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The Upper Palaeozoic rocks and Quaternary deposits of the Shap and Penrith district, Cumbria (part of Sheet 30, England and Wales)

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The Upper Palaeozoic rocks and Quaternary deposits of the Shap and Penrith district, Cumbria (part of Sheet 30, England and Wales)

Michael McCormac

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Carboniferous, Devonian, Lithostratigraphy, Limestone, Palaeontology, Glaciation.

Front cover

Limestone scar below crest of Lang Scar Pike, Crosby Ravensworth Fell, Cumbria. Wavy bedded, coralline limestone of the early Asbian Potts Beck Limestone Formation.

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Dr C R Rowley (formerly of Portsmouth University, now retired)
Dr Richard A Hughes (BGS)

Dr Colin Rowley (formerly of the University of Portsmouth, now retired) mapped part of the present area during the course of his PhD research during the early 1960s. Dr Rowley made available to the BGS his original field-slips during the course of the present resurvey work, and his generosity is most gratefully acknowledged.

NOTES

All grid references given in brackets [ ] throughout the report are within the 100 km square NY.

Contents

Summary

This report describes the distribution, lithology, structure and stratigraphic classification of Upper Palaeozoic rocks and overlying drift deposits found within the area of 1:10 000 sheets NY 42 NW, NY 42 NE, NY 42 SE, NY 50 NE, NY 51 NW, NY 51 NE, NY 51 SE, NY 52 NW, NY 52 SW, NY 50 NE, NY 60 SW and NY 60 SE. The report is based on field survey, air photogrammetrical interpretation and biostratigraphical analysis carried out between 1998 and 2000 in the course of systematic revision of the 1:50 000 map of the Appleby area (British Geological Survey Sheet 30).

The succession described includes conglomerate and sandstone beds deposited in a Devonian continental rift system, overlain by a laterally variable sequence of terriginous and marine clastic rocks and shelf carbonates laid down on the northern margin of the Carboniferous Stainmore Trough. Permian dune-bedded sandstones comprise a partly eroded cover to the Carboniferous.

The boulder clay deposits and erosional landforms created during the last Devensian ice age are described. Noted also, are tectonised sand and gravel deposits related to ice advance and retreat in the Ullswater valley.

The history and current extent of mineral working for limestone, sandstone, aggregate and coal are also outlined.

1 Introduction

This report describes the Upper Palaeozoic rocks and overlying Quaternary deposits found within the area of 1:10 000 sheets NY 42 NW, NY 42 NE, NY 42 SE, NY 50 NE, NY 51 NW, NY 51 NE, NY 51 SE, NY 52 NW, NY 52 SW and parts of NY 50 NE, NY 60 SW and NY 60 SE (Figure 1). The report is based on field survey carried out by the author between 1998 and 2000 but also incorporates findings of biostratigraphical analysis carried out (Dean, 2001) on a rock sample suite collected during the course of the field survey and previous work listed below (1.1).

The district described in this report lies in the Edenside area of Cumbria, immediately east of the Lakeland Fells, and located between the village of Tebay in the south and the town of Penrith in the north (Figure 1). The district is dominated by a west-facing, stepped escarpment of Carboniferous limestone orientated south-east to north-west. This is a bold, in places rocky, feature rising to an elevation of 300 to 400 m OD along much of its length. The escarpment is broken at Penrith by the valley of the River Eamont, whereas farther south, the feature is breached by narrow defiles occupied by the Rivers Lowther and Leith. To the west, the ground rises progressively to the Lakeland Fells, except in the area west of Penrith where a group of isolated sandstone hills, the Mell Fells, intervene. To the east of its crest, the escarpment presents an irregular slope dipping into the Vale of Eden.

Land use is largely agricultural, much of marginal quality, and includes small areas of forestry. South and west of Penrith, areas are given over to light industrial estates and housing developments. Small derelict limestone and sandstone quarries are a common feature of the district, but two major quarry sites, both close to Shap village, continue to provide limestone for the construction and steel-making industries.

The district encompasses two major highways (Figure 1); the M6 'corridor', which transects the district from north to south and the A66 following the Eamont Valley. Pre-construction highway site investigation works have provided the BGS with borehole transects along the length of both routes. These new data have aided the current map revision.

1.1 HISTORY OF RESEARCH

The first systematic geological survey of the district (outlined on Figure 1) was carried out at the six inch scale between 1892 and 1894 by J R Dakyns, W H Dalton, J G Goodchild, E J, Herbert, T McK Hughes, G H Lightfoot and R Russell. Aspects of the geology were published in a memoir (Dakyns et al., 1897).

Mapping, as part of regional stratigraphic studies of the Lower Carboniferous, was carried out independently

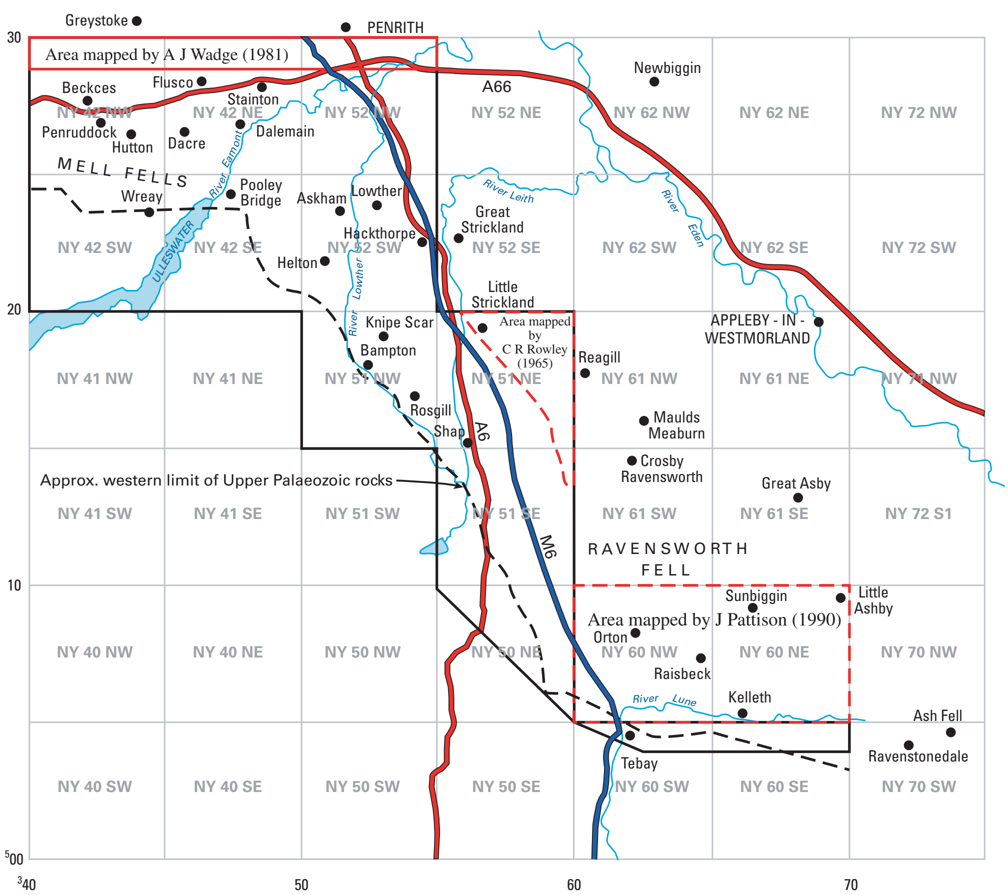


Figure 1 Location map showing extent of district and previous mapping described in the report.

between 1910 and 1930 by E J Garwood and J S Turner. The results of these studies were published in appropriate journals (Garwood, 1913; Miller and Turner, 1931) and Turner's 6 inch field-slips are retained in the British Geological Survey archive. Garwood's study included the collection and curation of faunal assemblages from the Dinantian succession of the Shap area. This remains a key, and to date unique, palaeontological reference work for the district.

In 1954a, J G Capewell published a detailed account of the nature and provenance of the 'basement beds' of Dakyns et al., (1897), the clastic rocks underlying the main Carboniferous succession in the west of the district.

Parts of quarter sheets NY 51 NE and NY 51 SE, located east of the River Leith (Figure 1), were the subject of PhD thesis mapping, at 6 inch scale, by Dr C R Rowley between 1961 and 1964. Dr Rowley has kindly allowed his map work and field observations to be incorporated in the current resurvey.

The northern margins of 1:10 000 sheets NY 42 NW, NY 42 NE and NY 52 NW were surveyed systematically as part of the Penrith Sheet (24) by A J Wadge between 1967 and 1968. An account of this work is given in a memoir (Arthurton and Wadge, 1981).

Recent PhD work by Ashton (1971) addressed the sedimentology of the early Dinantian carbonate succession of Cumbria while Kimber (1987) revisited the basal clastic rocks described earlier by Capewell (1954a). Neither produced maps of the district, but detailed accounts of type sections were presented.

2 Basin development and stratigraphical nomenclature

Post-orogenic sedimentation in the north of England area, began in Late Devonian times with the formation of molasse-style basins, probably in response to localised Caledonian fault reactivation. The basin fill was uplifted and peneplaned, prior to an episode of basalt magmatism that accompanied the development, in the early Carboniferous, of an extensionally driven regional block and basin system (Gawthorpe et al., 1989). The area considered in this report, hereinafter 'the district', overlaps the somewhat diffuse boundary between three major components of this system; the Lake District Block on the west, the Alston Block to the east and the Stainmore Trough to the south. The region as a whole underwent progressive, cyclical marine submergence (Ramsbottom, 1973) during the Dinantian.

Marine sedimentation began in Courceyan times, in the Stainmore Trough. This initial marine incursion was followed by a return to continental conditions, with rivers feeding coarse-grained arkosic sediment across the whole of the district from the north and west.

Marine conditions were re-established in the Stainmore Trough during the Chadian, and quickly spread onto the flanks of the blocks. All but the northern margin of the district was inundated at this time, and remained so until a fluvial-deltaic system, spreading from the north-east (Leeder, 1982), occupied the district in late Arundian times. However, even during relative sea-level maxima, the district was never deeply submerged; coastal plain, peri-tidal and lagoonal bioclastic carbonates figure prominently. Regressive interludes are represented by periods of non-deposition and interformational unconformities while short-lived emergence cycles gave rise to palaeokarstic surfaces and palaeosols.

The start of the Holkerian was marked by a major marine transgression which established shallow, inshore marine ramp environments over the district, and all but the core of the Lake District Block (Mitchell et al., 1978). Successively, more offshore inner ramp environments occupied the northern flank of the Stainmore Trough, including the southern margin of the district.

Towards the close of the Holkerian, periodic emergence and palaeosol formation became common. By that time, the carbonate ramp had evolved into a platform, on which water depths were generally less than 20 m, rendering wide areas of the platform emergent during lowstands. The Asbian platform carbonate succession in the district shows a cyclicity similar to that in the southern Lake District and north Lancashire (Horbury, 1989). Cycle boundaries are marked by palaeokarstic surfaces, commonly overlain by bentonitic clay palaeosols derived from volcanic ash falls. During some emergence phases, karstic surfaces were overridden by incursions of fluviodeltaic sediment. This pattern of sedimentation presaged the pattern of 'Yoredale' depositional cyclicity (Taylor et al., 1971) which became established at the end of the Asbian and persisted through to the early Namurian, when fully deltaic conditions were established.

From the Namurian through to the mid-Westphalian, supply of river-borne terrestrial sediment from the north and east balanced local subsidence sufficiently to maintain a freshwater deltaic environment with only brief marine incursions. Later in the Westphalian (the timing is imprecise) the north-west England area took on a continental aspect with red-bed deposition. Finally, at the end of the Carboniferous, sedimentation was terminated by Hercynian uplift and faulting.

Permian sediments were deposited across the eroded surface of the Carboniferous rocks. The rocks were deposited under desert conditions, filling a north-west trending half-graben, coincident in geometry and extent to the present day Vale of Eden. In some authors' views, the north-west England area was subject to periodic marine submergence during the Mesozoic era accumulating a now eroded pile of Early Jurassic and Cretaceous estuarine and marine sediments. Estimates of subsequent uplift across the Lake District block vary widely, but as much as 1.5 km could have occurred (Akhurst et al., 1997).

During the Quaternary, successive episodes of glaciation left extensive deposits of drumlinised boulder clay, gravel and lacustrine clays filling the valleys and flanks of the Eamont, Lowther and Eden rivers.

2.1 STRATIGRAPHICAL NOMENCLATURE

The lithostratigraphic succession of the district has never been formerly defined. The primary survey (Dakyns et al., 1897) assigned all Carboniferous rocks in the district to the 'Carboniferous Limestone Series' and overlying 'Millstone Grit'. Some of the more prominent limestone beds were identified with names derived earlier by Philips (1836) and a local naturalist, J S Bland (1862). Garwood (1913), devised a biostratigraphical classification of the Dinantian outcrop of north-west England, which included a part of the district. Garwood's work identified a number of macrofaunal beds which, though not always as unique as the author claimed, provide a chronostratigraphical framework for the Carboniferous of the district which remains valid today (Figure 2). Garwood also coined names for many of the major rock units in the area and these names have, with modification and refinement (e.g. Miller and Turner, 1931; Ramsbottom, 1973 and George et al., 1976), gained general acceptance.

In more recent times, the district has been included in regional reviews (Taylor et al., 1971; George et al., 1976; Mitchell et al., 1978). In these, the district is treated, somewhat erroneously, as an extension of the Ravenstonedale area, which has become a classic study area for the lower Carboniferous.

The group level nomenclature has been completely revised, and is that recommended by the British Geological Survey Carboniferous Stratigraphy Committee for use over the whole of northern England (Figure 3). Pertinent to the district described here is a new formation level lithostratigraphical scheme (Figure 3) erected by Pattison (1990) during revision mapping of the Dinantian of the adjacent Orton/Asby area. Pattison's scheme has been successfully applied to the south and

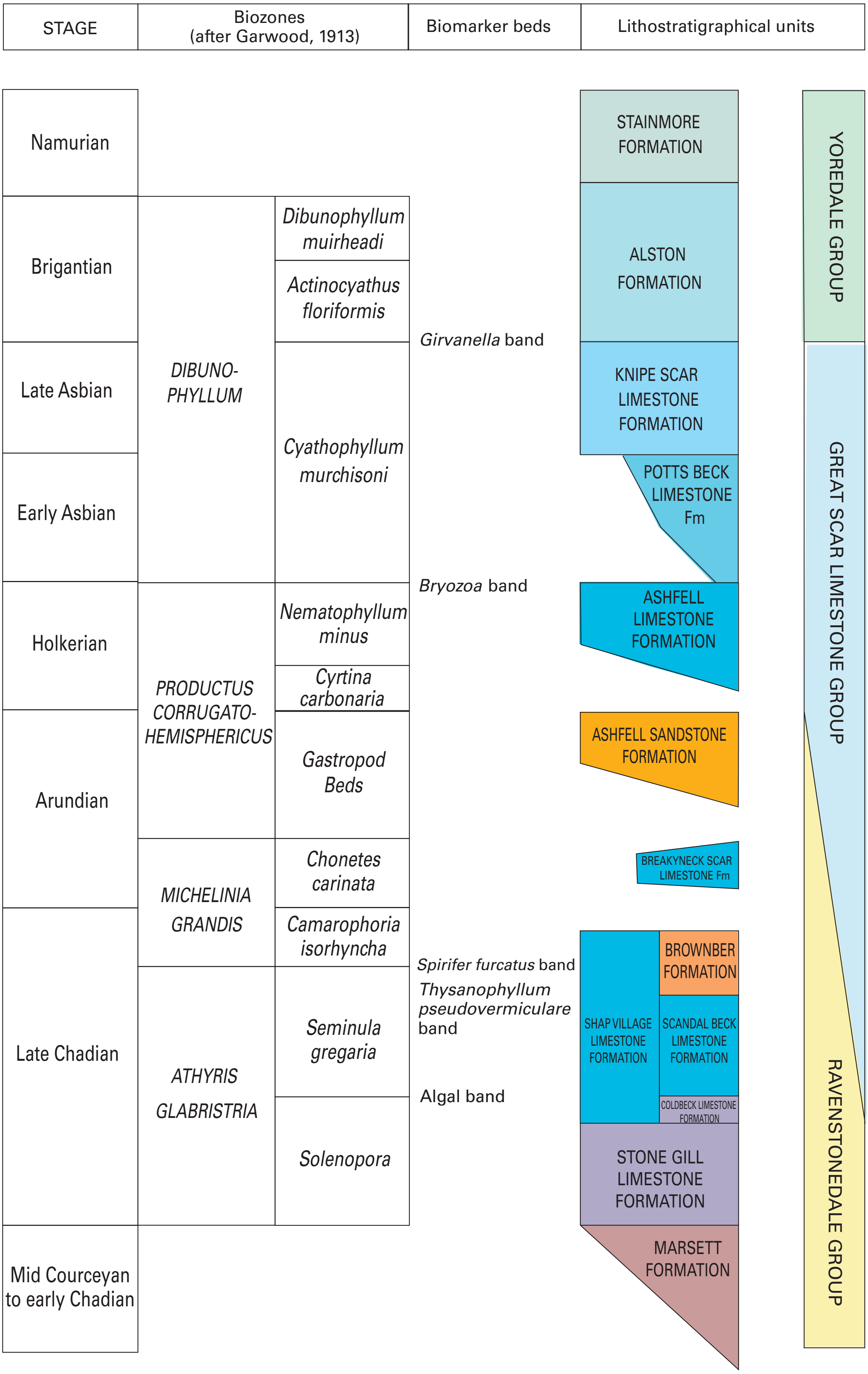


Figure 2 Chart showing age range and biozonal classification of Carboniferous rocks present in the district.

AGE	GROUP**	Fms: Appleby and Shap area	Formations: Orton area	Formations: Penrith area	Members
Arnsbergian-Pendleian	YOREDALE GROUP	STAINMORE FORMATION			
Pendleian		ALSTON FORMATION			Great Limestone Member
Brigantian					Iron Post Limestone Member Four Fathom Limestone Member Three Yard Limestone Member Five Yard Limestone Member Scar Limestone Member Single Post Limestone Member Tynebottom Limestone Member Jew Limestone Member Lower Little Limestone Member Askham Limestone Member Wintertarn Sandstone Member
Upper Asbian	GREAT SCAR LIMESTONE GROUP	KNIPE SCAR LIMESTONE FORMATION		ESKETT LIMESTONE FORMATION	White Limestone Member Fourth Shale Member Fifth Limestone Member Fifth Shale member
Lower Asbian		POTTS BECK LIMESTONE FORMATION			Sixth Limestone Member
Holkerian		ASHFELL LIMESTONE FORMATION		SEVENTH LIMESTONE FORMATION	
Arundian	GREAT SCAR LIMESTONE GROUP / RAVENSTONEDALE GROUP	ASHFELL SANDSTONE FORMATION			
Chadian		SHAP VILLAGE LIMESTONE FORMATION	BREAKYNECK SCAR LIMESTONE Fm * BROWNBER FORMATION * SCANDAL BECK LIMESTONE Fm * COLDBECK LIMESTONE FORMATION *		
		STONE GILL LIMESTONE FORMATION			
(Age range uncertain)	RAVENSTONEDALE GROUP	MARSETT FORMATION			
Courceyan			PINSKEY GILL BEDS		
Fammenian-Courceyan (or older)	UPPER OLD RED SANDSTONE GROUP	Blind Beck Sandstone Member SHAP WELLS CONGLOMERATE FORMATION		MELL FELL CONGLOMERATE Fm.	

* after Pattison 1990
**New BGS lithostratigraphical groups

Figure 3 Lithostratigraphical chart for the Devono-Carboniferous succession of the district.

central parts of the district, albeit in simplified form. The Dinantian succession in the northern part of the district was the subject of resurvey work carried out for the Penrith 1:50 000 sheet (Arthurton and Wadge, 1981). The nomenclature adopted by these surveyors is largely retained in this account, though the rank of some rock units has been adapted to fit with current stratigraphical practice (Figure 3).

For his PhD work, Rowley used a modified version of the nomenclature of Dakyns et al., (1897) for the principal limestone beds in the Yoredale succession (see Rowley, 1969, table 1). However, with the exception of the Askham Limestone (4.3.1.2), the nomenclature used in this report, and the accompanying BGS 1:10 000 geological sheets, is that of the adjacent BGS 1:50 000 sheets 31 and 24 (Brough-under-Stainmore, Burgess and Holliday, 1979; Penrith, Arthurton and Wadge, 1981). This nomenclature (Figure 3) is used widely on BGS 1:50 000 sheets over much of northern England, and is applied here to avoid the proliferation of local names.

3 Devonian

3.1 UPPER OLD RED SANDSTONE GROUP

Dakyns et al., (1897) originally mapped a single unit of 'basement beds' separating the main Dinantian limestone succession from the underlying Lower Palaeozoic basement. However, Capewell (1954a) recognised that these beds were arranged into two superimposed units. These comprise a lower, laterally discontinuous, red-bed succession unconformably overlain by an upper, mixed marine and terriginous clastic sequence that is contiguous with the overlying Dinantian limestone succession (Figure 4).

In accord with Taylor et al., (1971), the rocks of the lower succession are assigned to the Upper Old Red Sandstone lithostratigraphical group, because they were laid down in a continental, desert setting of moderate relief. Though lacking fossils that are biostratigraphically diagnostic, the rocks are considered, on regional evidence, to be of Late Devonian to earliest Carboniferous age. Modern analogues suggest that these coarse-grained deposits were laid down in north to north-north-east flowing, high energy, braided river systems (Kimber and Johnson, 1984) flanked by fault-aligned linear arrays of coalescent alluvial fans.

The rocks are found at three separate outcrops within the district (Figure 4). The first extending from the foot of Ullswater and the Mell Fells, northwards to the Carboniferous escarpment near Dacre [459 265]. The rocks have accumulated in a fault-bounded trough, the Mell Fell trough, which covers an area of some 15 km^2 The second extends from Shap railway summit [576 105], south-east along the valley of the Birk Beck, into the Lune Valley. The rocks here are contained in a smaller, topographically bounded trough, the Shap Wells trough. An isolated occurrence of boulder conglomerate in the Heltondale Beck [506 207] may represent a remnant of a third trough, possibly preserved on the line of the Rosgill Moor Fault (6.1.1).

3.1.1 Mell Fell trough

All sedimentary rocks preserved here belong to the Mell Fell Conglomerate Formation. Capewell (1954a) arbitrarily divided the succession into three superimposed units. The lowest unit consists largely of cobble conglomerate up to 900 m thick, overlain by two upper units of finer grained rocks, 360 and 180 m thick respectively. This gives a cumulative total of nearly 1500 m of sediment preserved within the trough. However, it is almost certainly the case that the lower conglomerate unit thins laterally across the trough (Capewell, 1954a, fig. 2) and the total is more likely less than 1000 m.

The cobble conglomerate beds crop out along the southern margin of the trough in a belt extending from Pooley Bridge [470 244] in the east to Troutbeck [390 260] in the west. The outcrop is largely free of superficial glacial deposits but exposure is poor, except on the steep flanks of Mell Fell [397 255], Little Mell Fell [423 240] and in stream sections south of Soulby Fell [457 248].

The most accessible section is seen in a road cutting on the A592 [4603 2400] at the foot of Ullswater. The conglomerate is generally dark red-brown in colour, clast-supported, very poorly sorted, with clast size in the range 1 cm to 0.5 m. The clasts are quite well rounded and are mainly composed of greywacke, graptolitic sandstone, limestone, and igneous material of Borrowdale Volcanic Group affinity. The sedimentary clasts are shown to belong to the Windermere Supergroup as they contain a lower Ludlovian monograptid, *Monograptus colonus* (Dean, 2001).

The conglomerate can seem almost structureless, but graded-bedding, pebble imbrication, and weak channelling can be discerned in the Ullswater exposure. The overall dip direction is towards the north at 10 to 12 degrees.

The degree of rounding of the large clasts is unusual for such a coarse-grained proximal deposit. As is the case with Devonian rocks in other parts of northern Britain, this may indicate that the clasts are reworked from a pre-existing deposit, probably a subaerial desert regolith.

The upper two units consist of finer grained, red-brown coloured pebble-conglomerates interbedded with coarse-grained lithic sandstone and lenses of cobble-conglomerate. The greater part of the outcrop is concealed beneath thick Quaternary deposits, but a laterally near continuous section is exposed along the course of the Dacre Beck between the villages of Hutton [435 266] and Dacre [468 263] and in Greaves Beck between [439 252] and [447 263]. Up to 10 m of vertical section are also exposed in bluffs flanking the beck in the grounds of Dalemain House [475 269] and the Skitwath Beck at Holghyll [424 272]. These finer-grained rocks are well bedded and dip at 10–20° to the east-north-east.

3.1.2 Shap Wells trough

The floor of the trough and its rock fill are extensively exposed in the valley of the Birk Beck between the Shap Wells Hotel [579 096] and Greenholme [598 058]. Two units are present, both of red-bed facies, the Shap Wells Conglomerate Formation and the Blind Beck Sandstone Member (Figure 4).

The Shap Wells Conglomerate Formation consists of up to 150 m of dark red-brown or green, poorly sorted, imbricate, lithic, cobble conglomerate, interbedded with dark red or grey-red mudstone. The rocks vary rapidly in thickness and appear to be banked against the western and southern margin of the trough, though the bedding is not steeply inclined, on average only 5–6°, locally increasing to 15°. Capewell (1954a) considered that the deposits were laid down in a set of periodically submerged, coalescent alluvial debris fans. Capewell considered the submergence of the fans to have been accomplished by an incursion of marine waters from the east. They have been reinterpreted as having formed in a lacustrine, playa or small rift lake environment.

The Blind Beck Sandstone Member consists of up to 200 m of cross-bedded, brick-red, fluvial channelled sandstone with siltstone interbeds. They contain a large component of well rounded sand grains with hematite pellicles (Capewell, 1954a), evidence of aeolian provenance.

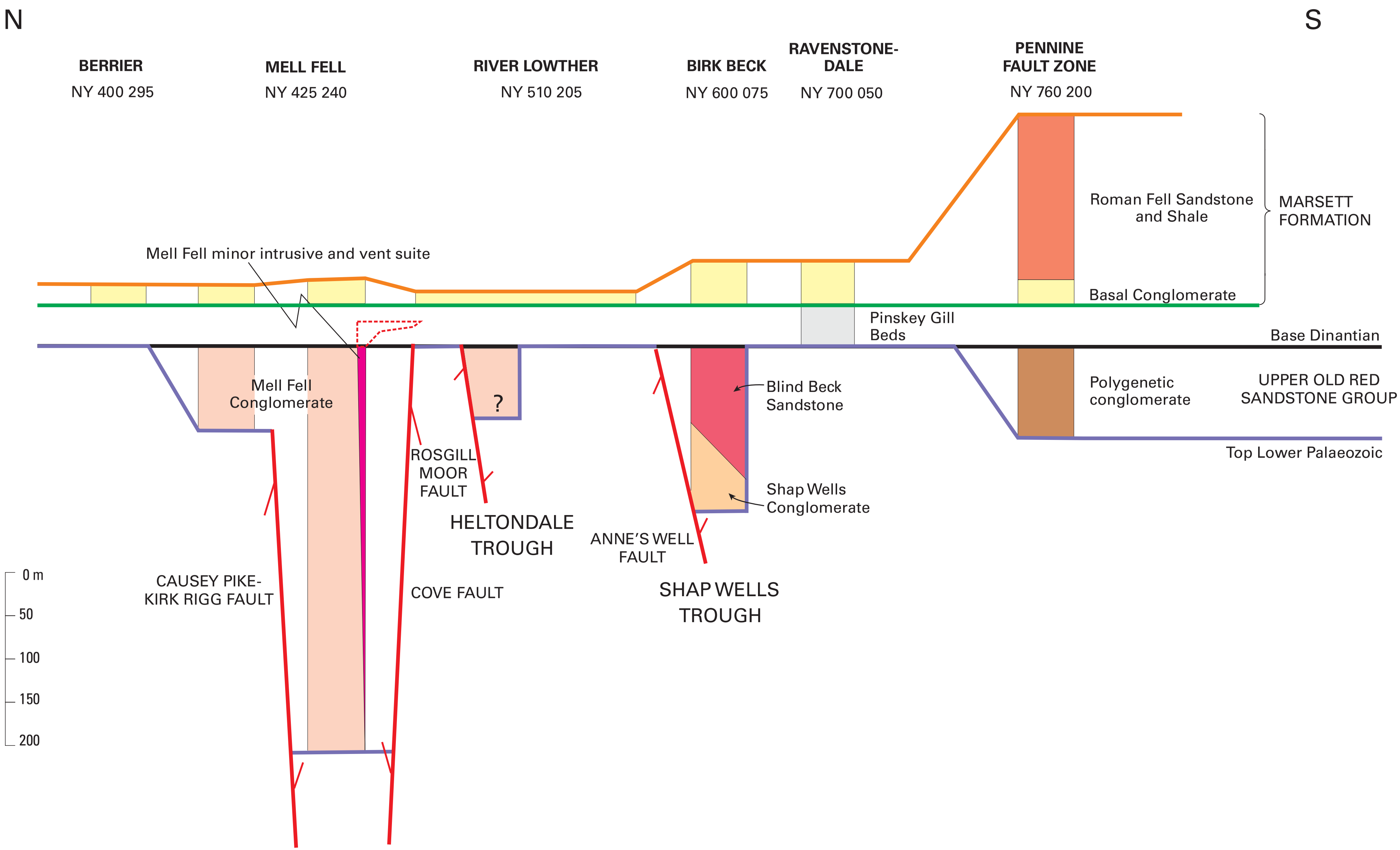


Figure 4 North to south sketch section, illustrating the distribution of ORS troughs and lateral variation in the Dinantian Marsett Formation.

The sandstone beds are well exposed in a 15 m high river cliff associated with Docker Force waterfall [5858 0881]. This feature marks the northern limit, at surface, of the underlying conglomerate. At a locality in the grounds of the Shap Wells Hotel [577 098], the sandstone beds are seen to have overlapped the conglomerates and rest directly on an uneven surface of Lower Palaeozoic basement. The beds were deposited in a braided river system.

3.1.3 Heltondale Beck

A subsidiary occurrence of cobble conglomerate is found in the bed and banks of Heltondale Beck [506 207]. The deposit is largely unstratified, composed of poorly sorted rounded clasts, up to 0.5 m in length, in a matrix of red/brown mudstone-siltstone. The clasts are mainly of Borrowdale Volcanic Group affinity, with a minor component of Windermere Supergroup sandstone and limestone. As such, the deposits are markedly similar to the Mell Fell Conglomerate, as seen at Pooley Bridge (3.1.1), and may be a time-equivalent deposit, possibly preserved in association with the Rosgill Moor Fault (6.1.1). The total thickness of the deposit is unproved. Up to 20 m of section is exposed in the beck, but from topographical evidence, up to 50 m could be present overall.

3.1.4 Minor intrusive and volcanic rocks

A feature of the Mell Fell area is the localised occurrence of a minor intrusive suite. This consists of a small swarm of north–south orientated bosses and dykes associated with a lapilli-tuff filled vent located on the southern flank of Little Mell Fell at Cove [427 241].

The tuff, first described by Capewell (1954b), is a green-grey porous rock containing subangular clasts of locally derived greywacke, siltstone, slaty mudstone and basaltic lapilli. The rock is unbedded but has a strong, vertically orientated fluxion texture.

The dyke rock is a jet black, very fine grained olivine micro-gabbro with vesiculated margins. Geochemical analysis reported by Macdonald and Walker (1985) shows the rock to be of tholeiitic affinity and the authors suggest that it is related to Courceyan age (Mitchell et al., 1978) basalt lavas present in the Cockermouth area (Eastwood et al., 1968) 32 km to the north-west. However, volcanic rocks were erupted at numerous separate locations around the Solway Basin at this time (Taylor et al., 1971), and the Mell Fell occurrence may represent an additional igneous centre.

These shallow intrusive rocks may have fed an eruptive centre, but no lava flows or tuff beds have been found within the Mell Fell Conglomerates, nor the basal beds of the overlying Dinantian limestone succession. It seems likely then, that the surficial deposits were eroded away during the interval prior to the first Dinantian marine transgression.

4 Carboniferous

The Carboniferous succession rests with angular unconformity on deformed Lower Palaeozoic rocks and the Devonian clastic rocks described above (3.1). The main succession in the district consists of three principal units. In ascending order these are; the Ravenstonedale Group, of coastal plain, shallow marine and lagoon facies carbonates and arenites, Chadian to Arundian in age; the Great Scar Limestone Group, almost entirely composed of rhythmically bedded shelf limestone of Holkerian to Asbian age; and the Yoredale Group, with its characteristic alternation of terriginous deltaic and shallow marine facies, of Brigantian and Namurian age.

A fourth unit of Westphalian Coal Measures, is found at outcrop farther north in Cumbria (Arthurton and Wadge, 1981) and may be present in the district, concealed beneath the Permian cover.

The rocks found in the district show stratigraphical and sedimentological affinity to contiguous successions found in north-east Cumbria (Eastwood et al., 1968; Arthurton and Wadge, 1981) and in the western part of the Stainmore Trough (Burgess and Holiday, 1979; Pattison, 1990).

4.1 RAVENSTONEDALE GROUP

The Ravenstonedale Group is a redefined term applied to lower Dinantian rocks previously assigned to the Ravenstonedale and Lower Orton groups of Taylor et al., (1971). Most of the rocks were deposited within a coastal plain environment and turbid, peritidal to shallow marine shelf conditions. They include lime mudstone, pelitoidal/algal limestone, dolostone, oolite, cross-bedded grainstone and calcarenite. Deltaic sandstone and argillite dominate the uppermost part of the group. Good fossil evidence (Garwood, 1913; Holliday et al., 1979; George et al., 1976) shows the group to have been deposited during Courceyan, Chadian and Arundian times.

In the southern part of the district the group is up to 240 m thick. As a whole, the group thins from south-east to north-west (Figure 5) and close to the northern limit of the outcrop, at Hutton John [440 272], the group is an estimated 60 m thick. Garwood (1913) asserted that this attenuation is due to the northward thinning of individual rock units.

The type area for the group (Garwood, 1913; Johnson and Marshall, 1971) lies a little way east of the district around the village of Ravenstonedale [723 040] in the valley of the Scandal Beck and its tributaries. Though containing resistant limestone and sandstone beds, the group is not well exposed in the district. The most complete section is to be found in Force Beck, located to the south of Shap village [5690 1385 to 5765 1360]. The rocks have been previously described by Garwood (1913), and in more detail by Ashton (1971). In conjunction with disused workings located in neighbouring fields, the beck provides a reference section for the Ravenstonedale Group in the Shap area. Other notable exposures are to be found in a river cliff on the east bank of the river Lowther, at Shap Abbey [5478 1550 and 5450 1585]; both sections have been described by Garwood (1913). Otherwise, exposure is restricted to small, albeit numerous, disused limestone and sandstone workings. Cored sections from investigative boreholes located in the southern part of the district have been described by Holliday et al. (1979).

The oldest rocks assigned to the group are the Pinskey Gill Beds which outcrop in Ravenstonedale on the southern margin of the district (Figure 1). In the Shap area [600 090] the beds are absent and the group can be subdivided into four formations, the Marsett, Stone Gill, Shap Village Limestone and Ashfell Sandstone formations (Figure 5). In the adjoining Orton area, west of the M6 motorway (Figure 1), the Shap Village Limestone Formation passes laterally into a shallow marine shelf limestone succession, included in the Great Scar Limestone Group (4.2). Immediately north of Hutton [440 272], the upper part of the Group is cut out by a major east-west trending fault, the Kirk Rigg Fault (6.3.2). Borehole records reported in the primary survey memoir (Dakyns et al., 1897), show that only the Marsett Formation is present north of the fault.

4.1.1 Pinskey Gill Beds

The beds rest on a basement of cleaved Lower Palaeozoic rocks. The basal unconformity is exposed in two tributary becks to the River Lune, east of Tebay, at Flakebridge Farm [6657 0474] and at Scar Sikes Farm [6834 0410]. The unconformity is seen as a remarkably smooth surface dipping regularly at 10º to the north. The rocks below the unconformity are only slightly altered, being stained purple or green and with some calcite veinings. At the localities mentioned above, the unconformity is atypically overlain by beds of black mudstone with interbeds of flaggy sandstone. These are the basal components of the Pinskey Gill Beds, 45 to 50 m of interbedded limestone, mudstone and sandstone deposited during the first marine incursion of the Dinantian. A large proportion of the total succession is exposed in the type section in the bed of the Pinskey Gill [6985 0386–6979 0400] a small watercourse draining off the north flank of the Howgill Fells into the River Lune. The beds contain an impoverished macrofauna, mainly casts of brachiopods. The fauna is described by Garwood (1913), but modern work by Holliday et al. (1979) and Varker and Higgins (1979) on both the stream section and investigative borehole cores, prove an age of mid Courceyan.

From Pinskey Gill, the beds can be traced westwards, through minor outcrops, along the south bank of the River Lune as far as Cotegill [6590 0474]. West of this point, at Langdale [644 050], red beds of the Blind Beck Sandstone Member are present above the unconformity, and there is little doubt that the Pinskey Gill Beds are cut out by a fault hidden below the superficial deposits (Figure 4).

Capewell (1954a) suggested that the Pinskey Gill Beds were deposited concurrently with the Shap Wells Conglomerate Formation (3.1.2). This hypothesis is untenable. The red beds were deposited in a seasonally arid, continental environment, in an area of moderate

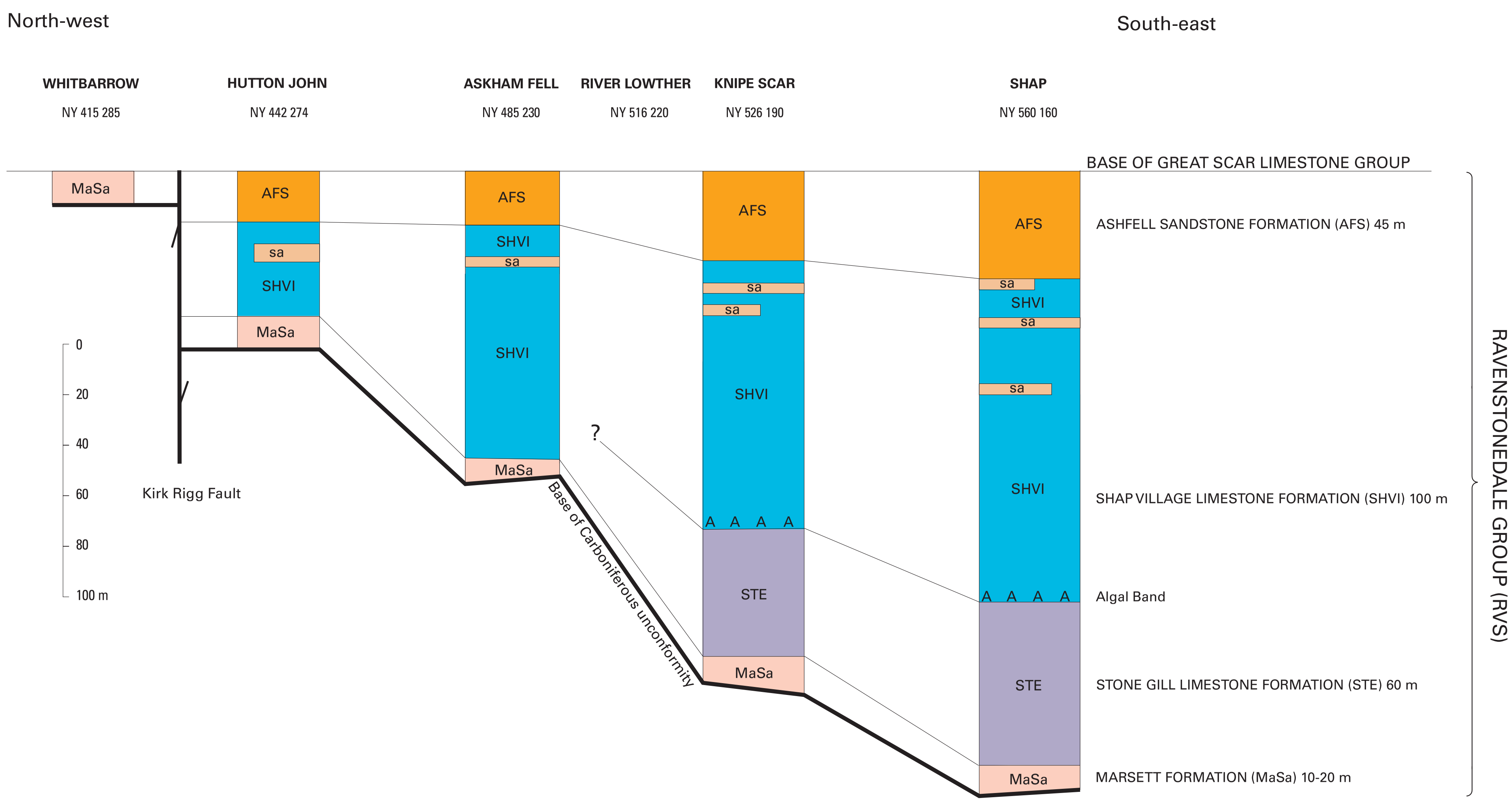


Figure 5 North to south correlation chart showing lateral change in thickness and stratigraphical division in the Ravenstonedale Group, north of the Anne's Well Fault.

relief. The Pinskey Gill Beds were deposited on a planation surface in shallow, low energy marine conditions. A considerable period of time must have elapsed to allow for the evolution of a peneplaned topography and establishment of a marine environment.

4.1.2 Marsett Formation

In the southern part of the district, Dakyns et al. (1897) assigned the lowest clastic beds in the limestone succession to the 'Lower Limestone Shales' division, a formation which, somewhat confusingly, could contain conglomerates that were in other areas included in their 'basement beds'.

This division is now obsolete. The Marsett (Cumbria) Formation, the term used here and throughout Cumbria, is applied specifically to terrestrial and marine clastic rocks laid down in advance of the main Dinantian limestone succession. These include all rocks previously mapped as 'Lower Limestone Shales' and all 'Basement Beds' not otherwise assigned to the Old Red Sandstone Group (see 3.1.1 above).

In the Ravenstonedale district the formation is of Courceyan age. The overlying limestone succession is of Chadian age (Holliday et al., 1979) giving an age range of Courceyan to Chadian for the formation in this area.

In the part of the district located north and west of Penrith the overlying limestone succession is of Holkerian age; in this case, the Marsett Formation may be, in part at least, of Arundian age

The formation has a maximum mapped thickness of about 60 m, but is generally much less, varying in sympathy with topographic irregularities on the underlying basement surface.

At their type locality, the Pinskey Gill Beds are overlain abruptly, by a distinctive suite of conglomerate and lithic sandstone beds. The basal conglomerate is variably reddened, grey to grey-green and, cross-bedded containing locally derived lithic fragments, fragmentary feldspar, and quartz pebbles. Exposures of the conglomerate are found intermittently along the east bank of the River Lowther, especially beside Shap Abbey [5482 1533]. An isolated occurrence is found in the bed of the River Eamont at Dalemain [4812 2675]. Here, the basal conglomerate is cemented with sparry calcite and contains fragments of the underlying Mell Fell Conglomerate, clear evidence that the latter is an older, separate, rock formation.

Dakyns et al. (1897) described a key locality in the railway cutting at Shap summit [5740 1060]. This outcrop can no longer be located, possibly due to expansion of the cutting during rail electrification works.

The conglomerate passes up into, and is interbedded with, current bedded, coarse-grained lithic sandstone interbedded with pale grey or vari-coloured calcareous mudstone. A thick section is accessible in the ravine at Holghyll [4290 2730], and minor occurrences can be found along the course of the Trundle Beck beside Beck Head Farm [5810 1070] and at Shap Wells cottages [5833 0990].

In the south of the district the formation is capped by a thick bed of black mudstone, seen in a railway cutting at Scout Green [593 082] and a nearby road cutting adjacent to the M6 motorway [600 075]. Marine bivalves have been recovered from this mudstone (Day, 1992), but miospores recovered from cored sections in the Ravenstonedale area (Holliday et al., 1979) are of Courceyan to Chadian age.

The top of the formation is exposed in the above mentioned railway cutting, where the dark mudstone is seen to grade abruptly upwards into a bed of calcareous siltstone at the base of the overlying Stone Gill Limestone. No break in sedimentation is seen.

4.1.3 Stone Gill Limestone Formation

The Stone Gill Limestone forms the first major 'step' in the limestone escarpment. It is 50 m thick in the south of the district but thins northwards to about 20–30 m in the Shap–Bampton area (Figure 5). No rocks have been found north of the village of Helton [510 220] that may be unequivocally assigned to this formation.

The formation is composed of a succession of about 1 m thick beds of blocky weathering, very tough, blue-grey porcellanous lime-mudstone/wackestone, alternating with fine grained buff-yellow dolostone. Separating the carbonate beds are thin laminae of pale-grey calcareous siltstone and sandstone. A full section of the formation is exposed in a river cliff on the east bank of the River Lowther at Shap Abbey [5478 1550]. Otherwise, the outcrop is almost entirely covered by Quaternary deposits, with a few minor exposures seen in road cuttings on the A6 at Wickersgill [567 118] and adjacent to the M6 west of Sproat Ghyll Farm [593 087].

The rocks are almost devoid of macrofossils, but thin beds containing clusters of small brachiopods and single gastropod shells are occasionally found. Garwood (1913) described beds in the Shap Abbey cliff containing the alga *Solenopora*, and the late Chadian chronozonal brachiopods *Camarotoechia proava,* and *Athyris glabristria*. Late Chadian-age miospores were recovered from cored borehole sections in the Ravenstonedale area (Holliday et al., 1979).

4.1.4 Shap Village Limestone Formation

The Shap Village Limestone Formation, is a new name to include the fluvial and marginal/shallow marine facies Chadian rocks succeeding the Stone Gill Limestone Formation, where differentiated, in the Shap/Penrith area. It is extended to include equivalent rocks assigned to the 'Ravenstonedale Limestone' in the Alston and Brough areas (Arthurton and Wadge, 1981; Burgess and Holliday, 1979).

The base of the Shap Village Limestone Formation is taken at the base of a unit of thin-bedded limestone/dolostone with siltstone interbeds containing the 'Algal Bed' of Garwood (1913). Garwood (1913) described exposures of the algal bed in a disused quarry, south of Shap village [5680 1385] and in a field north of Keld village [551 150]. In addition to Garwood's localities, now both obscured, the algal bed is well exposed in a disused limestone quarry on the hillside overlooking the Shap railway summit [5705 1134]. The bed, about 20–30 cm thick, occurs near the top of the quarry face in a bed of pale grey, thin-bedded part-dolomitised limestone with siltstone interbeds. The alga appear as crowds of 0.3 to 0.7 cm long ovoids (oncoliths) weathering pale grey in a darker groundmass.

In Force Beck, south of Shap village, the algal beds are overlain by a thick bed of mudstone seatearth. Immediately above, the lower part of the formation, 20–40 m thick, is almost entirely composed of dolostone. The dolostone is continuously exposed in the lower reach of the beck [5690 1385 to 5715 1375]. Here, the rock is flaggy, flat-bedded, buff to grey-buff in colour with a sandy texture. Thin siltstone interbeds are common, some grading to fine-grained sandstone. North of Shap village, the dolostone is commonly exposed in small disused workings [e.g.

530 185]. The rock is similar in nature to that seen in Force Beck, but the bedding is thin and wavy.

The dolomite beds are succeeded by 20–40 m of pale to dark grey, cross-bedded packstone/grainstone with thin interbeds of siltstone and cross-bedded sandstone. In Force Beck the limestone is coincident with a waterfall feature [5716 1373]. The limestone was worked in numerous small quarries along the length of its outcrop, especially in the vicinity of Shap village, giving rise to the old name 'Shap limestone', but also below Knipe Scar [527 187] and on Askham Moor [495 217]. In a disused moorland working at Shap Thorn [5770 1165], the limestone contains shelly horizons containing large specimens of the coral *Dorlodotia* (*Thysanophyllum pseudovermiculare* of Garwood 1913) and fragments of the same have been identified (Dean, 2001) in rocks taken from the above mentioned locality at Knipe Scar.

The limestone is succeeded in all parts of the district by the development of oolitic limestone. At another small waterfall feature in Force Beck [5730 1368] these rocks display a fine, subhorizontal lamination on weathered surfaces which reflects the pattern of finely layered graded bedding in the rock.

In Force Beck a thin bed of fragmented brachiopod shells is found within the oolitic beds. Garwood (1913) referred to this as the 'oatmeal bed' a supposed correlative of his *Spirifer furcatus* bed marking the top of the *Athyris glabristria* Zone (Figure 2).

The uppermost beds in the formation comprise a mixed succession of sandy oolites, pebbly sandstones and calcareous arenites. The beds are exposed in the upper reach of the Force Beck [5744 1368 to 5765 1360], but the section is incomplete due to faulting. The lowest beds seen in the beck are of pale grey/brown rippled calcareous sandstone. The sandstone is overlain by a bed of dark brown, micaceous, cross-bedded sandstone with well-rounded quartz pebbles up to 2 cm in diameter. The remainder of the section consists of pale grey bedded oolites topped with a second pebble bed containing centimetre grade clasts of rounded quartz and calcite.

Not seen in Force Beck, but prominent in old surface workings to both the north [5710 1470], and south [5730 1270], are up to three coarsening-up cycles of flaggy, pale coloured calcareous sandstone and siltstone/mudstone. Interleaved with the sandstone are beds of pale grey, sandy and oolitic limestone grading into a very coarse-grained cross-bedded calcarenite/calcirudite containing conspicuous well rounded clasts of quartz and calcite.

Sporadic shallow workings in the sandstones can be identified along the outcrop at Rosgill Head [549 170], Askham Moor [483 235] and close to the northern limit of the formation at Dacre Bank [4650 2725].

To the north of the River Lowther, neither the Algal band, nor the lithological succession seen in the Force Beck section, may be discerned. The base of the formation is taken as the top of the underlying Marsett Formation.

The coral *Dorlodotia* has been described from several localities in the Shap and Askham area (Dean, 2001), indicating a late Chadian age for the bulk of the formation. Garwood (1913) described a coral/brachiopod fauna typical of his *Camarophoria isoryncha* Subzone at the top of the succession at Shap. In the correlation of George et al., (1976), this would place the upper part of the formation in the Arundian. However, more recently, Riley (1993) argued that rocks containing these fauna in the Ravenstonedale area are all late Chadian in age.

4.1.5 Ashfell Sandstone Formation

The Ashfell Sandstone Formation can be traced across the entire district, and consists mainly of sandstone deposited by rivers flowing from the north-east. The formation consists of up to 50 m of massive or flaggy, orange-weathering, pale grey, cross-bedded, fluvial sandstone with subordinate interbeds of siltstone, mudstone and argillaceous dolostone.

In Force Beck [5759 1361], the base of the formation consists of flaggy, cross-bedded, sandstone resting on a coarsening-up unit of mid-grey, laminated micaceous mudstone and siltstone. Farther up in the succession, beds of calcareous mudstone and sandy limestone have been described (Garwood, 1913; Ashton, 1971) from the upper reach of the Force Beck, now buried under the M6 motorway. A fossil fauna derived from the mudstone has been listed by Garwood which shows the succession to belong to his 'Gastropod Beds' subzone, that is of late Arundian age (Figure 2). As such, the beds are markedly younger than the Shap Village Limestone Formation immediately below (4.1.4), indicating that either a hiatus, or an unconformity exists at the base of the Ashfell Sandstone Formation.

The upper part of the formation is composed entirely of sandstone and contains no diagnostic faunas, but as the overlying Ashfell Limestone is Holkerian (Mitchell et al., 1978) in age, the entire formation must be Arundian.

The sandstone usually forms a single bench feature which can be traced across country from the west-facing scarp of Ravensworth Fell in the south to the Eamont valley. In many places the feature is topped by a line of shallow pits, with larger abandoned workings present at Ravensworth Fell [5875 1110] and Askham Moor [4940 2255].

North of the Eamont, the outcrop is largely covered by Quaternary deposits, but a line of old workings expose the sandstone close to Highgate farm [4430 2733]. Here, the sandstone bedding is wholly disrupted by soft-sediment deformation structures, which may have formed as a consequence of fault movement on the nearby Kirk Rigg and Dacre Bank faults.

4.2 GREAT SCAR LIMESTONE GROUP

The Great Scar Limestone Group is the term now defined and extended to include all thick-bedded, shelf limestone facies rocks in northern England. Members of this group form conspicuous limestone scars at Ravensworth [595 112] and Hardendale Fell [580 140], Brinns Crag [560 172], Wilson [541 183] and Knipe Scar [528 193], Heugh Scar [488 230], and north of the River Eamont at Flusco Lodge [472 277] and Dacre Bank [453 274].

In the Stainmore Trough, shelf limestone deposition was more or less continuous from the Chadian through to the Asbian, with only minor influxes of fluvial-deltaic and prodelta sandstone. On the northern margin of the trough, and the southern part of the district considered here, shelf limestone deposition terminated during the late Arundian and fluviodeltaic rocks of the Ashfell Sandstone Formation were deposited. However, marine conditions were quickly re-established, spreading over the whole of the Lake District block during the Holkerian and Asbian (Mitchell et al., 1978).

The presence of the Ashfell Sandstone Formation, part of the Ravenstonedale Group, creates a local subdivision (Figure 6) of the group into a lower succession of late

Chadian/Arundian age, and an upper one of Holkerian to Asbian age.

4.2.1 Late Chadian to Arundian succession

The early succession is confined to the area east of the Anne's Well Fault and has been subdivided by Pattison (1990) into the Coldbeck Limestone, Scandal Beck Limestone, Brownber and Breakyneck Scar Limestone formations (Figure 6).

4.2.1.1 Coldbeck Limestone Formation

In the Orton area (Pattison 1990), the top of the Stone Gill Limestone formation is taken at the base of a unit of thin-bedded limestone with siltstone interbeds containing the 'Algal Band' of Garwood (1913). Though thin, Pattison separated this unit as a formation in its own right, the Coldbeck Limestone Formation.

The outcrop of the formation within the mapped district is largely obscured by superficial deposits and the formation limits are conjectural. An isolated occurrence of blocky grey limestone with algal pellets is seen in an M6 road cutting at [5967 0878].

4.2.1.2 Scandal Beck Limestone Formation

The Scandal Beck Limestone Formation is made up of two superimposed, lithologically distinct parts. Pattison (1990) divided the formation into two members, but the criteria for his division are not recognised within the district described here.

The lower part of the formation is exposed in shallow disused workings and natural scars across an area of open fell between the M6 motorway and the Shap to Orton road (B 6261). The rocks are largely buff to grey-buff, thin, wavy-bedded dolostone and packstone.

The upper part is well exposed in two quarries, one disused, and one active, located to the north of the B 6261. The limestone, seen in the active quarry [598 092], is a thick, rhythmically bedded dark-grey wackestone, markedly bituminous, and containing 0.5 m diameter colonies of the coral *Dorlodotia* (*Thysanophyllum pseudovermiculare* of Garwood 1913). Similar thick bedded rocks occur in the disused quarry to the west, but the rocks are extensively dolomitised, possibly in association with minor faults.

4.2.1.3 Brownber Formation

The Brownber Formation is comprised of a mixed succession of fine-grained sandstone, pebbly sandstone, oolitic limestone and dolostone. The formation was defined by Pattison (1991) in the Ravenstonedale area and is named after a characteristic set of pebbly sandstone and oolite beds first termed the 'Brownber Beds' by R H Tiddeman (in Aveline and Hughs, 1888). Rocks assigned to the formation occur only at the southern margin of the district, east of the Anne's Well Fault. Pattison's account (1991) gives a full description of natural and quarried sections within the adjacent Orton district (Figure 1).

The formation is poorly exposed in the district described here and the contact with the underlying Scandal Beck Limestone Formation cannot be mapped with any certainty. Pattison (1991) judged the formation to be up to 60 m thick, but only a maximum of 40 m was recorded during the current resurvey. Lateral thickness variation is most probably due to local stacking of channel sandstone bodies.

4.2.1.4 Breakyneck Scar Limestone Formation

Rocks of this formation are recognised at only one locality within the district. This is situated on Ravensworth Fell [597 098], where calcarenites of the Brownber Formation are seen to be overlain by a thin bed (3–5 m) of coarse-grained shelly limestone made up largely of crinoid, brachiopod and coral debris. This bed cannot be traced for any distance at the surface, but a line of sinkholes, associated with the bed, can be traced as far north as Hause Farm [NY 582 116].

From descriptions of the Breakyneck Scar Limestone Formation in the adjacent Orton area (Pattison, 1990), it seems likely that this limestone represents a marginal facies of the formation, developed close to its geographical limit.

4.2.2 Upper Holkerian to Asbian succession

The upper succession is widespread and consists of up to five variously named formations. Type sections and boundary definitions for the formations are described by Pattison (1990) in the area to the east of the district at Orton Scar [630 095] and Great Kinmond [673 090]. The adjacent area also contains the Asbian stratotype at Little Asby Scar [6988 0827]. Figure 6 illustrates the distribution, thickness variation and stratigraphic nomenclature of the Holkerian to Asbian age formations that occur in the district. Northwards, the Potts Beck Limestone Formation thins rapidly and is absent at Knipe Scar. The Ashfell Limestone Formation shows a reduction in thickness (100 reducing to 40 m), over the same distance (Figure 6). Palaeontological specimens taken from the base of the Great Scar Limestone Group on Askham Fell [NY 500 221], contain a late Asbian fauna (Dean, 2001) showing that the Ashfell Limestone Formation must pinch out over the intervening ground.

However, the Ashfell Limestone is present in the limestone escarpment flanking the north slope of the Eamont valley. In the area to the north of the Kirk Rigg Fault equivalent limestone units have been mapped (Arthurton and Wadge, 1981) using the stratigraphical terminology used in north and west Cumbria (4.2.4).

South of the Kirk Rigg Fault

4.2.2.1 Ashfell Limestone Formation

One of the most distinctive limestone formations in the group, the Ashfell Limestone is characteristically dark grey to dark blue-grey coloured, and mainly a packstone, shelly grainstone or lime-mudstone. In the adjacent Orton area (Pattisson, 1990), the formation is up to 100 m thick but is 40 to 50 m thick in the district described here. Also typical, are strongly cross-bedded units, with thin interlaminae of siltstone and fine-grained sandstone. Partial dolomitisation is common.

The rock is richly fossiliferous. In the northern part of the district recently constructed cuttings along the line of the A66 highway [4390 2750] expose a thick mudstone bed at the top of the formation containing rafts of shelly limestone crowded with brachiopod shells (especially spiriferid and rhynchonellid types), crinoid ossicles, bryozoa, fish scales, coral fragments and large tumbled stromatolite colonies.

Over the central parts of the district, the top of the formation is characteristically marked by beds of dark coloured, cross-bedded, coarse, crinoidal grainstone with

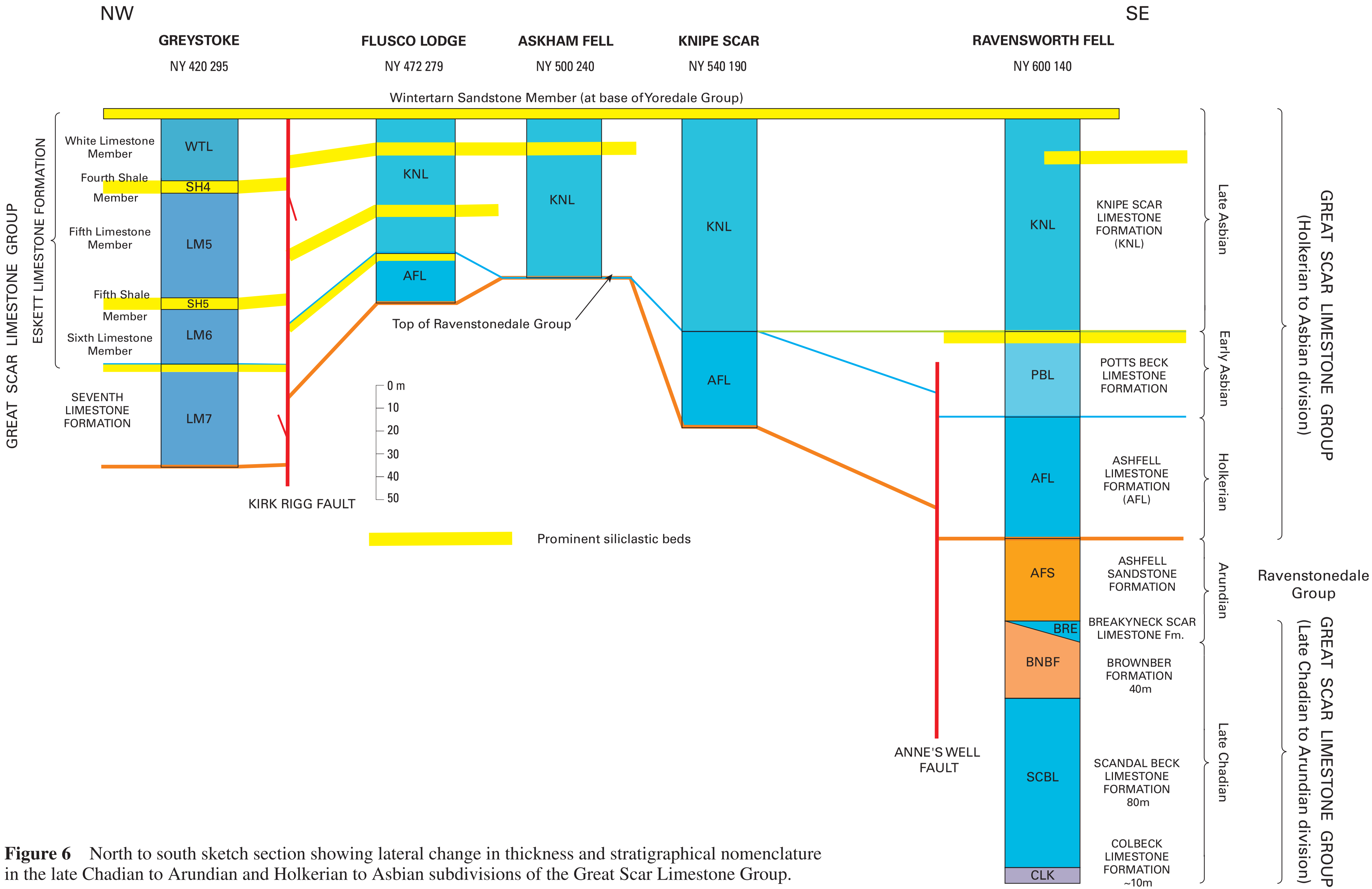


Figure 6 North to south sketch section showing lateral change in thickness and stratigraphical nomenclature in the late Chadian to Arundian and Holkerian to Asbian subdivisions of the Great Scar Limestone Group.

orange (iron oxide?) spotting. Sand filled burrows occur in shelly beds at Wilson Scar [5410 1773].

In the south of the district, where deposition occurred in relatively deeper water, low energy, conditions, gastropods feature prominently and the type Holkerian brachiopod *Davidsonina carbonaria* is recorded. In a small abandoned working on Ravensworth Fell [5885 1175] beds exposed contain convolute beds and nodules of dark grey chert. In the beck draining Long Mire [5915 1210], the formation is capped by beds of porcellanous, dark brown-grey, patchily dolomitised, lime-mudstone. Close by in the beck are unique outcrops of dark grey, micaceous mudstone with casts of '*Modiolis*' shells.

4.2.2.2 Potts Beck Limestone Formation

The formation is up to 40 m thick in the south of the district, but it thins to an estimated 15 m at Hardendale Nab [5810 1380] and must pinch out along strike (Figure 5) between there and Knipe Scar [5270 1910]. The formation is almost entirely composed of rhythmically bedded limestone and gives rise to stepped crags and small areas of pavement on the summit of Long Scar Pike [5940 1090]. Pattison (1990) records thin beds of calcareous sandstone occurring at, and just below, the top of the formation on Orton Beacon [6382 0975]. This sandstone is not exposed within the district, but its outcrop is located on the ground by a hollow feature with sinkholes which can be traced from Potrigg [597 121] to Hardendale Nab (582 141). North of Hardendale, the feature is obscured by a thick cover of Quaternary deposits.

The rock is largely a pale grey coloured, thick-bedded, strongly jointed, sparry packstone. Rubbly weathered calcrete horizons are present, as are beds with abundant *Siphonodendron junceum* and *Gigantoproductus*. The limestone beds on the summit of Long Scar Pike, mentioned above, contain the corals *Palaeosmilia murchisoni, Axophyllum* and *Dibunophyllum*.

4.2.2.3 Knipe Scar Limestone Formation

South of the Kirk Rigg Fault, the formation is wholly dominated by rhythmically bedded limestone. Thin interbeds of mudstone, siltstone and sandstone are present, especially towards the top of the succession, but are rarely seen at outcrop. North of Knipe Scar, a more substantial bed of sandstone is present in the upper part of the formation (Figure 6). The sandstone has been quarried in a few places [4925 2325], and the outcrop can be traced as a feature north to the Kirk Rigg Fault.

At outcrop, the limestone forms small crags, such as the cliff at Knipe Scar from which it derives its name, or on more level ground, areas of stepped karst [e.g. 527 193]. In all cases the formation gives rise to a stack of sharply stepped features, each from 0.5 to 1.5 m in height. This stepped weathering pattern is due to the alternation of beds with more or less resistance to erosion. The more resistant levels are more widely jointed and strongly cemented, due to the development of early diagenetic calcrete.

The formation is up to 70 m thick and comprises mostly thick-bedded, pale to mid-grey, wackestone and packstone, with some grainstone. Palaeokarst horizons and other indicators of emergent surfaces are reported by Vanstone (1996) from Shap Fell Quarry [587 138]. Here, stratiform mottled calcrete textures are conspicuous in 'beds' up to 1 m thick, and indicate emergence of the unconsolidated carbonate substrate. In the area to the north of Askham Moor, the limestone is conspicuously fossiliferous containing large broken *Siphonodendron*, *Lithostrotion* and *Hexaphyllia* coral colonies, *Gigantoproductus* shells, and stromatolites. The species identified by Dean (2001) indicate a late Asbian age.

North of the Kirk Rigg Fault

The Great Scar Limestone Group in this area is represented by a succession previously divided (Arthurton and Wadge, 1981) into rock units named in accordance with the scheme used in north and west Cumbria (Eastwood et al., 1968; Ackhurst et al., 1997). Although the names of the rock units are maintained here, their lithostratigraphical rank has been adapted to fit the new British Geological Survey regional scheme now under development (Figures 3 and 6). One new formation name, the Eskett Limestone Formation has been adopted here to accommodate rocks formerly included in the Chief Limestone Group.

4.2.2.4 Seventh Limestone Formation

The Holkerian Seventh Limestone Formation is the direct equivalent of the Ashfell Limestone. Borehole records reported by Dakyns et al. (1897) show that the limestone is interbedded with mudstone and overlies sandstone and mudstone beds of the Marsett Formation (4.1.2). None of the boreholes indicate the total thickness of the formation and an estimate of 60 m given by Eastwood et al. (1968) is likely to be a maximum value for the district considered here. Exposure of the formation is limited to a single disused quarry [418 281] and a faulted stream section in Skitwath Beck [4161 2843]. The limestone in the quarry is a dark grey-blue, thin, wavy bedded packstone with wispy siltstone laminae. The beckside exposure, probably higher in the section, proves a thicker bedded limestone, paler in colour, but cross-bedded and containing a large stromatolite colony.

4.2.2.5 Eskett Limestone Formation

This is a new term which embraces all shelf limestone facies rocks of Asbian to Brigantian age in north and west Cumbria. In the district described here, the formation is a direct equivalent of the Knipe Scar Formation (Figure 6), but it should be noted this is not true in all areas, as the defining facies boundaries are regionally diachronous. Rocks of the formation conformably overlie mudstone beds at the top of the Seventh Limestone Formation.

The formation is approximately 110 m thick and is subdivided into three limestone members, the Sixth, Fifth and White Limestone members, with two intervening clastic members, the Fifth and Fourth Shale members (Figure 3). These rocks have been adequately described by Eastwood et al. (1968) and Arthurton and Wadge (1981) and mention is made here simply to localities not described in their respective memoirs.

The lowest limestone unit is the Sixth Limestone Member, which is poorly exposed, both here, and in adjacent areas. A single exposure in a small quarry behind Spedding Farm [4207 2804] contains a pale grey, thick-bedded, packstone/wackestone with a patchy calcretised groundmass. Little else is known of the formation except that it contains a number of mudstone and sandstone intercalations (Dakyns et al., 1897) and is of the order of 30 m thick.

The lowest limestone is separated from the overlying Fifth Limestone by the Fifth Shale Member comprising 7 m of sandstone, siltstone and mudstone. The sandstone is exposed in a scattering of small pits lying east of the Skitwath Beck [4162 2845, 4170 2850]. The rock is a pale grey, cross-bedded, fine-grained, quartzitic sandstone and is underlain in the latter pit by dark grey, laminated mudstone.

The Fifth Limestone Member is a pale-grey, massively bedded shelly packstone, broken into two main units by a thin mudstone bed. The limestone is some 50 m thick and forms a rocky, quarried bluff behind the village of Motherby [425 284]. The limestone is fossiliferous and a rich, typically Asbian, coral-brachiopod fauna is described by Arthurton and Wadge (1981).

The Fourth Shale Member is represented in the district by a 3–4 m thick bed of sandstone which was previously exposed in a railway cutting [4435 2789] and described by Dakyns et al. (1897).

The White Limestone Member [4085 2940] is poorly exposed in the district. Sections described by Arthurton and Wadge, (1968) comprise 20 m of pale grey, massively bedded, pseudo-brecciated limestone (probably packstone) with a varied coral-brachiopod fauna.

4.3 YOREDALE GROUP

The Yoredale Group is a new, regionally defined, name adopted by the British Geological Survey Carboniferous Stratigraphic Committee for all Upper Dinantian to Namurian rocks that display Yoredale-type, shallow marine to deltaic facies and depositional cyclicity. Strata within this group were assigned previously to either the Upper Alston (e.g. Burgess and Holliday, 1979) or Wensleydale groups, if of Asbian or Brigantian age, or the Stainmore or Hensingham group (Akhurst et al., 1997) if of Namurian age.

As with other Carboniferous lithostratigraphical groupings, the base and top of the Yoredale Group are regionally diachronous (Taylor et al., 1961, fig. 18). In the district described here, the change from shelf limestone deposition to Yoredale facies occurred near to the end of Asbian times. The upper boundary is not exposed in this district (4.3.2), but is believed to be marked by an unconformity or depositional hiatus developed at the base of the overlying Westphalian Coal Measures (Arthurton and Wadge, 1981).

The group is subdivided into two formations, the Alston and Stainmore formations (Figure 3). This subdivision reflects the marked decrease in limestone deposition, within the marine phase of the Yoredale cycle, at the start of the Namurian.

4.3.1 Alston Formation

The term Alston Formation is a new term for those rocks in the Yoredale Group of largely Brigantian age (but may include some strata of late Asbian and Pendleian age), previously assigned to the Upper Alston Group. The base of the group is taken at the change from rocks of shelf limestone facies to cyclical shelfal marine/deltaic Yoredale facies. In the district reported on here, this change occurs at the base of the Wintertarn Sandstone Member (4.3.1.1) and is close below the Asbian–Brigantian boundary.

Though partially covered by Quaternary deposits, all but the highest beds in the formation are exposed in an west to east traverse across the Lowther Castle estate and leisure park between Whale Farm [525 216] and Hackthorpe Townend Farm [545 235]. The succession consists of ten main Yoredale cycles (Figure 7) in total some 220–250 m thick. Each begins with a limestone development, rarely exceeding 10 m in thickness, succeeded by a unit composed mainly of terriginous mudstone, siltstone and sandstone. The major limestone units display a remarkable lateral uniformity in both thickness and lithological character. The intervening clastic beds tend to remain constant in overall thickness, but their lithological make up is far more variable. Mudstone beds of marine origin occur at some intervening levels and may grade laterally into thin secondary limestone developments. Seatearths are recorded at the top and within some cycles and at least one seam of workable coal is present within the district (Figure 7).

Limestones belonging to this formation are variable in character, but are generally dark-grey in colour and show an upward change from massive, fine-grained wackestone with a notable algal component, to cross-bedded crinoidal packstone and grainstone. Dolomitisation is not common except at one level; the Single Post Limestone (4.3.1.6) being a vuggy dolostone. Towards the top of the succession proximity to the unconformity at the base of the Permian has produced local reddening, the limestone being variously, red/brown, pink, or violet in colour.

The area of Alston Formation rocks falling within the sheets NY51 NE and SE (Figure 1) was mapped in the course of a PhD study undertaken by Dr C R Rowley between 1960 and 1964. The succession and lithology of the rocks present in that area are fully accounted in the PhD thesis (Rowley, 1965) and subsequent publication (1969). The account given here focuses on the contiguous, previously unmapped, deposits present in 1:10 000 sheets NY 42 NE, NY 52 NW and NY 52 SW.

The laterally persistent limestone units have been mapped separately at the scale of 1:10 000 and are assigned member status. The limestone nomenclature used by Rowley (1969) was a local one, based largely on the primary geological survey account (Dakyns et al., 1897). As almost all the limestones can be correlated with equivalent units in adjacent parts of Cumbria and the north Pennines, in this account a unified nomenclature has been chosen (Figure 7) to maintain consistency with adjacent BGS 1:50 000 sheets.

With the exception of the sandstone beds at the base of the formation, siliclastic beds within each Yoredale cyclothem are undifferentiated and are described in the text in conjunction with the underlying limestone member.

4.3.1.1 Wintertarn Sandstone Member

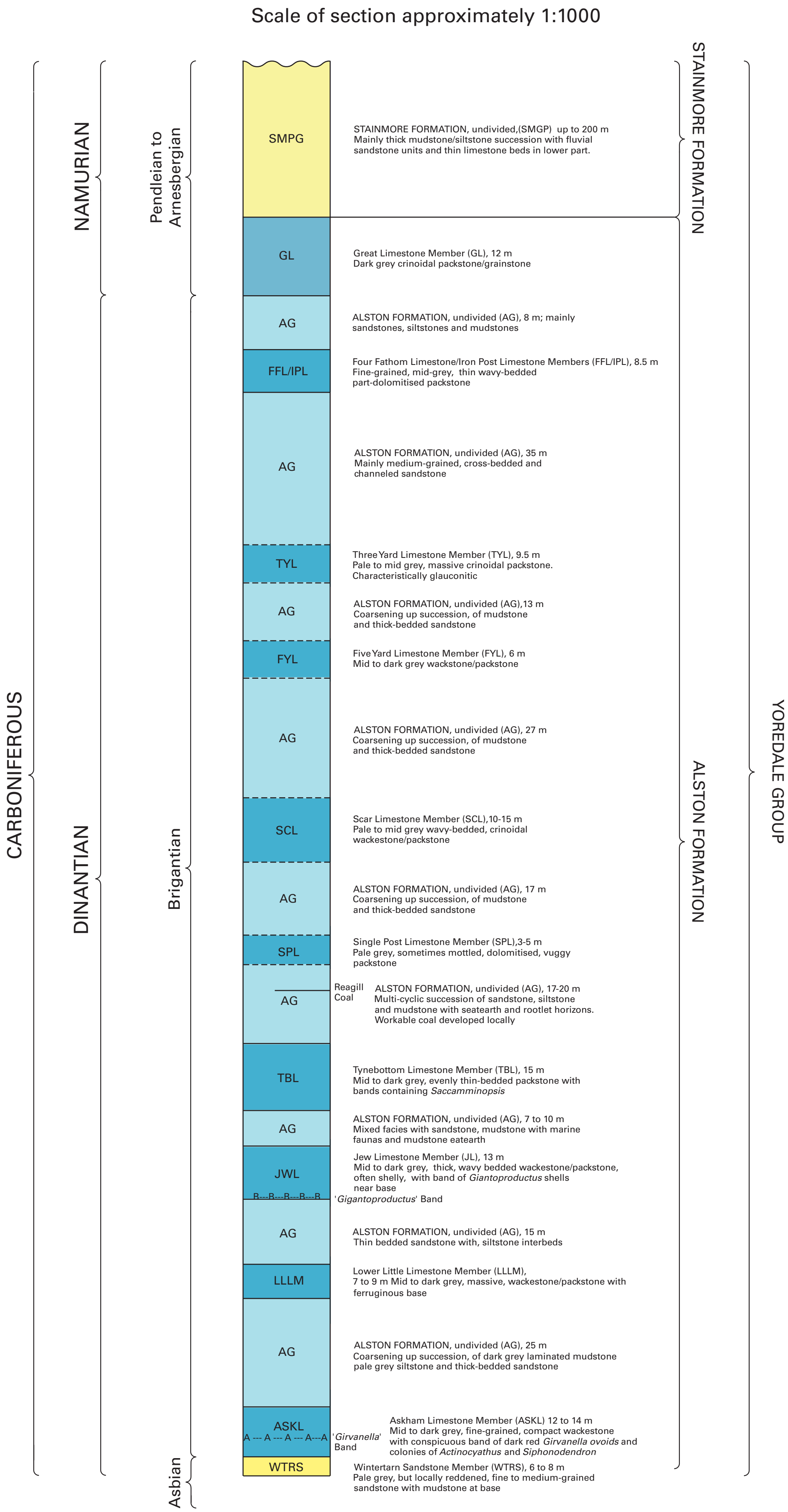
This previously unnamed member is laterally persistent across the district, a point marking it out from the similar, but discontinuous, sandstone units found within the underlying Knipe Scar Formation. The Member is 6 to 8 m thick and comprises a pale grey to brown, cross-bedded, fine- to medium-grained, quartzitic sandstone with strong purple-brown hematite staining at some localities. A bed of dark grey, laminated mudstone is usually present at the base.

The member is named after a small working at Wintertarn Farm [582 170], and is easily traced as a small step feature, between there, and exposures at Outscar [543 188], Whalemoor [532 204] and Flusco Lodge Quarry [474 281].

4.3.1.2 Askham Limestone Member

The first limestone in the succession is composed of two units of approximately equal thickness (5.5 and 7 m), separated by a thin bed of red mudstone. To the east of the district, these two leaves separate into individually named beds, the Peghorn and Smiddy Limestone members (Burgess and Holliday, 1979). However, as only a single

Figure 7 Generalised stratigraphical and lithological section of the Yoredale Group rocks in the district.



limestone unit can be mapped in the district described here the local name, Askham Limestone (Rowley, 1969), is retained. To the north, the same limestone is termed the Rough Limestone Member (Arthurton and Wadge, 1981).

Overall, the limestone is mainly a wackestone, characteristically dark grey in colour, very fine-grained, porcellanous in parts, but containing laterally extensive coral beds. The rock is especially tough, with a blocky fracture and has been a popular target for mineral working. Disused workings occur along the length of the outcrop such as at Oddendale [592 138], Wintertarn [583 171], Out Scar [547 191], Whalemoor [532 204], Askham [5005 2420], Thorpe [499 267], and more recently, at Flusco Lodge [474 282]. The last site has been used, in part, for landfill, but a full section of the limestone is preserved, along with the top part of the underlying Wintertarn Sandstone.

The top surface of the lower leaf, immediately below the mudstone, exhibits the features of a palaeokarst, being pitted, reddened and coated with laminar calcrete. Extending 2 to 3 m beneath this horizon, the limestone has a patchy pale grey/dark grey groundmass texture ('pseudobreccia' texture of some authors) typical of mottled calcrete (Vanstone, 1996).

A coral biostrome composed of a continuous mat of *Siphonodendron* is present in the lower limestone leaf throughout the central part of the district. It is conspicuous in disused workings at Out Scar [547 191], Whalemoor [532 204] and is seen in loose material in a working at Askham [5005 2420]. The coralites are compressed somewhat, but appear to be in growth position. Other coral species, such as *Actinocyathus* (formerly *Lonsdaleia*) *floriformis*, form colonies in the top of the lower leaf in the Flusco Lodge [474 282] and Wintertarn workings [583 171].

The upper limestone leaf contains a bed, circa 2 m above the base, of dark blue/grey, fine-grained limestone studded with hematite-stained *Girvanella* ovoids. This is not the *Girvanella* bed of Garwood (1913) which normally lies at the top of the lower leaf (Rowley, 1969).

The clastic interval above the Askham Limestone is one of the thickest (about 30 m) in the formation and tends to form part of a steep bank feature topped by the overlying Lower Little and Jew limestones. The base of the interval, exposed uniquely in a stream gully close to the A66 at Stainton [479 284], is a dark grey, hematite-stained, laminated mudstone, packed with fenestrate bryozoa and flattened shells of the Brigantian bivalves *Posidonia kochi* and *Pernopecten concentricum*. Above, the mudstone grades upwards through laminated siltstone into cross-bedded sandstone. The sandstone is exposed in the bed of the River Eamont at Sockbridge Mill [497 278] and at various points along the outcrop between Askham Bridge [518 239] and Whale [530 216], and between Gunnerwell [570 180] and Harberwain Rigg [597 143]. It is generally medium- to coarse-grained, micaceous, pale grey in places, but more usually stained a deep purple-brown colour.

The sandstone marks the top of the lower of two coarsening-up cycles. The upper cycle begins with dark to mid grey, laminated mudstone, containing rare brachiopod casts, grading abruptly upwards through laminated siltstone into a flaggy, rippled, fine-grained sandstone. The sandstone, as with the rest of the cycle, is well exposed in a quarried river-cliff on the River Eamont at Sockbridge Mill [497 278] and in small disused workings at Harberwain Rigg [597 143]. At both localities, the sandstone and the overlying Lower Little Limestone are strongly hematised. The junction between the two lithologies is commonly hard to discern, the sandstone appearing to be 'welded' to the base of the limestone.

The brachiopod remains in the mudstone at the base of the upper cycle show that marine conditions prevailed at that point in time. To the east of the district, Rowley (1969) recognised a thin limestone, the Halligill Limestone, preserved at this level.

4.3.1.3 Lower Little Limestone Member

The Lower Little Limestone named as the Bank Moor Limestone by Rowley (1969) after the primary geological survey (Dakyns et al., 1897), occurs as a single bed, 5 m or less thick. It is exposed in the above mentioned workings at Sockbridge Mill and Harberwain, but generally the limestone outcrop has little topographical expression and the primary survey failed to map the limestone over the ground between the Leith and the Eamont valleys.

The limestone has a ferruginous base, but otherwise it is a massive, dark to mid grey wackestone with little macrofossil content other than sporadic *Gigantoproductid* shells. In disused workings at Harberwain [597 146], a *Siphonodendron* biostrome, similar to that described above in the Askham Limestone (4.3.1.2), is present.

The overlying clastic interval is poorly exposed, but, where seen, is composed of red-brown, micaceous, cross-bedded, medium-grained sandstone overlying a thin mudstone at the base.

4.3.1.4 Jew Limestone Member

The Jew Limestone, named as the Maulds Meaburn Limestone by Rowley (1969) after the primary geological survey (Dakyns et al., 1897), forms a strong scarp feature, rocky in places, that can be traced from the northern margin of the district, south across the Eamont Valley, and through the Lowther Castle estate, forming Burtree Scar [525 226]. South of the River Leith, the feature is less prominent but it forms a rocky scar at Harberwain Rigg [598 145] on the southern boundary of the district.

The limestone is generally 12–15 m thick and has been extensively worked in the area west of Newbiggin [470 295] where the outcrop area is extended due to strike faulting. Over 1 km² of ground has been worked in this area, much now back-filled with landfill.

The rock is a mid-grey packstone/wackestone and quite well bedded. A bed close to the base of the limestone contains numerous gigantoproductid shells, an horizon used for regional correlation by both Garwood (1913) and Rowley (1969). Rowley (1969) and Dean (2001) report the occurrence of corals: *Siphonodendron junceum, martini*, *pauciradiale* and *sociale, Actinocyathus floriformis*, *Diphyphyllum* and *Palaeosmilia*.

The rocks directly overlying the limestone are described by Rowley (1969) as being of 'variable' facies; that is, a thinly interbedded succession of mudstone, siltstone, calcareous sandstone, silty limestone, ganister and coal. These rocks give way upwards to fine to medium-grained sandstone which is the only lithology exposed at this level in the district described here.

4.3.1.5 Tynebottom Limestone Member

The Tynebottom Limestone, named as the Little Strikland Limestone by Rowley (1969) after the primary geological survey (Dakyns et al., 1897), is of similar thickness (15 m) and superficial appearance to the Jew, and this has caused identification problems in faulted areas, such as in the neighbourhood of the Flusco limestone quarries (8.1).

The limestone member is partially exposed in old grassed over workings just north of the A66 [492 287], but almost complete sections are seen in small, disused, quarries at Highfield Farm [511 253] and Greenrigg Quarry [599 165]. The limestone is generally a mid to dark grey, characteristically flat-bedded, wackestone grading to packstone. Rowley (1969) recorded three beds of cross-bedded packstone containing abundant *Saccamminopsis*, and this is a distinguishing feature of the limestone.

The clastic succession above the limestone is thickly developed and in the south-eastern part of the district contains the Reagill Coal seam. The outcrop of the coal is marked by a line of disused shafts, small spoil heaps and pitted ground, extending across country from the village of Reagill [603 175] to Little Strickland [564 196].

The remainder of the succession is largely argillaceous, but encompasses a range of lithologies including mudstone, siltstone, seatearth, sandstone and impure limestone. The beds occur in a rapidly alternating succession (the 'Alternating Beds' of Arthurton and Wadge (1981), instead of the progressive coarsening-up cycle that is more typical of the Alston Formation. Exposures of these beds are rare in the district. Laminated mudstone, siltstone, silty sandstone and mudstone seatearth is seen beside the Low Gardens Bridge [522 251] on the River Lowther and isolated patches of mudstone and sandstone appear in now derelict garden features beside Lowther Castle [524 235].

4.3.1.6 Single Post Limestone Member

This limestone, named as the Johnny Hall's Tree Limestone by Rowley (1969) after the primary geological survey (Dakyns et al., 1897), is seen at only one location in the district, that being the southern boundary of the Lowther Leisure Park where it forms a 1 km long rocky scar and bench feature [529 226 to 538 223].

The limestone is only 3 to 5 m thick and is distinctive, being pale-grey to brown in colour, structureless, completely dolomitised and pock-marked with irregular, limonite-coated vugs.

North of the Lowther Castle Estate, the outcrop of the limestone is obscured by thick Quaternary deposits. However, it was intercepted in boreholes sunk along the line of the A66, where it is 3–4 m thick, and can be seen in the road cutting [5003 2850], subsequently constructed, as 2–3 m of limestone.

The clastic succession above the limestone at Lowther Castle is represented by 10 m of purple-brown, laminated, mudstone and medium- to coarse-grained sandstone. In the A66 road cutting [5025 2862] an interbedded succession, 20–25 m thick, of sandstone, siltstone, mudstone and a bed of thin limestone are present. The limestone may be the equivalent of the Bessygill Limestone mapped by Rowley (1969) at the locality of that name [547 219].

4.3.1.7 Scar Limestone Member

The Scar Limestone, named as the Maulds Meaburn Edge Limestone by Rowley (1969) after the primary geological survey (Dakyns et al., 1897), does not form a significant feature through the district described here. It is some 10 to 15 m thick, a full section of the limestone being exposed in an A66 road cutting close to the new Penrith market [505 287]. Further exposures are seen in disused workings at Red Hill [505 286], in both banks of the River Eamont beside Yanwath Farm [507 283] and in a river cliff overlooking the River Lowther at Horseholme Wood [522 252]. In the grounds of Lowther Castle the limestone forms a small rocky feature that runs down into Bessygill [5455 2196] and from there into the River Leith. Small, disused workings are scattered along the length of the feature, with a larger, but partly infilled, working located in Bessygill Wood next to the M6 [5485 2185].

The rock is conspicuously well bedded, pale to mid grey packstone with abundant crinoid fragments present at some levels. Rowley (1969) described a *Siphonodendron junceum* biostrome in the River Leith section and colonies of the species are found in the A66 road section mentioned above. However, the colonies are scattered and the biostrome lacks the lateral continuity of those seen in the Askham and Lower Little limestones.

The overlying clastic succession is composed mainly of a thick sandstone unit which forms a conspicuous bank feature in Lowther Castle Leisure Park [535 226]. The rock is red-brown, cross-bedded and grades to a laminated siltstone at the base. Rowley (1969) described a similar sandstone development farther east in the Hoff Moor area [676 175], but in the intervening ground a thinner, more argillaceous, in part marine, succession is present.

Where this succession intersects the A66 alignment, it is quite thin, about 7 m, but it still appears to be composed mainly of sandstone.

4.3.1.8 Five Yard Limestone Member

This limestone, named as the Brackenslack Limestone by Rowley (1969) after the primary geological survey (Dakyns et al., 1897), is very poorly exposed, both in the district described here and in neighbouring areas. The limestone is some 6 m thick and forms the crest of an escarpment in Lowther Castle Leisure Park [538 226] but, though free of Quaternary deposits, only limestone brash is seen at surface. Boreholes on the A66 alignment proved the limestone to be present below Quaternary deposits. The primary survey showed a limestone, possibly at the same stratigraphical level, to be at outcrop in the River Eamont beside Skirsgill House [513 285]. The recent resurvey suggests that this, conspicuously reddened, limestone is part of the Stainmore Formation, preserved at this location due to faulting. However, no palaeontological evidence can be offered to confirm or refute this conclusion.

The Five Yard Limestone can be little more than 3 to 4 m thick and is variously described as being a poorly fossiliferous, dark grey biomicrite (Rowley, 1969) or a grey, crinoidal, dolomitic packstone (Arthurton and Wadge, 1981).

The overlying clastic succession is composed mainly of sandstone and is well exposed on the crest of the above-mentioned feature in the Lowther Castle Leisure Park, west of the M6 [545 223]. The sandstone is atypical in being largely unreddened, and is pale grey, cross-bedded, fine- to medium-grained and quartzitic.

4.3.1.9 Three Yard Limestone Member

This limestone, named as the Grayber Limestone by Rowley (1969) after the primary geological survey (Dakyns et al., 1897), is a prominent feature of the district, being worked in a number of localities at Hackthorpe [541 227], Lowther Village [536 238], Yanwath Woodside Farm [522 263], and Glendowlin [515 273]. The limestone is some 10 m thick, most of which is exposed, despite refuse dumping, in the disused quarry at Lowther village. The rock is distinctive, being pale grey in colour with thin, wavy cross-bedding. In many occurrences the limestone is crowded with coarsely comminuted crinoid debris, such as in the quarry at Yanwath Woodhouse [5217 2628], and is notable for the occurrence of glauconite. Rowley (1969) divided the limestone into two beds, separated by a bed with abundant bryozoa and coral fragments. This subdivision is not recognised in the area reported here, but bryozoa are noted in the limestone worked in the fields behind Hackthorpe village [541 227].

At the top of the section in Lowther Village Quarry, the limestone is succeeded by fissile siltstone beds, which grade abruptly upwards into a fluvial sandstone. This sandstone gives rise to a rounded ridge feature partially covered by Quaternary deposits which can be followed from the River Lowther through to the Leith. North of the Lowther, the sandstone is cut out by the Yanwath Fault. Rowley showed the sandstone to be some 20 m thick east of the River Leith, but in the Hackthorpe area the M6 site investigation boreholes prove a wide outcrop tract commensurate with a section 30 to 35 m thick.

Exposures of the sandstone are seen in farm tracks around Hackthorpe village (e.g. [543 231]) and in Warren Gill [539 239]. The rock there is weathered, but quarry sections described by Rowley (1969) show the channel sandstone to be medium-grained, micaceous and cross-bedded, with pebble lags and rip-up clasts.

4.3.1.10 Four Fathom and Iron Post Limestone members

These limestones are encountered in the River Leith just to the east of the district. At that location they have a combined thickness of 8.5 m and are separated by only 1 m of mudstone, and Rowley (1969) treated them as two leaves (upper and lower) of what he preferred to call the Newby Mill Limestone, after the terminology of Bland (1862).

The limestone has no surface exposure in the district but the occurrence of these beds has been proved in the M6 site investigation boreholes which penetrate a limestone beneath thick drift just north of Bainbridge Gate [531 251].

Rowley (1969) described the rock as pale lilac or pink coloured with a powdery texture being strongly affected by sub-Permian reddening. It also contains chert nodules and glauconite grains but is poorly fossiliferous, though *Dibunophyllum* is locally present.

4.3.1.11 Great Limestone Member

Over much of the district, the top of the Alston Formation is affected by the Yanwath or Great Strickland Fault which has a significant downthrow to the north-east cutting out the higher members. The Great Limestone Member, locally the Great Strickland Limestone of Dakyns et al. (1897) and Rowley (1969), which marks the top of the Alston Formation, was shown on the primary survey map as underlying a broad swathe of ground covered by Quaternary deposits linking outcrops in the Rivers Leith and Lowther. The M6 boreholes preclude this interpretation because only argillaceous rocks of the Stainmore Formation are present in the area indicated. Furthermore, thin limestone beds seen in the River Lowther at Yanwath [526 269] are considered here to be part of the Stainmore Formation (4.3.2), and not the uppermost part of the Great Limestone, as inferred by Dakyns et al. (1897).

Thus, the characteristics of the Great Limestone Member are those given elsewhere (Dakyns et al., 1897; Burgess and Holliday, 1979; Arthurton and Wadge, 1981) It is a dark grey to dark blue-grey crinoidal packstone/grainstone, commonly dolomitised and locally red-stained due to Permian weathering. The member has an average thickness of approximately 12 m.

4.3.2 Stainmore Formation

The name Stainmore Group has come into common usage on British Geological Survey 1:50 000 maps for Yoredale lithofacies rocks of strictly Namurian age in northern England. Recent proposals by the British Geological Survey Carboniferous Stratigraphy Committee retain the group name but it is demoted to formation rank. The Great Limestone, traditionally the basal unit of the Stainmore Group, is redefined as the uppermost member of the new Alston Formation.

Stainmore Formation rocks underlie a wide linear tract of ground covered by Quaternary deposits south of Penrith, and is estimated to be 200 m thick. The outcrop is limited to the west by the Yanwath Fault, whereas to the east, the rocks are overstepped by the base of the Permian Penrith Sandstone (5.1).

Surface exposure is limited to two areas. These are in the gorge of the Lowther River, upstream from Eamont Bridge [525 270], and in the bed of the Eamont River beside Skirsgill House [515 282]. Stainmore Formation rocks are also encountered in a number of M6/A66 site investigation boreholes, but only a few metres are recorded in each.

The group consists of a largely deltaic, undivided cyclical succession of terriginous mudstone, siltstone and sandstone with a few beds of limestone in the lower part. Being faulted, the base of the succession is not seen. A bed of dark grey, crinoidal limestone is exposed in the River Lowther section, suspected to be the Little Limestone, described from deep boreholes sunk within the area of the adjacent Penrith sheet (e.g. Barrock Park Borehole, Arthurton and Wadge, 1981, fig. 21). Above this limestone, a major sandstone development, over 20 m thick, is seen in a disused quarry and railway bridge abutment at the entrance to Lowther Caravan Park [525 270]. The sandstone is also seen in the River Eamont and is thick-bedded, fine- to medium-grained with large scale southward dipping cross-bedding. The sandstone is underlain and interleaved with pale green-grey, laminated mudstone and siltstone and is red-stained in places.

Fossils indicative of the age of the rocks have not been recovered here, but by comparison to the borehole section mentioned above, it seems likely that the rocks are of early Namurian age, probably Pendleian to Arnsbergian.

5 Permian

The district lies on the western margin of the Vale of Eden Basin, a north-west striking half-graben which developed in the hanging wall of the Pennine Fault System (Hughes 2003b). The half-graben contains a succession of Permian and Triassic strata laid down in aeolian, fluvial and playa-lake environments. Only the earliest deposits, of Permian age, are present within the district. These include Brockram breccias and dune-bedded sandstones belonging to the Appleby Group.

5.1 APPLEBY GROUP

The Appleby Group is represented in the district solely by the Penrith Sandstone Formation. Rocks of this formation are seen at surface at only three points along the banks of the River Eamont close to Brougham Castle [542 295, 547 293, 540 291] and in the floor of a meltwater channel within the suburban area of Penrith [524 297]. The rocks in all cases are weathered, dark red-brown, aeolian, medium- to coarse-grained sandstone. Cross-bedding directions in the riverside exposures are 8 to 12° to the north-west and south-west. Regionally however, the strata dip towards the north-east. Within the area of the Penrith 1:50 000 sheet, located north of the district, the Penrith Sandstone is shown to be faulted against Stainmore Formation rocks (Arthurton and Wadge, 1981). No evidence for a faulted relationship can be demonstrated here, and the sandstone is considered to overlie the Stainmore Formation unconformably. The position of the contact is poorly constrained as it is not associated with any topographic feature and falls outside the area of good borehole cover. The line of contact shown on the 1:10 000 maps is conjectural.

6 Structure

The Devono-Carboniferous succession is largely free of structural complication. The beds strike generally north-west to south-east throughout the district, with regular dips to bedding of 10 to 20° in the lower part of the succession and 5 to 8° in the upper part. There are no large-scale folds in the district, though localised deflections of the regional dip and strike pattern occur in the vicinity of the faults that disturb bedding continuity. The unconformity at the base of the Dinantian succession is laterally uniform, but rises across what may well have been contemporaneous basement highs at Shap Summit [575 106] and Askham Moor [490 220].

6.1 FAULTING

Above the level of the Marsett Formation, few faults disturb the lateral continuity of the Upper Palaeozoic rocks. More significant, are strike parallel faults, which effect appreciable stratigraphical offset. No evidence has been found within the district for direct fault control on sedimentary processes. However, changes in stratigraphical thickness, facies and formation limits appear to coincide with the trace of major faults, or fault systems, and it is likely that some Carboniferous faults are rooted in the underlying Caledonian basement.

Fault azimuths fall into three main groups, north–south, north-east–south-west to east–west and north-west to south-east.

6.1.1 North–south trending faults

The Lower Palaeozoic rocks that outcrop to the west of the district contain numerous north to south trending faults (Woodall, 2000). Some of these structures pass into and offset the Upper Palaeozoic succession.

A prominent example is the Anne's Well Fault (NY 50 NE) which throws to the east and forms, in part, the western margin of the Shap Wells ORS Trough (3.1.2). On sheet NY 51 SE, the fault can be traced as a linear hollow from Shap Wells [583 100], up the valley of the Trundle Beck to Anne's Well [5831 1266] where the fault plane is exposed at surface. North of this point the trace of the fault is obscured by the Hardendale Quarry workings, where it probably dies out.

The line of a prominent Lower Palaeozoic fault, the Rosgill Moor Fault, intersects the base of the Carboniferous, just to the east of Bampton village [515 182]. Only a minor offset is inferred at this point, but if projected northward, the trace of the fault coincides with a well defined lineament defined by the northward course of the Lowther valley.

Elsewhere in the district north–south lineaments are a common feature, often picked out by the modern drainage system, but in most cases no fault offset can be identified. An exception is found within the narrow defile that carries Threaplands Gill. At one point in its course [5932 1810], the gill runs in a rock gutter cut along the line of a north-trending fault.

6.1.2 East–west to north-east–south-west trending faults

Faults in this grouping are most prominent in the lower part of the Dinantian succession and though generally of small offset, are responsible for marked steps or swings in the main limestone escarpment. As with north-trending faults, most members in this group spring off from faults mapped within the Lower Palaeozoic basement.

The principle member of this family is the Kirk Rigg fault [410 275 to 493 285], which effects a 20 km lateral offset in the main limestone escarpment. To the south, the parallel Cove Fault [390 250 to 506 235] and other, unnamed faults break the escarpment at Heugh Scar [488 238], Wilson Scar [545 179], Whale [523 216] and at Hardendale [5807 1392].

The Kirk Rigg and Cove faults trend slightly north of east and continue the line of the Lower Palaeozoic Causey Pike Fault (Woodhall, 2000). Together, these faults define the northern and southern limits of the Mell Fell Trough (3.1.1) and were active after, and probably during, deposition of the Mell Fell Conglomerate. The Kirk Rigg Fault also marks the furthest known northward extent of Chadian and Arundian strata (Figure 5), a function performed on the east side of the Vale of Eden by the Swindale Beck Fault (Burgess and Holliday, 1979).

6.1.3 North-west–south-east trending faults

Faults on this trend control the distribution and attitude of both Carboniferous and Permian strata within the district. In the south of the district, faults of this trend are limited to strata of Brigantian and later age, but in the north of the district they are prominent at all stratigraphic levels. As this trend runs parallel to the axis of the Permo-Triassic Vale of Eden Basin, its members may have been active during, and in some cases after, its formation.

The most prominent faults in the central part of the district are the Little Strickland (Hughes, 2003a) and Yanwath/Great Strickland Faults. Both are normal faults affecting Yoredale Group rocks, with throws of 10 to 50 m down to the north-east.

In the northern part of the district, a succession of north-west–south-east orientated faults on this trend causes visible offsets of the limestone escarpment north of the Eamont Valley. Examples are the Dalemain [4630 2815] and Dacrebank [4526 2790] faults, both of which intersect the Kirk Rigg Fault (6.1.2), and are offset laterally by it. To the north of that fault, the country is dominated by north-west–south-east faults (Arthurton and Wadge, 1981), though their existence is largely inferred from borehole intercepts and topographic feature offsets.

7 Quaternary

7.1 GLACIGENIC DEPOSITS AND LANDFORMS

Much of lowland Cumbria is blanketed with thick deposits of till, mostly deposited from regional Devensian ice-sheets, but locally derived from ice which flowed radially from the Lake District upland block. A substantial till cover is present east of the Carboniferous escarpment crest and in the Eamont, Lowther and Lune valleys. Over the crest and scarp slope of the escarpment, the deposits are thin and patchy.

7.1.1 Till (boulder clay)

The most extensive glacial deposits are of till. The deposits are largely contained within low-amplitude symmetrical drumlin landforms. The long axes of these features are generally aligned north to south, particularly in the western and southern parts of the district, but in north-eastern areas they are orientated north-west to south-east, reflecting the strike of underlying rock features.

Superficial exposures of till are rare. The thickest sections exposed in 1998/99 were seen at the top of the Shap Beck Limestone Quarry [552 181]. Good sections previously exposed in cuttings along the M6 and A66 are now all overgrown. The till deposits are typically grey to red-brown in colour (grading to brown/orange shades where weathered) with pebble to cobble-sized clasts in a clay/silty clay matrix. The clast content is varied, but is mainly derived from the adjacent Lake District block and includes granitoid blocks, mostly of Shap granite. This till is generally a firm, stable deposit, but is prone to mass movement on slopes, especially if waterlogged.

Large erratic blocks of Shap granite are a common feature, especially in the south of the district where some large examples bear individual names (Galloway Stone [587 099]; Thunder Stone [582 156]).

In the north-west of the district, around Penruddock, erratic boulders up to 2 m in length occur in swarms, covering appreciable areas of rough pasture. It may be that the boulders have been gathered together by human effort, as at one location they are closely associated with a prehistoric settlement, the 'Stone Carr' [419 283]. If a natural formation, they may represent the deposits of a terminal moraine which has been reworked by a later ice advance.

Boreholes show that laterally discontinuous beds of gravel are present within the till section, though there is no indication that all such occurrences are coeval. In the area west of Penrith the motorway boreholes intercepted a subsurface succession of lacustrine clay and silt, a relic of an interglacial lake that occupied part of the Eamont Valley (Arthurton and Wadge, 1981).

7.1.2 Glaciofluvial sand and gravel

Deposits of this type are not extensive and are largely confined to the Eamont Valley, representing the outwash and moraine deposits of ice advances in the Ullswater valley.

The deposits occur variously as small, round-topped, steep-sided mounds, kames or as stratified valley infill. Extensive deposits occupy the width of the Eamont valley from Pooley Bridge [470 244] east to Dalemain House [475 269]. The deposits are formed into broad rounded mounds, not dissimilar to a drumlin field, but lacking the typical streamlined profile. The deposits are exposed in the banks of the River Eamont and are seen to be a poorly sorted mix of sand and gravel with well rounded cobbles. A single small abandoned working close to Barton Church Farm [4820 2617] shows beds of sand and fine gravel thrust over imbricate blocks of poorly sorted gravel and cobbles. This gives a clear indication that the gravels were overrun by a later advance of glacial ice moving down the axis of the Eamont valley.

Other deposits, which clearly predate the last advance of glacial ice, are found to the south and west of the village of Penruddock where they are seen at surface and have been encountered in site investigation boreholes along the line of the A66 trunk road. The deposits are again a heterogeneous mix of sand, gravel and cobbles and are found as a part component, with till, of a cluster of north-trending steep-sided drumlins. The deposit has been worked on a small scale in pits over an area between Swinescales [415 272] and Beckces farms [4186 2788].

Farther east in the Eamont valley, gravel with a large component of well-rounded cobbles, forms a distinct terrace feature on the valley sides, and gives rise to drifts of cobble-float on tilled ground. Boreholes sunk for M6 site investigation to the north of Clifton [530 270] show that the gravels are interleaved with boulder clay (see also Arthurton and Wadge, 1981, fig. 40). A few occurrences have been worked for aggregate, such as at Skirsgill [522 289] and the larger cobbles are a feature of dry-stone walling in the area of Brougham Farm [534 280]. At locations between Stainton Village and Sockbridge Mill, these same gravels form small mounded features, some almost conical [e.g. 496 278], but their topographic form is likely to be erosional rather than depositional

Outwith the Eamont valley, surface occurrences of glaciofluvial sand and gravel are rare, but small mounded deposits are found in association with meltwater-channel systems, such as in the neighbourhood of Glendowlin Farm [513 263] and Bellmount Farm [4890 2876]. Linear mounds, located close to Old Riggs Farm [482 298], are part of an esker system extending north to Newton Reigny village (Arthurton and Wadge, 1981, fig. 41). A small group of north–south to north-west–south-east orientated gravel mounds extend up the west flank of the Birk Beck valley between Greenholme [596 059] and Rampshowe [588 077]. The mounds are steeply contoured [e.g. Buskethowe 591 071] and are interspersed with poorly drained hollows, probably kettle holes [e.g. 592 065]. Mounds of this type are likely to be ice-contact features.

7.1.3 Glacigenic landforms

The Carboniferous limestone escarpment acted as an obstruction to the northward flow of ice during the last major glaciation. The escarpment has behaved as a rather broad crag and tail feature with a northward thickening mantle of boulder clay, moulded into drumlin forms with long axes aligned to the direction of ice flow.

The ice-moulded landscape is entrenched by meltwater channels, some dry, some occupied by elements of the present-day drainage system. The channels come in all lengths and sizes, but share a common geometry and habit which marks them out against the form of modern day watercourses. The key aspects are a square-cut, steep sided, flat-floored, cross-section. They may run straight for long distances, change course at sharp angular bends, or start or stop abruptly. The larger channels divide into anastomosing sub-channels, but are never dendritic. The channels are often located on, or open on to, cols and may traverse watersheds. Many are orientated down the fall line of the present day slope, but others cut obliquely across the slope.

The most extensive channel system is nearly 3 km long running from a low col at a little over 190 m OD on the Lowther-Eamont watershed at Lowclose Farm [515 255] north to join the Eamont at Yanwath [516 279]. Feeding into this system, but more or less at right angles to it, are single channels feeding from the high ground of Askham Moor into the valley of the River Lowther. The most prominent example is deeply incised and extends from Riggingleys Top [499 228] to the River Lowther at Askham [516 241]. A short distance to the north, a parallel but weaker feature extends from High Winder [498 237] to Highside Farm [511 255].

The north flank of the Eamont/Dacre Beck valley is seamed with short dry channels, most extend straight down from the main limestone escarpment into the valley bottom [e.g. 4695 2747 to 473 269], but others follow an oblique course [e.g. 461 270 to 467 269]. A number of channels continue across breaks in the crest of the escarpment [e.g. 462 281 to 467 278] linking with a system of north-flowing channels following the present-day Petteril river (Arthurton and Wadge, 1981).

In the south of the district another large and well formed channel extends from High Keverigg [578 168] north to merge with the River Leith at Gunnerkeld [567 182]. This channel is of interest because it is associated with a low-lying area which is the site of a seasonal impondment centred on Wintertarn Farm [5798 1706]. The site is underlain by limestone, and runoff drainage must normally occur through a subsurface conduit. During periods of heavy precipitation this subsurface system becomes overloaded, causing a small lake to form (hence the 'winter tarn') at the surface, while the normally dry meltwater channel becomes a temporary watercourse.

7.2 HOLOCENE LACUSTRINE DEPOSITS

Areas of poorly drained, flat ground are a common feature in the district. They are found, as might be expected, on valley floors, such as the valley of the Threapthwaite Gill, south of Great Mell Fell [410 240] and the Swinescales Beck between Troutbeck [390 270] and Beckces [417 275]. Other common occurrences are in interdrumlin tracts, such as Greenrigg Sike [540 215], Rosgill Head [545 173] Broadslack [587 166] and Nell's Moss [588 130].

A few sites are located in small, subcircular depressions, and are assumed to be kettle holes. Examples are found in the vicinity of Dalemain [Daws Pond, 4795 2615], Hawes Farm [584 117], Mossy Beck [491 211] and among hummocky ground at Greystoke Moor [Bright Tarn, 421 293].

Most of these sites have held bodies of standing water in historical times, but almost all are now drained and cultivated. Rarely, deposits of grey, or red-stained, clay or fine silt may be found. Nowhere are they of any appreciable thickness and none found in the district are laminated or varved.

7.3 PEAT

At poorly drained sites, such as those described in the previous section, the soil profile commonly includes a thin layer of peat, or a peat-silt mixture. In the Threapthwaite and Swinescales Becks, mentioned above, the peat deposit is thick enough to be delineated on the 1:10 000 maps. However, such areas have dwindled over time as the ground has been subjected to agricultural improvement.

On higher ground, such as parts of Askham Fell, the till or limestone substrate is veneered with turf. Boggy areas are present, but no areas of hill-peat were mapped during the present resurvey.

7.4 ALLUVIAL DEPOSITS

There are four large watercourses in the district, the River Eamont and its major tributary Dacre Beck, the River Lowther, the River Leith and its headwater Shap Beck, and the River Lune and its tributary Birk Beck. The upper reaches of most of these rivers have immature profiles. In a number of locations, the watercourses occur in steep-sided channels or rock-cut gorges. Alluvial fans are developed at tributary intersections [e.g. 512 202].

Where the river course is confined, only minor spreads of alluvium are present, commonly deposits of coarse gravels with cobbles and boulders arranged in terraces well above the normal river level.

At other locations the streams may meander across wide alluvial tracts that, prior to modern drainage schemes, held marshland or areas of standing water. Prominent examples occur along the River Lowther between Bampton Grange [520 180] and Helton [515 215], in the Thackthwaite Gill, a tributary of Dacre Beck, between [407 229 and 423 262], and in the Shap Beck between [559 156] and [554 172]. The alluvium here is sand and gravel interspersed with over-bank and oxbow deposits of silt or peat.

Below Eamont Bridge [522 287], the rivers Eamont and Lowther merge and take on a mature profile, within a broad meander belt flanked by a succession of wide, low-angled alluvial terraces. The alluvium of these terraced flood-plains is commensurately fine-grained sand and silt, though the modern watercourse is still bedded in gravel with cobbles, or, in a few localities [e.g. 542 295] is floored with bedrock.

Bedrock is rarely exposed apart from areas of limestone pavement. Most of the ground is blanketed by a regolith composed of angular fragments of locally derived bedrock, usually limestone, or sandstone with variable amounts of fine silt. In all cases, downhill creep affects these deposits, giving substantial accumulations at the base of slopes or against field boundaries.

7.5 MASS MOVEMENT

Few areas are prone to landslip in the district. The steep face of the main limestone escarpment has proved to be largely stable, mainly due to a lack of argillaceous interbedding in the limestone which would afford slip planes. Some land-slipping has occurred in the Ashfell Sandstone on the scarp face of Crosby Fell [594 103]. The slip plane responsible is probably developed in a water-logged muddy dolostone present at the base of the formation. Other small examples, mainly rock falls, have occurred below fault-shattered limestone crags above Dalemain [471 276], Dacre Bank [451 274] and river cliffs cut by the River Lowther at Horseholme Wood [5217 2510].

A more immediate hazard is posed by rock faces in abandoned quarries. Two visibly unstable faces are present in the north of the district at Flusco Lodge Quarry [4746 2820] and beside Stockbridge Mill [4975 2784].

A few areas of steep ground in the north-west of the district contain mature, and currently stable, landslip features. The north-east slope of Little Mell Fell above Grovefoot Farm [4265 2460 to 4315 2475] is affected by a large rotational slip and lobate creep terraces in boulder clay. A similar feature is present on the hill slope above Waterfoot [4600 2425] and on the flank of a gravel mound at Barton [481 266]. The valley side above Dalemain House [476 273] is also extensively marked by lobate creep terraces.

Small slip features occur on steep drift banks undercut by river action. These are mainly found in gravely till along the banks of the River Eamont [e.g. 473 250], the Dacre Beck at [4275 2630] and Brockhole Hag [4440 2710]; none offer any appreciable hazard.

The limestone pavements in the district lack any major development of sinkholes or collapse features related to subsurface voids. By contrast however, all areas of limestone with a cover of Quaternary deposits are marked out by the occurrence of what are locally termed 'shake-holes'. These features are conical pits, up to 4 m deep, occurring singly or as linear sets occasionally merging to produce trench-like depressions up to 100 m long. It is assumed that the pits have formed over points of drainage down into the underlying strata, though it is not known if they have developed progressively through time or were created under periglacial conditions after the last ice age.

None of the features seen during the resurvey were identified as sites of active ground subsidence, though they are often a hindrance to livestock management and small construction projects.

8 Artificial deposits and mineral working

8.1 WORKED GROUND/DISTURBED GROUND

Man-made disturbance of the ground is restricted in the district to large-scale limestone quarry development. The two active quarries at Hardendale [588 139] and Shap Beck [552 181] are still expanding and 1:10 000 sheets 51 NE and SE show the extent of the cut as of summer 1999.

Major quarries at Flusco [455 299 to 465 290], west of Newbiggin village, are now exhausted and the sites used for landfill. Apart from the backfill of excavated ground, restoration of these sites has entailed the creation of a remodelled and wholly artificial landscape. The degree to which any one part of the site has been cut, made-up or simply cleared to its original condition is unrecorded on available plans. All such areas can only be represented on the map as 'landscaped' ground.

An historical legacy of small, disused workings are scattered across the district. These workings were mainly for limestone [e.g. 5722 1170] and dolostone [e.g. 4818 2310], but also exploit beds of sandstone within the Brownber Formation [5730 1218], Ashfell Sandstone Formation [5868 1110] and thin beds occurring within the Knipe Scar Formation.

Despite the existence of thick sand and gravel deposits in the valley of the River Eamont, very few aggregate workings were identified, none are of any great size. Recently active sites include those at Barton Church Farm [4820 2617] and around the village of Beckces [4152 2740].

Brick clay was formerly dug from pits in till east of Shap Village [5680 1525].

Of historical interest are workings in the Reagill Coal present in the lower part of the Yoredale Group. The seam is quite thin and impersistent and could never have sustained any worthwhile industry. The outcrop of the seam is marked by a belt of overgrown shallow workings, mainly bell pits, extending across country from the village of Reagill [600 170] to Little Strikland [564 196]. A deeper shaft, with associated spoil heaps, is located on the map in fields at [5731 1914].

8.2 MADE GROUND/LANDSCAPED GROUND

Most of the small mineral workings in the district have associated spoil heaps, abandoned in situ; the heaps are composed of fragmentary rock tailings. As explained above, spoil from the large exhausted sites located west of Newbiggin village, has been back-filled or used to restore the topography of the site. However, apparently permanent mounds of landscaped spoil have been created next to Shap Beck Quarry [549 180] and in Nell's Moss [5840 1324] at Hardendale Quarry.

The other significant occurrences of made ground, are the various embankments, revetments, service roads and depots constructed for the M6 and A66 highways. Much of the material used is locally derived till, taken out of adjacent cuttings, though recently completed works at Red Hills, west of Penrith, have utilised spoil from the previously abandoned Red Hills Limestone Quarry [498 283].

A section of the River Lune [659 051 to 673 050] has been diverted to accommodate realignment of the A685 trunk road. An artificial channel was cut and the abandoned course filled and levelled with unspecified aggregate.

Mineral working locations

Limestone/dolostone
Flusco, Newbiggin, 455 299 to 465 290
Hardendale, 588 139
Shap Beck, 552 181
Flusco Lodge Quarry, 4746 2820
Stockbridge Mill, 4975 2784
Hackthorpe, 541 227
Lowther Village, 536 238
Glendowlin, 515 273
Yanwath Woodhouse, 5217 2628
Beckces Farm [4182 2810]
5722 1170
4818 2310
530 185

Sandstone
Lowther Caravan Park, 525 270
Brownber Formation, 5730 1218
Ashfell Sandstone Formation, 5868 1110

Brick clay
4152 2740

Sand and gravel
5680 1525
4820 2617
4152 2740

Coal pit
5731 1914

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