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A BRANDON

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1 INTRODUCTION

This report describes the geology of the 1:10 000 Sheet SD 56 SE (Littledale) which lies on the 1:50 000 Sheet 59 (Lancaster). The map is available as an uncoloured dyeline print and includes the generalised geological sequence and details of selected sections.

The first geological survey of the area on the scale of 1:10 560 was carried out by R H Tiddeman and J R Dakyns and published as part of the Lancashire County Series Sheet 31 in 1880. A small part in the south-west of the area, around Littledale, was studied in 1985 in connection with the Wyresdale Tunnel investigation (Wilson *et al.*, 1989). The present survey, at the 1:10 000 scale, was carried out by A Brandon in 1989 and 1990, under the supervision of J I Chisholm, Regional Geologist. Palaeontological collecting was carried out by N J Riley and A Brandon and registered under the suffix letters RH, RHR, AB and ABR. Biostratigraphical reports are in preparation.

The following is a list of BGS geological maps covering the area:

One inch to one mile scale:
Primary Series Sheet 91NE (New Series Sheet 59) Solid, published 1884;
Drift, published 1884
1:10 560 scale New Meridian County Sheets:
Lancashire 31; geology published 1880

A geological memoir summarizing the work of the primary survey was not published though Tiddeman presented a brief account of the glaciation of the area in 1872. The area was mapped by Moseley and the geology summarised in his general account of the Namurian of the Lancaster Fells in 1954. He also described some aspects of the Quaternary geology of the area (Moseley and Walker, 1952).

All exposed sections in the area, most of which are only indicated on the map by a dip arrow, have been logged. All details are in field notebooks 5 and 6. As a general rule, selected information on the more important sections is given either on the map or in the left hand side margin. Sections listed in the map side margin are lettered A to J. Further information is given in this

account and in the Appendix. Sections in the Appendix are numbered 1 to 10 and cross referenced to sections A to J of the map where appropriate.

2 DINANTIAN AND NAMURIAN ROCKS OF THE WHITMOOR HYDROCARBON BOREHOLE

The Whitmoor No 1 borehole (SD 56 SE/1) [5874 6315], in the north-eastern part of the area, was drilled in 1966-7 by Place Oil and Gas (U.K.) Ltd to a depth of 1560m (below the drilling platform). The borehole started in the lower part of the Caton Shale Formation and penetrated deeply into Dinantian strata. The general biostratigraphy and lithostratigraphy, based on well cuttings and geophysics, is shown on the left hand side margin of the map. A more detailed log of the Namurian strata down to the upper part of the Brennand Grit Formation in given in Wilson *et al.* (1989, figure 1).

The following BGS reports cover aspects of the biostratigraphy of the core:

PDL/67/27 - Arnsbergian and Pendleian palynology - Dr B Owens
PD/85/200 - Visean calcareous microfossils - Dr N J Riley
PD/86/27 - late Visean to Arnsbergian palynology - Dr B Owens

Depths of the lithostratigraphical units, measured from the drilling platform 3.2m above ground level, are given below. Thicknesses are in brackets:

Millstone Grit Group	953 - 3.2m (953m)
Caton Shale Formation	?13 - 3.2m (?10m)
Ward's Stone Sandstone Formation	38 - ?13m (?25m)
Roeburndale Formation	?305 - 38m (267m)
Cravenoceras cowlingense Marine Band	256 - 253m (3m)
Brennand Grit Formation	?495 - ?305m (?190m)
Pendle Grit Formation	953 - ?495m (?458m)
Bowland Shale Group	1212 - 953m (259m)
Upper Bowland Shale Formation	1049 - 953m (96m)
Lower Bowland Shale Formation	1212 - 1049m (163m)
Pendleside Sandstones Member	1169 - 1117m (52m)
Park Style Limestone Member	1212 - 1195m (17m)
Worston Shale Group	1560 - 1212m (348m)
Pendleside Limestone Formation	1267 - 1212m (55m)
Hodderense Limestone Formation	1273 - 1267m (6m)
Hodder Mudstone Formation	1560 - 1273m (287m)
Chaigley Limestone Member	1515 - ?1357m (?158m)
Hetton Beck Limestone Member	1560 - 1515m (45m)

The Cravenoceras cowlingense Marine Band, between 256 and 253m depth, corresponds with a strong peak on the gamma log. *Posidonia corrugata* was collected from chips of dark grey mudstone at this level.

3 MILLSTONE GRIT GROUP

The bedrock of the area belongs entirely to the Millstone Grit Group. Most exposures are confined to stream gullies incised through the Drift deposits. A generalised stratigraphy of the component formations that crop out in the area is depicted on the right hand side margin of the map. Estimated thicknesses and general depositional environments are as follows:

Claughton Formation	circa 150m (top not present)	mostly delta slope with delta top and marginal marine
Caton Shale Formation	circa 70m	marine
Ward's Stone Sandstone Formation	circa 6 to 50m	delta top
Roeburndale Formation	circa 215m (upper part only)	mostly delta slope with delta top and marine

Many of the named units are adapted from Slinger's (1936) summary stratigraphy of Caton Moor. Listric faults, as evidenced by oblique, low angle, slickensided planes are common, particularly in beds deposited in a delta slope environment. The faults are attributable to syndepositional growth faulting. Slumped beds are also common in rocks of this facies.

Petrographical descriptions of Millstone Grit sandstones are given in BGS Technical Report WG/91/36R by G E Strong. Heavy mineral analyses of Millstone Grit sandstones are given in BGS Technical Report WH/91/399R by C Hallsworth.

3.1 ROEBURNDALE FORMATION

The general stratigraphy is shown on the side margin of the map. The formation consists of the following five fairly distinctive general lithologies, ranging in facies from marine to delta top:

1. Relatively thin units of tough, grey, shaly calcareous mudstone containing argillaceous limestones and calcite mudstone nodules and with a marine fauna dominated by bivalve and ammonoid molluscs; the Eumorphoceras ferrimontanum and Eumorphoceras yatesae marine bands.

2. Uniform, grey, shaly, sandy, micaceous, calcareous siltstones containing only sandstones on the centimetre scale and with levels of large calcisiltite lenses and a sparse fauna of restricted or marginal marine bivalve and gastropod molluscs; the Close Hill Siltstone Member

3. Grey to blue-grey, shaly, finely micaceous mudstones with lenses of siderite mudstone; the lithology, where differentiated, is mapped as "md".

4. Interbeds of grey weathering brown, fine-grained, parallel and ripple cross-laminated, micaceous, sole-marked sandstones and grey, shaly, sandy, micaceous siltstones with comminuted plant debris; this lithology is mapped as "sa/sl" or "sl/sa" and some thicker sandstones mapped as "sa". The sandstones were probably deposited by turbidity currents. Palaeocurrent data suggest that the palaeoslope faced south.

5. Grey weathering pale orange-brown, fine- to medium-grained, clean, siliceous sandstones and ganister sandstones with rare thin coals; the Sapling Clough Sandstone Member.

There is good evidence of a local angular unconformity at the base of the Ward's Stone Sandstone. This results in beds younger than the Close Hill Siltstone being locally absent, as shown on the side margin of the map.

3.1.1 *Eumorphoceras ferrimontanum Marine Band*: The marine band is the lowest unit exposed in the area. Sections occur in Sweet Beck [around 5508 6108] and a small unnamed tributary [downstream of 5514 6101] on the north side of the Foxdale Beck Fault. The Sweet Beck occurrence was previously identified as the Eumorphoceras yatesae Marine Band during the Wyresdale Tunnel investigation (Wilson *et al.*, 1989, p.13). Fossils collected at that time are listed on p. 6 of Biostratigraphical Report PD 85/158 by Dr N J Riley. They are: crinoid ossicles and brachioles, *Dunbarella yatesae*, *Posidonia corrugata*, orthocone fragments, *Anthracoceras* or dimorphoceratids, *Cravenoceras gairense*, *Eumorphoceras* sp. and entomozoacean ostracods (see Wilkinson and Riley, 1990). Further collecting has been undertaken and a report is in preparation.

In Sweet Beck the section is:

b	Rbl	Claystone, blue-grey, shaly, finely micaceous	c. 3
a	E2a2	Mudstone, grey, shaly to platy, silty, calcareous with sporadic phosphatic nodules; crinoid ossicles, orthocone nautiloids, *Posidonia corrugata*, *Pseudamussium*, *Eumorphoceras* and *Cravenoceras*	c. 2

In the unnamed tributary stream to Sweet Beck, adjacent to the fault, about 5m of brown-weathering grey, shaly, silty, calcareous, poorly fossiliferous mudstone are exposed.

Thewlis (1962, pp.23 & 33 and 1:10 560 map) records "small *Posidonia-type* lamellibranchs" from "black and dark grey shales along Udale Beck [559 609] (shown at [5593 6099] on the map). No exposure could be found here during the survey, the nearest one [5595 6092] being of 11m of blue-grey, shaly claystone with siderite mudstone lenses.

3.1.2 *Siltstones and mudstones above the Eumorphoceras ferrimontanum Marine Band:* About 30m of grey, shaly, micaceous, sandy siltstones, with sporadic fine-grained sandstone beds up to 5cm thick and calcisiltite lenses, are intermittently exposed in Sweet Beck [c. 5520 6125] and in the gullied hillside to the south-east. The siltstones are mapped as Rbl and apparently overlie the marine band sequence described above and underlie the sa/sl unit exposed further downstream and described in the next section. These beds so closely resemble siltstones of the Close Hill Siltstone Member, however, that it is possible that the marine band is faulted against that member locally.

The highest beds are exposed below Cocklett Scar along Foxdale Beck [5773 6090]:

c	sa/sl	Sandstones, orange-brown, fine-grained with thin interbedded grey siltstones	c. 2
b	Rbl	Siltstone, grey, micaceous, sandy; fine-grained, micaceous sandstone lenses to 0.1 and burrow infills	c. 1
a	Rbl	Mudstone, blue-grey, finely micaceous, silty; sporadic siderite mudstone lenses up to 6cm thick	c. 6

About 1m of similar mudstone are exposed downstream [5744 6098]. The

Eumorphoceras ferrimontanum Marine Band probably lies at no great depth at these two localities. Estimated to be at about the same stratigraphical level are up to 12m of grey, micaceous, shaly to platy, sandy siltstones containing a few fine-grained sandstones to 3cm that are exposed higher up Foxdale Beck, in two southern tributary gullies [5800 6062 and 5841 6055].

3.1.3 "sa/sl" *below the Close Hill Siltstone*: These interbedded sandstones and siltstones, equivalent to the Cocklett Scar Flags of Slinger (1936), are estimated to be up to 65m thick. They are exposed intermittently along several streams in the south part of the area, i.e. along Crossgill [5780 6204 to 5747 6206], along Ragill Beck and around the confluence with Crossgill [5792 6214 to 5802 6181], along Udale Beck and tributary Sweet Beck [5528 6168 to 5524 6131], and especially in Foxdale [5692 6156 to 5863 6056] (see Appendix: Section 7). There are impressive sections of up to 50m of strata in Cocklett Scar [c. 576 610], on the north side of Foxdale. There are also excellent sections up to 20m high along Ragill Beck. Details of selected sections are given on the map.

The beds consist of interbedded sandstones and siltstones in overall roughly equal proportions, though on some levels sandstones predominate and vice versa. Both lithologies vary from mere partings in thicker beds of the other lithology, up to individual beds about 3m thick. Comminuted plant fragments, commonly current orientated, are abundant at many levels. The sandstones are grey, weathering brown or orange-brown and fine- to medium-grained. They are generally thin- to medium-bedded, finely parallel-laminated and sharp-soled. Ripple-cross laminated beds are common. Sole marks, primary current lineations and lenses of siltstone pebble conglomerate are recorded. Many of the sandstone beds are cemented with ferroan calcite. Individual beds are variable in thickness and lensing is common. Striped beds up to 5m thick, consisting of alternations of flaggy and platy, micaceous sandstones and siltstones and silty sandstones on the centimetre to ten centimetre scale are common.

The lower boundary is exposed in Foxdale Beck, below Cocklett Scar (see above for section). The upper boundary of the unit is generally gradational over a few metres. Small stream gullies, cut into the steep west side of Udale Beck gorge [c. 5525 6158], expose about 11m of siltstones at the top of the unit, that contain numerous sandstones to 0.3m, overlain by about 14m of siltstones

at the base of the Close Hill Siltstone, with fewer, thinner sandstones and with sporadic calcisiltite lenses.

3.1.4 *Close Hill Siltstone Member*: The member, estimated to be between 75 and 100m thick within the area, was named the Close Hill Shales by Slinger (1936), presumably from the well exposed section along Ragill Beck (see below), on the north side of Close Hill. The beds are well exposed in numerous widely distributed stream sections annotated on the maps. The lower part of the member and lower boundary are exposed along Udale Beck (see above section). In Ragill Beck [5801 6184 to 5842 6129], the upper part of the member and the contact with the overlying unit are exposed. Other sections of the upper part of the member and the contact with the overlying unit occur along Azers Gill [5980 6140 to 5970 6124], along Foxdale [5909 6046 to 5932 6030] including the backscarp of a landslip [5924 6047] (see Appendix: Section 8), and along Lambclose Syke [6000 6192 to 5975 6188] (see Appendix: Section 9). In the north-east part of the area, there are numerous excellent sections in the uppermost 29m of the member along the River Roeburn, its tributaries Crogley Gill Beck and Warm Beck, and in a landslip backscarp in Winder Wood [5970 6390 to 5984 6350] (see Section E and Appendix: Section 6d). Numerous other intermittent sections in the siltstones in this general area occur along Gill Syke [5948 6330 to 5989 6330] and Stone Beck [5935 6245 to 5994 6301].

The member consists of uniform, grey, shaly to platy, finely micaceous, commonly calcareous siltstones which grade into platy, silty, very fine-grained sandstones. There are less common levels of finer clayey siltstone. Thin beds of fine-grained sandstone of the order of 1cm or less thick, and weathering rusty brown, occur about every 10cms or so throughout the member and are commonly ripple-marked. Thicker, sandstones, up to about 0.5m in thickness and cemented with ferroan calcite, are generally rare. Comminuted plant debris is not conspicuous. Rare *Calamites* is recorded, e.g. from the uppermost 4m in Lambclose Syke [5999 6191]. The beds are bioturbated in places and contain numerous burrow infills. Burrows ascribed to cf. *Aulichnites* sp. are commonly abundant on bedding planes. The more calcareous levels contain large ovoidal septarian nodules of sandy calcisiltite, up to about 2m in diameter and 0.5m in thickness. The upper and lower boundaries of the member are generally fairly well defined but can be gradational over a few metres.

At several places the siltstones have been syndepositionally slumped and are severely contorted. Excellent sections in slumped beds occur along the River Roeburn and in the adjacent part of Warm Beck [5979 6390 to 5999 6330], in the region of the Claughton Fault zone. The beds are cut by numerous slickensided growth faults. Slumping has also been recorded along Foxdale [5922 6048], in the uppermost 3m of the member. Soft sediment deformation also occurs in the uppermost 4m of the member in Lambclose Syke [5999 6192].

The member contains sparse *Sanguinolites* sp., which is also locally common on some levels, particularly in the finer clayey siltstones. The localities where *Sanguinolites* has been found are indicated on the map by an asterisk. They areas follows: River Roeburn [5998 6374, 5995 6361, 5998 6341]; Warm Beck [5945 6397]; an unnamed tributary to Warm Beck [5949 6390].

3.1.5 "sa/sl" *and mudstones above the Close Hill Siltstone*: In most parts of the area, the Close Hill Siltstone is overlain by a further unit of sa/sl interbeds. In the Littledale area, however, a unit of shaly mudstones with siderite mudstone lenses intervenes.

"*sa/sl*": These interbeds are of similar delta slope facies to the unit below the Close Hill Siltstone. The unit is present above the Close Hill Siltstone up to a thickness of about 35m over most parts of the area and details of selected sections are given on the map. Unusually, in the Roeburn area (see Section E on map side margin), up to 90m of beds may be present, but uncertainty arises from the degree of both local growth faulting and tectonic faulting. In the western part of the area, around the lower part of Crossgill [562 622] and Artle Beck [551 626] (see Section F and Appendix: sections 4a, 4b, 4c, 4e), sandstones are subordinate to siltstones and the beds have been mapped as sl/sa. Locally, around Littledale [552 621], the unit is apparently absent due to an unconformity at the base of the Ward's Stone Sandstone. In some places the Sapling Clough Sandstone may have been incorporated into the unit owing to difficulties of differentiation in poorly exposed ground.

The sa/sl beds consist of interbedded sandstones and siltstones in overall roughly equal proportions, though on some levels sandstones predominate and vice versa. Both lithologies vary from mere partings in thicker beds of the other lithology, up to individual beds of the order of one or two metres

thick. The siltstones are grey, shaly to platy, sandy and micaceous with comminuted plant debris. The sandstones are grey, weathering brown or orange-brown, fine- to medium-grained, micaceous and commonly cemented with ferroan calcite. They are generally thin- to medium-bedded and parallel-laminated and ripple cross-laminated. The sandstones are generally sharp-soled with sole marks, particularly groove casts and bounce marks. In the Roeburndale area, a basal sandstone (sa) has been mapped (see Section E and Appendix: Section 6d) and sharply overlies the Close Hill Siltstone. The sandstone, between 3 and 8m thick, is grey, weathering orange-brown, fine-grained and thick-bedded. It is cemented with ferroan calcite and locally slumped. A 2.5m thick sandstone occurs at the same stratigraphical level in Lambclose Syke [5991 6190] (see Appendix: Section 9). A similar sandstone is present at the base of the equivalent sl/sa unit along Artle Beck on Sheet SD 56 SW. The unit is usually sharply overlain by either the Sapling Clough Sandstone, the Eumorphoceras yatesae Marine Band or the Ward's Stone Sandstone.

Sections through the base of the unit occur in Winder Wood and Warm Beck (see Section E4 and Appendix: Section 6d), along Foxdale Beck (see Appendix: Section 8) and along Lambclose Syke (see Appendix: Section 9). Sections through the top of the unit occur along Artle Beck (see sections F, F2, F3 and Appendix: sections 4a, 4b, 4c, 4e) and along Warm Beck (see sections E2, E3 and Appendix: sections 6b, 6c).

The sa/sl beds are intermittently well exposed in northern tributary stream gullies to Crossgill [580 623, 577 624, 578 624 and 587 624], Azers Gill [597 612] and Ragill Beck [5842 6127].

Sideritic mudstones: Two gullies in the Littledale area [558 618 and 561 619] expose up to 9m of blue-grey, shaly, finely micaceous mudstones (claystones), with sporadic siderite mudstone lenses. Similar mudstones are also present to the south. They are poorly exposed along Rotten Clough [5603 6055, 5598 6080] and 11m are well exposed in a section in Udale Beck [5595 6092]. The unit appears to overlie the Close Hill Siltstone and to be overlain in places directly by the Ward's Stone Sandstone.

3.1.6 *Sapling Clough Sandstone Member:* The member is of delta top facies and

is very similar to the ganisteroid facies of the upper part of the Ward's Stone Sandstone. It consists of up to about 20m of mainly clean, orange-brown weathered, fine- to medium-grained, very thick-bedded, low angle tabular cross-stratified, siliceous sandstones. Carbonaceous plant fragments are abundant in some of the finer beds. It is only locally present and has only been recognised in two small stream gullies on the south side of Foxdale Beck Fault. In most parts of the area the member is absent due to the unconformity at the base of the Ward's Stone Sandstone. However, there are clearly other factors controlling its distribution, as it is also absent below the Eumorphoceras yatesae Marine Band in the continuous sections along Artle Beck. The best section, through about 12m of sandstone, is exposed in the western gully (see Section J on the side margin of the map and Appendix: Section 10). A 0.5m thick ganister sandstone occurs at the top of the section, and a thin coal occurs in the lower part. Similar sandstones are intermittently exposed through a thickness of about 18m in the easterly gully [5865 6038]. There, a 1.8m thick ganister sandstone is the highest bed exposed.

3.1.7 *Eumorphoceras yatesae Marine Band and overlying beds*: The marine band is exposed in two areas, namely in well exposed sections along Artle Beck below Fostal Bridge, and in small scrapings below the escarpment formed by the Ward's Stone Sandstone, high up on the south side of Foxdale. Fossils collected from the marine band below Fostal Bridge during the Wyresdale Tunnel investigation are listed in Biostratigraphical Report PD 85/158 by Dr N J Riley. A report is being prepared on additional material subsequently collected from this locality and the fauna obtained from the Foxdale localities.

Foxdale localities: At the western locality [5825 6040], about 0.3m of blue-grey, weathering pinkish, shaly claystone was dug out and yielded *Posidonia corrugata* and *Anthracoceras* or a dimorphoceratid. There were also small pieces of darker, tougher mudstone of marine band aspect around. The site is approximately level with an outcrop in a landslip backscarp, only 20m to the south-east, of grey, micaceous, shaly siltstone, which in turn lies about 2m lower than an outcrop of Ward's Stone Sandstone in the escarpment crag. Landslipped blue-grey, shaly claystone with *P. corrugata* occurs below this locality [5821 6050]. At the eastern locality [5850 6026], pieces of blue-grey, shaly claystone yielded *P. corrugata* and *?Selenimyalina*, and a 2cm

thick bed of siderite mudstone contained abundant *P. corrugata*. The locality is situated close to the foot of the escarpment feature formed of unexposed Ward's Stone Sandstone, and 60m upstream of fine-grained, siliceous sandstones at, or near, the top of the Sapling Clough Sandstone.

Artle Beck: Continuous and impressive exposures of the 18.5m thick marine band, including the basal and top boundaries, occur along the beck for a distance of about 250m downstream of a fault crossing Artle Beck [5537 6226 to 5525 6246]. Sections occur for another 150m downstream of this point [to 5517 6257] in several gullies descending the steep sides of Artle Beck (see Section F on the left hand margin of the map for a composite section, and Appendix: sections 4b, 4c, 4d, 4e, and 4f for individual sections). A basal conglomerate, up to 1m thick, consists of reworked, and commonly irregularly shaped, calcite mudstone nodules in a grey, calcareous mudstone matrix. There are also very large blocks, up to 3m across, of grey, calcite-veined, calcite mudstone which protrude into the siltstone bed below. The overlying bed is draped over the upper part of the blocks as a result of differential compaction. The marine band consists of medium grey, slightly silty, finely micaceous, shaly mudstones with sporadic calcite mudstone nodules and abundant small phosphatic nodules. The lower part of the unit is more calcareous and less fissile and contains an argillaceous limestone about 0.5m thick. There is only a fairly sparse marine fauna in the lower part and the unit is more fossiliferous towards the top.

Overlying the marine band in these sections along Artle Beck is a unit of silty mudstone and siltstone, mapped as md on the map. This unit is estimated to be up to 11.5m thick (see Appendix: Section 4f) in the south part of the outcrop along the beck, though only the lowest 4m of grey, micaceous mudstone, with siderite mudstone lenses and a thin basal sandy conglomerate is well exposed. Along the beck from this point, in a generally north-westerly direction, the unit md progressively thins beneath the Ward' Stone Sandstone. The sections (Appendix: sections 4a to 4f) clearly demonstrate an angular unconformity at the base of the Ward's Stone Sandstone as the underlying beds are cut out downstream. At one point [5522 6244] (see Section F1 and Appendix: Section 4d), the md unit is only 1m thick. South of this locality, the md unit is absent, and the Ward Stone Sandstone oversteps onto lower stratigraphical levels within the marine band. At Section F2 (see Appendix: Section 4b), only

about 1m of marine band is present. At Section F3 (see Appendix: Section 4a), the Ward's Stone Sandstone overlies the interbedded siltstones and sandstones below the marine band directly.

3.2 WARD'S STONE SANDSTONE FORMATION

This is equivalent to the Roeburndale Grit of Slinger (1936) and Moseley (1954) and estimated to be 6 to 50m thick in the area, thinning in a generally north-easterly direction. It is of delta top facies and consists mostly of pale orange-brown weathered, fine- to coarse-grained, very thick-bedded sandstones up to about 2m thick. Coaly plant debris is locally abundant. Regionally the formation is divisible into two units, and in the present area this stratigraphy is clearly established. Exposures in the formation are numerous and most are annotated on the map. Selected sections are given on the left hand side margin of map and in the Appendix.

The base of the Ward's Stone Sandstone is sharp and locally rests on various levels of the Roeburndale Formation with an angular unconformity. Evidence for this is particularly strong in Crogley Gill, in north-east part of the area, where dips in the exposed Ward's Stone Sandstone are in a different direction to those in the adjacent Roeburndale Formation (see Section E3 and Appendix: Section 6c). At two places, 60m apart, in the north bank of Crogley Gill [5935 6370 and 5933 6365], sandstones at base of the formation dip at 7° towards 45° and beds in the underlying sa/sl unit of Roeburndale Formation dip at 7° towards 305°. It is also apparent along Artle Beck (see above), where dips in the Ward's Stone Sandstone are less than in those units of the Roeburndale Formation that the sandstone progressively oversteps. It is further brought out by mapping regionally, which indicates that the Ward's Stone Sandstone oversteps onto different units of the Roeburndale Formation.

Lower unit: This consists mainly of pale orange-brown, medium- to coarse-grained, very thick-bedded, commonly parallel-laminated sandstones with large scale, low angle tabular cross-bedding. The coarser beds contain sporadic small pebbles of quartz up to 0.5cm in size. Soft sediment deformation is recorded at several places, e.g. on Haylot Fell [5894 6125]. The lower unit is very variable in thickness and this accounts for most of the range in thickness of the formation across the area. In the moorland south of

the Foxdale Fault, only the lower unit, estimated to be about 30m thick, is present due to erosion of the overlying strata. North of the fault, the lower unit thins considerably. It is about 12m thick in a quarry near Crossgill [5615 6234], up to 4m thick, but locally absent, along Artle Beck (see sections F, F1, F2, F3 and Appendix: sections 4a, 4b, 4c, 4d, 4f), and about 2m thick in Crogley Beck (see Section E3 and Appendix: Section 6c) and absent in Warm Beck (see Section E2 and Appendix: Section 6b).

Upper unit: This mainly comprises fine- to medium-grained, typically trough cross-bedded and ripple cross-laminated, siliceous sandstones with several massive ganisters with hummocky surfaces. Several thin coals and sporadic siltstone lenses occur. The unit is more uniform in thickness that the lower unit, ranging in thickness from 6m in Warm Beck area (see Section E2 and Appendix: Section 6b) to about 10m elsewhere. The unit was previously called the Pott Yeats Sandstone (Wilson, *et al.*, 1989). The sharp base of the upper unit, on siltstones of the Roeburndale Formation, is exposed along Artle Beck (see Appendix 4c). The highest few centimetres of the formation are probably reworked by ?marine bioturbation. The top, as exposed in Warm Beck, is typically sharp and hummocky.

Moseley (1954, p.431) refers to two coals, namely a lower Smeer Hall Coal and an upper Crow Coal. However, sections measured in the area show that several thin, and probably impersistent, coals between 0.1 and 0.3m thick, occur in the upper unit of the formation (see Section F2 and Appendix: Section 4b, Appendix: Section 4c, Section G and Appendix: Section 4g, Section E2 and Appendix: Section 6b, and Section I). In Section I [5782 6238], two 0.1m argillaceous coals are separated by about 3.5m of mainly fine- to medium-grained sandstone. See section 5.3 for local coal exploitation.

3.3 CATON SHALE FORMATION

The Caton Shale Formation sharply overlies the Ward's Stone Sandstone and consists of about 70m of fairly uniform, grey to blue-grey, shaly, fossiliferous mudstones (claystones) with beds of tougher calcareous mudstone and layers of calcite mudstone nodules. Many of the nodules are septarian. In the upper part of the formation, siderite mudstone lenses, up to a few centimetres thick, are common. The uppermost 0.5m of the mudstones are very

finely micaceous and slightly silty. Sporadic, thin bentonites are recorded. Exposures are annotated on the map and selected sections are given in the map side margin and Appendix.

The formation contains marine fossils throughout and generally the fauna is of a restricted marine phase containing the *Anthracoceras* and dimorphoceratid goniatites, and the bivalves *Selenimyalina variabilis* and *Posidonia corrugata*. Discrete beds of darker, generally more calcareous, platy mudstone, of the order of several metres in thickness, contain a richer marine fauna with the addition of cravenoceratid and eumorphoceratid goniatites and abundant *P. corrugata* etc. Two such "marine bands" have been recognised in the area, namely the Cravenoceratoides edalensis Marine Band at the base of the formation, and the Cravenoceratoides nitidus Marine Band, approximately 30m higher. The latter is associated with a thin argillaceous limestone, named by Moseley (1954) the Cravenoceratoides nitidus limestone. *Lingula* sp. is recorded from the top 1m of the formation.

A chemical and mineralogical investigation of carbonate nodules collected from exposures of Caton Shale Formation along Greenholes Beck has been undertaken (Vaughan, 1977). The nodules were grouped into two types. The smaller nodules examined were sideritic and the larger nodules were mainly calcite, commonly with pyrite-enriched outer zones.

The sharp basal boundary is exposed along Warm Beck [5934 6405] (Section E2 and Appendix: Section 6b). Cravenoceratids in the overlying mudstones indicate the Cravenoceratoides edalensis Marine Band. This basal "marine band" is also exposed in the bed of Crossgill [5602 6289], in a graben flanked by Ward's Stone Sandstone in the adjacent footwall blocks. The section here is:

c	CSh	Claystone, grey, shaly, calcareous; a 0.03 thick platy, bituminous layer at about 0.3; cravenoceratids, *P. corrugata*, *Anthracoceras* sp. or dimorphoceratids, coiled and orthocone nautiloids, ?*Selenimyalina* sp.	c. 1
b	CSh	Calcite mudstone, grey, as lenticular nodules up to 0.12 thick and 0.8 across	0.12
a	CSh	Claystone, grey, shaly, calcareous; spherical calcite mudstone nodules up to about 0.04 across	c. 0.4

Thewlis (1962, p.29) records nodules containing traces of galena and sphalerite from this section.

The top part of the "marine band" may also be exposed 3.3m below a thin bentonite further down the beck (see section given below).

The Cravenoceratoides nitidus Marine Band, in the middle part of the formation, is well exposed along Warm Beck [5924 6421 to 5928 6417] (Section E1 and Appendix Section 6a). Moseley (1954, p. 449) records an exposure of the marine band along Crossgill, near Tunnel Plantation [566 630 to 567 630]. Additional well exposed sections in the middle part of the formation occur along Tarnbrook and Crossgill.

A solid specimen of Tylonautilus nodiferus, 9.4cm in diameter, from Greenholes Beck, is illustrated by Vaughan (1977, pl. 7).

A 1cm thick bentonite bed, possibly lying about 6m above the base of the formation, is exposed along Crossgill [5590 6259]. The section is:

	Till	Diamict, grey	
d	CSh	Claystone, blue-grey, shaly; layer of 0.03 thick siderite lenses 4 up; poorly fossiliferous with *P. corrugata* and ?*Anthracoceras* sp.	c. 7
c	CSh	Bentonitic clay, grey weathering pale yellow at top and bottom,	0.01
b	CSh	Claystone, blue-grey, shaly; sideritic nodule 0.05 ?*Anthracoceras* sp.; more sparsely fossiliferous in top part; possible 0.5cm thick bentonite about 0.8 from top	c. 3.3
a	CSh	Claystone, grey, platy, calcareous, slightly silty; sporadic ovoidal calcite mudstone nodules; cravenoceratids, *P. corrugata*, ?*Anthracoceras* sp. (?Cravenoceratoides edalensis Marine Band)	c. 1

Another bentonite, lying around the middle part of the formation, is exposed higher up Crossgill [5685 6317]. The section measured is:

k	CSh	Claystone, as bed a	c. 1.4

j	CSh	Siderite mudstone lenses as bed d	c. 0.04
i	CSh	Claystone, as bed a	c. 0.8
h	CSh	Calcite mudstone nodules as bed f	c. 0.08
g	CSh	Claystone, as bed a	c. 0.3
f	CSh	Calcite mudstone, ferruginous, weathered, as a layer of ovoidal nodules up to 0.08 thick	to 0.08
e	CSh	Claystone, as bed a	c. 2
d	CSh	Siderite mudstone, as a lenticular layer	c. 0.03
c	CSh	Claystone, as bed a	c. 1.5
b	CSh	Bentonitic clay, pale pinky grey; sharp boundaries	0.01
a	CSh	Claystone, blue-grey, shaly, poorly fossiliferous; sporadic *Anthracoceras* sp. or dimorphoceratids	c. 2

Sections across the upper boundary of the formation occur along Mears Beck [5560 6466] (Section A and Appendix Section 1), along Greenholes Beck [5693 6328] (Section C and Appendix: Section 2), and along Tarnbrook [5634 6334] (Section B). *Lingula* sp. has been found within 0.4m of the top of the formation here.

3.4 CLAUGHTON FORMATION

The formation is mainly confined to an outlier forming most of Caton and Claughton moors in the north part of the sheet. In the north-east, and on Sheet 56 NE, it is divisible into members corresponding in upward sequence to Slinger's (1936) "Claughton Flag Series", Nottage Crag Grit, "Claughton Moor Shales" and "Moorcock Flags". The Nottage Crag Grit (the only name formally used here) is apparently absent over most of the outlier so that below the "Moorcock Flags" (mapped as sa/sl) the formation is generally not subdivided. Moseley (1954, p.436) and Thewlis (1962. p.31) correlated the Nottage Crag Grit with the "Moorcock Flags" but the recent survey confirms Slinger's interpretation..

3.4.1 *"Claughton Flags"*: This is of delta slope facies and consists of very variably interstratified siltstones and sandstones, up to an estimated thickness of about 80m. A magnificent, continuous, but faulted, section

through approximately 70m of the unit into the Caton Shale Formation occurs along Greenholes Beck [5688 6314 to 5737 6340] (see Section C and Appendix: Section 2). A further good section of the lowest 29.04m of the formation and basal contact is to be found in a gully formed by an eastern tributary of Mears Beck [5559 6466 to 5571 6465] (see Section A and Appendix: Section 1). The lowest 9m and basal contact are exposed along Tarnbrook [5634 6334] (see Section B). There are also scrappy exposures of the lowest 6m of beds on the south-east escarpment of Whit Moor [5872 6340 and 5886 6368] (see map face).

The siltstones are grey, micaceous, shaly to platy and sandy, commonly grading into very fine-grained sandstones, and comminuted plant debris is ubiquitous. The siltstone units are commonly up to several metres thick, and contain thin, commonly ripple-marked, fine-grained sandstone beds up to a few centimetres thick and common channel-filled sandstone lenses. The thicker sandstones are brown-weathering, grey, fine-grained, micaceous, massive to parallel-laminated beds, commonly up to about 3m thick and recorded up to a thickness of 7m. Comminuted, carbonaceous plant fragments are conspicuous. Many lenticular sandstone beds vary abruptly in thickness and are probably channel infills. The sandstones are commonly cemented with ferroan calcite or siderite and weather to a strong orange-brown. The sandstones are generally sharp-soled with abundant sole marks. Individual sandstones are usually not traceable laterally and only a few have been mapped (as sa). Bioturbated beds are common. The third main sandstone in the sequence in the Greenholes Beck section (bed o, Section C) is highly bioturbated. ?*Aulichnites* burrows are abundant along bedding planes at several levels, particularly on the upper surface of the second main sandstone in the Greenholes Beck sequence (bed m). Locally, syndepositionally slumped beds are common and suggest that the member has been affected by growth faulting. Slumped siltstones and sandstones are exposed at several places along Greenholes Beck.

The base of the formation is well defined in the sections mentioned above; unfossiliferous siltstones with thin sandstones overlying fossiliferous, shaly, slightly silty mudstones with a sparse marine fauna. The highest beds and upper contact are not exposed.

3.4.2 *Nottage Crag Grit*: The member forms a prominent feature, entering the area from the north, continuous with Nottage Crag on the hillside above

Claughton. It mainly consists of pale orange-brown weathering, coarse- to very coarse-grained, very thick-bedded, micaceous, felspathic sandstone of delta top facies, locally up to an estimated thickness of about 10m. The sandstones are feebly parallel-laminated and low angle tabular cross-stratified. They contain sporadic, small quartz pebbles to about 1cm across. Numerous large blocks up to 1.3m thick occur along the feature, and 1.5m are exposed in a small degraded quarry [5615 6479]. The feature formed by the sandstone can be traced for about 300m south-west of the quarry and the outcrop is presumed to terminate against the Deep Clough Fault. The member must thin southwards since it is apparently absent on the south side of Caton Moor. The base and top of the member are not exposed.

3.4.3 *"Claughton Moor Shales"*: These siltstones are about 24m thick. They are grey, micaceous, sandy and shaly with thin very, fine-grained sandstones, typically about 1cm thick and of the order of 10 cm apart. Thicker, parallel-laminated sandstones, to about 0.4m thick, are uncommon. The siltstones are extensively worked for brick making at Claughton brick pit [578 648], on the north edge of the area, and the pit and nearby Claughton Beck [5756 6493 to 5836 6444] provide superb sections in all by the basal few metres of the unit (see Section D and Appendix: Section 5). Some bedding planes on loose blocks from the upper 10m of the siltstones contain sporadic, small *Dunbarella* sp., unusually with the shells preserved in white calcite. The range of this marine bivalve within the unit, and whether one or more bedding planes are represented, are unknown. The gradational top of the unit is well exposed on the south side of Claughton brick pit [579 646].

3.4.4. *"Moorcock Flags"*: The local Millstone Grit sequence is completed by an outlier of about 18m of interbedded fine-grained sandstones and siltstones, mapped as sa/sl, on Caton and Claughton moors. Numerous degraded pits, arranged in an east to west line south of the derelict Moorcock Hall, provide small sections (see map); the best is at Claughton Quarries [5700 6422] (see Appendix: Section 3). The sandstones are grey, weathering brown, fine-grained, micaceous, parallel-laminated and ripple cross-laminated, platy to flaggy, commonly with thin, sandy siltstone partings. Many of the bases are gradational. The siltstones are grey, shaly, micaceous and sandy, and generally contain numerous thin, fine-grained sandstones seams. The two lithologies typically form packets 0.5 to 2m thick. Bedding planes contain abundant *?Aulichnites* burrows.

4 IGNEOUS ROCKS

The Caton Dyke, a subvertical intrusion of strongly altered, vesicular olivine basalt up to 1.4m wide, is exposed along Tarnbrook [5601 6336] and Crossgill [5632 6302], cutting through blue-grey, shaly, fossiliferous claystones with sporadic limestone nodules of the Caton Shale Formation. The dyke is parallel to close jointing in the adjacent Caton Shale, but otherwise the host rock appears not to be not affected by the intrusion. Where exposed, the dyke is also subparallel to the main faults in the area, e.g. the Deep Clough and Crossgill faults.

In the north bank of Tarnbrook, the dyke consists of weathered, fine-grained, pale bluish grey vesicular basalt with numerous joints stained with iron oxide. The dyke trends at 150°. At stream level, the dyke is subvertical with a width of 1.45m. At about 0.6m up, much host claystone becomes incorporated within the dyke, which dips by about 50° towards about 060° and thins to a width of only 0.3m. At 2m above stream level, the dyke is of about 0.45m wide. About 0.5m higher, the dyke is 0.6m wide and patches of pyrite were noted along the joints. The dyke is exposed in relatively fresh condition for up to 0.5m above stream level on the south bank of Tarnbrook. Here it is at least 1.5m wide and trends at 332°.

The dyke is well exposed on the south bank and in the bed of Crossgill, about 20m below the road bridge. It is 1.5m wide, vertical and trends at 145°. Here the dyke is mainly deeply spheroidally weathered to a brown rottenstone, but a fresher zone of pale greenish, highly vesicular basalt occurs about 0.2m in from the south-west margin. Vesicles are arranged in zones parallel to the margins of the dyke. Thewlis (1962, p.55) records vesicles lined with pyrite.

A detailed petrography and geochemistry of rock specimens from the dyke at Tarnbrook are given by Fortey (1991). The rock is described as a strongly altered, micro-porphyritic basalt.

The Caton Dyke has proved non-magnetic, or only weakly so, and a magnetic survey was unable to trace the dyke beyond the extent indicated by the three known outcrops on sheets SD 56 NE and SD 56 SE (Smith, 1988). It has long been thought to be contiguous with the Grindleton Dyke, about 25km to the

south-east near Clitheroe (Eccles, 1870; Earp et al., 1961). Although the Grindleton Dyke is a less altered olivine-phyric basalt, the two dykes have the same trend and are closely aligned. In the unexposed ground between the two dykes Eccles (1870) reported that Tiddeman found a basalt fragment on dumps near the Whitendale lead mines, and circa 1871 de Rance (field note book 3, undated, p.180) noted a "fragment of basalt at Brennand [or Brinnow] Mine" and a "fragment of dolerite near White Hill [?Whitendale] House". However, it is notable that a dyke was not encountered during the construction of the Bowland Forest Tunnel (Earp, 1955). It would have been expected to pass through the south part of the tunnel below Eller Beck [690 527]. The Caton Dyke is probably Tertiary in age and may fall on an extension of the Antrim dyke swarm of c. 60 Ma (Fortey, 1991).

5 STRUCTURE

A synthesis of the structure of the area is to be published in the explanatory memoir for the Lancaster 1: 50 000 sheet and only the descriptive details concerning the immediate area are included in this account. Regionally, the steeper dips are recorded near faults. The main structural elements are shown in Figure 1.

5.1 FAULTS

5.1.1 *WNW to ESE-trending and NW to SE-trending faults*: As in adjacent areas, the structure of the present area is dominated by a set of approximately WNW to ESE-trending, normal faults, roughly at a spacing of 1km. The faults mostly downthrow to the south, though there are notable exceptions. Fault planes dip at between 60° and 80°. The names of the Claughton, Deep Clough, Crossgill and Artle Beck faults are taken from faults mapped in very similar positions by Moseley (1954). Though these faults have typically been mapped over long distances and many cross the entire width of the area, throws vary considerably. Several faults lie in zones of faulting where closely spaced faults may have throws in opposite sense, so that the affective throw across the fault zone is minimal. Faults north of the Artle Beck Fault Zone are orientated more in a north-west to south-east direction than the Artle Beck and Foxdale faults.

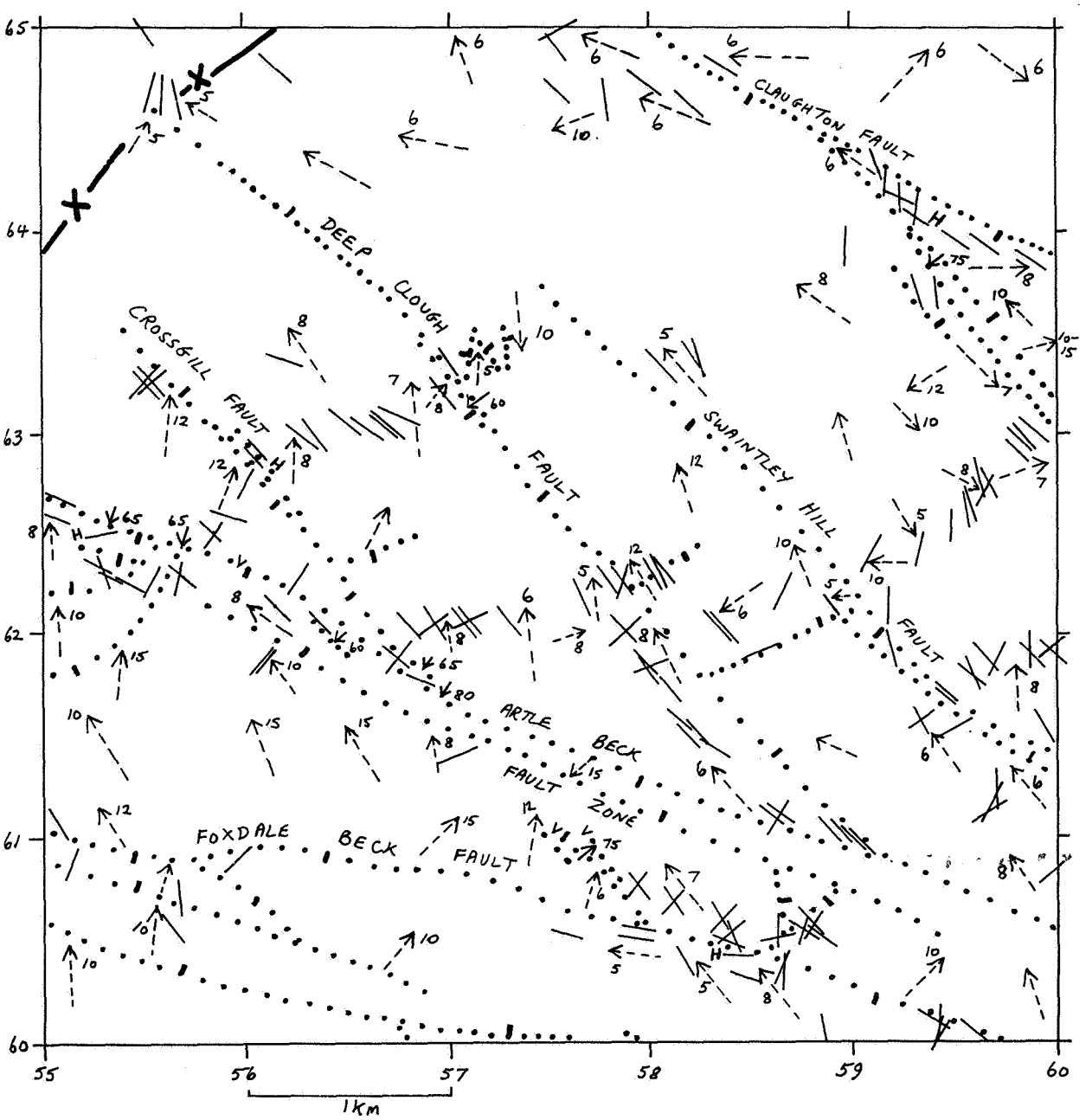

Figure 1. Structural elements on Sheet SD 56 SE (Littledale).

The Claughton Fault enters the area from the north, where it is a simple fault downthrowing to the south by several tens of metres. The fault continues north of Warm Beck, but several splinter faults to the south, with throws in the opposite sense, effectively decrease the throw across the structurally disturbed zone. These splinter faults are exposed in Crogley Beck. Within the fault zone, siltstones of the Close Hill Siltstones of the Roeburndale Formation are considerably disturbed by syndepositional slumping.

The main evidence for the *Swaintley Hill Fault* is the abrupt displacement of the outcrop of Ward' Stone Sandstone and adjacent strata, an exposure of shattered ganister [5867 6279], and small faults exposed, or formerly exposed, along Lambclose Syke [594 617]. The main fault has a downthrow to the south-west of about 85m.

The *Deep Clough Fault* downthrows to the north-east by about 15m. It is exposed in deep gullies near Deep Clough (see Sections I and J) and is superbly exposed in a cliff section along Greenholes Beck [5698 6332]. Here, the fault downthrows 14m and is the most north-easterly of three faults in a fault zone about 40m wide. The most south-westerly fault downthrows 3m to the south-west and the fault plane dips at about 60°.

The *Crossgill Fault* downthrows to the south-west by several tens of metres and is the most south-westerly of three closely spaced faults crossing Crossgill [561 629]. The middle fault downthrows in the opposite sense and causes the outcrops of Ward's Stone Sandstone and Caton Shale to be repeated within the zone. The south-easterly continuation of the fault may be exposed along Foxdale [5668 6196], where a fault plane is seen dipping to the south-west by 65°. North-west of Crossgill, where the fault zone crosses Tarnbrook [5562 6325], the throw on the main fault appears to be reversed and the fault zone cannot be traced further to the north-west.

Faults with opposing throws within the *Artle Beck Fault Zone* are exposed in numerous places along Artle Beck, at the edge of the present area and to the west. The main fault downthrows by varying amounts to the south and is closely associated with a fault on the north side which downthrows in the opposite sense, producing a narrow horst. The main fault appears to extend south-eastwards across the area but the vertical throw is never more than 10m.

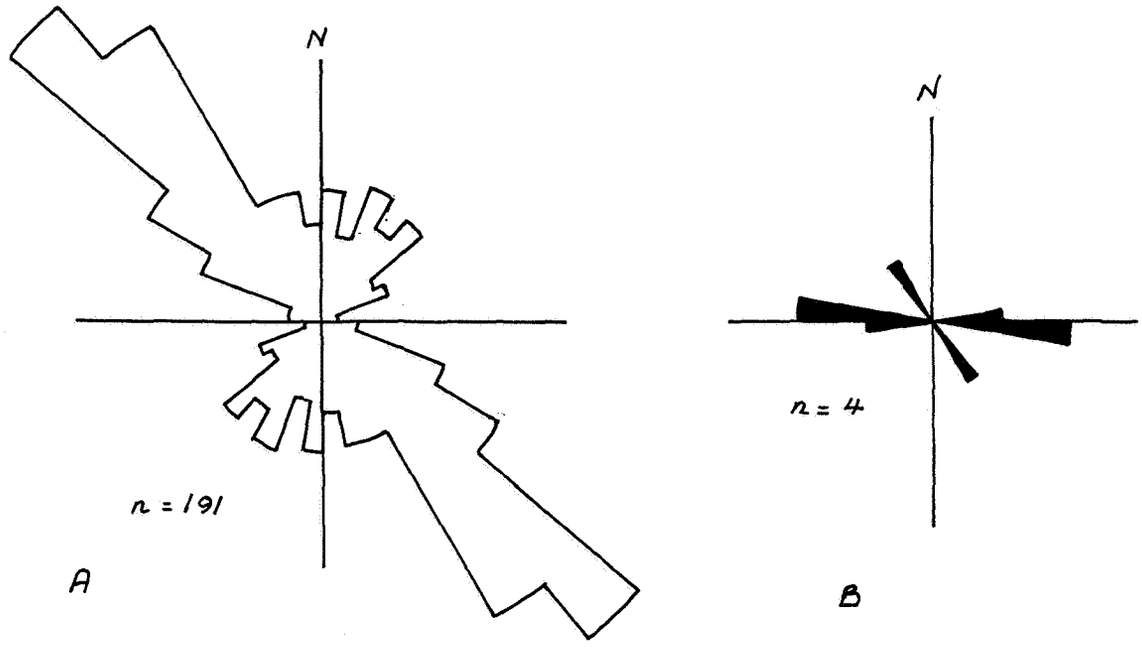

Figure 2b. Subvertical joint orientations on Sheet SD 56 SE (Littledale).
A - all joints, B - joints associated with horizontal slickensides.

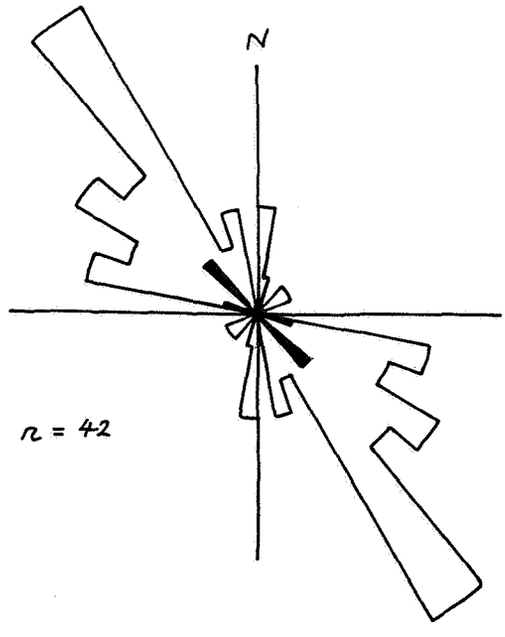

Figure 2a. Orientation of exposed faults on Sheet SD 56 SE (Littledale).
Faults associated with vertical slickensides are in black.

It is exposed along Littledale [561 623] and along Foxdale [568 618], where the fault plane dips to the south-west by 60 to 80°. This fault, and a further fault to the south, which is also exposed along Foxdale [569 616], are traceable further south-eastwards on satellite imagery.

The *Foxdale Fault* downthrows to the south by an amount that steadily increases westwards to about 200m. The fault is readily traced along south side ofFoxdale and is exposed near Sweet Beck [5505 6103], the fault plane apparently dipping by about 60° to the south.

Though the trend and position of the faults are largely inferred from mapping, exposed faults (Figure 2a) bear out the predominant approximately WNW-ESE to NW-SE strike. Only vertical slickensides are recorded with the exposed faults. The same trend is also reflected in the dominant joint orientation across the area (Figures 1 & 2b). Joints with a WNW-ESE orientation are clearly associated with horizontal slickensides. It is probable that faults with this orientation have undergone a late strike slip component of movement.

5.1.2 *WSW to ENE trending faults*: A minor set of ?normal faults trending in this direction have been mapped, the best example being the unexposed faults with opposing throws crossing Udale and Artle becks [554 623].

5.2 FOLDS

There only distinctive fold in the area is a broad syncline, orientated north-east to south-west, crossing the north-west corner of the area. Evidence for the fold is to be found in adjacent areas where strata is inclined at 10 to 15° south-eastwards on the north-west side of fold axis. Moseley (1954, p.446 and figure 10) refers to this syncline as the continuation of the Quernmore Syncline. He also refers to the "Whitmoor Anticline", which is a short, parallel, rather poorly defined, anticlinal structure between the Swaintley Hill and Claughton faults.

5.3 JOINTS

The joints are subvertical, generally perpendicular to the dip of the beds. Summaries of the joint orientations recorded in the area during the survey are

shown in Figures 1 & 2b. A predominant south-east - north-west set occur. It is associated with horizontal slickensides, as is a minor set of more ESE -WNW orientated joints. A further minor set of joints are orientated north-east to south-west, parallel to a group of minor faults. No vertically slickensided joints were recorded. The joint system of the Lancaster Fells area is discussed by Moseley and Ahmed (1967).

6 QUATERNARY

6.1 GLACIAL DEPOSITS AND EROSIONAL FEATURES

The area was entirely covered by ice during the last glaciation. Although these deposits cover a large part of the area, they are seldom well exposed. The main aspects of the glaciation of the area are shown in Figure 3.

6.1.1 *Till*: This deposit forms a fairly smooth cover to the bedrock over much of the area. It is estimated to be up to about 12m thick in the area of Tarnbrook [566 635] but in most places is between 1 and 4m thick. Till is absent on the upland fells on the south side of the area. This is thought to be due to erosion, but surprisingly few exotic clasts have been observed south of the till limit.

The till consists mostly of a firm, grey, clayey, sandy silt diamict, invariably weathered to orange-brown and mottled by gleying in the top few metres. It contains abundant subangular to rounded stones, up to boulder grade, of Millstone Grit lithologies (mostly sandstones and siltstones, but also mudstones, sideritic mudstones and calcite mudstones), minor amounts of well rounded, hard, green Lower Palaeozoic sandstones, and a variable content of Lower Carboniferous limestones. The last two lithologies are commonly ice-striated. Other lithologies, such as chert, are rare. The variability of the Lower Carboniferous limestone clasts is probably partly due to dissolution, and the rock is usually absent from superficial sections. The basal part of the till, up to the order of 1m in thickness, is commonly composed of ground up local bedrock without any farther travelled erratics. No significant regional variation in the till has been detected across the area. There are numerous small sections, rarely more than about 2m high. The best are indicated on the maps. Sections about 4m high occur at the top of the old brick pit along Crossgill [5615 6288]. Up to 5m are exposed in a deeply incised gully near Deep Clough [5765 6254]. Up to 3m of till are exposed in the banks of stream gullies on the north side of Foxdale [572 614]. In a stream gully in West Field Wood [5874 6233], till infills an ENE to WSW-trending palaeochannel at least 15m deep and about 15m wide, cut into siltstones and sandstones of the Roeburndale Formation (see Figure 3).

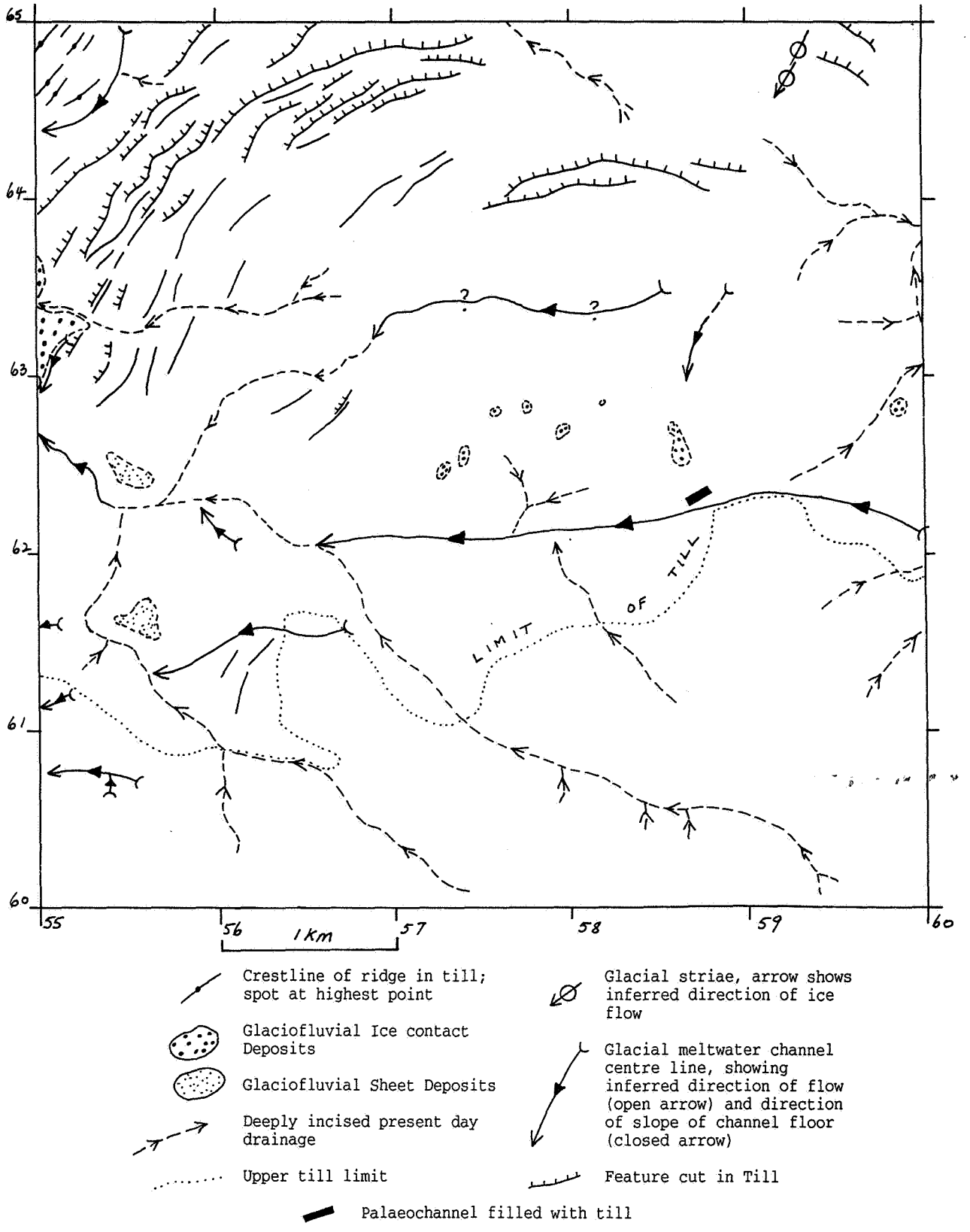

Figure. 3. Glacial features of SD 56 SE (Littledale).

Large boulders at surface have generally been removed for use in wall construction etc. but there are a few occurrences of large erratic sandstone blocks several metres across [e.g. 5565 6360].

At several localities the till evidently incorporates large pods of coarse ill-sorted gravel. About 3.5m of brown, ill-sorted gravel, up to cobble grade, and consisting entirely of local sandstone and siltstone clasts, is exposed near the top of the north bank of Greenholes Beck [5681 6317], adjacent to exposures of 4m of weathered till.

North-west of Mears Beck (Anas Gill), the till forms low, elongated, drumlinoid ridges orientated at about 035°. These ridges probably indicate the direction of ice movement and are subparallel to regional ice striations measured on sandstone bedrock recorded by Tiddeman (1872) and during the recent survey. Related drumlinoid features also occur in the Littledale area [c. 562 613]. Other features developed on till are more problematical, and are probably related to meltout (see below). Glacially polished and striated sandstone bedrock has been recorded at the following places (ps = recorded during primary survey by Tiddeman):

5923 6468 ice direction to 210° (ps)

5935 6484 ice striae at 205° strike

In the banks of streams thick till is prone to landslipping. Numerous examples occur in the area, e.g. in the upper reaches of Tarnbrook [565 635], on the south side of Artle Beck [551 630, 551 627] and along Udale Beck [559 610].

6.1.2 *Glaciofluvial Ice-contact Deposits*: There are only limited outcrops of these late glacial deposits in the area (see Figure 3). Glaciofluvial sands and gravels were deposited adjacent to ice masses. Subsequent melting resulted in slumping and deformation, and the formation of a generally heterogeneous deposit through the incorporation of tills from englacial dirt bands and laminated clays and silts from ponding. The deposit characteristically underlies highly irregular, hummocky ground. Along the south bank of Tarnbrook [5501 6339 to 5530 6329] there are several exposures, up to 4m high, of brown, poorly bedded, ill-sorted, silty to sandy, coarse gravels, up to boulder grade, with clasts composed mostly of local sandstones and siltstones. The

deposit, probably up to about 10m thick, probably overlies till.

A line of irregular gravelly mounds along the north side of the Closegill Beck meltwater channel [5727 6244 to 5985 6280] (Figure 3) are thought to be moulin kames formed close to a former ice margin (see below). The largest, Swaintley Hill [586 626], has a characteristic conical shape. The tract of mounds continues eastwards onto the adjacent area as a NNE-trending series of gravelly hummocks east of Roeburndale. There are small degraded pits with gravel traces on several of the mounds [e.g. 5726 6243]. Traces of gravel near the summit of Swaintley Hill are composed mainly of chips of Caton Shale with a few sandstone pebbles. A small pit in the most easterly mound [5989 6282], south of Stone Beck, exposes up to 1.5m of sandy gravel with clasts mostly of local rocks. An exposure of 0.8m of brown, medium- to coarse-grained sand with interbeds of small gravel, composed of local siltstone and sandstone clasts up to about 4cm in size, occurs in a small landslip backscarp on the north side of the mound.

6.1.3 *Glaciofluvial Sheet Deposits*: Two small remnant patches of these proglacial outwash or valley sandar deposits have been mapped (Figure 3). They consist of undeformed, well bedded sands and gravels underlying high level flat terraces and are probably only remnants of what were formerly widespread valley deposits. One patch occurs above the confluence of Crossgill and Udale Beck. About 5m of pale brown, ill-sorted gravel containing clasts to boulder grade, with lenses up to 1m thick of pebble grade gravel in the lower part, are exposed in the backscarp to a landslip [5552 6238] on the north side of Crossgill valley. Clast imbrication indicates a palaeocurrent flowing towards 253°. The front of the terrace lies at about 130m O.D., about 17m above the level of Crossgill. The other remnant lies below a terrace at about 180m O.D. near Bellhill Farm, on the east side of Udale Beck, at a height of about 30m above the beck. About 3.5m of clean, brown, mainly pebble-grade gravel, containing a 0.4m thick sand lens, is exposed in the backscarp of a landslip [5558 6154]. Many of the clasts are of siltstone and mudstone and there are few over 5cm. In the top 0.3m, many of the pebbles are orientated vertically due to cryoturbation. Near the western end of the remnant [5546 6160], there are indications of former small workings.

6.1.4 *Meltwater channels and other erosional features*: A series of deeply

incised dry or misfit valleys are to be found in the area (see Figure 3). From their orientation and inclination they were probably formed by meltwaters flowing east to west at the ice margin during successive stages as the glacier retreated northwards (Moseley and Walker, 1952). The best example is the one now occupied by Closegill Beck, and its completely dry upstream continuation near Haylot Farm [622 598]. At its downstream end the channel fed into the Artle Beck gorge. The channel probably received drainage from the Roeburn valley area at a time when ice was blocking an outlet to the north, along the present course of the Roeburn. The tract of small gravel mounds on the north side of Deep Clough (see above) may indicate the approximate contemporary ice margin. Other excellent examples of dry, or nearly dry, meltwater channels are Anas Gill [554 646] and Bellhill Clough [561 615]. Many of the meltwater channels may have been coincident with parts of the courses of present day active downcutting streams, so that their origin is speculative, e.g. the upper reaches of Foxdale and Udale becks.

A series of step-like escarpment features incised into till run subhorizontally along the hillside of Caton and Claughton moors, and are associated with some low ridges (see Figure 3). They are of uncertain origin but appear not to be related to bedrock disposition. In the north-west part of the area, these features run south-westwards, coincident with ridges believed to have formed during glacial encroachment, but eastwards their orientation departs markedly from this direction as they contour the hill slope. They may have been formed during short periods of meltwater drainage parallel to the ice margin during successive deglacial stages. The north side of the channels would have originally been ice.

6.2 FLANDRIAN DEPOSITS

6.2.1 RIVER TERRACE DEPOSITS

Along most of the streams in the area there are minor undifferentiated terrace facets, typically up to 5m above stream level, underlain by 2 to 3m of mostly brown, imbricated, coarse, ill-sorted, sandy gravels with clasts up to boulder grade. There are subordinate beds of sand and fine gravel. About 1m of pale buff silt commonly overlies the gravel. Bedrock may outcrop between adjacent terrace levels. Good examples occur above the confluence [554 623] of Udale

Beck and Crossgill, and along Artle Beck, below that confluence. Along Artle Beck, remnant facets occur up to 11m above the level of the beck. A similar flight of undifferentiated river terrace deposits form terraces up to 10m above the river along the Roeburn [595 635]. Some of the higher deposits may have a glaciofluvial origin.

6.2.2 ALLUVIAL FAN DEPOSITS

Minor fan-shaped areas, underlain by coarse gravel, occur at the foot of steeply inclined stream gullies where they enter larger valleys. A good example along Udale Beck, at the foot of Rotten Clough [560 609], is composed of 1m of sandy silt overlying 1.3m of coarse, ill-sorted boulder gravel. Several minor alluvial fans occur along Closegill and Bladder Stone Beck [572 621 to 592 624].

6.2.3 ALLUVIUM

This is the deposit of the alluvial flood plains and in most of the streams consists of up to 1m clayey silt overlying generally up to 2m of coarse, imbricated, sandy gravels.

6.2.4 PEAT

Thin deposits of peat, between 0.5 and 1m thick, have been mapped on four flat-lying boggy areas on Claughton Moor [584 643, 590 633, 585 635 and 588 626]. On Blanch Fell [580 602] the peat cover is eroding and is patchy. Only the larger remnants over 1m thick are shown. Three small peat patches, about 1m thick, occur on Black Fell [552 608].

6.2.5 HEAD

This is a very variable slope deposit generally underlying concave-upwards slacks. It has been mapped flooring three dry, or misfit, meltwater channels [564 615, 551 631 and 596 622]. There are few exposures and the deposit probably consists mostly of brown, stony, clayey silts.

6.2.6 LANDSLIP

Mass movements on oversteepened slopes are very common along many of the valley sides (see map). Slips affecting till occur along Tarnbrook [e.g. 566 635] and Udale Beck [e.g. 560 610]. Large examples of rotational mass movement in the Roeburndale Formation and Ward's Stone Sandstone are to be found along Foxdale Beck [570 613 to 594 601], along Udale Beck [e.g. 567 603] and east of Haylot Fell [599 607]. Large areas of rotational slip involving till and Caton Shale occur on the south-east side of Claughton Moor [590 636] and along Crossgill [568 630]. Many of these slips are still potentially active.

6.2.7 MADE GROUND

There are only minor areas of made ground. Most occurrences are discarded waste dumps adjacent to former quarries, the largest being around the Claughton flagstone quarries [570 643].

7 ECONOMIC GEOLOGY

Four types of local deposits were formerly exploited, namely sandstones for wallstone, flagstone and tilestone, siltstones for brick making, coal and sand and gravel. Except for the Claughton brickworks, all workings are now defunct. Details of the locations of the quarries or pits are given in the relevant sections and indicated on the maps.

7.1 STONE QUARRYING

7.1.1 *Ward's Stone Sandstone*: A strong platy fissility related to the parallel-lamination is commonly developed in the sandstones of the lower unit and there are numerous former small slate or tilestone pits, probably mostly worked in the Nineteenth Century, dotted around Black Fell [c. 552 603]. These are shown on the map. Up to 12m of medium- to coarse-grained sandstones were worked from a pit [5615 6234] located in Quarryhill Wood. Other pits where coarse-grained sandstones of the lower unit were formerly worked are near Swaintley Hill [5885 6282] and near Hawes House [5650 6255]. The hard, siliceous, thick-bedded sandstones and ganisters of the upper unit of the formation were formerly quarried for building stone, wall stone etc. from numerous small pits, e.g. at Littledale [5510 6233], in the Hawes House area [5630 6259; 568 626], along Crossgill [5640 6290], on Whit Moor [593 648; 590 630] and near Deep Clough [5757 6246].

7.1.2 *Claughton Formation*: A sandstone within the "Claughton Flags" unit, probably the same as bed o of the nearby Greenholes Beck section (Section C, Section 2, Appendix) was quarried at a small pit on Caton Moor [5748 6318]. The sandstones of the "Moorcock Flags" unit were formerly worked for flagstone from numerous degraded pits, arranged in an east to west line south of the derelict Moorcock Hall, the largest pit workings were Claughton Quarries [5700 6422].

7.2 BRICK MAKING

7.2.1 *Caton Shale*: The less calcareous mudstones have been worked for brick making in the past from pits up to 10m deep at "Brookhouse brickyard" along the Crossgill [562 629 and 5647 6303]. Numerous reject bricks around the east

pit are embossed "Lune 1965". The Brookhouse Brick Company works [563 631] has been demolished but Thewlis (1962, p.57-58) reproduced a photograph as it was in the 1960's. He states that the company "is at present owned by a Wigan firm, and started work about 1900 with four kilns. It now has eighteen and appears to specialise in the "rustic" brick, apparently made by sandblasting the unfired claymodel. Holes are often bored through these bricks to reduce their weight, normally by as much as one pound. ---- The yields are 15, 000 bricks per kiln per week, (i.e. 14, 094,000 bricks per year) which is exceptional for a brickworks manned by twenty men." He showed by x-ray diffraction analyses that pyrite and calcite are present in the rock. These minerals must have had a deleterious affect and may partly explain why the siltstones of the Claughton Formation, which lack these minerals according to Thewlis, are now exploited.

7.2.2 *Claughton Formation*: The sandy siltstones of the "Claughton Moor Shale" are extensively worked for brick making at Claughton brick pit [578 648], on the north edge of the area. After being blasted from the face, the rock is left on the quarry floor to degrade by weathering. It is then transported by two aerial ropeways to Claughton brick yard [560 662 and 563 664]. Thewlis (1962. p. 56) states that the Claughton Manor Company was formed in 1898 from the amalgamation of two or three small companies and utilised mudstones of the Caton Shale until 1930. The pit is now owned by Butterley Brick Ltd of Ripley, Derbyshire.

7.3 COAL

The thin coals in the upper unit of the Ward's Stone Sandstone were locally exploited, at least between 1820 and 1846, from clusters of bell pits and possibly small open cast pits (see map) in the area around Hawes House [c. 566 626] (Docton, 1971, Clare and Hudson, 1987, pp.8-9 and map 2). The pit sites are now evident as degraded circular hollows, 3 to 4m in diameter, with surrounding mounds of coaly shale and ganister sandstone debris. A good proportion are believed to have been unproductive trials.

7.4 SAND AND GRAVEL

7.4.1 *Glaciofluvial Ice-contact Deposits*: There are small degraded pits with

gravel traces on several of the gravelly mounds north of Deep Clough [e.g. 5726 6243]. A small pit has also been dug in the most easterly mound [5989 6282].

7.4.2 *Glaciofluvial Sheet Deposits*: Near the western end [5546 6160] of the small remnant of sand and gravel near Bellhill Farm there are indications of former small workings.

7.5 HYDROCARBON EXPLORATION

The Whitmoor borehole was a wildcat hole drilled by Place Oil and Gas (U.K.) Ltd in 1966-7. In the last few years the area has been investigated geophysically in connection with hydrocarbon exploration.

7.6 HYDROGEOLOGY

There is little available information on the hydrogeological potential of the area. Most farmsteads probably had there own supply from wells. Those at Hawes House [563 624] and Winder [5944 6315] penetrated 40 to 50m into interbedded siltstones and sandstones of the top part of the Roeburndale Formation.

7.7 HAZARDS

Landslipping is the main hazard in the area. Many of the steep valley sides formed of siltstones or interbedded siltstones and sandstones of the Roeburndale Formation, mudstones of the Caton Shale or till are prone to slippage if further undercut by streams or road construction. An active slip in till on the north side of Artle Beck [551 627] seriously damaged the road in 1990.

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APPENDIX: DETAILS OF SELECTED SECTIONS

Where appropriate, sections are also lettered as on the side margin of the map i.e. *sections A* to *J*. The lithostratigraphical codes are as used on the maps. E2a3 denotes the Eumorphoceras yatesae Marine Band

1. *Section A*: Tributary gully to Mears Beck [5559 6466 to 5571 6465].

y	Clau	Sandstone, as bed x	c. 0.6
		GAP	c. 0.5
x	Clau	Sandstone, orange-brown, fine- to medium-grained, thick-bedded, micaceous	c. 1
w	Clau	Sandstone, grey, fine-grained, micaceous, laminated; some silty layers	c. 0.5
v	Clau	Siltstone, as bed p	c. 0.3
		GAP	c. 0.5
u	sa	Sandstone, orange-brown, fine- to medium-grained, medium- to thick-bedded, micaceous; waterfall caprock	c. 7
t	Clau	Siltstone, grey, micaceous, shaly, sandy in places	c. 2.4
s	Clau	Sandstone, as bed q	0.10
r	Clau	Siltstone, as bed p	0.20
q	Clau	Sandstone, grey, fine-grained, hard, lenticular; sharp boundaries	0.03
p	Clau	Siltstone, grey, micaceous, shaly	c. 1.5
		GAP	c. 3
o	sa	Sandstone, pale to medium orange-brown, fine-grained, mostly medium- to thick-bedded, parallel-laminated, lensing in basal 2m; sharp base; waterfall caprock	c. 5
		GAP	c. 0.3
n	Clau	Siltstone, grey, micaceous, finely sandy, blocky	c. 2
m	Clau	blue-grey, shaly	c. 2.3
l	Clau	Claystone, grey, finely micaceous, slightly silty	0.20
k	Clau	Sandstone, fine-grained, micaceous	up to 0.07
j	Clau	Claystone, grey, micaceous, silty, shaly	0.38

i	Clau	Sandstone, orange-brown, laminated; two shaly siltstones to 0.02	0.18
h	Clau	Siltstone, grey micaceous, shaly	0.15
g	Clau	Sandstone, as bed e	0.02
f	Clau	Sandstone, orange-brown, fine-grained, hard	0.24
e	Clau	Sandstone, grey, very fine-grained, silty; greywacke-type with chaotic mica	0.15
d	Clau	Claystone, grey, finely micaceous, slightly silty, shaly	0.3
c	Clau	Sandstone, fine-grained, laminated; sharp boundaries	0.12
b	CSh	Claystone, grey, shaly	c. 3
a	CSh	Claystone, grey, finely micaceous, slightly silty, shaly	c. 1.7

2. *Section C*: Greenholes Beck [5688 6314 to 5737 6340].

t	Clau	Siltstone, grey, sandy; grades to very fine-grained sandstone	c. 3 seen
s	Clau	Sandstone, grey, very fine-grained, silty, thin-bedded	c. 0.6
r	Clau	Siltstone, grey, shaly, sandy, micaceous; numerous thin, parallel-laminated, fine-grained sandstones	c. 7.5
q	sa	Sandstone, orange-brown, fine-grained, thin- to medium-bedded, parallel-laminated; some rapid lensing; numerous interbeds of grey, micaceous siltstone to 0.3 with comminuted plant debris	c. 2.5 to 4.5
p	Clau	Siltstone, grey, micaceous; interbeds of fine-grained sandstone to 0.1	c. 4.6
o	sa	Sandstone, orange-brown, fine-grained, thin-bedded, micaceous, sharp-soled with sole marks; highly bioturbated; some slumping	c. 2
n	Clau	Interbedded siltstones, grey, micaceous, shaly with comminuted plant debris, and parallel-bedded, ripple-marked sandstones to c. 0.12; burrows in top 2	c. 10
m	sa	Sandstone, pale orange-brown, fine-grained, thin- to thick-bedded, sharp-soled with sole marks; locally much lensing with siltstones; ?*Aulichnites* at top; local slumping	2.7 to c. 4
l	Clau	Siltstone, grey, shaly, sandy; numerous sandstones to	

		c. 0.2, one 0.12 thick; some slumping about 5m up	c. 13
k	sa	Sandstone, grey, fine-grained, thick-bedded, ripple-marked; *?Rhizocorallium*	c. 1.0 to 1.5
j	Clau	Siltstone, grey; sandstones to 0.03; slumped in places	0 to 1.5
i	Clau	Interbedded sandstones, orange-brown, fine-grained to 0.15 and grey siltstones; slumped in places	0.9 to c. 2
h	Clau	Siltstone, grey; lenses of siderite mudstone to 0.02	c. 4
g	Clau	Mudstone, grey, silty grading to siltstone; numerous fine-grained sandstones to 0.01 thick	c. 2.5
f	Clau	Interbedded sandstones, brown, fine-grained, massive to parallel-laminated, sharp-soled, thicker at top to 0.15, and grey, shaly siltstones	c. 0.6 to 1.6
e	Clau	Siltstone, grey, shaly; a few fine-grained sandstones to c. 0.01	c. 2
d	Clau	Sandstone, orange-brown, fine-grained; a 0.03 thick siltstone	0.16
c	Clau	Mudstone, blue-grey, shaly, silty in lower part	c. 3.3
b	Clau	Mudstone, blue-grey, shaly, silty; numerous grey, fine-grained, sharp-soled sandstones to 0.04	c. 2.2
a	CSh	Mudstone, blue-grey, shaly; layers of ovoidal, commonly ferruginous calcite mudstone nodules to 0.35 thick and numerous siderite mudstone lenses to 0.06 thick; sporadic *Anthracoceras* or dimorphoceratids	c. 32

3. *Claughton Quarries* [5700 6422]. Section in "Moorcock Flags", Claughton Formation.

h	sa/sl (Clau)	Sandstone, as bed f	0.3
g	sa/sl	Siltstone, brown, micaceous, very sandy, grading to sandstone	0.6
f	sa/sl	Sandstone, brown, fine-grained, micaceous, parallel-laminated	0.3
e	sa/sl	Siltstone, grey, finely sandy, micaceous; a few fine-grained sandstones to 0.15 in basal 0.8; gradational base	2.3
d	sa/sl	Sandstone, orange-brown, micaceous, platy; ripple cross-laminated in top 0.3	1.3

c	sa/sl	Sandstone, grey to brown, silty, micaceous, fine-grained, parallel-laminated, platy; gradational base	0.4
b	sa/sl	Siltstone, grey, micaceous, very sandy with indistinct fine-grained sandstones to 0.05	1.7
a	sa/sl	Sandstone, grey to brown, fine-grained, micaceous, platy, parallel-laminated; a few grey silty partings	1.0 to 1.3

4. Series of sections along Artle Beck [5510 6262 to 5538 6226] arranged in an upriver or north-west to south-east sequence.

4a. *Section F3*: Section along north side of gorge, Artle Beck [5510 6260].

d	WrSt	Ganister sandstone, orange-brown, fine- to medium-grained, massive, siliceous	c. 1
c	WrSt	Sandstone, orange-brown, fine- to medium-grained, thick-bedded, siliceous	c. 3
b	WrSt	Sandstone, orange-brown, thick-bedded; sharp discordant base; inaccessible	c. 4
a	sl/sa (Rbl)	Siltstone, grey, micaceous, shaly; numerous grey, fine-grained, micaceous, silty, sharp-soled sandstones to c. 0.08 thick	c. 18 to 32

4b. *Section F2*: Section in small gully on north side of Artle Beck gorge [5517 6256].

f	WrSt	Sandstone, orange-brown, medium-grained, siliceous, massive	c. 1
e	WrSt	Coal, shaly, bright	c. 0.3
d	WrSt	Sandstone, grey, fine-grained, micaceous; rootlets	c. 0.2
c	WrSt	Siltstone, pale grey, clayey; ?rootlets	c. 0.5
		GAP	c. 1.5
b	E2a3	Claystone, grey, finely micaceous, shaly; marine fossils	c. 1
a	sl/sa (Rbl)	Siltstone, grey, micaceous, sandy; numerous fine-grained parallel-laminated, ripple-marked sandstones from laminae to 0.12; layer of sandy, calcisiltite lenses 7m down	c. 27

4c. Section in small gully on south side of Artle Beck gorge [5514 6247].

j	WrSt	Sandstone, orange-brown, fine-grained, thin- to thick-bedded; primary current lineations on slabs	c.5.5
i	WrSt	Sandstone, pale orange-brown, medium-grained grading upwards to medium-grained, thick-bedded; low angle tabular cross-bedded; sharp base; forms waterfall	c. 4
h	WrSt	Siltstone, grey, carbonaceous with sandstone laminae; coaly in top 0.1; adit mine at this level	c. 0.4
g	WrSt	Sandstone, grey weathering orange-brown, fine- to medium-grained; grey, sandy siltstone lenses to 0.06; sharp base	c. 0.6
f	?WrSt	Siltstone, pale grey, very sandy, micaceous; gradational base	0.9
e	?WrSt	Siltstone, medium grey, laminated, micaceous	c. 0.5
		GAP	c. 4
e	E2a3	Claystone, grey, shaly; marine fossils	c. 0.7
d	E2a3	Claystone, grey, shaly, calcareous, very poorly exposed with many gaps	c. 7
		GAP	c. 1
c	E2a3	Conglomerate of scattered calcite mudstone nodules in grey, clayey siltstone	c. 0.3
b	sl/sa (Rbl)	Siltstone, grey, shaly, sandy, micaceous; numerous sandstones to c. 0.1 (at base of gully)	

4d. *Section F* (part): Section in banks of Artle Beck gorge [5522 6244].

d	WrSt	Sandstone, orange-brown, medium- to coarse-grained, very thick bedded; sharp base with probable angular unconformity (5.5 exposed on opposite bank [5525 6248])	c. 2.5
c	md (Rbl)	Siltstone, medium grey, sandy, micaceous	0 to c. 1
b	E2a3	Claystone, dark grey, shaly, micaceous, silty; sporadic crinoid ossicles, *Posidonia corrugata* and *Eumorphoceras*	c. 4

a	E2a3	Claystone, grey, calcareous, tough; marine fossils; possibly faulted below since only 5.5m estimated down to base of marine band	c. 1.5

4e. *Section F* (main part): Section along Artle Beck [5520 6247 to 5531 6243].

		Sandstone debris (?Head)	
h	md (Rbl)	Siltstone, grey, micaceous, clayey, shaly; exposed in small right bank gully [5530 6248]	c. 1
g	E2a3	Claystone, grey, shaly, tough; marine fossils; numerous phosphatic nodules to 2cm; sporadic flattish calcite mudstone nodules to 0.12 thick; silty and more shaly in uppermost c. 4	11.5
f	E2a3	Claystone, grey, silty, micaceous, calcareous, tough, blocky; layer of lenticular limestone nodules up to 0.3 thick at 2.5; sporadic marine fossils	c. 5
e	E2a3	Limestone, grey, argillaceous, laminated; gradational boundaries	0.5 to 0.6
d	E2a3	Claystone, grey, silty, shaly, micaceous, calcareous, tough; sporadic marine fossils	0.3 to 0.4
c	E2a3	Conglomerate, irregular calcite mudstone nodules in grey, calcareous mudstone; locally, allochthonous blocks of grey, calcite-veined limestone, up to 3, embedded in this and adjacent beds; long axes of nodules orientated at 180° and 200°	0.46 to 1
b	sl/sa	Siltstone, grey, finely sandy, micaceous; numerous grey, fine-grained sandstones to c. 0.08; gradational base	c.16
a	sl/sa	Siltstone, as bed a, with abundant grey, fine-grained, platy, micaceous sandstones to c. 0.3	c. 2.5

4f. Section (part of *Section F)* along Artle Beck [5530 6239 to 5538 6226].

f	WrSt	Sandstone, orange-brown, medium- to coarse-grained; sharp base; mostly loose blocks	c. 1.3
e	md (Rbl)	Siltstone, grey-brown, micaceous, sandy	c. 0.5
		GAP	c. 7
c	md (Rbl)	Mudstone, grey, micaceous, silty, grading upwards into siltstone; numerous siderite-mudstone lenses to 0.03 thick	c. 4

b	md (Rbl)	Conglomerate, grey, calcareous, sandy, silty, pyritous	0 to 0.15
a	E2a3	Claystone, grey, shaly, tough; marine fossils; numerous phosphatic nodules to 2cm; sporadic flattish calcite mudstone nodules to 0.12 thick	c. 3

4g. *Section G*: Artle Beck, near top of left bank in small gully [5524 6231].

		Head	c. 1.3
g	WrSt	Sandstone, orange-brown, medium-grained, thick-bedded	c. 0.8
f	WrSt	Coal, black, soft and weathered	0.25
e	WrSt	Siltstone, grey, micaceous, sandy, planty; pale brown fine-grained sandstone laminae	c. 0.4
d	WrSt	Ganister sandstone, pale orange-brown, fine- to medium-grained, siliceous, massive	0.7
c	WrSt	Sandstone, fine-grained, micaceous, platy	0.1
b	WrSt	Siltstone, grey, micaceous, sandy, planty	0.2
a	WrSt	Sandstone, orange-brown, medium-grained becoming fine-grained at top, thick-bedded	c. 2.5

5. *Section D*: Claughton brick pit and Claughton Beck [5756 6493 to 5836 6444].

	Till	clay, silty, orange-brown, stony	c. 1.5
e	sa/sl (Clau)	Sandstone, grey weathering orange-brown, fine-grained, thinly bedded, micaceous, parallel-laminated, partly cross bedded; ripple cross lamination in lower part	c. 2.5
d	sa/sl	Sandstones, grey, fine-grained, micaceous, laminated, lensing up to 0.4, interbedded with grey, sandy, micaceous siltstones	c.1
c	sa/sl	Siltstone, grey, micaceous, sandy; few sandstones; inaccessible	c. 4
b	sa/sl	Siltstone, grey, micaceous, variably sandy; numerous fine-grained, micaceous, grey sandstones typically 0.2 to 0.3 thick, but lensing down to a few centimetres in thickness, and 0.3 to 0.5 apart	c. 3 to 5
a	sl (Clau)	Siltstone, medium grey, micaceous, shaly, laminated, variably sandy, bioturbated; numerous beds of pale grey, weathering brown, fine-grained, micaceous, ripple cross laminated sandstones typically about 1cm	

		thick, spaced a few centimetres apart, very rarely lensing up to c. 0.2; ripple marked tops common; siltstones grade on some levels to very fine-grained, silty, platy sandstones; sporadic lenticular concretionary layers of grey weathering orange-brown, laminated, micaceous, planty calcisiltite/ calcisandstone, some lenses veined with calcite; beds with common comminuted plant debris, bioturbated with numerous burrows, including casts of vertical tubes and *?Aulichnites*; some bedding planes on loose blocks with scattered white *Dunbarella* (at least one level in upper 10m), rare coiled ?nautiloids	c. 22

6. Sections in the Warm Beck and Crogley Beck area.

6a. *Section E1*: Warm Beck Gill [5928 6417 to 5915 6432].

d	CSh	Claystone, blue-grey, shaly, sporadic calcite mudstone nodules to 0.2 thick; several layers of lenticular siderite mudstone to 0.02 thick; *Anthracoceras* sp. or dimorphoceratids, orthocone nautiloids, *Selenimyalina* sp.	c. 25
c	CSh	Claystone, dark grey, shaly, calcareous; abundant *P. corrugata*, *?Eumorphoceras* sp.	c. 0.8
b	CSh	Limestone, grey, shaly, argillaceous, silty; cravenoceratids and *Eumorphoceras* sp. (Cravenoceratoides nitidus Limestone)	0.2
a	CSh	Claystone, grey, shaly; sporadic calcite mudstone nodules; a 0.02 thick siderite mudstone lens 0.2 up; *Anthracoceras* sp. or dimorphoceratids	c. 8

6b. *Section E2:* Warm Beck Gill [5934 6405].

	Till	Clay, orange brown weathered, silty, stony	c. 3
i	CSh	Claystone, grey weathered pink-brown, shaly; indet. fossils	c. 0.5
h	CSh	Rottenstone, orange (probably a decalcified argillaceous limestone), abundant *P. corrugata*; also cravenoceratid, orthocone nautiloid and *?Selenimyalina*	0.13
g	CSh	Claystone, grey, shaly, weathered; indet. goniatites	0.4
f	WrSt	Sandstone, strong orange-brown, fine- to medium-grained, thick-bedded; hummocky surface	c. 1.6
e	WrSt	Coal	c. 0.1

d	WrSt	Ganister sandstone, pale orange-brown, fine-grained, thick-bedded, siliceous, massive; rootlets in top c. 0.3	c. 1.2
c	WrSt	Sandstone, pale orange-brown, fine-grained, medium-bedded, ripple marked, siliceous	1.2
b	WrSt	Sandstone, pale orange-brown, fine-grained, medium- to thick-bedded, siliceous	c. 1.9
a	sa/sl (Rbl)	Siltstone, grey, micaceous, sandy; numerous fine-grained, micaceous sandstones to 0.2	c. 3

6c. *Section E3*: Crogley Gill Beck [5933 6365].

e	WrSt	Sandstone, pale orange-brown, medium- to coarse-grained, micaceous, thick-bedded; carbonaceous plant fragments	c. 1.2
d	WrSt	Sandstone, orange-brown, fine- to medium-grained, micaceous, parallel-laminated, platy; discordant erosional base	c. 1
c	sa/sl (Rbl)	Siltstone, grey, shaly, micaceous, very sandy	c. 2.5
b	sa/sl	Sandstone, fine- to medium-grained, micaceous, parallel-laminated, highly micaceous; some siltstone laminae	c. 2
a	sa/sl	Siltstone, grey, shaly; a few thin sandstone beds (inaccessible)	c. 12

6d. *Section E4*: Winder Wood and Warm Beck [5970 6390 to 5984 6350].

c	sa/sl (Rbl)	Siltstone, grey, shaly, micaceous, sandy; numerous fine-grained sandstones from laminae to c. 0.4, a few sandstones to 0.2 in top 4; some slumping in lower part	c. 16
b	sa (Rbl)	Sandstone, grey, weathering brown to orange-brown, fine-grained, micaceous, well bedded, some massive beds to 1.5; cemented with ferroan calcite; basal 2 with irregular siltstone lenses locally	c. 3 to 8
a	ClHS	Siltstones, grey, micaceous, shaly, sandy; sporadic sandy calcisiltite lenses; common sandstones to 0.15 in upper part; beds highly slumped	c. 6

7. Section in Foxdale Beck [5821 6071 to 5850 6058].

l	sa/sl (Rbl)	Siltstone, as j	c. 2
k	sa/sl	Sandstone, fine-grained, parallel-laminated, thin- to medium-bedded; numerous thin, sandy siltstones; numerous carbonaceous plant fragments	c.2
j	sa/sl	Siltstone, grey, sandy, micaceous; numerous fine-grained, micaceous sandstones to 0.08	c. 8
i	sa/sl	Sandstone, medium-grained, parallel-laminated, thin- to medium-bedded; primary current lineations	c. 1.3
h	sa/sl	Siltstone, as bed j; sandstones to 0.02 thick	c. 1.5
g	sa/sl	Sandstone, pale orange-brown, fine- to medium-grained, parallel-bedded, parallel-laminated, micaceous; thin siltstones to a few centimetres; primary current lineations	c. 4
f	sa/sl	Interbeds of sandstone and siltstone; siltstones, grey, micaceous, sandy; sandstones to 0.1 with sharp soles, with sole marks, and gradational tops	c. 1
e	sa/sl	Siltstone, grey, micaceous, sandy; a few sandstones to c. 0.01; bioturbated top; numerous sideritic beds c. 1cm thick	c. 6
		GAP	c.1
d	sa/sl	Sandstone, weathered reddish brown, fine-grained, micaceous, parallel-laminated, cemented with ferroan calcite	c. 0.6
c	sa/sl	Siltstone, grey, micaceous, sandy; comminuted plant fragments; numerous sideritic beds c. 1cm thick; one fine-grained sandstone 0.08 thick	c. 2
b	sa/sl	Siltstone, grey, micaceous, sandy; abundant comminuted plant debris; numerous thin, fine-grained, sharp-soled sandstones, a few up to 0.4 thick	c. 12
a	sa/sl	Sandstone, grey, weathering reddish brown, fine-grained, thick-bedded, cemented with ferroan calcite; some pebbles of siltstone and siderite mudstone; abundant comminuted plant debris	c. 2.5

8. Section along Foxdale Beck and in landslip backscarp [5909 6046 to 5931 6033].

e	sa/sl (Rbl)	Siltstone, as b	c. 2
d	sa/sl	Sandstones, fine- to medium-grained, parallel-laminated to 0.5 thick; numerous grey siltstone and interlaminated siltstone/sandstone beds; thickness of individual sandstones laterally variable	c. 10
c	sa/sl	Siltstone, grey, micaceous, sandy; numerous fine-grained, parallel-laminated, ferroan calcite-cemented, sharp-soled sandstones from laminae to 0.4 thick; abundant comminuted plant debris; base discordant	c. 6
b	sa/sl	Siltstone, grey, micaceous, sandy; numerous fine-grained sandstones to 0.04; top slumped in places	c.3
a	ClHS	Siltstone, grey, micaceous, sandy; reddish brown-weathering, very fine-grained sandstones about 1cm thick every few centimetres; comminuted plant debris	c. 11

9. Section along Lambclose Syke [6000 6192 to 5975 6187].

e	sa/sl (Rbl)	Siltstone, grey, micaceous, shaly; abundant fine-grained, platy, ripple-marked sandstones to c. 0.1; also interlaminated siltstone/sandstone beds	c. 10
d	sa/sl	Sandstone, fine-grained, parallel-laminated, micaceous, platy; comminuted plant fragments; caps waterfall	c. 4
c	sa/sl	Siltstone, grey, micaceous, sandy; numerous thin fine-grained, platy sandstones	c. 10
b	sa/sl	Sandstone, fine-grained, parallel-laminated, micaceous, platy; comminuted plant debris; thin siltstone interbeds	c. 2 to 2.5
a	ClHS	Siltstone, grey, micaceous, shaly, sandy; comminuted plant fragments; sporadic large calcisiltite lenses; numerous brown-weathering, very fine-grained, ripple-marked sandstones to c. 0.02; soft sediment deformation about 4 down	c. 15

10. *Section J*: Unnamed left bank tributary of Foxdale Beck [5842 6047].

g	SpCS	Sandstone, pale orange-brown, mostly fine-grained, medium-grained in top 0.5, medium- to thick-bedded, siliceous; mostly parallel-bedded, some low angle tabular cross-stratification; sporadic large plant fragments	c. 11
f	SpCS	Sandstone, grey to orange-brown, fine-grained, micaceous, laminated; abundant carbonaceous plant remains; gradational base	c. 0.4
e	SpCS	Sandstone, grey, fine-grained, siliceous; large carbonaceous plant remains	c. 0.2
d	SpCS	Coal, shaly and irregular "rolls" of grey, siliceous, carbonaceous sandstone, with rootlets, up to 0.15 thick	c. 0.2
c	SpCS	Siltstone, grey, micaceous, carbonaceous	c. 0.1
b	SpCS	Sandstone, orange-brown, fine- to medium-grained, massive, siliceous; carbonaceous plant fragments	c. 0.7
		GAP	c. 2
a	SpCS	Sandstone, as b	c. 1.5
		Faulted against sa/sl of Roeburndale Formation	