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Carboniferous rocks and Quaternary deposits of the Appleby district (part of Sheet 30, England and Wales)

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Richard A Hughes

Cover illustration

Step-featured escarpment on Bank Moor viewed from Crosby Ravensworth village, Cumbria. The escarpment is developed in alternating sandstone and limestone of the Brigantian Alston Formation. The foreground shows Shap Granite glacial erractics resting on thin till.

Bibliographical reference

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British Geological Survey offices

Keyworth, Nottingham NG12 5GG
☎ 0115–936 3100 Fax 0115–936 3200
e-mail: sales @bgs.ac.uk
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Forde House, Park Five Business Centre, Harrier Way, Sowton, Exeter, Devon EX2 7HU
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Geological Survey of Northern Ireland, 20 College Gardens, Belfast BT9 6BS
☎ 028–9066 6595 Fax 028–9066 2835

Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB
☎ 01491–838800 Fax 01491–692345

Sophia House, 28 Cathedral Road, Cardiff, CF11 9LJ
☎ 029–2066 0147 Fax 029–2066 0159

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU
☎ 01793–411500 Fax 01793–411501

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Mr Michael McCormac (BGS)

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NOTES

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

Contents

Figures

Summary

This report describes the Carboniferous rocks and Quaternary deposits of the Ordnance Survey 1:10 000 scale sheets NY 52 SE, NY 61 NW, NY 61 NE, NY 61 SW, NY 61 SE, NY 62 SW and NY 62 SE, part of the BGS (England and Wales) 1:50 000 sheet 30 (Appleby). The bedrock and Quaternary geology of this area was partially surveyed between 1998 and 2000 during the revision of the Appleby 1:50 000 sheet.

An early Carboniferous (Arundian–Holkerian–Asbian) platform-carbonate sequence is well exposed in the southern part of the area, where it forms the extensive and spectacular limestone pavements of the Asby Scar National Nature Reserve. Northwards, this sequence is succeeded by a Brigantian to early Namurian mixed clastic and carbonate fluviodeltaic and platform carbonate cyclic sedimentary rocks. Their distribution, stratigraphical relationships and structure are described in detail.

The Carboniferous rocks are covered by a widespread mantle of Quaternary deposits, consisting mainly of Devensian till, with extensive postglacial alluvium in the river valleys. The distribution and typical lithologies of these deposits, and the Quaternary history of the area are described.

1 Introduction

This report describes the Carboniferous rocks and Quaternary deposits of the Ordnance Survey 1:10 000 scale sheets NY 52 SE, NY 61 NW, NY 61 NE, NY 61 SW, NY 61 SE, NY 62 SW and NY 62 SE (Figure 1), part of the BGS (England and Wales) 1:50 000 Sheet 30 (Appleby). The bedrock and Quaternary geology of this area was partially surveyed during the summer and autumn months of 1998, 1999 and 2000, as part of the resurvey of the Appleby 1:50 000 Sheet. The area comprises gently northward dipping, early Carboniferous platform-carbonate and fluviodeltaic cyclic sedimentary sequences, overlain by Permian and Triassic, mainly continental, sedimentary rocks in the north-east (Hughes, 2003). Quaternary cover is patchy in the south, but almost complete in the north where the landscape is dominated by drumlins.

In the south of the area are some of the most extensive and best preserved limestone pavements in England, many of which are protected within the Asby Scar National Nature Reserve. Elevation here climbs gently to about 385 m at Beacon Hill [635 100], and the poor grazing offered by the limestone pavement areas supports only sheep and a few cattle. Elevation falls gradually to the north, to a minimum of about 100 m in the valley of the River Eden [620 240] north-west of Appleby. Land use is a mixture of pastoral and arable in these lower lying but Quaternary covered areas.

Appleby lies just east of the present area and is the main town. The villages of Crosby Ravensworth, Maulds Meaburn, Reagill, Great Asby, Drybeck, Bolton, King's Meaburn, Cliburn, Newby and Great Strickland are the main rural centres of population (Figure 1).

The Carboniferous sequence of the present area is one of the poorest known in the whole of northern England. The first recorded geological study of the area is that of Bland (1862), who named some of the limestones of the Yoredale Group. Systematic mapping by the Geological Survey began in the Vale of Eden in the 1860s, and a written account of the work was published in 1897 (Dakyns et al.) These authors did not subdivide the Great Scar Limestone Group, but recognised nine mappable limestones within the Yoredale Group. Garwood (1913), and Miller and Turner (1931) considered the Carboniferous sequence in a more regional context.

In more recent years, the most important contribution to the stratigraphical understanding of the Yoredale Group (Brigantian) in the present area has been that of Rowley (1965, 1969), who systematically mapped these rocks (but not the overlying Quaternary deposits) at the 1:10 560 scale throughout much of the present area during the early 1960s. Dr Rowley (formerly of the University of Portsmouth, now retired) most generously placed his field slips at the disposal of the BGS during the course of the present resurvey programme, and his contribution is most gratefully acknowledged. The mapped geological boundaries of the Yoredale Group units on the BGS 1:10 000 scale sheets are mostly those of Rowley; major differences occur only where thick Quaternary deposits are present.

Rowley followed the nomenclature of Dakyns et al. (1897) for the Yoredale Group (see Rowley 1969, table 1 for a summary of the history of Yoredale Group lithostratigraphical nomenclature in the area). However, the Yoredale Group limestone nomenclature on the BGS 1:10 000 scale geological sheets that complement this report is that of the adjacent BGS 1:50 000 Sheet 31 (Brough-under-Stainmore; Burgess and Holliday, 1979). The Brough nomenclature (which also is used on the Alston Block) is used in order to maintain consistency between the two adjacent BGS 1:50 000 Sheets, and to avoid the proliferation of local names.

The lithostratigraphical nomenclature of the Great Scar Limestone Group (Holkerian to Asbian) follows that of Pattison (1990), who mapped the Sheets NY 60 NW and NY 60 NE (immediately adjacent to the south) during the early 1980s. The global stratotype of the Asbian Stage is in Potts Beck, within 2 kms of the southern limit of the present area (George et al. 1976); the term 'Asbian' is derived from the nearby village of Little Asby [698 097]. The lithostratigraphic scheme used in this report therefore largely follows previous BGS practice, but the hierarchical status of many of the units is revised. The lithostratigraphies of the Great Scar Limestone Group and Alston Formation of the Yoredale Group are presently graphically in Figures 2 and 3.

The demands of the BGS mapping programme did not allow time for section logging or detailed petrographical analysis, and the following account describes mainly the general distribution and notes the best sections through the individual rock units. For further detail of the Great Scar Limestone Group in the Vale of Eden the reader is referred to Pattison (1990) and Burgess and Holliday (1979), and for the Yoredale Group to Rowley (1965, 1969) and Burgess and Holliday (1979).

2 Regional setting

There is general agreement that an extensional or transtensional tectonic regime prevailed in early Carboniferous times, in response to regional lithospheric stretching (e.g. Leeder 1982). The Carboniferous rocks of the present area are part of the Stainmore Trough sequence, deposited in a basin bounded to the north by the Alston Block, to the south by the Askrigg Block, and to the west by the Lake District High (see, for example, Gawthorpe et al., 1989). Gawthorpe et al. described the Stainmore Trough as a half-graben, the northern margin of which is defined along the gravity high which coincides with the Eden–Pennine Fault and the Butterknowle–Lunedale–Swindale Beck Fault System, and the southern margin of which coincides with the northern flank of the Askrigg Block. Within this half-graben the sequence in the present area is believed to have been deposited on the hanging-wall of the Eden–Pennine and the Butterknowle–Lunedale–Swindale Beck Fault systems, and represents the thickest accumulation of Dinantian rocks in the Stainmore Trough (Gawthorpe et al., 1989).

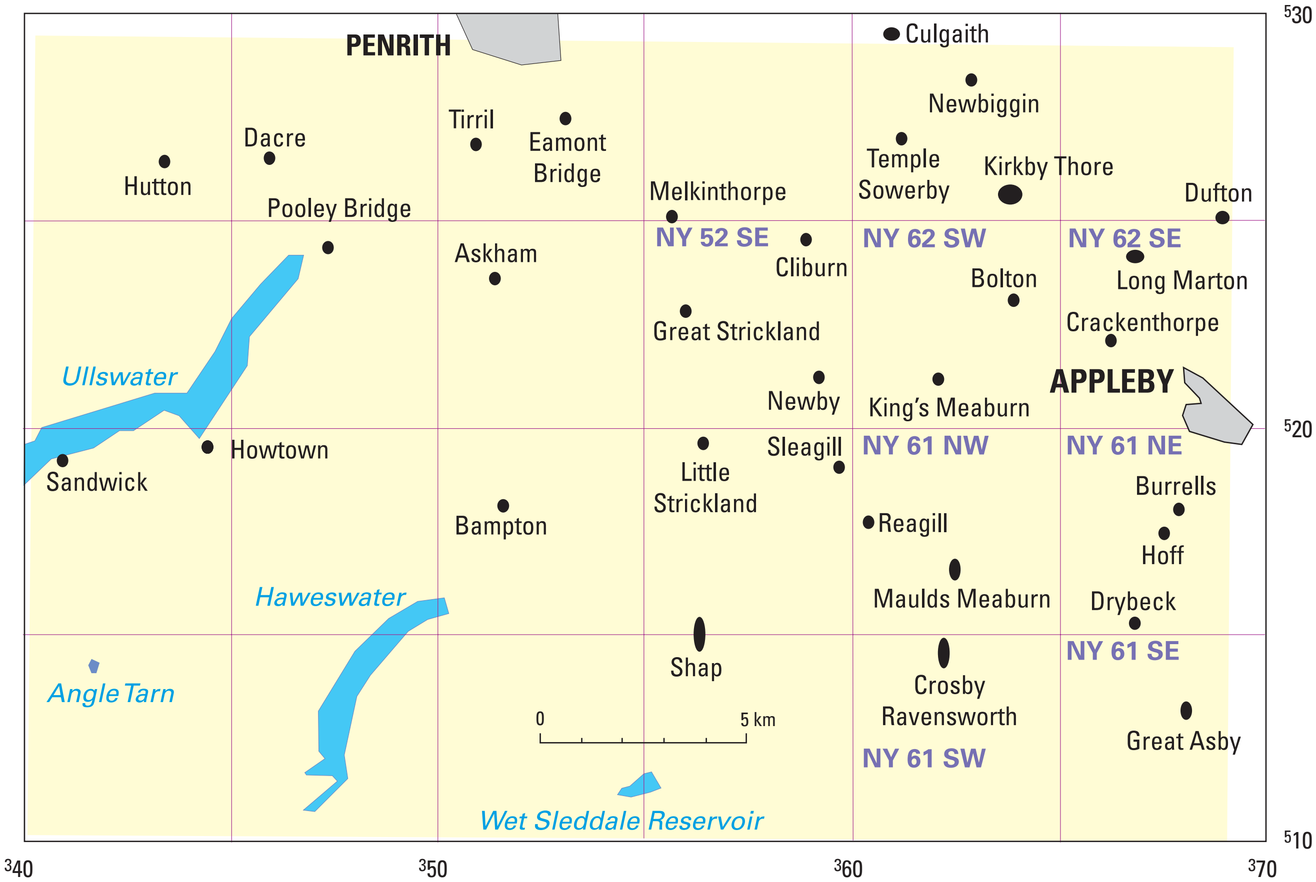

Figure 1 Locality map, showing area of Appleby 1:50 000 sheet (pale yellow), 1:10 000 sheet tiles, and main settlements.

3 Carboniferous Limestone Supergroup

3.1 RAVENSTONEDALE GROUP

3.1.1 Ashfell Sandstone Formation (AFS)

The highest few metres of this formation are present on Crosby Ravensworth Fell [600 100] in the extreme south of the area described, but are not exposed. Pattison (1990) described the unit as consisting of interbedded quartz arenite, mudstone and limestone rich in corals, with sandstone comprising up to 80%. Burgess and Holliday (1979) noted the presence of several ganister (seatearth) beds towards the top of the formation in the Brough-under-Stainmore district. The thickness of the formation is apparently very variable. Pattison (1990) recorded a westward decrease in thickness in the area immediately to the south, from 160 m at Ravenstonedale on the Kirkby Stephen 1:50 000 sheet (sheet 40), to 80 m west of Little Asby (in the eastern half of NY 60 NE), and 40 m to the north of Orton (the western part of NY 60 NW), a horizontal distance of some 15 km. The age of the formation is believed to be Arundian (George et al., 1976; Burgess and Holliday, 1979).

3.2 GREAT SCAR LIMESTONE GROUP

This group (see Burgess and Holliday, 1979, for further details) comprises a thick sequence of Holkerian to Asbian ramp and platform limestones with thin clastic (mainly

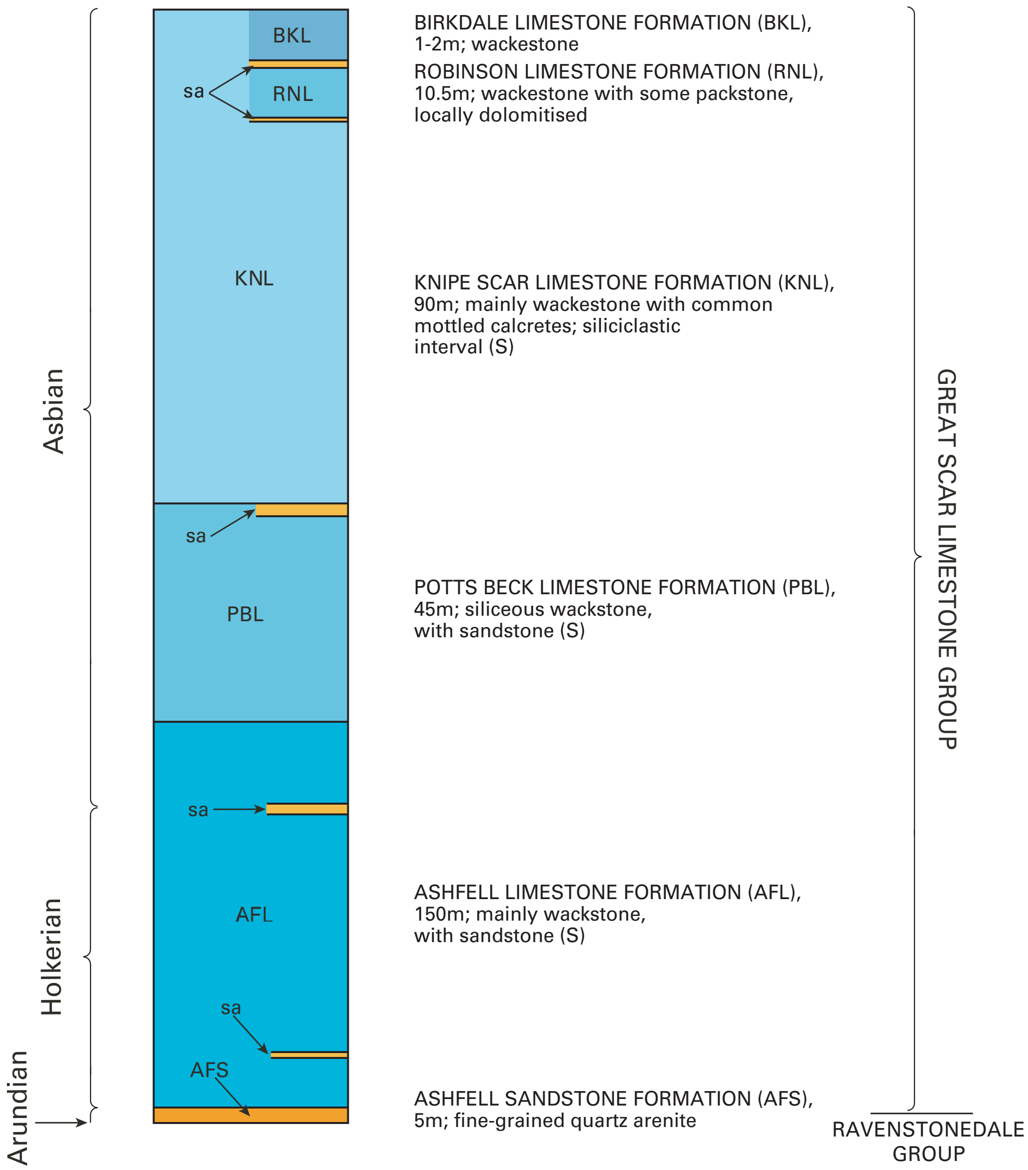

Figure 2 Generalised vertical section through the Great Scar Limestone Group.

sandstone) intercalations. The lithostratigraphy and thickness of the five formations of the Great Scar Limestone Group recognised in the present area are shown in Figure 2.

3.2.1 Ashfell Limestone Formation (AFL)

The Ashfell Limestone Formation is present only on Crosby Ravensworth Fell [600 100 to 620 110], where it is poorly exposed due to an extensive cover of till. The best exposures are to be seen on the north side of Crosby Gill [610 115] just south of White Hag. Its maximum thickness is approximately 80 m in the present area.

Pattison (1990) recognised an informal three-fold division of the formation to the south of the present area, and the reader is referred to this work for further details. Two thin sandstone units within the formation mapped by Pattison are not exposed in the present area.

The Ashfell Limestone Formation was believed previously to be of entirely Holkerian age (George et al., 1976; Burgess and Holliday, 1979). However, the highest part of the formation as defined by Pattison (1990) is of Asbian age, and therefore the Holkerian–Asbian boundary equates to an horizon in the upper part of the formation.

3.2.2 Potts Beck Limestone Formation (PBL)

The Potts Beck Formation is present in the southern and south-western parts of NY 61 SW. Once again exposure is poor, mainly due to an extensive cover of Quaternary deposits. The thickness in the present area is approximately 45 m. According to Pattison (1990), at least 80% of the formation is limestone, but interbedded sandstone and mudstone also occur. The limestone is mostly thick bedded, massive, pale grey wackestone, commonly with mottled calcrete textures. West of Beacon Hill [633 100] a thin sandstone unit (not exposed in the present area) separates the Potts Beck Limestone Formation from the overlying Knipe Scar Limestone Formation. The formation is of early Asbian age.

3.2.3 Knipe Scar Limestone Formation (KNL)

The Knipe Scar Limestone Formation is exposed extensively in the southern half of the area, where it forms spectacular limestone pavements with typically stepped topography. The most extensive exposures are present on the north-facing dip-slopes of Beacon Fell [630 100] and within the Asby Scar National Nature Reserve [640 100 to 670 110]. However, the best exposures are in a spasmodically active, unnamed quarry [642 104] on Gaythorne Plain. The thickness of the formation is approximately 90 m in the present area.

The formation comprises mostly thick-bedded wackestone and packstone, with some grainstone. Pattison (1990) also recorded thin siliciclastic units, though these have not been seen in the present area. In the south-eastern corner of the present area and on the adjacent Brough-under-Stainmore 1:50 000 sheet, Pattison (1990) and Burgess and Holliday (1979) recorded a thin (<5 m) siliciclastic unit at the top of the Knipe Scar Limestone Formation, separating it from the overlying Robinson Formation. This interval is not exposed within the present area.

Palaeokarst horizons and other indicators of emergent surfaces in the Knipe Scar Limestone are reported by Vanstone (1996) from Shap Fell Quarry (some 3 km west of the present area). Fresh surfaces in the quarry [641 104] on Gaythorne Plain offer the most instructive exposures in the present area. Here, stratiform mottled calcrete textures are conspicuous in 'beds' up to 1 m thick, and indicate emergence of the unconsolidated carbonate substrate (Vanstone, 1996). Probable palaeokarst surfaces are also present here, but palaeosols have not been seen. The formation is of late Asbian age.

3.2.4 Robinson Limestone Formation (RNL)

The Robinson Limestone Formation is recognised throughout most of the southern part of the present area, where it forms a conspicuous topographical feature at the top of the Great Scar Limestone Group. However, it has not been recognised in the heavily Quaternary deposit covered areas to the west of Crosby Ravensworth. Its thickness in the Great Asby area is 10.5 m. The best exposures are between Burtree [693 100] and Grange Hall [685 108], where the unit forms a classical scarp and dip-slope feature. The formation is also exposed in a small inlier in the unnamed tributary [647 127] of Scale Beck, 700 m south-south-west of Gaythorne Hall.

The formation consists of mainly thick-bedded, pale grey wackestone and packstone, commonly with mottled calcrete textures, and locally dolomitised.

The age of the formation is believed to late Asbian. However, the base of the Brigantian is poorly defined in this part of the succession — it is correlated roughly with the base of the 'Yoredale'-type cyclic sedimentary sequences, and it is possible that the upper part of the formation may be of Brigantian age.

3.2.5 Birkdale Limestone Formation (BKL)

The Birkdale Limestone Formation (the Gaythorn Limestone of Rowley, 1969; Miller and Turner, 1931; and Dakyns et al., 1897) is present locally in the south of the present area. Its thickness is 1.85 m (Rowley, 1969), and it consists mainly of wackestone. It can be traced as a topographical feature with sporadic but generally poor exposure across much of Gaythorne Plain [640 110], but is best exposed in an inlier [640 120], 700 m south-south-west of Gaythorne Hall. A section in the unnamed tributary [647 127] of Scale Beck here exposes discontinuously the sequence from the top of the Robinson Limestone Formation through the Birkdale Limestone Formation to the base of the Askham Limestone Member, including the interbedded siliciclastic rocks which themselves contain at least two ganister beds.

In the extreme south-east of the area the Birkdale Limestone Formation is exposed in a small quarry [6971 1048] approximately 550 m north-east of Burtree.

4 Yoredale Group

This group consists of the Alston and Stainmore formations. There is a difference between the present and previous usage in the horizon that represents the boundary between the two units. This horizon, formerly taken at the base of the Great Limestone Member, is now defined at the top of the Great Limestone Member.

4.1 ALSTON FORMATION (AG)

As mentioned above, the lithostratigraphy of the Alston Formation rocks throughout most of the present area was established and described thoroughly by Rowley (1965, 1969). Rowley's work extended only as far east as Great Asby [680 131], and an area of approximately 10 km^2 between here and easting [70] was surveyed in detail during the present phase of BGS work. The quality of Rowley's mapping is generally excellent, and much of the solid geological linework in the present area is taken directly from Rowley's field slips. However, Rowley did not map the thick and extensive till deposits, and he interpolated boundary lines between exposed contacts on the assumption that the topographical surface represented rockhead. In these areas (particularly in the north of the present area) there are significant differences between Rowley's lines and those depicted on the accompanying BGS 1:10 000 scale sheets.

In the present area at least thirteen cyclic sedimentary sequences are recognised in the Alston Formation (Figure 3). In these sequences marine calcitic limestones separate siliciclastic intervals (mostly sandstones and siltstones, commonly with seatearth horizons) of mainly fluvial origin, classified as undifferentiated Alston Formation. In sequence stratigraphic terminology the bases of the limestones correspond to maximum marine flooding surfaces, related to high stands of sea level.

The locations of representative sections and the general distribution of units are described in the following account. For further details the reader is referred to Rowley (1965, 1969) and to Burgess and Holliday (1979).

4.1.1 Askham Limestone Member (ASKL)

The Askham Limestone Member is the equivalent of the Smiddy and Peghorn limestones of the adjacent Brough-under-Stainmore 1:50 000 sheet (Dr Colin Rowley and Mr Iain Burgess, personal communications, 1998). The member is 12.2 m thick (Rowley, 1969).

The member consists mainly of calcitic wackestone. Rowley (1969, p. 335) noted the presence of a *Girvanella*-rich bed within the member, but this is not seen in the present area. This bed almost certainly correlates with an algal bed noted by Burgess and Holliday (1979, fig. 25) which separates the Peghorn and Smiddy limestones, in the absence of a siliciclastic interval, in parts of the Brough district.

4.1.2 Halligill Limestone Member (HGL)

The siliciclastic sequence between the Askham and Lower Little Limestone members is well exposed in a gorge at Halligill [659 131], where it contains a 1.2 m limestone unit. This unit can be mapped for several kilometres on the NY 61 SE sheet, and was named the Halligill Limestone Member by Rowley (1965; 1969). A correlation with the Grain Beck Limestone of the Brough sheet (Burgess and Holliday, 1979) seems probable.

On Linglow Hill [65 12] the siliciclastic interval above the Halligill Limestone Member contains a thick (up to 10 m), coarse-grained sandstone body, probably of fluvial origin.

4.1.3 Lower Little Limestone Member (LLLM)

The Lower Little Limestone Member (the Bank Moor Limestone of Rowley, 1969; Miller and Turner, 1931; and Dakyns et al., 1897) is present throughout the area. Its thickness is 9.15 m (Rowley, 1969), and it consists mainly of wackestone. It has been quarried on a local scale throughout the area (for example 250 m west of Turkeytarn Hill [6895 1277], 500 m south-south-west of Bank Head [6285 1343]). The 11 m of siliciclastic rocks overlying the member are poorly exposed in the present area, but at Swathburn Crag [699 128] the uppermost 3 m of this interval consist of fluvial coarse-grained sandstone.

4.1.4 Jew Limestone Member (JWL)

The Jew Limestone Member (the Maulds Meaburn Limestone of Rowley, 1969; Miller and Turner, 1931; and Dakyns et al., 1897) is also present throughout the area. Its thickness is 12.2 m (Rowley, 1969), and it consists mainly of wackestone. It has been quarried extensively throughout the area on a local scale, and the best single exposure is in the now partially infilled roadside quarry [637 129] at Raise Howe, where a *Gigantoproductus* Bed is exposed (see Rowley, 1969). Here the limestone is locally dolomitised.

In the vicinity of Turkeytarn Hill [692 127] a laterally impersistent 1.5 m sandstone bed is present 3 m above the base of the member. Rowley (1969) noted the presence of a thin sandstone within the Lower Little (Bank Moor) Limestone Member in this area, suggesting that the limestone exposed at Turkeytarn Hill may be the Lower Little and not the Jew. However, this possibility is contradicted by the presence of a *Gigantoproductus* bed within the limestone in a small quarry [6905 1314] 360 m north-west of Turkeytarn Hill; these beds are normally indicative of the Jew and not the Lower Little Limestone Member. The identity of the limestones in this area remains problematical because of Quaternary cover and the possibility of strike faulting. However, the limestone at Turkeytarn Hill is believed to be the Jew Limestone Member because of other structural and stratigraphical considerations.

Interbedded sandstone, siltstone and mudstone belonging to the siliciclastic succession above the Jew Limestone Member are well exposed in Dry Beck [657 148]. Farther east, 3 m of fluvial, coarse-grained sandstone with foreset bedding indicating palaeocurrents from the south and east are exposed in a small quarry [6885 1428] 150 m east of Asby Mill.

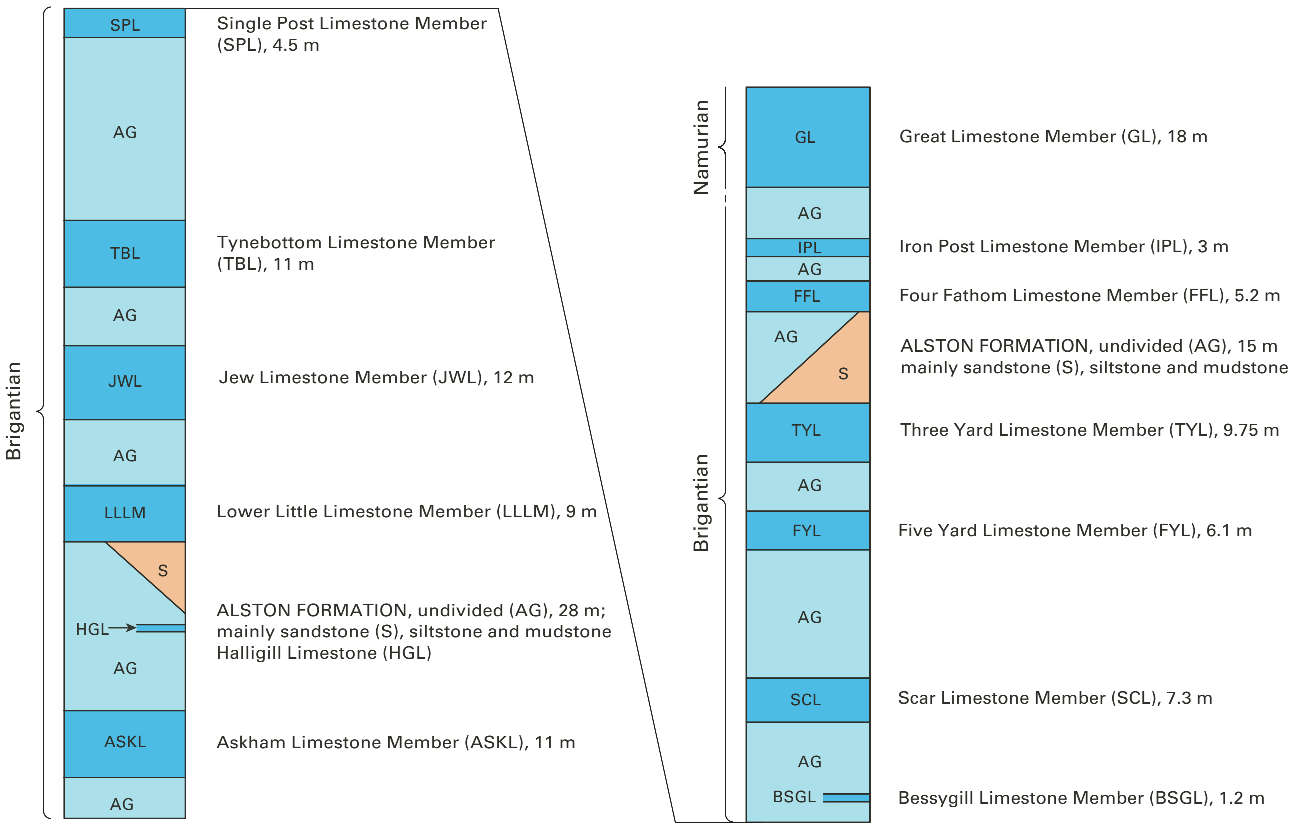

Figure 3 Generalised vertical section through the Alston Formation.

4.1.5 Tynebottom Limestone Member (TBL)

The Tynebottom Limestone Member is the Little Strickland Limestone of Rowley (1969), Miller and Turner (1931) and Dakyns et al. (1897). Its thickness is 11.6 m (Rowley, 1969) and it consists mainly of wackestone with some packstone. It is rather poorly exposed throughout the area. The lower part can be seen in exposures [6139 1739] 750 m north-east of Reagill Grange, and the upper part is exposed [666 154] in small quarries north of the village of Drybeck.

The thick (up to 30 m) siliciclastic succession overlying the Tynebottom Limestone Member is described in some detail by Rowley (1969). Interestingly, west of the River Lyvenet this sequence contains a thin coal bed. The coal was not seen during the present survey, and is probably no longer exposed. However, a note on the Old Series field slip records 'Coal -?8 inches', at an unspecified locality just east of Reagill. In the extreme east of the area at Heights Castle [694 151], the limestone is overlain by a fluvial, thick-bedded, muscovitic medium- to coarse-grained sandstone, up to 30 m thick. This sandstone is well exposed in disused quarries around Heights Castle, where it was worked formerly for building materials.

4.1.6 Single Post Limestone Member (SPL)

The Single Post Limestone member is the Johnny Hall's Trees Limestone of Rowley (1969), Miller and Turner (1931) and Dakyns et al. (1897). Its thickness is 4.5 m (Rowley, 1969) and it consists mainly of wackestone with some packstone. The limestone is very poorly exposed, but its upper part can be seen in Scattergate Gill [628 166]. The siliciclastic units above the limestone are also poorly exposed, but can be seen in the upper reaches of Oak Beck [659 166].

4.1.7 Bessygill Limestone Member (BSGL)

This thin (<1.2 m), discontinuous limestone is present between Hoff Moor [659 156] and Scattergate Gill [627 168], but is very poorly exposed. The best exposures are to the west of the present area in Gillmoor Syke [586 195], and were described by Rowley (1969). The Bessygill Limestone Member is correlated with the Cockleshell Limestone of the adjacent Brough district (Burgess and Holliday, 1979).

4.1.8 Scar Limestone Member (SCL)

The Scar Limestone Member is the Maulds Meaburn Edge Limestone of Rowley (1969), Miller and Turner (1931) and Dakyns et al. (1897). Its thickness is 7.3 m (Rowley, 1969). This limestone is relatively well exposed, the best section being in Maulds Meaburn Edge quarry [633 159] where 2 m of wackestone with some packstone are present. Other exposures occur in Scattergate Gill [6320 1666], Blind Beck [612 188], a disused quarry [611 187] south-east of Blind Beck, at a disused lime kiln [602 189] north of Reagill, and in the River Leith [552 220] south-west of Great Strickland.

Sandstone and siltstone belonging to the overlying siliciclastic sequence are exposed in Oak Beck [663 166], in poor exposures to the west of Hoff Moor, in the River Leith [552 221], and in a disused quarry at Bessy Gill [550 217].

4.1.9 Five Yard Limestone Member (FYL)

The Five Yard Limestone Member is the Brackenslack Limestone of Rowley (1969), Miller and Turner (1931) and Dakyns et al. (1897). Its thickness is 6.1 m (Rowley, 1969). This member, and its overlying siliciclastic strata, are the least well exposed of all the Alston Formation cyclic sedimentary sequences. The limestone is very poorly exposed on

Maulds Meaburn Moor [6435 1554], where it was once quarried, and in the River Leith [552 223]. Fluvial, cross-bedded, coarse-grained sandstone above the limestone is exposed in Barwise Syke [660 176] and Oak Beck [667 168].

4.1.10 Three Yard Limestone Member (TYL)

The Three Yard Limestone Member is the Grayber Limestone of Rowley (1969), Miller and Turner (1931) and Dakyns et al. (1897). Its thickness is 6.1 m (Rowley, 1969), and it is best exposed in Little Beck in the vicinity of Holesfoot [642 175], where medium- to thick-bedded wackestone is present. Rowley (1969) noted the presence of abundant diagenetic glauconite as a diagnostic feature of the member. The overlying siliciclastic unit is best exposed further downstream in Little Beck (e.g. [636 183]), where mappable, fluvial, thick-bedded, coarse-grained sandstone (the Littlebeck Sandstone of Rowley, 1969) is present.

Other exposures of the Three Yard Limestone Member occur in the north-west in a disused quarry [608 198] on Sleagill Moor, and in the River Leith [551 228].

4.1.11 Four Fathom Limestone Member (FFL)

The Four Fathom Limestone Member is the Newby Mill (Lower Leaf) Limestone of Rowley (1969), and the lower part of the Underset Limestone of Miller and Turner (1931) and Dakyns et al. (1897). Its thickness is 5.2 m (Rowley, 1969), and it is exposed in Little Beck at [1900 6345] and [6284 1968]. The overlying siliciclastic rocks are exposed immediately downstream and upstream respectively of these last mentioned localities. The limestone is also exposed in a fault-bounded inlier at Rainbow Plantation [6665 1775], and in the River Leith [553 233 to 550 239]. Approximately 4 m of sandstone and siltstone separate the Four Fathom Limestone Member from the Iron Post Limestone Member.

4.1.12 Iron Post Limestone Member (IPL)

The Iron Post Limestone Member is the Newby Mill (Upper Leaf) Limestone of Rowley (1969), and the upper part of the Underset Limestone of Miller and Turner (1931) and Dakyns et al. (1897). Its thickness is 3.05 m (Rowley, 1969). It is exposed in Little Beck between [6302 1953] and [6328 1924]. The siliciclastic rocks overlying the limestone are best exposed at Rowley Wood [6784 1754], where some 5 m of calcareous sandstone are overlain by wackestone of the Great Limestone Member.

4.1.13 Great Limestone Member (GL)

The Great Limestone Member (the Great Strickland Limestone of Rowley, 1969; also widely known as the Main Limestone) is locally well exposed throughout the area, and has an average thickness of approximately 18 m. The base of the Great Limestone Member has long been regarded as the base of the Namurian (e.g. Burgess and Holliday, 1979), though new evidence from the Throckley area of Northumberland (Mark Dean, personal communication) suggests that the base of the Namurian may be at an horizon below the base of the Great Limestone Member.

The limestone is mainly medium- to thick-bedded wackestone and packstone, commonly rich in corals. The best exposures of the Great Limestone are in Byesteads Quarry [603 217] south-east of Morland; other good exposures can be seen in the River Leith [between 552 241 and 554 244], in Morland Beck at Morland [e.g. 559 225], along the River Lyvenet [610 210] west of King’s Meaburn, in a number of small quarries [580 210] between Newby and Great Strickland, in a series of old quarries [654 187] south-east of Fousons Rigg, and at Rowley Wood [6786 1755]. Further exposures are present in partly infilled small quarries [641 187], east of Sideway Bank.

4.2 STAINMORE FORMATION (SMGP)

The siliciclastic sequence overlying the Great Limestone Member belongs to the Stainmore Formation, and is the youngest exposed part of the Carboniferous sequence in the present area. There is no fossil evidence to indicate the stratigraphical range of these rocks, and they are believed to be entirely of early Namurian age.

Generally, the Stainmore Formation is extremely poorly exposed in the present area. However, it can be seen in Hoff Beck at Cuddling Hole [6729 1835], where thin- to medium-bedded, medium-grained sandstone and siltstone are present. Farther downstream, north of Bandley Wood [671 192], reddened mudstone and coarse-grained quartz arenite are exposed [6689 1966] in an inlier within the overlying Brockram.

The higher parts of the Stainmore Formation in the present area are also exposed in Teas Sike [64 21], east of King’s Meaburn, where the mapping of Dr Colin Rowley identified a discrete (but unnamed) limestone unit [644 210]. Poor exposures of the Stainmore Formation are also present in the River Leith section [north of 544 244], south of the village of Melkinthorpe.

Evidence abstracted from old field slips in the BGS archives at Murchison House indicates the presence of an inlier of Carboniferous rocks to the north of Appleby [670 230, 680 210]. These rocks were not seen during the present survey, but judging by their stratigraphical position they probably belong to the Stainmore Formation.

5 Structure

The area is very simple structurally. The Carboniferous sequence dips gently northwards at between 5 and 15°. An angular discordance of less than 5° exists between the Carboniferous and Permian sequences, but the contact is not exposed.

5.1 FAULTING

A north-east-trending fault set is dominant throughout most of the area, and these faults produce conspicuous topographical offsets of limestone pavement features of the Great Scar Limestone Group. These faults have small throws (less than 10 m, where determinable) and very steeply dipping fault surfaces. The best example occurs within the Asby Scar National Nature Reserve east of Thunder Stone [645 104], where the Knipe Scar Limestone Formation is thrown down to the south-east. Further examples occur south of Bank Head [630 135], and in the south-east of the area at Asby Grange [689 107] and Burtree [690 100].

In the east and south-east of the area a north-west-trending, strike-parallel fault set dominates. These faults are largely inferred from displacements of recognised limestone units of the Alston Formation, and because of more extensive drift cover have little or no topographical expression.

5.2 FOLDING

North-east-trending, open synclines and anticlines are common in the south of the area, where they are conspicuous because of their topographical expression in the limestone pavements of the Great Scar Limestone Group. Good examples occur on Great Asby Scar [64 10, 65 10], where synclinal-anticlinal pairs are present.

The geographical proximity and parallelism of the fold axes and the north-east-trending fault set described above suggests that these structures may have formed during the same deformation event. If this is indeed the case, it may be inferred that the faults are of the reverse type.

6 Quaternary

Alluvial deposits within this area were identified and mapped in part during the primary survey of the Appleby 1:50 000 geological sheet in the 1880s, and also (within the NY 61 quadrangle) by Dr Colin Rowley during his PhD mapping project in the early 1960s. However, the first systematic mapping of till deposits was carried out by the present author during the summers of 1998, 1999 and 2000. It should be emphasised, however, that this mapping was a rapid, partial survey exercise, and that the limits of the till deposits are generalised.

6.1 TILL

With the exception of the limestone pavement areas in the south, till covers most of the area, but is believed to be generally only a thin (< 5m) veneer. Probably the greatest thickness occurs in the drumlin field trending north-north-west [690 180] to the south-east of Appleby on the north-east side of the River Eden.

Throughout much of the area the till is a stiff, dark grey to red-grey clay with abundant erratics of typical Lake District volcanic and intrusive lithologies, including Shap Granite. Typical till deposits are exposed in Dry Beck [650 140] and Crosby Gill [610 110]. However, in the north-west of the area (exposed, for example, along the banks of the River Eden [6062 2774]), the till is pale brown with a much sandier matrix, though the erratic population remains the same. This till type is widespread along the valley of the River Eden, but its matrix-supported nature, and the angularity of its clasts clearly indicate deposition by non-fluvial agents. The temporal and spatial relationships between the two till types are unknown.

Trotter (1929) described a series of differently coloured tills from the Vale of Eden, and concluded that the tills were of different ages. The idea gathered little support from subsequent authors, and, with our improved knowledge of the complexity of till-outwash sequences, is now disregarded.

Letzer (1978; and in Boardman, 1981) carried out a detailed study of the Quaternary succession of the area to the south, whose northern limit coincides with the southern limit of the area described here. She noted that colour was largely ineffective in distinguishing till deposits of differing age, except where other lines of evidence were available to prove their polygenetic origins.

However, Letzer described a locality in Scandal Beck [7420 0240], some 13 km south-east of Great Asby, where a Devensian 'Upper Limestone Till' and a Wolstonian 'Lower Sandstone Till' are separated by Ipswichian interglacial deposits. Although there are no known exposures of the older, Wolstonian till in the area described in this report, its presence is clearly a strong possibility.

6.2 GLACIAL LANDFORMS

Drumlin landforms trending north-west to north-north-west are common throughout the northern half of the area. Many of these drumlins are known to be rock-cored, but the very smooth, symmetrical, elongate dome form of the drumlins north-east of the River Eden [690 180] in the Appleby area suggests that these may be composed entirely of till.

Letzer (1978; and in Boardman, 1981) described two suites of drumlins in the area to the south. The 'Howgill suite' drumlins are orientated north to south, and the 'Lake District suite' is orientated north-west to south-east. In the present area, the Howgill suite is represented by the north to south drumlins present, for example, at Crosby Ravensworth [620 140 to 640 160]. The Lake District suite dominates the north-eastern part of the area, particularly in the valley of the River Eden around Appleby [690 180]. Letzer (in Boardman, 1981) described small, Howgill suite drumlins superimposed upon larger, Lake District suite drumlins around Brough. From this relationship she deduced that the north to south orientated Howgill suite drumlins were formed during a younger glacial event than the north-west to south-east orientated Lake District suite drumlins. Both events are believed to be of late Devensian (Dimlington Stadial) age (Letzer, 1978; and in Boardman, 1981).

Glacial meltwater channels are common throughout the area, and form part of a very extensive network present in the Vale of Eden (see Burgess and Holliday, 1979). The best examples in the present area are Frith Beck [690 210 to 700 230], Dufton Beck [680 240 to 700 250], Crowdundle Beck [620 280, 640 300], the upper reaches of Scale Beck [640 120], in the area of Robin Hood's Grave [617 107], and south-east of Burtree [693 100]. In the south of the area there are numerous examples in the area of Great Asby Scar [650 100] and Asby Winderwath Common. Here, the channels most commonly have a north to south or north-east to south-west orientation. Till is commonly absent from their bases, and boulders of Shap Granite are typically very abundant.

Tiddeman (in Dakyns et al., 1897) described a buried channel, proved during the driving of a sewage tunnel, that he interpreted as the preglacial course of the river Eden (see also Burgess and Holliday, 1979, fig. 50). The channel fill was described as comprising a thick sequence of fluvial gravels beneath till deposits. Tiddeman also reported the finding of a bison tooth from the gravels. The age of the buried gravels is unknown, but it is tempting to speculate that, unless the overlying till deposits were emplaced in that position tectonically, the gravels are of pre-late Devensian age (i.e. interglacial).

Site investigation boreholes along the A66 road at Chapel Wood [670 217], north-west of Appleby, revealed up to 18.5 m of sand and gravel lying directly upon rockhead, and overlain by up to 8 m of till. This sequence of sand and gravel is laterally continuous, and may be part of the buried channel fill described by Tiddeman, or part of a larger outwash deposit.

6.3 DIRECTION OF ICE MOVEMENT

Letzer (in Boardman, 1981) recognised that the most pronounced trends in erratic transfer were the north-eastward movement of Silurian sedimentary rocks, the eastward movement of Borrowdale Volcanic Group rocks towards Stainmore, and the northward movement of Shap granite from its outcrop. The distribution of Shap Granite contradicts Hollingworth's conclusion (1931) that these erratics are concentrated in a belt extending east-north-eastwards from Shap towards Stainmore.

Letzer believed that it is impossible to explain such contrasting trends by any single ice movement event, and she concluded that the distribution of erratics indicated a multi-directional glaciation that could be accounted for by migrating ice-sheds.

6.4 ALLUVIUM

Alluvium, of presumed Holocene age, occurs along all the main river valleys. By far the most extensive alluvial deposits are in the valley of the River Eden [e.g. 690 100], where minor terraces are also present. There is no direct evidence for the thickness of these deposits. Typical lithologies are pale brown-yellow silt and sand, and the terrace deposits commonly contain thin units of gravel.

6.5 PEAT

Peat deposits, of post-Devensian age, are widespread on the higher ground in the south of the area. The thickest and most extensive deposits are present on Crosby Ravensworth Fell [600 100 to 620 110], where they rest upon till deposits and Great Scar Limestone Group bedrock.

6.6 LANDSLIP

Small landslips in drift deposits are relatively common (e.g. around Crosby Gill and the River Lyvenet on NY 61 SW), but there are no known landslips in solid bedrock in the present area.

Larger landslips are to be found along the valley of the River Eden, where river meanders have undercut and over-steepened the river banks. Examples occur just west of the town of Appleby [679 201], and just south of the A66 trunk road [670 217] between Appleby and Crackenthorpe. The last mentioned slip has a long history of movement. The cause of this troublesome landslip may be the buried channel deposits described above in Section 6.2.

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