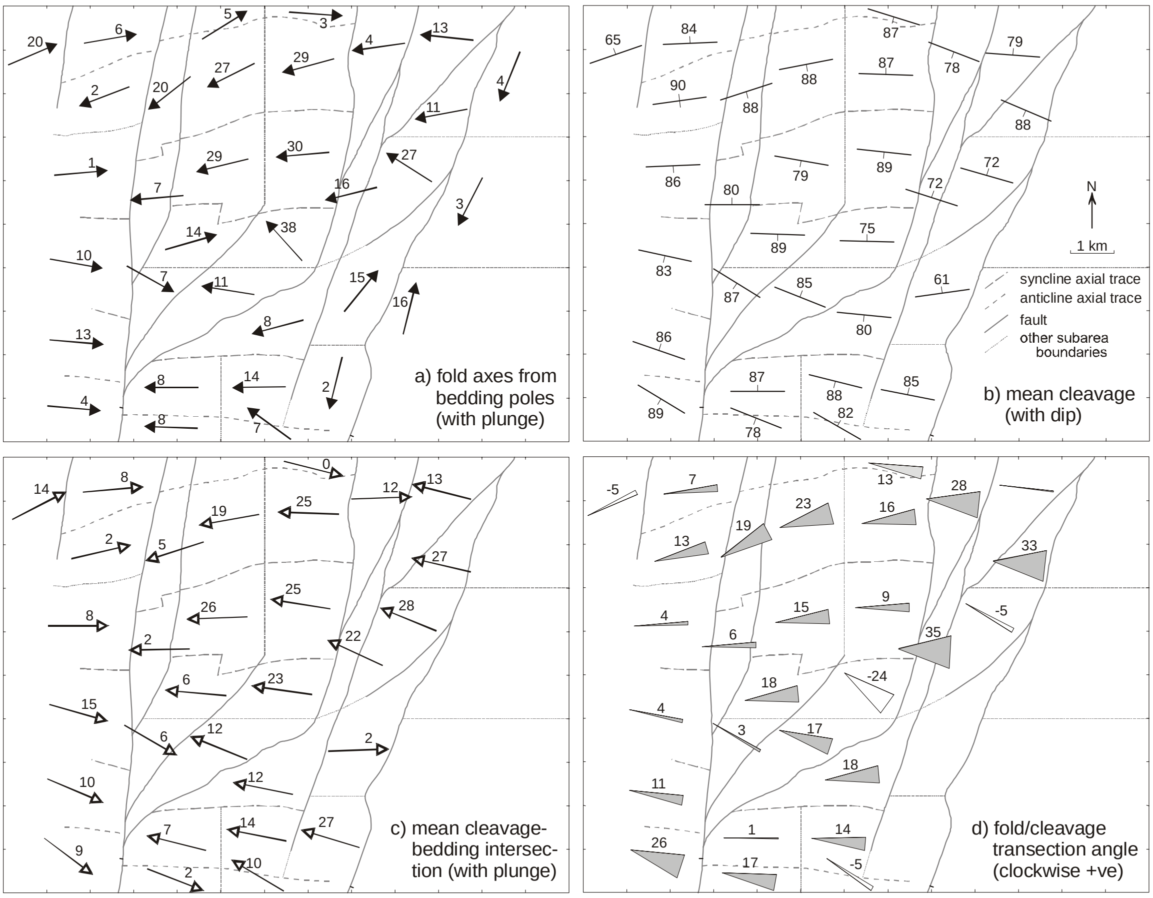


Figure 10 . Structural data from pre-Acadian rocks on sheet SD69 and the area to the east.

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).

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 10) and therefore also tends to transect fold hinges in a clockwise sense.

10.1.4 Minor faults

Minor, approximately east–west striking faults, associated with Caledonian folds have been mapped on Hazelgill Knott [6687 9970], at Black Force [6414 9920], Fleetholme Dub [6241 9663], Beck Houses Gate [6382 9703] and at the mouth of Bram Rigg Beck [6448 9576]. These examples take up localised brittle strain within intensely deformed parts of the Caledonian fold stack. The major faults in the area, striking between north and north-east, have more debatable Caledonian origins and are discussed below.

10.2 MAJOR FAULTS: CALEDONIAN AND/OR VARISCAN(?)

A major component of the structure of Sheet SD 69 is the series of large, steep faults striking between north and north-east. The more easterly of these faults cut the Carboniferous succession or its basal conglomerate, and can therefore be assigned a 'Variscan' age, at least in part. Carbonate-cemented breccias are a common feature along the Variscan faults, and probably fingerprint this displacement phase, even on more western faults that lack stratigraphical evidence of Variscan movement. On this basis, all the major faults in the area could have Variscan displacement. However, several lines of evidence, outlined at the end of this section, suggest that some of these faults could also have had Caledonian movements, or even have been inherited from pre-Windermere Supergroup basement.

The *Dent Fault* is the largest structure in the region, though it only crosses the south-east corner of Sheet SD 69. The sections on Figure 11 show also its mapped continuation north-north-eastward onto sheet SD 79. The fault has been mapped between Penny Farm Gill [6987 9316] and the Clough River [6947 9148], south of which it is drift covered. The fault has a marked easterly downthrow, but Underhill et al. (1988) assembled regional evidence for an additional sinistral strike-slip component on the fault during Variscan deformation. A number of more north-east-striking splays from the Dent Fault have been mapped crossing Whinny Gill [6997 9429 and 6977 9421], Crosshaw Beck [6951 9416 and 6889 9386] and Ecker Secker Beck [6986 9580 and 6992 9591]. The three splays closest to the Dent Fault throw down to the south-east and the two furthest away throw down to the north-west (Figure 11). These displacements are in sympathy with the more ductile Variscan strains that formed the Taythes Anticline on which the faults are superimposed. Although the splays do not cut Carboniferous rocks, they are therefore inferred to be of Variscan age.

The next major fault to the west is the *Rawthey Fault* (Rickards, 1967). The River Rawthey closely follows this fault between the Cross Keys Inn [6970 9680] and Rake Wood [6845 9338], displaying a number of zones of carbonate-cemented fault breccias, presumably of Variscan age. The fault develops two persistent strands 400 m south of Crook Holme [6891 9454]. Both strands clearly displace the base of the Sedbergh Conglomerate, the western fault at Rake Wood [6843 9335] and the eastern one in Hebblethwaite Hall Gill [6862 9288], again confirming Variscan displacement. Both faults then probably lose displacement southwards, the eastern fault through a monoclinal fold exposed on the Clough River [6853 9173]. South of the Cross Keys, the Rawthey Faults downthrow to the west, but local Riedel shear patterns suggest a component of sinistral strike-slip. North of the Cross Keys, two splays develop, both apparently with east or south-east downthrow. The western splay runs along the west side of Wandale Hill to join the Wandale Hill Faults there. The eastern splay strikes north-east, initially along the Rawthey Valley, to join the Dent Fault after about 4 km. Both splays show local Riedel shear patterns suggesting a component of sinistral strike-slip.

The *Wandale Hill Faults* (Dakyns et al., 1891) closely parallel the Rawthey Fault on Wandale Hill. Three strands cross Backside Beck [6984 9804] and, just south of Pickering Gill [6892 9647], they amalgamate with the Kensgriff Fault. The amalgamated fault is the south-easternmost of the Sedbergh Faults (Aveline and Hughes, 1888). The Wandale Hill Fault throws down to the east, with a possible component of sinistral strike-slip.

The north-striking *Kensgriff Fault* (Woodcock and Rickards, 1999) is inferred east of Kensgriff [6900 9915], where it cuts out much of the Brathay Formation. Southwards, near Yarlside [6900 9823] it is joined by a south-east-striking splay, before continuing to join the Wandale Hill Faults just south of Pickering Gill [6892 9647]. Northwards, the Kensgriff Fault continues for about 4 km beyond the northern boundary of Sheet SD 69 (Soper, 1999) to the Carboniferous unconformity. The fault is apparently overstepped by, rather than cuts, the unconformable Carboniferous cover, though in an area of poor exposure. The Kensgriff Fault and its splay throw down to the west.

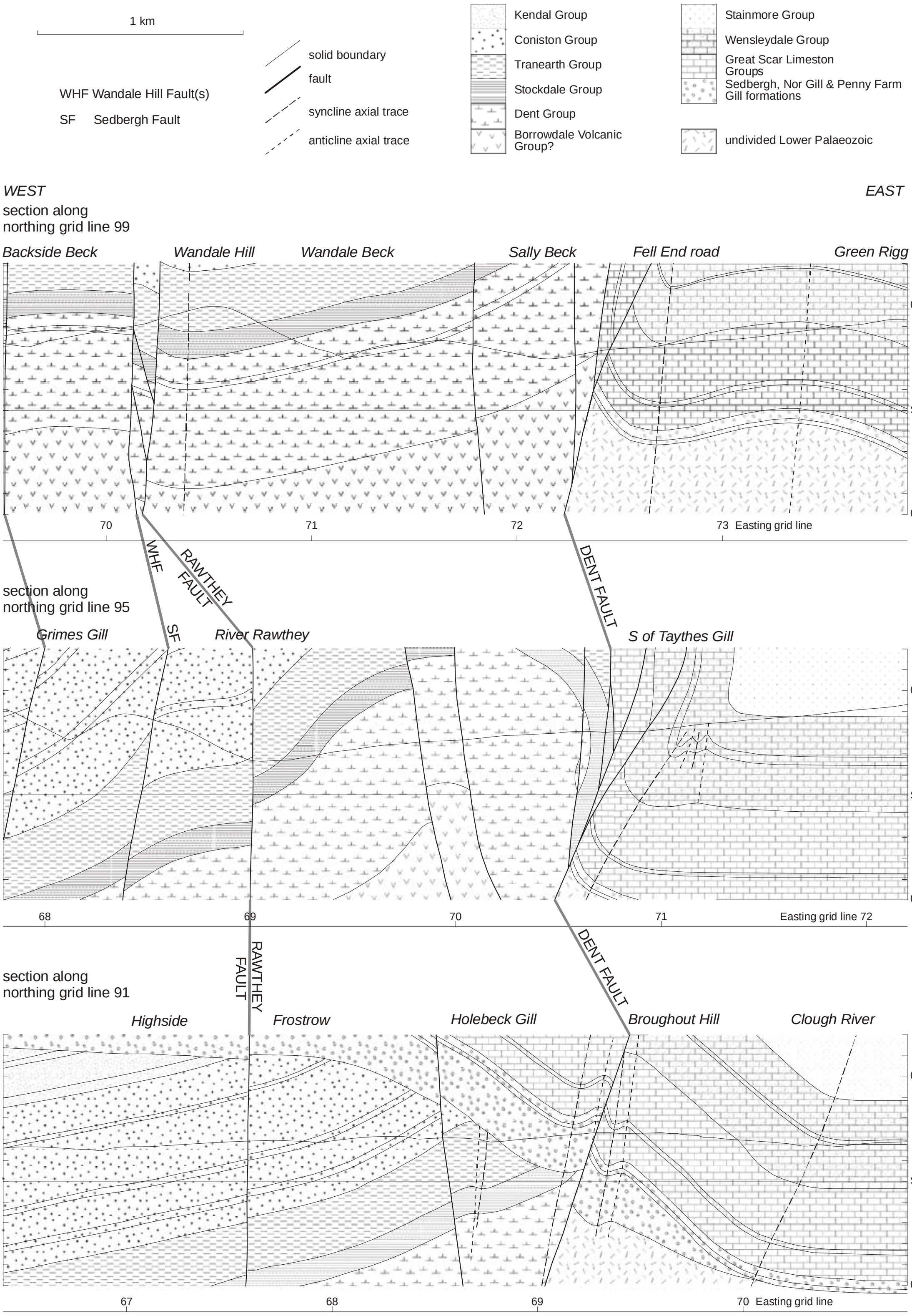


Figure 11 Structural cross-sections along three E-W lines across the Dent Fault system, including the area immediately to the east of sheet SD 69.

The *Sedbergh Faults* (Aveline and Hughes, 1888), strike north-east to south-west north of Sedbergh town, and throw down to the south-east. The south-eastern branch is taken through the brecciated sandstones in Settlebeck Gill [6604 9282]. It can be traced north-eastward across

Ashbeck Gill to Hobdale Beck [6824 9415] where it turns north-north-east to join the Wandale Hill and Kensgriff Faults. The north-western splay to the Sedbergh Fault is exposed in Ashbeck Gill [6666 9401], then inferred to strike north-eastward over Hobdale and Grimes Gills. It is joined by a north-west downthrowing splay, which probably continues northwards to merge with the Kensgriff Fault. The southern Sedbergh Fault apparently cuts the Sedbergh Conglomerate west of Settlebeck Gill, in which case it has a Variscan component of displacement.

The *Nursery Wood Faults* (new name) are inferred from the heavily fractured rocks hosting calcite-cemented fault breccias, exposed in the streams bordering Nursery Wood [6440 9270]. Further south, the faults are inferred to turn southward and merge with the Barbon Fault. To the north, two fault strands can be traced, through breccias on the north slope of Winder [9522 9357] and to breccias in Swarth Greaves Beck [6592 9496]. Both the faults apparently downthrow north-west, but sinistral strike-slip is equally compatible with the field evidence.

The *Swang Head Fault* (new name) appears to splay off the Barbon Fault in two strands that cross Crosdale Beck. The western strand is evidenced by a substantial thickness of calcite-cemented fault breccia [6398 9364] and the eastern strand by north-north-east-striking offsets of the Wotey Gill siltstone unit [6428 9369]. The two strands are inferred to amalgamate to the north-north-east, cross the col at Swang Head [6483 9530] and pass through a brecciated zone on Bram Rigg Beck [6487 9573]. The main north-striking fault and a north-north-west-striking splay are both evidenced by fault breccias in Calf Beck [6473 9635; 6499 9644]. The main fault is then inferred to run 3.5 km northward on the basis of offset lithological contacts and mismatched fold hinges. The fault was not mapped further north by Soper (1999). From offsets of the limbs of the Castley Knotts Syncline, the displacements on the Swang Head Fault appear to be predominantly sinistral strike slip, reaching 400 m on its northern segment.

The *Barbon Fault* (Aveline et al. 1872) enters Sheet SD 69 from its type area to the south, bounding the west side of the Barbon Fells. For the first 3.5 km of its course, the fault is evidenced only by the marked westerly downthrow of the Bannisdale Formation against the Coniston Group. Fault breccias occur in Crosdale Beck [9397 9358] where the Swang Head Fault splays from the Barbon Fault. The fault strikes north to a fault breccia in Chapel Beck [6394 9548]. It then appears to lose displacement and cross Great Ulgill Beck [6468 8960], but was not mapped by Soper (1999) on Sheet NY 60 to the north. The Barbon Fault appears to displace the axial trace of the Castley Knotts Syncline sinistrally by a few hundred metres. To the north, offsets of lithological boudaries are consistent with decreasing sinistral strike slip. To the south, folds cannot easily be correlated across the Barbon Fault, and the sense of any strike-slip component cannot be determined.

In summary, the major faults of sheet SD 69 are steeply dipping and strike between north-east and north. Their sense of throw is less consistent than the sinistral strike-slip component diagnosed on many of the faults. Variscan displacement is suggested directly in the east by cross-cutting of Carboniferous rocks and indirectly in the west by carbonate-veined fault breccias. However, Caledonian components on some faults are suggested by four lines of evidence:

1. The Barbon and Swang Head faults show a mismatch across them of Caledonian fold axial traces. A similar mismatch was noted in the Shap Fells by Moseley (1968) and in the northern Howgill Fells by Soper (1999).
2. A Caledonian precursor to the zone between the Kensgriff and Rawthey faults is suggested by the anomalously high transection angles of Caledonian folds by their cleavage; 28° between the Kensgriff and Wandale Hill Faults and 35° between the Wandale Hill and Rawthey faults. Strong Variscan east–west shortening might have increased the Caledonian transection angle, but the ductile strains associated with this event do not seem high enough. Alternatively the enhanced transection could be due to localised sinistral strike-slip on a north-north-east striking Caledonian shear zone.

3. The orientation of lamprophyre dykes with respects to the faults (Figure 7) is compatible with tension induced by sinistral strike slip along a north-north-east-striking zone including the major faults.
4. The Sedbergh Conglomerate may be the fluvial fill to a valley bounded by at least the Sedbergh and Dent faults, implying a residual topography in Late Devonian or Early Carboniferous time.

10.3 VARISCAN FOLDS AND CLEAVAGE

10.4 MAJOR FOLDS

The only major Variscan fold evident in Carboniferous rocks on sheet SD 69 occurs in a small area in its south-east corner. However, the structure there, particularly in the Clough River [6947 9148 to 7100 9127] is analogous to that east of the Dent Fault for at least 10 km along the fault strike, both to the north and south (Figure 11). A zone of steep or overturned beds borders the fault, with Carboniferous rocks younging east. The steep zone flattens abruptly eastward through a synformal monocline, into flat-lying Carboniferous strata about 500 m or more from the fault. The S-bend in the trace of the Dent Fault on sheet SD 69 is responsible for the steep limb of the monocline being rather wider here than usual. There is a minor north-trending anticline–syncline pair within the hinge region of the monocline.

Major Variscan folds occur for 2-3 km west of the Dent Fault, as far as the Kensgriff Fault. The Variscan folds trend between north and north-north-east (Figure 8). Interference with Caledonian folds has produced periclinal domes at the intersections of Variscan anticlines with east-trending Caledonian anticlines. Three such domes are developed in the eastern Howgill Fells, all elongated in a north-north-east direction. The best developed is the Taythes Anticline, the southern end of which crops out on Sheet SD 69 between the Rawthey Fault and the Dent Fault (Figure 11). These faults throw down in opposite directions, away from the hinge of the Taythes Anticline, and the Dent Fault removes some of the eastern limb of the fold. The dome most extensively displayed on Sheet SD 69 is the Westerdale ‘Anticline’, between the Kensgriff Fault and the Wandale Hill Fault. Again, the flanking faults downthrow away from the core of the dome, but the Wandale Hill Faults have removed most of the eastern limb of the anticline to leave a half dome. The third dome is the Murthwaite Anticline, occurring east of the Westerdale Anticline and of the margin of Sheet SD 69, between the Rawthey and Dent Faults.

The thin sliver of downthrown strata, mostly comprising Brathay Formation at outcrop, between the Wandale Hill-Sedbergh Faults and the Rawthey Fault has the structural role of an intervening Variscan syncline between the Taythes and Westerdale Anticlines, although no remnants of a discrete hinge remain.

The Caledonian anticlines responsible for the domal interference folds cannot satisfactorily be matched with structures in the Caledonian zone to the west. If the Westerdale dome continues as the Carlingill Anticline, about a kilometre of dextral displacement would be required on the Kensgriff Fault. However, if the regional evidence for Variscan sinistral displacement on the Dent Fault and related faults is accepted (Underhill et al., 1988), the Kensgriff/Sedbergh faults would require about 6 km of slip to align the Westerdale structure with the Winder Anticline, and the Taythes dome would need at least 5 km of slip on the Rawthey Fault to align with the Riggs Anticline.

10.4.1 Variscan effects on Caledonian structures

Caledonian folds and cleavage are refolded by the Variscan structures. To the west of the Barbon Fault, Caledonian folds are near horizontal or east-plunging. Further east, but still some 5 km from the Dent Fault, these folds and their associated cleavage/bedding intersection are tilted westward by up to 30° (Figures 10, 11).

Within the belt of Variscan domes, the cleavage-bedding intersection is dispersed and refolded about the Variscan anticlines, particularly the Taythes dome. The trend of the Caledonian folds is also variable in this belt (Figure 10a). West of the Wandale Hill Faults, these folds are east- or east-north-east-trending, although they swing towards a north-east trend close to faults (e.g. in Backside Beck [6980 9817]). This more north-easterly trend is characteristic of the narrow zone between the Wandale Hill-Sedbergh Faults and the Rawthey Fault, most notably in the River Rawthey near Iseman's Dub [6843 9383]. Farther east still, between the Rawthey and Dent Faults, the Caledonian folds trend close to east–west, or even swing gently south of east.

The swing in trend of the minor Caledonian folds reflects in part the regional structural arc of northern England (Soper et al., 1987). However the local deflections against and between the major faults probably record Variscan reorientation of these Caledonian structures. The sense of rotation is compatible with sinistral strike-slip on the Wandale Hill-Sedbergh Fault and on the Rawthey Fault, in harmony with estimates on the Dent Fault (Underhill et al., 1988). The possibility that some of this strike-slip reorientation may be Caledonian in age has already been suggested by the anomalous transection angles in this zone.

10.4.2 Variscan kinematics

The Variscan structures of sheet SD 69 can be interpreted in terms of a phase of sinistral transpression along the zone including and between the Dent and Barbon faults. Local evidence for this hypothesis has already been discussed, and the regional arguments for such a history, during Late Carboniferous time, have been assembled by Underhill et al. (1988). During this event, the Barbon Fault seems to have taken up pure sinistral strike slip, whereas the zone between the Dent and Wandale Hill faults has suffered sinistral transpression. This transpression is reflected in the Variscan monocline and fault-bounded domes (Figure 11). Together these structures form a belt of Variscan uplift, cored by the domal push-up horsts of Lower Palaeozoic rock.

The Sedbergh and Nursery Wood faults act as a north-east-striking kinematic link between the Barbon and Dent systems. The Sedbergh Faults have taken up substantial reverse dip-slip, as the sinistral displacements thrust the rocks of the Howgill Fells block over the putative palaeovalley occupied by the Sedbergh Conglomerate. Pre-existing Caledonian faults or shear zones may have determined the location of the Sedbergh Faults and the Dent/Wandale Hill belt.

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 12. Areas marked as 'solid' 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 solid is the upper feather edge of the valley-bottom till sheet.

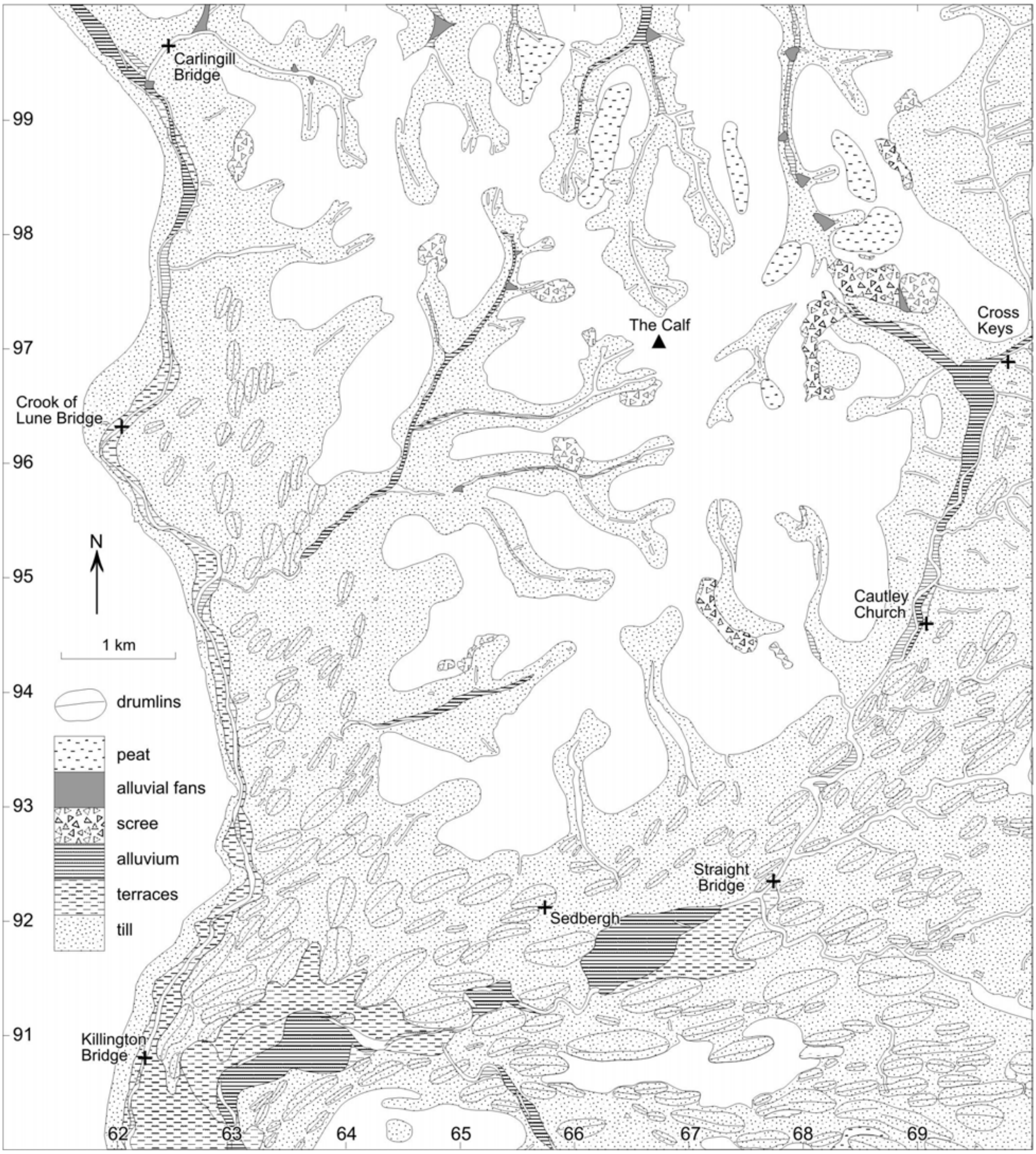


Figure 12 Outline drift map of sheet SD69.

11.1 TILL AND SOLIFLUCTED TILL

Unstratified, poorly sorted, matrix-supported conglomerate forms sheets in the lower parts of most of the main valleys of the area. 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. Solifluction has affected the till slopes to some degree, but no attempt has been made to distinguish soliflucted till from primary till. 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 the major valleys of the Rawthey, Clough and Lune, and over some of the interfluves, notably the Frostrow Fells. Mapped drumlins vary in length from 100 to 900 m and in width from 50 to 350 m. The drumlin axes approximately follow the present valley trends of the Rawthey and the Clough (Garsdale), indicating ice flowing south-west down the Rawthey and west down Garsdale. The two ice-streams joined and flowed west-south-west over the Frostrow Fells and down the lower Rawthey, with little evidence of a major input from Dentdale. The drumlin axes along the Lune approximately parallel the north–south valley as far south as the mouth of Chapel Beck. This valley tapped ice from a large part of the south-west Howgills, and the resultantly strong ice-stream deflected the Lune ice south-westward towards the southern part of the Firbank Fells. South of Lincoln’s Inn Bridge, the Lune ice met the west-south-west flowing Rawthey ice, the combined stream flowing south-west then south-south-west.

11.2 ALLUVIUM AND RIVER TERRACE DEPOSITS

Stratified, moderately well sorted, clast-supported gravel to cobble conglomerate forms the present river flood-plains of the Lune and Rawthey, and of a number of the upland streams. Older river terraces with a veneer of similar alluvium border parts of Calf Beck and Cautley Holme Beck, but are best displayed along the Lune and lower Rawthey valleys. Extensive terraces of two discrete generations occur near the Rawthey/Lune confluence, and upstream along the Rawthey for 3 km.

11.3 ALLUVIAL CONE AND FAN DEPOSITS

Numerous small (typically 20 to 100 m wide) alluvial cones and fans are forming at the base of erosional gully systems supplying debris down the slopes of the upland valleys. Only the main cones and fans are shown on the standard maps. A more comprehensive display is given by Harvey (e.g. 1986). The cones and fans postdate lower terrace deposits dated at 2500 - 1000 years BP (Harvey et al., 1981, 1996). Gullying was probably triggered by the start of upland sheep grazing in the tenth century A.D. Fans and cones are still active, particularly during 100-year storm events (Harvey, 1986; Wells and Harvey, 1987).

11.4 TALUS (SCREE)

Weakly stratified, angular, clast-supported breccia has been mapped in the uplands. It typically occurs below the main crags; Cautley Crags, The Screes, Yarlside, Kensgriff, Hobdale Scar, Fell Head Scar and Far White Stones.

11.5 PEAT

Blanket peat occurs sporadically over much of the flatter upland areas, but only thicker and more extensive spreads have been mapped as such. These patches occur mainly in the north-east of the sheet; on Weathercalf Moss, Cobles, the East Grain/Bowderdale interfluve, Yarlside, Hare Shaw and Bowderdale Head. The peat is said to date from about 7000 to 5000 years BP (Harvey, 1985), and is mostly now eroding.

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.

Aveline, W T, and Hughes, T M. 1872. The geology of the country around Kendal, Sedbergh, Bowness and Tebay. *Memoir, Geological Survey of Great Britain* Sheet 98NE.

Aveline, W. T. and Hughes, T. M. 1888. The geology of the country around Kendal, Sedbergh, Bowness and Tebay. *Memoir, Geological Survey of Great Britain* Sheet 98NE.

Aveline, W. T., Hughes, T. M. and Tiddeman, R. H. 1872. The geology of the neighbourhood of Kirkby Lonsdale and Kendal. *Memoir, Geological Survey of Great Britain* Sheet 98SE.

Bonney, T. G. and Houghton, F. T. S. 1878. On some mica-traps from the Kendal and Sedbergh Districts. *Quarterly Journal of the Geological Society, London,* Vol. 35, 165-180.

British Geological Survey. 1997. Kirkby Stephen, England and Wales Sheet 40. British Geological Survey, Keyworth, Nottingham.

Buckland, W. 1840. Evidences of glaciers in Scotland and the North of England. *Proceedings of the Geological Society, London* Vol. 3, 332-337.

Burgess, I. C. 1986. Lower Carboniferous sections in the Sedbergh district, Cumbria. *Transactions of the Leeds Geological Association,* Vol. 11, 1-23.

Burgess, I. C., Rickards, R. B. and Strachan, I. 1970. The Silurian strata of the Cross Fell area. *Bulletin, Geological Survey of Great Britain*, Vol. 32, 167-182.

Butterfield, J. A. 1920. The conglomerates underlying the Carboniferous Limestone in the N.W. of England. *Naturalist* (for 1920), 249-252, 281-284,.

Cocks, L. R. M., Holland, C. H. and Rickards, R. B. 1992. A revised correlation of Silurian rocks in the British Isles. Geological Society, London, Special Report 21, 1-32.

Dakyns, J. R., Tiddeman, R. H., Russell, R., Clough, C. T. and Strahan, A. 1891. The geology of the country around Mallerstang with parts of Wensleydale, Swaledale and Arkendale. *Memoir, Geological Survey of Great Britain* 97NW.

Dimberline, A. J., Bell, A. and Woodcock, N. H. 1990. A laminated hemipelagic facies from the Wenlock and Ludlow of the Welsh Basin. *Journal of the Geological Society, London*, Vol. 147, 693-701.

Dunham, K. C. and Wilson, A. A. 1985. Geology of the Northern Pennine orefield: Volume 2 , Stainmore to Craven. Economic *Memoir, British Geological Survey*. H. M. S. O., London.

Furness, R. R., Llewellyn, P. G., Norman, T. N. and Rickards, R. B. 1967. A review of Wenlock and Ludlow stratigraphy and sedimentation in N.W. England. *Geological Magazine*, Vol. 104, 132-147.

Goodchild, J. G. 1875. The glacial phenomena of the Eden Valley and the western part of the Yorkshire-Dale district. *Quarterly Journal of the Geological Society, London*, Vol. 31, 55-99.

Harvey, A. M. 1974. Gully erosion and sediment yield in the Howgill Fells, Westmorland. In: Fluvial processes in instrumental watersheds (edited by Gregory, K. J. and D.E., W.) 6. Special Publication of the Institute of British Geographers, 45-58.

Harvey, A. M. 1977. Event frequency in sediment production and channel change. In: *River channel changes* (edited by Gregory, K. J.). Wiley, Chichester, 301-315.

Harvey, A. M. 1985. The river systems of North-west England. In: *The geomorphology of north-west England* (edited by Johnson, R. H.). Manchester University Press, Manchester, 122-142.

Harvey, A. M. 1986. Geomorphic effects of a 100 year storm in the Howgill Fells, Northwest England. *Zeitschrift fur Geomorphologie*, Vol. 30, 71-91.

Harvey, A. M. 1991. The influence of sediment supply on the channel morphology of upland streams: Howgill Fells, northwest England. *Earth Surface Processes and Landforms,* Vol. 16, 675-684.

Harvey, A. M. 1992. Process interactions, temporal scales and the development of hillslope gully systems: Howgill Fells, northwest England. *Geomorphology*, Vol. 5, 323-344.

Harvey, A. M. 1996. Holocene hillslope gully systems in the Howgill Fells. In: *Advances in hillslope processes* (edited by Anderson, M. G. and Brooks, S. M.). John Wiley and Sons Ltd., 731-752.

Harvey, A. M., Alexander, R. W. and P.A., J. 1984. Lichens, soil development and the age of Holocene valley floor landforms: Howgill Fells, Cumbria. *Geographiska Annaler,* Vol. 66, 353-366.

Harvey, A. M., Hitchcock, D. H. and Hughes, D. J. 1979. Event frequency and morphological adjustment of fluvial systems in upland Britain. In: *Adjustments of the fluvial system* (edited by Rhodes, D. D. and Williams, G. P.). Kendall/Hunt Publishing Co., Dubuque, Iowa, 139-167.

Harvey, A. M., Oldfield, F., Baron, A. F. and Pearson, G. W. 1981. Dating of post-glacial landforms in the central Howgills. *Earth Surface Processes and Landforms*, Vol. 6, 401-412.

Hollingworth, S. E. 1931. The glaciation of Western Edenside and adjoining areas and the drumlins of Edenside and the Solway Basin. *Quarterly Journal of the Geological Society, London*, Vol. 87, 281-357.

Hollingworth, S. E. 1938. The recognition and correlation of high level erosion surfaces in Britain: a statistical study. *Quarterly Journal of the Geological Society, London*, Vol. 94, 55-84.

Hutt, J. E. 1974. *The Llandovery graptolites of the English Lake District, Part 1*. Monograph of the Palaeontographical Society, London 128.

Ingham, J. K. 1966. The Ordovician rocks in the Cautley and Dent districts of Westmorland and Yorkshire. *Proceedings of the Yorkshire Geological Society*, Vol. 35, 455-505.

Ingham, J. K. and McNamara, K. J. 1978. The Coniston Limestone Group. In: *The geology of the Lake District* (edited by Moseley, F.). Yorkshire Geological Society, Leeds, 121-139.

Ingham, J. K., McNamara, K. J. and Rickards, R. B. 1978. The Upper Ordovician and Silurian rocks. In: *The geology of the Lake District* (edited by Moseley, F.). Yorkshire Geological Society, Leeds, 121-145.

Ingham, J. K. and Rickards, R. B. 1974. Lower Palaeozoic rocks. In: *The geology and mineral resources of Yorkshire* (edited by Rayner, D. H. and Hemingway, J. E.). Yorkshire Geological Society, Leeds, 29-44.

Ingham, J. K. and Wright, A. D. 1972. The north of England. In: *A correlation of Ordovician rocks in the British Isles* (edited by Williams, A., Strachan, I., Bassett, D. A., Dean, W. T., Ingham, J. K., Wright, A. D. and Whittington, H. B.). Geological Society, London, Special Report 3, London, 43-49.

Kemp, A. E. S. 1991. Mid Silurian pelagic and hemipelagic sedimentation and paleoceanography. Special Papers in Palaeontology, *Palaeontological Society*, Vol. 44, 261-299.

King, L. M. 1992. A basin study of the early Palaeozoic Windermere Group, NW England. Unpublished Ph.D. thesis, University of Cambridge.

King, L. M. 1994. Turbidite to storm transition in a migrating foreland basin: the Kendal Group (Upper Silurian), northwest England. *Geological Magazine*, Vol. 131, 255-267.

Kneller, B. C. 1990. The Wenlock rocks of Sheet 38 (Ambleside). *Technical Report, British Geological Survey* WA/90/64.

Kneller, B. C., Scott, R. W., Soper, N. J., Johnson, E. W. and Allen, P. M. 1994. Lithostratigraphy of the Windermere Supergroup, Northern England. *Geological Journal*, Vol. 29, 219-240.

Leggett, J. K. 1980. British Lower Palaeozoic black shales and their palaeo-oceanographic significance. *Journal of the Geological Society, London*, Vol. 137, 139-156.

Letzer, J. M. 1981. The upper Eden Valley (Ravenstonedale). In: *Field Guide to Cumbria*. Quaternary Research Association, 43-60.

Llewellyn, P. G. 1960. The Middle and Upper Silurian rocks between Longsleddale and the Shap granite, Westmoreland. Unpublished Ph.D. thesis, University of Cambridge.

Manley, G. 1959. The late-glacial climate of north-west England. Liverpool and Manchester *Geological Journal*, Vol. 2, 188-215.

Marr, J. E. 1878. On some well defined life zones in the lower part of the Silurian (Sedgwick) of the Lake District. *Quarterly Journal of the Geological Society, London*, Vol. 34, 871-885.

Marr, J. E. 1892a. The Coniston Limestone Series. *Geological Magazine*, Vol. (3) 9, 97-110.

Marr, J. E. 1892b. On the Wenlock and Ludlow strata of the Lake District. *Geological Magazine*, Vol. (3) 9, 534-541.

Marr, J. E. 1906. The influence of the geological structure of English Lakeland upon its present features - a study in physiography. *Proceedings of the Geological Society, London*, Vol. 62, 66-128.

Marr, J. E. 1913. The Lower Palaeozoic rocks of the Cautley District (Yorkshire). *Quarterly Journal of the Geological Society, London*, Vol. 69, 1-17.

Marr, J. E. 1916. *The geology of the Lake District and the scenery as influenced by geological structure*. Cambridge University Press, Cambridge.

Marr, J. E. and Fearnsides, W. G. 1909. The Howgill Fells and their topography. *Quarterly Journal of the Geological Society, London*, Vol. 65, 587-610.

Marr, J. E. and Nicholson, H. A. 1888. The Stockdale Shales. *Quarterly Journal of the Geological Society, London*, Vol. 44, 654-732.

McConnell, R. B. 1940. The relic surfaces of the Howgill Fells. *Proceedings of the Yorkshire Geological Society*, Vol. 24, 152-164.

McNamara, K. J. 1979. The age, stratigraphy and genesis of the Coniston Limestone group in the southern Lake District. *Geological Journal*, Vol. 14, 41-69.

Moseley, F. 1968. Joints and other structures in the Silurian rocks of the southern Shap Fells, Westmorland. *Geological Journal*, Vol. 6, 79-96.

Moseley, F. 1984. Lower Palaeozoic lithostratigraphical classification in the English Lake District. *Geological Journal*, Vol. 19, 239-247.

Nixon, P. H., Rex, D. C. and Condliffe, E. 1984. A note on the age and petrogenesis of lamprophyre dykes of the Cautley area, Yorkshire Dales National Park. *Transactions of the Leeds Geological Association*, Vol. 10(4), 40-45.

Phillips, J. 1837. On the removal of large blocks or boulders from the Cumbrian Mountains in various directions. *Report of the British Association for the Advancement of Science*, Vol. 6, 87-88.

Raistrick, A. 1926. The glaciation of Wensleydale, Swaledale and adjoining parts of the Pennines. *Proceedings of the Yorkshire Geological Society*, Vol. 20, 366-410.

Rickards, R. B. 1963. The Silurian strata of the Howgill Fells. Unpublished Ph.D. thesis, University of Hull.

Rickards, R. B. 1964. The graptolitic mudstone and associated facies in the Silurian strata of the Howgill Fells. *Geological Magazine*, Vol. 101, 435-451.

Rickards, R. B. 1967. The Wenlock and Ludlow succession in the Howgill Fells (north-west Yorkshire and Westmorland). *Quarterly Journal of the Geological Society, London*, Vol. 123, 215-151.

Rickards, R. B. 1969. Wenlock graptolite zones in the English Lake District. *Proceedings of the Geological Society, London*, Vol. 1654, 61-65.

Rickards, R. B. 1970a. The age of the Middle Coldwell Beds. *Proceedings of the Geological Society, London*, Vol. 1663, 111-114.

Rickards, R. B. 1970b. *The Llandovery (Silurian) graptolites of the Howgill Fells, northern England*. Monograph of the Palaeontographical Society, London, 1-108.

Rickards, R. B. 1973. On some highest Llandovery red beds and graptolite assemblages in Britain and Eire. *Geological Magazine*, Vol. 110, 70-72.

Rickards, R. B. 1978. Silurian. In: *The geology of the Lake District* (edited by Moseley, F.). Yorkshire Geological Society, 130-145.

Rickards, R. B. 1988. The base of the Silurian in the Lake District and Howgill Fells, Northern England. *Bulletin of the British Museum (Natural History) London, Geology Series*, Vol. 43, 53-57.

Rickards, R. B. 1989. Northern England. In: *A global standard for the Silurian System* (edited by Holland, C. H. and Bassett, M. G.). National Museum of Wales, Cardiff, 267-274.

Rickards, R. B. 2002. The graptolitic age of the type Ashgill Series (Ordovician), Cumbria, UK. *Proceedings of the Yorkshire Geological Society*, Vol. 54, 1-16.

Rock, N. M. S. 1988. Late Caledonian dyke-swarms of Northern Britain: some preliminary petrogenetic and tectonic implications of their province-wide distribution and chemical variation. *Canadian Mineralogist*, Vol. 26, 3-22.

Salter, J. W. 1873. *A catalogue of the collection of Cambrian and Silurian fossils contained in the Geological Museum of the University of Cambridge*. University of Cambridge.

Scott, R. W. and Kneller, B. C. 1990. A report on the Ashgill and Llandovery age rocks of Sheet 38 (Ambleside). *Technical Report, British Geological Survey* WA/90/63.

Sedgwick, A. 1845. On the comparative classification of the fossiliferous strata of North Wales, with the corresponding deposits of Cumberland, Westmoreland and Lancashire. *Quarterly Journal of the Geological Society, London*, Vol. 1, 442-450.

Sedgwick, A. 1846. On the classification of the fossiliferous slates of Cumberland, Westmoreland and Lancashire. *Quarterly Journal of the Geological Society, London*, Vol. 2, 106-131.

Sedgwick, A. 1852. On the Lower Palaeozoic rocks at the base of the Carboniferous Chain between Ravenstonedale and Ribblesdale. *Quarterly Journal of the Geological Society, London*, Vol. 8, 35-54.

Soper, N. J. 1999. The Windermere Supergroup of 1:25,000 sheets NY50 and NY60, Southern Shap Fells and Northern Howgill Fells, Cumbria. *Technical Report, British Geological Survey* WA/99/35.

Soper, N J. 2006. Notes on the Windermere Supergroup of the country between Kendal and the River Lune on 1:25 000-scale sheets SD59 and SD69(W). *British Geological Survey Internal Report* IR/06/081.

Soper, N. J., Webb, B. C. and Woodcock, N. H. 1987. Late Caledonian (Acadian) transpression in North West England: timing, geometry and geotectonic significance. *Proceedings of the Yorkshire Geological Society*, Vol. 46, 175-192.

Spencer, D. 1966. Factors affecting element distributions in a Silurian graptolite band. *Chemical Geology*, Vol. 1, 221-249.

Tiddeman, R. H. 1872. On the evidence for the ice-sheet in North Lancashire and adjacent parts of Yorkshire and Westmoreland. *Quarterly Journal of the Geological Society, London*, Vol. 28, 471-491.

Turner, J. S. 1961. Report of a field meeting to Cautley. *Proceedings of the Yorkshire Geological Society*, Vol. 33, 36-37.

Underhill, J. R., Gayer, R. A., Woodcock, N. H., Donnelly, R., Jolley, E. J. and Stimpson, I. G. 1988. The Dent Fault System, northern England - reinterpreted as a major oblique-slip fault zone. *Journal of the Geological Society, London*, Vol. 145, 303-316.

Vaughan, A. P. M. 1996. A tectonomagmatic model for the genesis and emplacement of Caledonian calc-alkaline lamprophyres. *Journal of the Geological Society, London*, Vol. 153, 613-623.

Ward, J. C. 1873. The glaciation of the northern part of the Lake District. *Quarterly Journal of the Geological Society, London*, Vol. 29, 422-441.

Ward, J. C. 1875. The glaciation of the southern part of the Lake District and the glacial origin of the lake-basins of Cumberland and Westmoreland. *Quarterly Journal of the Geological Society, London*, Vol. 31, 152-166.

Wells, S. G. and Harvey, A. M. 1987. Sedimentologic and geomorphic variations in storm-generated alluvial fans, Howgill Fells, Northwest England. *Geological Society of America Bulletin*, Vol. 98, 182-198.

Wilson, D. W. R. 1954. The stratigraphy and palaeontology of the Valentian rocks of Cautley (Yorks. W. R.). Unpublished Ph.D. thesis, University of Birmingham.

Woodcock, N. H. and Rickards, R. B. 1999. Geological notes and local details for 1:10 000 sheets: Sheet SD 69 NE (Westerdale) and parts of Sheets SD 69 NW (Howgill), SD 69 SW (Firbank) and SD 69 SE (Sedbergh). *British Geological Survey Technical Report*, WA/99/34.

Ziegler, A. M. and McKerrow, W. S. 1975. Silurian marine red beds. *American Journal of Science*, Vol. 275, 31-56.

Table 1 Representative exposures of the Cautley Mudstone Formation.

Cautley Mudstone Formation	base of section	top of section
Backside Beck	SD 6983 9864	SD 6976 9965
Watley Gill	SD 6958 9880	SD 6933 9833
Wandale Beck	*SD 7080 9819*	*SD 7073 9788*
Wandale Beck	*SD 7080 9819*	*SD 7115 9903*
River Rawthey	*SD 7141 9771*	*SD 7086 9785*
Sally Brow	*SD 7176 9864*	*SD 7163 9866*
Sally Beck	*SD 7237 9937*	*SD 7176 9852*
Pickering Gill	SD 6912 9677	SD 6899 9663
Ecker Secker Beck	*SD 7057 9589*	SD 6980 9572
Taythes Gill	*SD 7057 9583*	*SD 7084 9525*
Birksfield Beck	SD 6986 9400	SD 6937 9488
Whinny Gill	SD 6977 9421	SD 6966 9413
Cautley Volcanic Member		
Backside Beck	SD 6957 9918	SD 6967 9953
Watley Gill	SD 6943 9888	SD 6937 9891
Wandale Beck	*SD 7117 9898*	------------------
Wandale Beck	*SD 7074 9758*	------------------

Italicised sections or grid references are outside grid square SD 69.

Table 2 Representative exposures of the Ashgill Formation.

Ashgill Formation	base of section	top of section
Backside Beck	SD 6976 9965	SD 6986 9978
Watley Gill	SD 6932 9891	SD 6913 9887
Wandale Hill	*SD 7082 9848*	*SD 7076 9857*
Wandale Beck	*SD 7074 9790*	*SD 7074 9785*
River Rawthey	*SD 7142 9770*	*SD 7158 9760*
Pickering Gill	SD 6898 9663	SD 6896 9662
Ecker Secker Beck	SD 6974 9568	SD 6958 9552
Fairy Gill	*SD 7054 9613*	*SD 7064 9627*
Birksfield Beck	SD 6938 9488	SD 6932 9489
Birks Wood Beck	SD 6938 9472	SD 6932 9469
Whinny Gill	SD 6967 9412	SD 6963 9411
Cystoid Limestone Member		
Backside Beck	SD 6976 9965	------------------
Watley Gill	SD 6932 9891	------------------
Odd Gill	*SD 7146 9912*	------------------
Wandale Hill	*SD 7082 9848*	------------------
Wandale Beck	*SD 7074 9790*	------------------
Three Gills	*SD 7225 9956*	------------------
Ecker Secker Beck	SD 6998 9586	------------------
Taythes Gill	*SD 7084 9526*	------------------
Birksfield Beck	SD 6938 9488	------------------
Birks Wood Beck	SD 6938 9472	------------------
Whinny Gill	SD 6967 9412	------------------
Conglomerate or sandstone		
Spengill	SD 6984 9978	------------------
Stockless Gill	SD 6982 9978	------------------
Watley Gill	SD 6919 9888	------------------
Tributary of Backside Beck	SD 6984 9816	------------------
Wandale Hill	*SD 7077 9855*	------------------
North of Handley's Bridge	*SD 7053 9789*	------------------
Five Gills	*SD 7256 9988*	------------------
Rawthey Bridge	*SD 7142 9767*	------------------
Wards Intake	*SD 7156 9762*	------------------
Ecker Secker Beck (cong)	SD 6971 9567	------------------
Fairy Gill (cong, not *in situ*)	*SD 7063 9627*	------------------
Wraymire Gill (cong, not *in situ*)	*SD 7089 9612*	------------------
Taythes Gill	*SD 7084 9525*	------------------
Birksfield Beck	SD 6934 9488	------------------
Crosshaw Beck	SD 6952 9416	------------------
Whinny Gill (cong)	SD 6964 9411	------------------

Italicised sections or grid references are outside grid square SD 69.

Table 3 Representative exposures of the Skelgill Formation.

Skelgill Formation	base of section	top of section
Stockless Gill	SD 6982 9978	SD 6980 9982
Spen Gill	SD 6986 9978	SD 6990 9982
Watley Gill	SD 6913 9888	SD 6906 9890
North of Handley's Bridge	*SD 7050 9790*	*SD 7046 9797*
Ward's Intake	*SD 7157 9761*	*SD 7160 9757*
Pickering Gill	SD 6894 9661	SD 6893 9658
Birksfield Beck	SD 6932 9489	SD 6927 9490
Birks Wood Beck	SD 6932 9470	SD 6928 9470
Spengill Member		
Stockless Gill	SD 6982 9978	
Spen Gill	SD 6986 9978	
South of Mountain View	SD 6987 9815	
Watley Gill	SD 6913 9888	
Five Gills	*SD 7252 9989*	
Five Gills	*SD 7247 9983*	
Wandale Hill	*SD 7075 9857*	
North of Handley's Bridge	*SD 7050 9790*	
Rawthey Bridge	*SD 7142 9769*	
Ward's Intake	*SD 7157 9761*	
Pickering Gill	SD 6894 9661	
Birksfield Beck	SD 6932 9489	
Birks Wood Beck	SD 6932 9470	
Marsh Lane	SD 6931 9431	
Crosshaw Beck	SD 6950 9414	
Whinny Gill	SD 6963 9411	
The 'Green Streak'		
Spen Gill	SD 6990 9982	
Watley Gill	SD 6906 9890	
Wandale Hill	*SD 7075 9857*	
Bluecaster Side	*SD 7013 9637*	
Ben End Beck	SD 6921 9755	
Ecker Secker Beck	SD 6955 9551	
Taythes Gill	*SD 7080 9525*	
Birksfield Beck	SD 6927 9490	
Birks Wood Beck	SD 6928 9470	
Crosshaw Beck	SD 6950 9414	

Italicised sections or grid references are outside grid square SD 69.

Table 4 Representative exposures of the Browgill Formation.

Browgill Formation	base of section	top of section
Stockless Gill	SD 6980 9982	*NY 6950 0002*
Spen Gill	SD 6990 9982	*SD 7003 9993*
Ben End	SD 6917 9758	SD 6918 9751
North of Handley's Bridge	*SD 7046 9797*	*SD 7043 9797*
Ward's Intake	*SD 7160 9757*	*SD 7163 9752*
Ecker Secker Beck	SD 6955 9553	SD 6938 9543
Birksfield Beck	SD 6927 9490	SD 6915 9495
Birks Wood Beck	SD 6928 9470	SD 6920 9473
Whinny Gill	SD 6997 9430	SD 6979 9422
Hebblethwaite Hall Gill	SD 6898 9317	SD 6912 9319
Hebblethwaite Member		
Stockless Gill	SD 6977 9988	SD 6956 9999
Spen Gill	*SD 7001 9981*	*SD 7003 9990*
Tributary of Backside Beck	SD 6945 9957	------------------
Ward's Intake	*SD 7163 9752*	------------------
Ecker Secker Beck	SD 6942 9543	SD 6939 9544
Birksfield Beck	SD 6917 9494	SD 6915 9495
Marsh Lane	SD 6911 9418	------------------
Whinny Gill	*SD 7005 9434*	------------------
Hebblethwaite Hall Gill	SD 6910 9317	SD 6910 9318
Far House Member		
Stockless Gill	SD 6956 9999	*NY 6950 0002*
Spen Gill	*SD 7003 9990*	*SD 7003 9993*
Mouth of Wandale Beck	*SD 7087 9784*	*SD 7075 9780*
Ecker Secker Beck	SD 6939 9544	SD 6938 9543
Hebblethwaite Hall Gill	SD 6910 9318	SD 6912 9319

Italicised sections or grid references are outside grid square SD 69.

Table 5 Representative exposures of the Brathay Formation.

Brathay Formation	base of section	top of section
Spen Gill	*SD 7003 9993*	*NY 6991 0015*
Stockless Gill	*NY 6951 0000*	*NY 6938 0026*
Great Randy Gill	SD 6833 9950	SD 6883 9957
Pickering Gill	SD 6896 9657	SD 6872 9647
Adamthwaite	*SD 7082 9982*	*SD 7111 9993*
Wandale Hill east	*SD 7056 9843*	*SD 7048 9843*
Backside Beck	SD 6988 9777	SD 6984 9803
River Rawthey (Handley's Bridge)	*SD 7075 9778*	*SD 7041 9732*
Far Gill	*SD 7080 9743*	*SD 7062 9747*
Middle Gill	*SD 7073 9719*	*SD 7056 9730*
Near Gill	*SD 7054 9704*	*SD 7031 9722*
River Rawthey (Wardses)	SD 6942 9590	SD 6968 9663
River Rawthey (Beck Side)	SD 6942 9590	SD 6918 9547
River Rawthey (Cocks Dub)	SD 6918 9506	SD 6912 9527
River Rawthey (Crookholm)	SD 6914 9494	SD 6895 9473
Crosshaw Beck	SD 6935 9407	SD 6890 9387
Hebblethwaite Hall Gill	SD 6919 9318	SD 6938 9323
Hebblethwaite Hall Gill	SD 6881 9296	SD 6863 9292
Hobdale Beck	SD 6823 9415	SD 6804 9449
Little Ashbeck Gill	SD 6733 9347	SD 6730 9378
Ashbeck Gill	SD 6698 9337	SD 6690 9366
Clough River	SD 6914 9165	SD 6830 9167
Holebeck Gill	SD 6876 9107	SD 6878 9098
Dixon Ground Member		
Spen Gill	*SD 7003 9993*	------------------
Stockless Gill	*NY 6951 0000*	------------------
Pickering Gill	SD 6896 9657	------------------
Adamthwaite	*SD 7082 9982*	------------------
Wandale Hill east	*SD 7056 9843*	------------------
River Rawthey (Handley's Bridge)	*SD 7075 9778*	------------------
Middle Gill	*SD 7073 9719*	------------------
Near Gill	*SD 7054 9704*	------------------
River Rawthey (Cocks Dub)	SD 6918 9506	------------------
River Rawthey (Crookholm)	SD 6914 9494	------------------
Hebblethwaite Hall Gill	SD 6919 9318	------------------
Hebblethwaite Hall Gill	SD 6881 9296	------------------

Italicised sections or grid references are outside grid square SD 69.

Table 6 Representative exposures of the Coldwell Formation.

Coldwell Formation	base of section	top of section
Spen Gill	*NY 6991 0015*	------------------
Stockless Gill	*NY 6938 0026*	------------------
Great Randy Gill	SD 6802 9958	------------------
Bowderdale	SD 6795 9976	------------------
Screes Gill	SD 6886 9743	------------------
Gais Gill	*NY 7184 0117*	------------------
Mouth of Backside Beck	SD 6981 9697	*SD 7007 9709*
Mouth of Ecker Secker Beck	SD 6916 9543	------------------
Crosshaw Beck	SD 6867 9382	------------------
Ashbeck Gill	SD 6690 9366	------------------
Knott	SD 6793 9408	------------------
Clough River	SD 6868 9173	SD 6862 9172

Italicised sections or grid references are outside grid square SD 69.

Table 7 Representative exposures of the Wray Castle Formation.

Wray Castle Formation	base of section	top of section
Spen Gill	*NY 6991 0015*	------------------
Stockless Gill	*NY 6938 0027*	------------------
Screes Gill	SD 6885 9744	------------------
Wandale Hill west	*SD 7022 9900*	------------------
Ashbeck Gill	SD 6688 9368	------------------
Knott	SD 6791 9409	------------------
Clough River	SD 6862 9172	

Italicised sections or grid references are outside grid square SD 69.

Table 8 Representative exposures of the Screes Gill Formation.

Screes Gill Formation	base of section	top of section
Carlingill	SD 6287 9972	SD 6340 9943
Deep Slack	SD 6265 9824	SD 6269 9835
Spen Gill	*NY 6991 0025*	*NY 6977 0050*
Stockless Gill	*NY 6938 0022*	*NY 6933 0043*
Kensgriff	SD 6891 9925	SD 6877 9915
Yarlside	SD 6877 9859	SD 6861 9864
Backside Beck	*SD 7003 9710*	SD 6990 9778
Screes Gill	SD 6886 9764	SD 6848 9773
Cautley Spout Gill	SD 6827 9749	SD 6817 9753
Cautley Crags South	SD 6844 9644	SD 6833 9649
Pickering Gill	SD 6862 9630	SD 6842 9628
Lattera Gill	SD 6937 9604	SD 6903 9615
Rooker Gill	SD 6916 9550	SD 6888 9557
River Rawthey (Hobdale Bridge)	SD 6843 9358	SD 6873 9420
Knott	SD 6782 9400	SD 6772 9436
Middle Ashbeck Gill	SD 6687 9368	SD 6670 9388
Upper Ashbeck Gill	SD 6666 9400	SD 6667 9418
Settlebeck Gill	SD 6603 9281	SD 6602 9320
Clough River	SD 6857 9173	SD 6847 9164

Italicised sections or grid references are outside grid square SD 69.

Table 9 Representative exposures of the undivided Coniston Group.

undivided Coniston Group (sandstone units)	base of section	top of section
Black Force	SD 6433 9924	SD 6450 9886
Fairmile Beck	SD 6298 9782	SD 6368 9782
Deep Gill	SD 6719 9912	SD 6683 9902
Middle Grain	SD 6667 9886	SD 6650 9837
East Grain	SD 6678 9903	SD 6726 9809
Screes	SD 6839 9778	SD 6831 9780
Swere Gill	SD 6806 9753	SD 6754 9749
Cautley Crags North	SD 6812 9744	SD 6794 9720
Cautley Crags South	SD 6818 9648	SD 6807 9642
Calf Beck	SD 6660 9672	SD 6643 9668
Calf Beck	SD 6630 9664	SD 6587 9643
Bram Rigg Beck	SD 6700 9623	SD 6628 9593
Long Gill	SD 6778 9592	SD 6768 9600
Hobdale Gill	SD 6737 9518	SD 6724 9582
Hobdale Scar	SD 6696 9474	SD 6706 9483
Crosdale Beck	SD 6408 9374	SD 6458 9377
Millthrop	SD 6609 9122	SD 6599 9122
River Dee (Abbot Holme)	SD 6512 9060	SD 6483 9095
Riggs Quarry	SD 6606 9068	------------------
Clatterbeck	SD 6718 9075	SD 6682 9113
Rash Mill	SD 6568 9010	SD 6583 9000

Italicised sections or grid references are outside grid square SD 69.

Table 10 Representative exposures of the siltstone units within the undivided Coniston Group.

Undivided Coniston Group (siltstone units)	base of section	top of section
Wotey Gill siltstone unit		
Weasel Gill	SD 6281 9992	*NY 6308 0018*
Haskaw Gill	SD 6368 9922	SD 6368 9918
Carlin Gill	SD 6392 9928	SD 6393 9924
The Spout	SD 6458 9948	SD 6463 9956
West Grain	SD 6639 9957	SD 6648 9961
Bowderdale	SD 6782 9900	------------------
Screes Gill	SD 6848 9773	SD 6839 9778
Cautley Spout Gill	SD 6817 9753	SD 6806 9753
Cautley Crags South	SD 6833 9649	SD 6818 9648
Cautley Crags North	SD 6820 9744	SD 6812 9744
Grimes Gill Head	SD 6821 9587	SD 6818 9566
Ashbeck Gill	SD 6671 9387	SD 6665 9401
Upper Ashbeck Gill	SD 6667 9418	SD 6661 9438
Settlebeck Gill	SD 6602 9327	SD 6596 9342
Crosdale Beck	SD 6428 9368	SD 6447 9374
Clough River	SD 6845 9164	SD 6842 9168
Thorny Hills	SD 6799 9000	------------------
East Grain siltstone unit		
Midgehole	SD 6235 9777	------------------
Fairmile Gate	SD 6272 9777	SD 6283 9781
Fairmile Beck	SD 6400 9822	------------------
East Grain	SD 6676 9907	------------------
East Grain	SD 6687 9898	------------------
East Grain	SD 6697 9870	------------------
Swere Gill	SD 9754 9749	SD 6752 9744
Hobdale Scar	SD 6699 8978	SD 6708 9000
West Grain siltstone unit		
River Lune	SD 6240 9730	------------------
Blind Gill	SD 6396 9777	SD 6387 9773
Fell Head Scar	SD 6471 9801	------------------
West Grain Head	SD 6600 9842	SD 6601 9836
Middle Grain	SD 6648 9796	------------------
Middle Grain Head	SD 6683 9748	------------------
Calf Beck	SD 6669 9670	SD 6660 9672
Comb Gill	SD 6550 9452	------------------
Abbot Holme	SD 6493 9075	------------------

Italicised sections or grid references are outside grid square SD 69

Table 11 Representative exposures of the Bannisdale Formation.

Bannisdale Formation	base of section	top of section
River Lune (Fleet Holme)	SD 6247 9702	SD 6223 9646
River Lune (Black Dub)	SD 6200 9594	SD 6260 9537
Castley Knotts	SD 6437 9674	SD 6420 9630
Strangler Gill	SD 6600 9754	SD 6577 9759
Ragger Gill	SD 6551 9723	SD 6523 9719
Calf Beck	SD 6587 9643	SD 6580 9642
Bram Rigg Beck	SD 6602 9589	SD 6590 9593
Rowantree Grains Gill	SD 6610 9573	SD 6622 9554
Swarth Greaves Beck	SD 6567 9500	SD 6507 9572
Swarth Greaves	SD 6454 9526	SD 6464 9547
River Lune (Firbank)	SD 6310 9314	SD 6272 9483
River Lune (Winster's Hole)	SD 6262 9163	SD 6283 9196
Killington Bridge	SD 6238 9126	SD 6213 9043
Elysian Shades	SD 6506 9108	SD 6513 9114
Millthrop Bridge	SD 6619 9138	SD 6614 9139
Holme Fell	SD 6416 9029	SD 6427 9024
sandstone units		
Ragger Gill	SD 6573 9725	SD 6551 9723
Crook of Lune	SD 6242 9663	SD 6236 9654
Calf Beck	SD 6563 9641	SD 6529 9643
Long Rigg Beck	SD 6482 9680	SD 6450 9602
Crowder's Leaps	SD 6317 9238	SD 6313 9254
Lincoln's Inn Bridge	SD 6293 9204	SD 6316 9221
Farthing Hole Dub	SD 6257 9156	SD 6238 9125
Lords' Dub Loups	SD 6392 9111	SD 6390 9114
Birks Mill	SD 6513 9114	SD 6506 9136
Akay Dub	SD 6595 9128	SD 6592 9128
Holme Fell	SD 6423 9014	SD 6420 9008

Italicised sections or grid references are outside grid square SD 69.

Table 12 Known exposures of dolerite in the Howgill Fells.

Dolerite	grid reference	**Dolerite**	grid reference
Wards Intake	*SD 7147 9763*	Crosshaw Beck	SD 6951 9415
Bluecaster	*SD 7127 9713*	Marsh Lane	SD 6928 9429
Bluecaster Side	*SD 7011 9632*	*Wandale Hill east*	*SD 7068 9823*
Taythes Gill	*SD 7080 9517*	Wandale Hill west	SD 6987 9817
Intake Gill	SD 6989 9599	Ben End	SD 6938 9776
Ecker Secker Beck	SD 6963 9554	Ben End Beck	SD 6921 9755

Italicised exposures are outside grid square SD 69.

Table 13 Exposures of felsite in the Howgill Fells.

Felsite intrusions	grid reference	**Felsite intrusions**	grid reference
Stock Gill	SD 6593 9965	River Rawthey	SD 6968 9654
Backside Beck	SD 6948 9837	West Gill	SD 6984 9659
Backside Beck	SD 6957 9849	West Gill	SD 6994 9656
Backside Beck	SD 6963 9860	Foxhole Rigg	SD 6957 9514
Mountain View	SD 6968 9885	Ecker Secker Beck	SD 6964 9553
Backside Beck	SD 6971 9839	*Taythes Gill*	*SD 7050 9593*
Mountain View	SD 6976 9884	*Taythes Gill*	*SD 7058 9588*
Mountain View	SD 6988 9853	*Taythes Gill*	*SD 7077 9535*
Sally Beck	*SD 7168 9815*	*Taythes Gill*	*SD 7083 9528*
Far Gill	*SD 7081 9743*		

Italicised exposures are outside grid square SD 69.

Table 14 Exposures of lamprophyre intrusions in the Howgill Fells.

Discordant lamprophyres	grid reference	**Discordant lamprophyres**	grid reference
Carlingill	SD 6253 9972	Cautley Crags	SD 6813 9645
Carlingill	SD 6358 9967	Cross Keys	SD 6986 9698
Langdale	SD 6679 9974	Cross Keys	SD 6992 9684
Deep Gill	SD 6687 9094	Ecker Secker Beck	SD 6956 9552
Great Randy Gill	SD 6884 9955	Ecker Secker Beck	SD 6970 9566
Backside Beck	SD 6960 9903	Middle Tongue	SD 6582 9449
Stockless Gill	SD 6966 9988	Whinny Gill	SD 6994 9427
Backside Beck	SD 6976 9966	Birksfield Beck	SD 6961 9489
Sprintgill	*SD 7194 9911*	Ashbeck Gill	SD 6691 9365
East Grain	SD 6691 9883	Ashbeck Gill	SD 6703 9324
Watley Gill	SD 6931 9894	Crosshaw Beck	SD 6888 9384
Watley Gill	SD 6947 9888	Killington Bridge	SD 6224 9077
Backside Beck	SD 6977 9820	Killington Bridge	SD 6227 9093
Mountain View	*SD 7003 9890*		
Sally Beck	*SD 7200 9886*	**Concordant lamprophyres**	grid reference
River Rawthey	*SD 7030 9727*	Backside Beck	SD 6971 9839
River Rawthey	*SD 7090 9779*	Backside Beck	SD 6964 9852
River Rawthey	*SD 7099 9792*	Pickering Gill	SD 6907 9674
River Rawthey	*SD 7112 9794*	*Fairy Gill*	*SD 7058 9621*
Ward's Intake Bridge	*SD 7148 9763*	*Ecker Secker Beck*	*SD 7015 9594*
Low Gill	SD 6177 9638	*Ecker Secker Beck*	*SD 7032 9597*
River Lune	SD 6338 9656	Whinny Gill	SD 6986 9424
Calf Beck	SD 6618 9666	Crosshaw Beck	SD 6938 9412
Pickering Gill	SD 6887 9655	Crosshaw Beck	SD 6947 9413

Italicised exposures are outside grid square SD 69.

Table 15 Representative exposures of the Sedbergh Conglomerate southeast of the Howgill Fells.

Sedbergh Conglomerate	base of section	top of section
Whinny Gill	***SD 7004 9433***	------------------
Hebblethwaite Hall Gill (Cowpasture)	**SD 6937 9323**	SD 6983 9333
Hebblethwaite Hall Gill (Ghyllas Wood)	SD 6742 9258	SD 6860 9290
River Rawthey (Iseman's Dub)	**SD 6844 9357**	SD 6847 9352
River Rawthey (Mackereth)	SD 6847 9338	SD 6814 9300
River Rawthey (Straight Bridge)	**SD 6767 9226**	SD 6800 9274
Little Dovecote Gill	**SD 6918 9194**	SD 6934 9203
Great Dovecote Gill (east)	**SD 6937 9192**	SD 6921 9183
Great Dovecote Gill (west)	**SD 6910 9175**	SD 6921 9183
Clough River (Tom Croft Hill)	**SD 6939 9148**	SD 6937 9148
Clough River (Tom Croft Hill)	**SD 6933 9150**	SD 6928 9153
Clough River (Sparram Ford)	**SD 6916 9162**	SD 6928 9153
Holebeck Gill	**SD 6878 9096**	**SD 6872 9059**
Little Ashbeck Gill	SD 6738 9323	SD 6740 9300
Settlebeck Gill	SD 6605 9268	SD 6623 9250

Italicised localities or grid references are outside the boundaries of sheet SD 69. Grid references in bold type expose the basal unconformity.

Table 16 Representative exposures of Carboniferous units southeast of the Howgill Fells, within sheet SD 69

Nor Gill Sandstone Formation	base of section	top of section
Nor Gill	SD 6983 9332	SD 6987 9333
Penny Farm Gill	SD 6978 9322	SD 6982 9313
Penny Farm Gill Dolomite Formation		
Nor Gill	SD 6987 9333	SD 7000 9362
Penny Farm Gill	SD 6982 9313	SD 6987 9317
Great Scar Limestone Group		
Penny Farm Gill	SD 6987 9317	SD 7000 9313
Clough River	SD 6947 9148	SD 6967 9131
Wensleydale Group		
Great Dovecote Gill	SD 6943 9192	SD 7000 9215
Clough River	SD 6967 9131	SD 7100 9127