Natural Environment Research Council

British Geological Survey

Onshore Geology Series

TECHNICAL REPORT WA/89/52

Geology of the Goodber Common area

1:10 000 sheet **SD66SW**

Part of 1:50 000 Sheet 59 (Lancaster)

R A HUGHES

Geographical index
Lancaster, Bowland Fells, Goodber Common

Subject index
Geology, Craven Basin, Carboniferous,
Namurian, Arnsbergian

Bibliographic reference
Hughes, R A. 1989
Geology of the Goodber Common area
British Geological Survey Technical Report
WA/89/52

 Keyworth, Nottingham British Geological Survey 1989

1. INTRODUCTION

This report describes the geology of the 1:10,000 sheet SD 66 SW (Goodber Common), part of the 1:50,000 Series sheet 59 (Lancaster). The first geological survey of the area, at the 1:10,560 scale, was carried out by R.C. Tiddeman and published as part of the Lancashire County Series sheets 31 and 32, and as part of the 1:50,000 Primary Series sheet 91 NE (1884). The present survey was carried out during the summer of 1988 by Richard A. Hughes, under the direction of Dr A.J. Wadge, Regional Geologist.

The only published work on the area is by Moseley. The area was part of the ground described in his (1954) account and map of the Namurian of the Lancaster Fells. Some of the glacial features are mentioned in a wider context in his account of the glacial history of the area (Moseley and Walker, 1952).

The Goodber Common sheet (see figure 1) lies on the northern watershed of the Bowland Fells. Altitude decreases steadily northwards from a high point of approximately 495 m in the extreme south-west corner, to approximately 105 m in Roeburndale [611 649] on the northern margin of the sheet. Goodber Common and Summersgill Fell form a broad, flat, north-south watershed. To the east the land is drained by the River Hindburn and its tributaries, to the west the land is drained by the River Roeburn and its tributaries, notably Mallow Gill and Pedders Gill. Much of the higher ground is very poor quality land used only for sheep grazing and for grouse shooting. The slightly better quality land of the northern part of the area is used for cattle and sheep grazing and for animal fodder crops. A large area in the south-east on Thrushgill Fell has been planted with conifers. Access to the southern part of the area is difficult, and the rough track (passable only by four-wheel driven vehicles) which links Hornby and Slaidburn is a very useful way of access.

Ten graphical section logs (Figures 2-11) are presented in Appendix 1 at the back of the report.

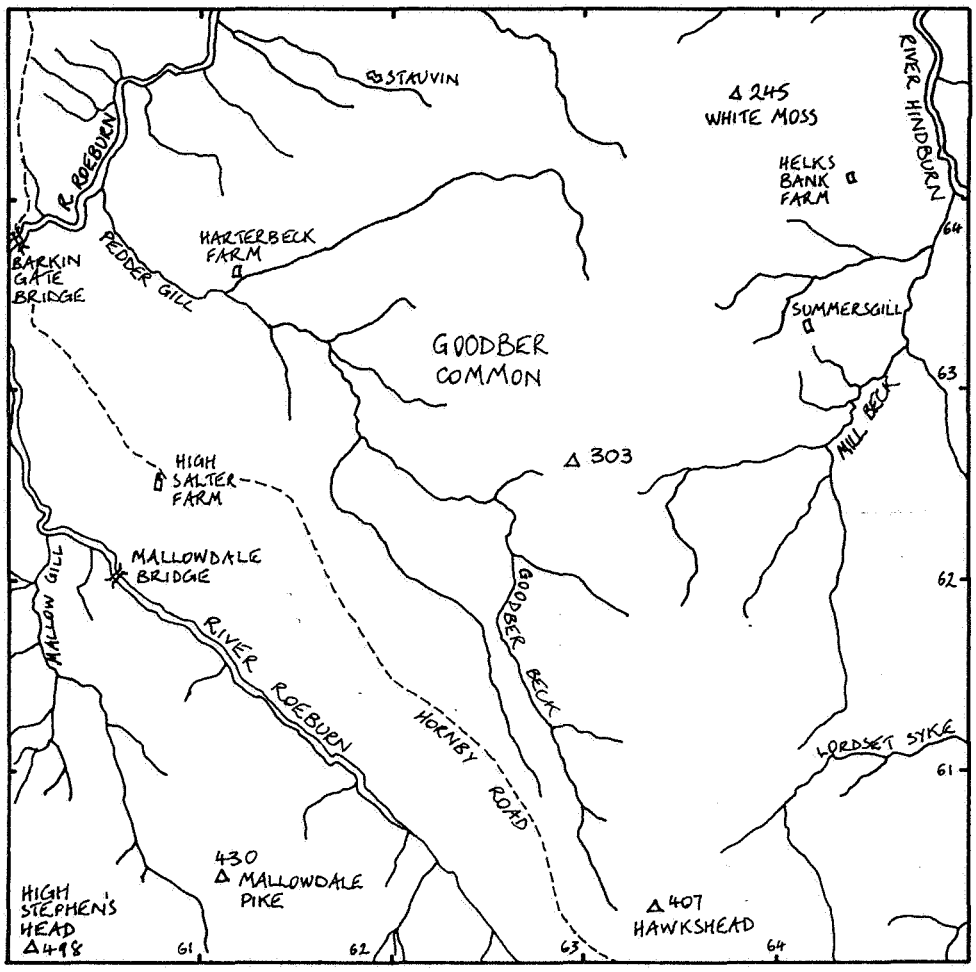


FIGURE 1: SKETCH MAP SHOWING IMPORTANT LOCALITIES MENTIONED IN TEXT. HEIGHTS ARE IN METRES.

2. GEOLOGICAL SUCCESSION

DRIFT

QUATERNARY

- Landslip
- Peat
- Head
- Alluvial fan deposits
- River terrace deposits
- Alluvium
- Glacial sand and gravel
- Till

SOLID

MILLSTONE GRIT GROUP

- Kirkbeck Formation
- Crossdale Mudstone Formation
- Silver Hills Sandstone Formation
- Claughton Formation
  - Hawkshead Sandstone Member
- Caton Shale Formation
- Ward's Stone Sandstone Formation
- Roeburndale Formation

3. MILLSTONE GRIT GROUP

3.1 ROEBURNDALE FORMATION The oldest rocks within the sheet area belong to the upper part of the Roeburndale Formation. A maximum thickness of up to 385 m may be present in Roeburndale itself. The interval contains the *Eumorphoceras ferrimontanum* Marine Band, but in the present area, fossils diagnostic of this band have been found only in locally derived head deposits. The *E. yatesae* Marine Band, which in other parts of the Bowland Fells occurs within a few metres of the base of the Ward's Stone Sandstone Formation, has not been found in the present area. Subsequent mapping in adjacent areas, e.g. around Littledale (Brandon, 1992), has enabled the strata between the two marine bands to be subdivided into the Close Hill Siltstone Member, underlain and overlain by units of interbedded sandstones and siltstones ("sa/sl"). These have not been differentiated in this area.

Rocks belonging to the formation crop out in four discrete areas. On the eastern margin of the sheet they are exposed in Horseholes Gill [648 603], in the lower reaches of Lordset Syke [648 612], and in Mill Beck [648 637]. By far the most extensive exposures of these rocks are in the western half of the sheet, in the bed and banks of the River Roeburn and its tributaries, notably Mallow Gill [60 61] and Pedder Gill [60 63].

3.1.1 *The River Roeburn and its tributaries*
Most of the sections are in the Close Hill Siltstone Member and the overlying "sa/sl" unit. Rocks of the formation crop out along the River Roeburn downstream from the point [618 609] where the river is crossed by the Roeburn Fault. Shallow, north to north-westerly dips ensure very gradual northward younging of the succession throughout almost the entire Roeburn section.

Exposures on the right bank of the River Roeburn [6186 6101], immediately north of the Roeburn Fault, consist of thinly bedded and parallel-bedded, muddy siltstones, with silty, fine- to medium-grained sandstones, and thin (less than 0.15 m), hard, flaggy, micaceous, medium-grained sandstones. Many of the finer-grained beds are parallel- or wavy-laminated. Comminuted plant remains are abundant within the siltstones and silty sandstones. Calcareous

nodules up to 0.08 m are common within some beds, and within one bed here is a single calcareous mudstone nodule, 0.5 m across. Trace fossils are present on some bedding planes, but these are better exposed downstream (see below).

Between here and a locality on the right bank of the river [6162 6115], some 280 m to the north-west, are further exposures of similar lithologies. At this locality, many bedding planes are covered with horizontal burrows and trails. The burrows consist of branching tubes, up to 0.01 m across, and oval in cross-section, and are composed of pale grey, fine- to medium-grained sandstone. These burrows are conspicuous on the bedding planes of dark grey, muddy siltstone on which they are most commonly found. The trails appear as narrow (approximately 0.02 m wide), unbranched, meandering lines on bedding planes of dark grey siltstone and muddy siltstone, and are probably gastropod trails.

Exposures of similar lithologies to those described above are abundant between here and a locality [6080 6183] on the left bank of the river some 275 m south-east of Mallowdale Bridge. Here, the monotony of the dark grey siltstones and silty sandstones is broken by a 0.30 m thickness of bedded, pale brown, calcareous, fine-grained sandstone. On the right bank of the river [6078 6188] some 50 m downstream from here are four beds, each less than 0.25 m thick, of fine- to medium-grained sandstone. One of these beds has an irregular base and top. The sandstones occur within a sequence of parallel-bedded, dark grey siltstones and silty sandstones.

Downstream of Mallowdale Bridge as far as the point west of Middle Salter where the River Roeburn leaves the sheet [600 633], are abundant exposures of dark grey, thinly bedded, commonly parallel-laminated, siltstones and silty, fine- to medium-grained sandstones. Within this part of the section, on the right bank some 50 m downstream from Mallowdale Bridge [6055 6206], are 2.5 m of hard, fine- to medium-grained sandstones in beds up to 0.35 m thick. On the left bank of the river at Wilson Wood [6015 6242] is a 0.40 m thickness of low angle cross-laminated, calcareous, fine- to medium-grained sandstone.

Exposures along the River Roeburn section downstream from Barkin Bridge [601 637] are equally good as those upstream. On the left bank, some 350 m north of Roeburndale Church [6011 6388] are up to 4.5 m of thinly bedded, parallel- and wavy-laminated, sandy siltstones and fine-grained sandstones. Some of the sandstone beds have horizontal trails, small flute marks on their bases, and load structures. Current-generated, parallel-crested and linguoid ripples are also present. In an inaccessible cliff section on the left bank of the river [6025 6391] west of Shoefoot Wood, are approximately 25 m of interbedded fine- to medium-grained sandstones, siltstones, and silty sandstones.

On the left bank of the River Roeburn [6038 6403] upstream from its confluence with Pedder Gill is another inaccessible cliff section. In the section are exposed up to 15 m of interbedded, fine- to medium-grained sandstones and siltstones. The soles of some of the sandstone beds have flute marks, and the bedding planes have trails and ripples. This 15 m thickness overlies approximately 5 m of sediment (sand grade and finer), which has been highly disrupted by syn-sedimentary deformation (see below). This deformed bed overlies at least 2 m of siltstone and silty sandstone, the base of which is not exposed. 2 m of calcareous sandstone is exposed on both banks of the river [605 642] downstream from its confluence with Pedder Gill.

Further, extensive but inaccessible cliff exposures are present downstream on the left bank at Cowfold Scar [606 646]. Here, approximately 15 m of thinly bedded, fine- to medium-grained sandstones are interbedded with soft weathering siltstones and silty sandstones. These rocks overlie a 5 m thickness of sandstones and siltstones which have been affected by syn-sedimentary deformation (see below), the base of which is not seen.

Downstream from Cowfold Scar as far as where the River Roeburn flows beyond the sheet boundary are many exposures of rocks similar to those described above. High on the western side of Roeburndale [6091 6497] on the northern margin of the sheet, are exposures of sandstone in the backscar of a landslip. Up to 4.5 m of medium- to coarse-grained, thickly bedded sandstones are

present. These rocks are along strike from the Ward's Stone Sandstone on the eastern side of Roeburndale, but their precise stratigraphical position cannot be confirmed until the ground to the west and north is mapped.

Exposures of the Roeburndale Formation are abundant but discontinuous in Pedder Gill [60 63]. As in the River Roeburn section, the dominant lithologies here are siltstones, silty sandstones, and fine- to medium-grained sandstones. Trace fossils and flute marks are common in the sandstones, and the siltstones are commonly rich in comminuted plant debris. Further, minor exposures of rocks of the Roeburndale Formation are present in the lesser tributaries of the River Roeburn, such as Middle Salter Gill [603 632], Lemma Gill [603 629], the un-named tributary in Barkin Gate Wood [607 647], and in the sides of the glacial meltwater channel now occupied by Salter Clough Beck [60 62].

More extensive and more continuous exposures of the rocks of the Roeburndale Formation are present in Mallow Gill, Colros Gill, and Long Gill and their minor tributaries, in the south-west of the sheet [60 60 and 60 61]. Throughout these sections the rocks exposed consist of thinly bedded, laminated siltstones, silty sandstones, and fine- to medium-grained sandstones with calcareous nodules. Trace fossils, flute casts, and current-generated, parallel-crested and linguoid ripples are present in many of the sandstones. On the right bank of Colros Gill [610 603] south-west of Mallowdale Pike, a 4 m thickness of strata contains several discrete sandstone beds up to 0.8 m thick. The sandstones are fine- to medium-grained, with erosive, sole-marked bases and flat tops. This thickness of sandstone-dominated strata can be traced northward for at least 100 m, and is mapped as a discrete unit.

3.1.2 *Horseholes Gill and Goodam Syke*

Rocks belonging to the Roeburndale Formation are exposed in these two streams in the extreme south-eastern corner of the sheet [64 60]. The best exposures [649 602] are at the confluence of the un-named, north-easterly flowing tributary and Horseholes Gill. The sequence exposed here consists of some 4 m (base not exposed) of dark grey, soft-weathering, parallel-bedded, silty sandstones and fine-grained sandstones. These are overlain by approximately 5 m of fine- to medium-grained sandstones and siltstones, with trace fossils

and current-generated, parallel-crested and linguoid ripples. Exposure is poor above these rocks, but the sequence appears to be composed almost entirely of dark grey siltstones and silty sandstones.

Dark grey to black, silty mudstone, siltstone and silty sandstone blocks are common in the locally derived head deposits on both the north- and south-facing slopes in this small area. These rocks contain abundant marine fossils diagnostic of the *Eumorphoceras ferrimontanum* Marine Band, and it is concluded that the band is present, but not exposed in the area. It is estimated that the marine band occurs approximately 35 m below the base of the Ward's Stone Sandstone in the area.

3.1.3 *Lordset Syke*

Rocks of the Roeburndale Formation are exposed in the lower parts of Lordset Syke [64 61] in the south-east of the sheet. A 15 m interval of sandstone-dominated rocks is mapped here within dark grey, soft-weathering, laminated siltstones and silty sandstones. The sandstones are generally medium-grained, hard, commonly flaggy, and occur in beds up to 1 m thick. Flute marks are common on the soles of the beds, and current-generated ripples are present on the tops of some units. Starved ripple-laminations are present within one sandstone bed.

This sandstone-dominated interval is underlain on the extreme eastern margin of the sheet by dark grey, soft-weathering, laminated siltstones and silty sandstones.

3.1.4 *Mill Beck*

Good exposures of the Roeburndale Formation are present in Mill Beck [64 63] north of Botton Mill. The oldest rocks here are pale brown to grey, thinly bedded, low angle cross-laminated, fine- to coarse-grained sandstones, at least 4 m thick (base not seen). These are overlain by up to 15 m of dark grey, thin- and parallel-bedded, siltstones and silty sandstones, with flaggy, micaceous, medium-grained sandstones up to 0.8 m thick. The thickness of some of the flaggy sandstone beds is laterally variable: one bed exposed [6481 6371] just upstream from the point where Mill Beck is joined by a small,

un-named, north-westerly flowing tributary, varies between 0.30 and 0.45 m in thickness within 5 horizonatal metres. Comminuted plant remains are abundant in the siltstones, and linguoid ripples and trace fossils including *Cruziana*? are present on some of the sandstone bedding planes.

3.1.5 *Biostratigraphy of the Roeburndale Formation*
As mentioned above, the only marine band present within the Roeburndale Formation on the present sheet is the *Eumorphoceras ferrimontanum* Marine Band (E_2a_2), and the faunas of this band are known only from loose blocks found in locally derived head deposits. *Eumorphoceras* sp., *Posidonia corrugata*, crinoid ossicles, and indeterminate conodont elements have been identified from these rocks.

Bivalves have been collected from two localities in the River Roeburn section from siltstones equivalent to the Close Hill Siltstone Member of adjoining areas (e.g. Brandon, 1992). The bivalve cf. *Anthraconeilo* has been found in silty sandstones on the right bank of the river [6107 6170] some 580 m south-east of Mallowdale Bridge. This genus is thought to indicate a brackish or marine environment. Bivalves belonging to an undescribed genus similar to *Sanguinolites* have been collected from a locality on the left bank of the Roeburn [6015 6242] 220 m northnorthwest of its confluence with Mallow Gill.

3.1.6 *Syn-sedimentary deformation within the Roeburndale Formation.*
Evidence of syn-sedimentary deformation occurs throughout the Roeburndale Formation in the area, but is particularly common in the River Roeburn section.

Small scale (between bounding layers 2 m or less apart), intra-folial folds, produced by slumping of soft sediment, have been observed at three localities along the River Roeburn. On the right bank of the river immediately upstream from the Roeburn Fault [6185 6100] are small slump folds within interbedded siltstones and silty sandstones. On the right bank of the river [6119 6158] some 730 m south-east of Mallowdale Bridge are small slump folds within fine-grained sandstones in a sequence of interbedded siltstones, silty sandstones and fine- to medium-grained sandstones. On the right bank of Colros

Gill [6094 6035] south-west of Mallowdale Pike, is abundant evidence of soft sediment deformation in the form of slump folds and disrupted bedding. One particularly fine intrafolial fold here, with a thickness of 0.45 m, indicates a south-easterly facing palaeoslope. Other examples of intrafolial slump folds are present in siltstones and sandstones in Azers Gill [601 616], and on the left bank of Lordset Syke [6485 6118].

Larger scale syn-sedimentary deformation is evident at many localities along the River Roeburn downstream from Barkin Bridge [601 647]. In a small cliff section on the left bank of the river [6016 6387] 125 m north-east of Barkin Bridge, are at least 3 m (base not seen) of highly contorted siltstones, silty sandstones, and fine-grained sandstones. Above a regular contact, these rocks are overlain by thinly bedded, parallel- and wavy-laminated, siltstones and fine-grained sandstones. On the left bank [6016 6387] 50 m east of here are further examples of contorted and disrupted bedding. Cavities within a sedimentary breccia here are lined with drusy quartz and galena. In a cliff section on the left bank [6024 6391] a further 90 m to the north-east, is a spectacular disrupted and slumped unit, 5 m thick, with regular lower and upper contacts. The unit consists of disrupted beds of siltstone, silty sandstone, and fine- to medium-grained sandstones, and contains sandstone balls and "pods" up to 7 m across. Further evidence of soft sediment deformation is present in the higher, inaccessible parts of the cliff section here, in the form of small scale slumps.

More slump folds are present on both banks of the river in the vicinity of Shoefoot Wood [604 638], and spectacular folds can be seen in exposures in the wood which are difficult of access. In another cliff section on the left bank of the River Roeburn [6038 6402], 120 m upstream from the confluence of the Roeburn and Pedder Gill, is another highly disrupted unit of siltstones, silty sandstones, and sandstones. The unit is at least 5 m thick (base not exposed), and has regular lower and upper contacts.

Further evidence of soft sediment deformation, in the form of sandstone dykes, is present in the right bank of Long Gill [6015 6103] some 950 m north of High Stephen's Head. A number of anastomosing dykes consisting of fine- to

medium-grained sandstone, up to 0.05 m wide and roughly perpendicular to the bedding, are intruded into dark grey, laminated siltstones and silty sandstones.

3.2 WARD'S STONE SANDSTONE FORMATION

The Ward's Stone Sandstone Formation is a sandstone-dominated sequence containing ganister horizons and impersistent coals, which varies in thickness from a maximum of 36.6 m in Bowskill Wood [612 648] in the north-west, to a minimum of 3.2 m in Well Beck [647 636] in the east. In the western part of the area it caps Mallowdale Pike [61 60] and the escarpment on the eastern side of Roeburndale. There are many other exposures of the sandstone in stream sections throughout the area.

In the western part of the sheet the two most continuous sections through the Ward's Stone Sandstone are in Bowskill Wood and Pedder Gill (see Figures 2 and 3). In both these sections the sandstone forms spectacular waterfalls. Farther south, the sandstone is exposed at the eastern end of the glacial meltwater channel [615 625] now occupied by Salter Clough Beck. Up to 3 m of massive, fine- to coarse-grained sandstone is exposed here, and the sandstone was once worked for local building material.

Along strike to the south-east, the Ward's Stone Sandstone caps the escarpment along which runs the Hornby road. Small exposures on the crest and dip-slope of the escarpment are common, and the feature is generally covered with large, fine- to coarse-grained sandstone blocks. Exposures are abundant at the southern end of the escarpment on Alderstone Bank [62 60], where the sandstone forms two topographical features. The lower of these is composed of approximately 10 m of coarse-grained sandstone, commonly pebbly, and commonly in large scale, planar and trough cross-laminated units. The upper feature consists of up to 6 m of fine- to coarse-grained, planar and trough cross-laminated sets up to 0.40 m thick, and parallel-laminated beds. No rootlet layers have been seen here, but U-shaped burrows (cf. *Arenicolites*) are common on some bedding planes in the uppermost 2 m of the sequence.

A fault bounded inlier [630 607] on the Ward's Stone Sandstone dip-slope, in the upper reaches of Goodber Beck north-west of Hawkshead, exposes the uppermost 1.6 m of the sandstone and the contact with the overlying Caton Shale Formation (see Figure 4). In Goodber Beck [627 613] 700 m northnorthwest

of here is a second fault bounded inlier of Ward's Stone Sandstone, in which the highest 1 m of the sandstone is exposed. It consists of medium-grained sandstone with two ganister layers.

West of the River Roeburn, the Ward's Stone Sandstone caps Mallowdale Pike [61 60] and forms the dip-slope which extends north-eastwards to the River Roeburn. The rocks are well exposed on the higher parts of Mallowdale Pike itself, where they consist of medium- to coarse-grained sandstones with rare quartz pebbles. All beds here are either parallel-laminated or have low angle, planar cross-laminations, and some have contorted laminations.

Along strike from Mallowdale Pike, the Ward's Stone Sandstone is exposed throughout the River Roeburn section upstream of the Roeburn Fault [618 609]. The rocks exposed in the Roeburn section are in the upper part of the Ward's Stone Sandstone, within 7 m of the base of the overlying Caton Shale Formation. Particularly good exposures are present some 220 m to the south-east of the Roeburn Fault, where the sandstone produces a waterfall. The sandstone contains at least six rootlet horizons here, and a laterally impersistent coal, up to 0.20 m thick (see Figures 5 and 6). Exposures farther south-east in the River Roeburn show fine- to coarse-grained sandstones with rootlet layers, and small scale, trough and planar cross-laminations. The section exposed in Bushy Clough [62 60], a tributary of the River Roeburn, repeats the section exposed in the main river.

The Ward's Stone Sandstone crops out on the high ground in the extreme south-western corner of the map. Loose blocks are abundant at the surface, but the best exposures in this area are around High Stephen's Head [602 602]. Trough cross-laminated and parallel-laminated, medium- to coarse-grained sandstones, with burrowed surfaces (cf. *Arenicolites*) crop out here. A medium-grained sandstone with rootlets is exposed in the middle of the three tributaries [6099 6003] which join to form Colros Gill on the southern margin of the sheet.

East of Hawkshead the Ward's Stone Sandstone crops out over a large area on Greenbank Fell [64 60]. On the south-eastern (the upthrown) side of the Lordset Syke Fault, the exact thickness of the sandstone is unknown because its top is not exposed, but it is at least 6 m. On the hillside at "Greens" [647 609] are abundant loose blocks, not far removed from their positions of outcrop, of medium- to very coarse-grained sandstones, normally parallel-bedded, but with uncommon, small scale, trough cross-laminations. A rootlet layer is present in the rocks exposed [6484 6100] just to the west of the northnorthwest trending dry stone wall. A second rootlet layer in a fine- to medium-grained ganister sandstone, approximately 2 m above the first, is exposed in an un-named stream [6460 6075] to the south-west of "Greens". The frost-heaved, craggy outcrops [646 608] 230 m south of the confluence of Hawkshead Gill and Lordset Syke, consist of up to 1.5 m of fine- to medium-grained, parallel bedded sandstone with abundant external moulds of *Stigmaria*. The topmost 0.15 m of this thickness is composed of trough cross-sets. Higher on Greenbank Fell a third ganister sandstone is exposed on the hillside [6419 6024] 150 m west of the un-named, northerly flowing tributary of Hawkshead Gill.

On the north-western (the downthrown) side of the Lordset Syke Fault, the Ward's Stone Sandstone is exposed at several localities on a northerly dipping dip-slope. The sandstone is medium- to coarse-grained, parallel-bedded, and contains at least two rootlet horizons with large external moulds of *Stigmaria*. At least 2 m of sandstone are present on the dip-slope, but its total thickness here is unknown as its base is not exposed. Farther north-east at the confluence of Hawkshead Gill and Lordset Syke [646 610], an almost complete section through the Ward's Stone Sandstone shows its thickness to be 7.1 m (Figure 7).

North of Lordset Syke [64 61] the Ward's Stone Sandstone forms a strong topographical feature. There are signs of old workings but no longer any exposures here; a note on Tiddeman's field slip recorded "Quarries in fine flaggy and blocky grit, quartzitic with rootlets". Along strike to the north, the Ward's Stone Sandstone is exposed in a disused quarry north-east of Higher

Thrushgill Plantation. 2 m of thickly bedded, massive, medium-grained sandstone are present here. The sandstone is also exposed in an inlier [643 620] in Higher Thrushgill Plantation. Up to 1.5 m of flaggy, medium-grained sandstones with rootlet layers, in beds up to 0.40 m thick, are exposed here.

In the north-east of the sheet the Ward's Stone Sandstone is exposed in three areas, separated by faults. In the southernmost of these, on the south-western side of the Helks Bank Fault, the sandstone is exposed in Mill Beck [6478 6359, and south of here] and Well Beck [6473 6369]. In Well Beck, 2 m of thinly bedded, fine- to medium-grained sandstone overlain by 1.2 m of massive, fine-grained sandstone with a ganister cap, produces a small waterfall. Along strike in Mill Beck the lower sandstones of the Ward's Stone Sandstone form a waterfall immediately downstream from Botton Mill. The cliff section behind the waterfall is in a dangerous condition, and was not logged. A ganister sandstone forms the bed of the stream for 330 m upstream of here. The ganister is overlain by a coal, up to 0.20 m thick, exposed on the left bank of Mill Beck [6470 6340] south of Fall Wood Coppice. Up to 2 m of poorly bedded, medium-grained, sandstone is present above the coal and below the Caton Shale Formation.

The coal allows a correlation to be made with the section exposed in the River Hindburn [648 642], north of the Hollinhurst Fault. The Ward's Stone Sandstone is at least 2.5 m thick in the Hindburn, and the lowest exposed ganister forms spectacular bedding plane exposures. The section exposed in the Hindburn is presented in Figure 8.

The third section exposing the Ward's Stone Sandstone in the area is in Mill Beck [6488 6392], where 1.8 m of fine- to medium-grained sandstones with a ganister cap are exposed immediately adjacent to the Helks Bank Fault.

3.3 CATON SHALE FORMATION

The Caton Shale Formation overlies the Ward's Stone Sandstone throughout the entire area, and are approximately 35 m thick. They consist predominantly of highly fossiliferous, blue-grey, shaly mudstones, with thin limestones and limestone bullions throughout, and were deposited in a marine environment. The *Cravenoceratoides nitidus* Limestone, recorded by Moseley (1954) throughout the area, consists of a limestone nodule horizon which, in some localities has coalesced to form a bed, approximately 0.20 m thick. The "limestone" does not constitute a mappable, continuous, lithological unit, but it occurs at the horizon of the *Eumorphoceras leitrimense* Marine Band, a band exposed in the River Hindburn section.

3.3.1 *Details of sections*

The only outcrops of the Caton Shale Formation in the north-west quarter of the sheet occur in two streams to the east of Bowskill Wood [613 648]. 0.4 m of blue-grey shaly mudstones, within 0.6 m of the top of the Ward's Stone Sandstone, occur in the right bank [6132 6485] of the un-named stream, immediately east of the wall which encloses Bowskill Wood. Further, very poor exposures of grey mudstones occur upstream of here [6138 6483], just north of the point where the stream runs beneath a wall. South of here, 0.25 m of fossiliferous mudstones crop out [6130 6480] in the right bank of a second un-named stream, immediately east of Bowskill Wood.

Caton Shales crop out at a number of localities in Roeburndale upstream of the Roeburn Fault. Fossiliferous, grey, shaly mudstone material in the slipped material at the eastern end [616 610] of the landslip on the left bank of the River Roeburn, and very small amounts of grey, shaly mudstone in the head exposed in the left bank [6181 6092] of an un-named, easterly flowing tributary of the Roeburn, prove the existence of a small outlier of Caton Shales here. There are no *in situ* exposures of Caton Shales on the left bank of the Roeburn here. At the top of a cliff on the right bank of the river [6197 6084] 180 m south-east of the last locality, is a poor exposure of pale grey, shaly mudstone, within 1 m of the top of the Ward's Stone Sandstone. On the right bank [62236062] 130 m north of the confluence of Bushy Clough and the River Roeburn, is an exposure of blue-grey, shaly mudstones with a 0.20 m

laminated, argillaceous limestone bed. This bed passes laterally into a series of septarian nodules, and small septarian nodules are common throughout the section. Upstream of here, there are no further *in situ* exposures of Caton Shales, but typical Caton Shales lithologies are common in the head deposits.

Above Roeburndale and on the western side of the Hawkshead-Goodber Fell interfluve, exposures of the Caton Shales occur only in the upper parts of Goodber Beck. Caton Shales are exposed at two localities in the part of Goodber Beck which runs between Hawkshead and Alderstone Bank. On the left bank [6319 6039] of the stream, 240 m east of the 383 m spot height on the Hornby Road, is a small, deeply weathered exposure of pale grey, shaly mudstone and silty mudstone. 200 m northnorthwest of here, 1 m of fossiliferous, pale grey, shaly mudstone is exposed on the right bank [6303 6058] of the stream. Further downstream, the contact between the Ward's Stone Sandstone and the Caton Shales, and the lowest 12.4 m of the Caton Shales is exposed in a cliff section on the right bank [6302 6078] north of the waterfall marked on the map. The section present at this locality contains two, thin bentonites, and is presented in Figure 4. Downstream from here are a few poor exposures of pale grey, shaly mudstones and silty mudstones.

The contact between the top of the Ward's Stone Sandstone and the base of the Caton Shales is repeated by faulting in Goodber Beck [6271 6143], 720 m eastsoutheast of the 322.85 m benchmark on the Hornby Road. The lowest rocks above the Ward's Stone Sandstone are argillaceous limestones, whose base is not exposed. These are overlain by pale grey mudstones and silty mudstones with septarian limestone nodules.

North-east of Hawkshead the Caton Shales are intermittently exposed in Hawkshead Gill [63 60]. The contact betweeen the Caton Shales and the underlying Ward's Stone Sandstone is exposed [6460 6113] just upstream from the confluence with Lordset Syke. 0.10 m of fossiliferous, grey, shaly mudstones here overlie the ganister top of the Ward's Stone Sandstone. 200 m westsouthwest of the last locality [6441 6108], further stream bed exposures of pale grey, shaly mudstones contain fossiliferous calcareous nodules which, at two horizons, coalesce to form an almost continuous bed. The sequence is

discontinuously exposed upstream of here. A parallel laminated, blue-grey, argillaceous limestone of unknown thickness is exposed [6400 6100] in the stream close to the southern extremity of Higher Thrushgill Plantation. Exposures are more infrequent upstream of here, but fossiliferous, grey shaly mudstones with septarian nodules are present at several more localities in the stream east of Hawkshead.

Caton Shales are exposed [6432 6188] at the confluence of the two un-named streams 75 m south of the southern end of the inlier of Ward's Stone Sandstone in Higher Thrushgill Plantation. Exposures are small, and consist of fossiliferous, pale grey, shaly mudstones.

Several exposures of Caton Shales occur in the north-eastern quarter of the sheet. South of the Helks Bank Fault, the lower parts of the Caton Shales are exposed in Helks Brow [64 63], where their thickness is approximately 35 m. The underlying Ward's Stone Sandstone is well exposed in a waterfall a few metres north of the point where the road crosses the stream, but the contact with the Caton Shales is not exposed. The Caton Shales are intermittently exposed upstream of here, and consist of fossiliferous, pale grey to blue-grey, shaly mudstones and silty mudstones, with abundant septarian nodules. Comminuted plant material is present in the upper parts of the Caton Shales in this section. The incomplete section exposed in Helks Brow is presented in Figure 9.

The sequence through the Caton Shales exposed in Helks Brow is repeated in Mill Beck to the south [64 63], but exposure here is very poor and incomplete. The contact between the Caton Shales and the Ward's Stone Sandstone is not exposed, and the lowest rocks of the Caton Shales are seen in a very small, un-named tributary on the left bank of Mill Beck [646 633], 450 m east of Summersgill. Fossiliferous, pale grey shaly mudstones are present here in the bed of the stream. Caton Shales stratigraphically above the last described are present in the bed of Mill Beck [646 631], immediately upstream from the aqueduct west of Birks Barn. More continuous exposures are present upstream of here, in the un-named easterly flowing tributary [643 629] which joins Mill Beck at the southern end of Over Close Wood: fossiliferous, pale grey, shaly

mudstones with septarian nodules are exposed here. The southernmost exposure of Caton Shales in the Mill Beck area occurs at the confluence of the two major tributaries [6429 6271] which merge to form Mill Beck. Small exposures of pale grey, shaly mudstones are present in the stream bed here, and are visible only at low water.

The Caton Shales are exposed in an un-named tributary to the east of Mill Beck [64 62], where the stream has cut through the thin till cover. The succession youngs northwards in this area, and the oldest of the two exposures, on the western margin of the sheet [649 626] 120 m north of a disused quarry, is the southernmost. Fossiliferous, dark grey, shaly mudstones are exposed here. Fossiliferous, grey, shaly mudstones with septarian nodules are exposed at the younger locality to the north [648 628].

Between the Helks Bank Fault and the Hollinhurst Fault the Caton Shales are exposed in Mill Beck and in the River Hindburn. In Mill Beck [649 639], fossiliferous, pale grey to blue-grey, shaly mudstones and silty mudstones, with common septarian nodules, are generally well exposed on the right bank of the stream. Fossiliferous, pale grey, shaly mudstones with septarian nodules are exposed in the left bank of the River Hindburn [6498 6402], 20 m west of the sheet margin. Downstream of here, on the left bank of the river east of Briery Wood [6489 6421], are exposures of shaly mudstones which are accesible only at times of low water.

North of the Hollinhurst Fault the Caton Shales are extensively exposed in the banks of the River Hindburn. The rocks consist of fossiliferous, pale grey, shaly, mudstones and silty mudstone, with abundant septarian nodules.

3.3.2 *Biostratigraphy of the Caton Shale Formation*

Moseley (1954) recognised four ammonite sub-zones within the Caton Shales, namely (in ascending order) the *Cravenoceratoides bisati* Sub-zone, the *Ct. nitidus* Sub-zone, the *Cravenoceratoides holmesi* Sub-zone, and the *?Ct. and Pedder*s Gill. Much of the higher ground is very poor quality land used the four marine bands recorded within the Caton Shales are (in ascending order) the *Cravenoceratoides edalensis* Marine Band, the *Ct. nitidus* Marine

Band, the *Glaphyrites holmesi* Marine Band, and the *G. kettlesingense* Marine Band. The *Ct. nitidus* Marine Band is re-named the *Eumorphoceras leitrimense* Marine Band here. In the present area, despite an abundance of fossiliferous outcrops, only the *Ct. edalensis* and *E. leitrimense* Marine Bands are exposed.

The *Ct. edalensis* Marine Band (E_{2b1}) occurs in the lowest 0.35 m of the Caton Shales in the section in Goodber Beck [6302 6078], north-west of Hawkshead (see Figure 4). Along with the eponymous goniatite, the marine band here has yielded *Cravenoceras subplicatum*, *Metadimorphoceras* sp., *Anthracoceras* sp., and *Selenimyalina variabilis*. The higher parts of the section here have yielded *Metadimorphoceras saleswheelense*, *Anthracoceras* sp., *A. glabrum*, *A. discus*, *Dimorphoceras* sp., *Posidonia corrugata*, and *Selenimyalina* sp. The *Ct. edalensis* Marine Band has not been found elsewhere in the area, despite good exposures through this interval, and it is probable that its absence is due to local non-sequence at this horizon.

A locality on the left bank of Goodber Beck [6267 6146] downstream from the last locality, and within 5 m of the base of the Caton Shales, has yielded *Cravenoceras* cf. *subplicatum* and *Posidonia corrugata*.

Dark grey, shaly mudstones exposed on the right bank of Hawkshead Gill [6390 6067] north-east of Hawkshead, contain *Cravenoceras subplicatum* and *Posidonia corrugata*. Similar rocks exposed on the right bank approximately 175 m upstream of here [6375 6060] have yielded *P. corrugata*, *Selenimyalina variabilis*, and ?*Anthracoceras*.

Specimens of *Posidonia corrugata* have been collected from the spoil of an old shaft [6139 6481] in the north-west of the area, east of Bowskill Wood.

The only exposure of the *Eumorphoceras leitrimense* Marine Band on the sheet is in the River Hindburn section [6486 6466], some 25 m north of the point where Bull Gill joins the Hindburn. The band is approximately 8 m above the base of the Caton Shales. A series of dark grey, bitumenous limestone nodules here coalesce in places to form a bed up to 0.20 m thick. The horizon has yielded *Cravenoceratoides nitidus*, *Dimorphoceras* sp., and *Selenimyalina variabilis*.

Dark grey, shaly mudstones exposed on the left bank of the Hindburn [6485 6438], 280 m south of the last locality have yielded *Cravenoceras subplicatum* and *Posidonia corrugata*. A locality on the left bank of the Hindburn [6480 6452] some 20 m south of a wall which meets the river on the left bank, has yielded *C.* cf. *subplicatum* and *Anthracoceras* sp.

3.4 CLAUGHTON AND SILVER HILLS SANDSTONE FORMATIONS

These rocks are best exposed in the north-eastern quarter of the sheet; elsewhere, exposures are small and isolated. The total thickness of this part of the sequence is approximately 115 m. In the north-east, the two most important sections are in Helks Brow and Well Beck [64 63], north of Summersgill, but the sections cannot be accurately correlated because there are no parts of the sequence common to both.

The term Keasden Flags was coined by Moseley (1956), and used by Arthurton et al.(1988) to name the sequence of interbedded sandstones and siltstones which overlie the Caton Shales in the area to the east. The Silver Hills Grit (Silver Hills Sandstone in Arthurton et al.) was originally coined by Bisat and Hudson (1943) to name a sequence of sandstones with ganisters and thin coals, immediately underlying the marine Crossdale Mudstone Formation.

The Keasden Sandstone and Silver Hills Sandstone can be correlated with the Claughton Flags and Crossdale Grit of the Lancaster Fells area (Moseley, 1954). In this account Claughton Flags has been renamed Claughton Formation. At the base of the Claughton Formation in the present area is the laterally impersistent Hawkshead Sandstone. Slinger (1936) correlated this last unit (named by him the Hawkshead Grit) with a horizon above the Crossdale Grit of Moseley (1954). Moseley considered the Hawkshead Sandstone to be equivalent to the lower part of the Bentham Grit Group, but the present survey has established the stratigraphical position of the sandstone to be at the base of the Claughton Formation (i.e. Moseley's (1954) Claughton Flags).

3.4.1 *Claughton Formation*

The section exposed in Helks Brow is very discontinuous, but the relationships with the Caton Shales can be interpreted. The sequence exposed here is summarised in Figure 9, and consists of siltstones, silty sandstones, and fine- to medium-grained sandstones. At least 84 m has been measured in the section, and the total thickness of the unit is estimated to be approximately 100 m. The lowest rocks of the formation are exposed on the left bank of the stream [6446 6375] 110 m westnorthwest of the confluence of Helks Brow and Well Beck. They consist of thinly bedded, grey to cream, siltstones and

fine-grained sandstones with parallel- and wavy-laminations, wave-generated ripples, and de-watering structures. Upstream of here are many discontinuous exposures of thinly bedded, siltstones and silty, fine-grained sandstones. A 0.30 m thick, fine- to medium-grained sandstone bed, exposed [6420 6388] 150 m east of the cattle grid marked on the map, has low angle cross-laminations.

Two isolated exposures of Claughton Formation occur on Goodber Fell. Firstly, in an un-named tributary of Goodber Beck [631 611] north-west of Hawkshead, are exposures of 1.55 m of interbedded, fine- to medium-grained sandstones and siltstones, overlying siltstones and silty sandstones. Secondly, in an un-named stream [638 617] at the eastern side of Higher Thrushgill Plantation, there are exposures of interbedded, flaggy, fine- to medium-grained sandstones and sandy siltstones. In both these localities the bases of the flaggy sandstones have abundant flute casts.

The Hawkshead Sandstone: is exposed only at Hawkshead [63 60], in the south-east quarter of the sheet, where its thickness is up to 8 m. The contact between the Hawkshead Sandstone and the underlying rocks is exposed at one locality only [6363 6029], in the backscar at the eastern end of the landslip on the north-eastern facing side of Hawkshead. The sandstone here overlies dark grey, shaly, mudstones and silty mudstones. Rocks within 3 m below the base of the Hawkshead Sandstone are exposed [6314 6050] at the north-western end of Hawkshead. They consist of grey, shaly mudstones, with silty mudstones and thin (up to 0.06 m thick), fine-grained sandstones containing comminuted plant remains.

The Hawkshead Sandstone itself consists predominantly of medium- to coarse-grained sandstones, with some fine-grained beds. The lowest 0.5 m is parallel-bedded, but the entire remainder consists of trough cross-sets, usually less than 0.4 m thick, but exceptionally up to 1 m thick. Palaeocurrent directions are unidirectional without exception, from the north-west.

3.4.2 *Silver Hills Sandstone Formation*

This sandstone has an estimated maximum thickness of 15 m. The 7.75 m thickness of sandstone exposed [641 636] immediately west of Well Beck Wood (see Figure 10) is part of the Silver Hills Sandstone (the base of the sandstone is not exposed). The lowest 7 m are thinly bedded siltstones and fine-grained sandstones, with thin, hard, flaggy, fine- to medium-grained sandstones. These are overlain by 0.75 m of medium-grained sandstones with a current-rippled, ganister top, which cap a small waterfall. Above these rocks there is a gap in exposure of approximately 9 m, below the base of the overlying Crossdale Mudstone Formation.

The Silver Hills Sandstone is further exposed in the un-named stream [644 643] north of Helks Bank Farm. Up to 8 m of grey siltstones and silty, fine-grained sandstones are present here. To the north of here, several exposures in the backscar of the large landslip on the western side of the Hindburn valley, of siltstones, silty sandstones, and fine-grained flaggy sandstones, also belong to the Silver Hills Sandstone.

A number of exposures of the Silver Hills Sandstone occur in the un-named stream [63 62] to the north-west of Higher Thrushgill Plantation. The exposures are small and discontinuous, and consist of interbedded, flaggy, medium-grained sandstones, siltstones, and silty sandstones, all rich in comminuted plant debris. 10 m east [6358 6258] of the confluence of the two minor tributaries which combine to form the stream, is a 1 m thick, medium-grained sandstone.

3.5 CROSSDALE MUDSTONE FORMATION

The Crossdale Shales of Moseley (1954) are here re-named the Crossdale Mudstone Formation.

The formation is up to 15 m thick, and where exposed, consists of dark grey, shaly mudstones. They are exposed at only one locality, in the banks of Well Beck [635 640], north-west of Summersgill, where the highest *Isohomoceras subglobosum* Marine Band, and the *Homoceras beyrichianum* Marine Band are present. Moseley (1954) recognised the *H. beyrichianum* Marine Band here, but did not record the *I. subglobosum Marine Band.* These are the most northerly known occurrences of these marine bands in the world. The section exposed in the right bank of Well Beck [6398 6360] 10 m downstream from the track was logged by Dr N.J.Riley, and the log is presented in Figure 11. The *H. beyrichianum* Marine Band here has yielded the eponymous goniatite, *Caneyella semisulcata,* and *Coleolus* sp. The *I. subglobosum* Marine Band has yielded the eponymous goniatite, *Caneyella semisulcata, Dunbarella* cf. *carbonaria*, and *Coleolus* sp.

3.6 KIRKBECK FORMATION

These rocks are the equivalent of Moseley's (1954) Bentham Grit Group. They cap the highest ground in the northern half of the sheet, where a maximum thickness of up to 170 m may be present. Much of this area is covered by drift, and the best exposures occur in a few, frost-heaved crags on the highest parts of Goodber Common. On the drift free ground away from these outcrops, the Millstone Grit Group produces vague topographical features, strewn with sandstone blocks.

The lowest sandstones of the group form a strong topographical feature south of Grey Stone [6310 6275]. Loose blocks of fine- to coarse-grained sandstone are abundant along the length of this feature. *In situ* exposures of the rocks which form the feature occur along the broad spur [63 62] to the east of Grey Stone. Coarse- to very coarse-grained sandstones, with trough cross-laminations are present here. Exposures along strike [627 628], some 380 m westnorthwest of Grey Stone, consist of fine- to medium-grained sandstones with trough and planar cross-laminations. Massive, thinly bedded units here contain trails and burrows.

Younger sandstones produce three topographical features [62 63] northnorthwest of Grey Stone. The rocks which form the oldest of these three are exposed on a dip-slope [630 630] 250 m northnorthwest of Grey Stone, where they consist of weakly laminated, thickly bedded, fine-grained sandstones.

The middle sandstone, 5 m thick, forms a craggy outcrop 100 m north of the last locality. The rocks are mainly thickly bedded, fine- to medium-grained sandstones. The topmost 0.02-0.03 m of these beds is commonly coarser-grained than the remainder, with quartz pebbles present on some bedding planes. These top surfaces also have linguoid and parallel-crested, current-generated ripples. The coarser grain size of the tops of the units was probably produced by current winnowing.

The youngest of the three sandstones is exposed in a series of crags [629 632]

400 m northnorthwest of Grey Stone. The unit is up to 5 m thick, and consists of parallel- and cross-laminated, fine- to medium-grained sandstones. Some bedding planes are burrowed and have parallel-crested ripples.

Loose sandstone blocks are common on the crest [6280 6362] of a low relief topographical feature, 150 m east of Thornton Castle, which protrudes from the flat, till-covered ground to the north, east, and west. The sandstone is fine- to coarse-grained and pebbly, with rippled bedding planes. The stratigraphical relationship of this sandstone to those described above is unclear because of local faulting.

A local abundance of thickly bedded, massive, medium- to coarse-grained sandstone blocks on a hillside [624 640] 800 m south-east of Stauvin are probably *ex situ*. Sandstone has been worked for walling here in the past.

Spoil from three old shafts to the north-east of Stauvin [62 64] contains fragments of coal in beds up to 0.05 m thick. The shafts would have penetrated the lower parts of Moseley's (1954) Bentham Grit Group, in which the Clintsfield Coal is present. According to Moseley (p. 438), this coal consists of several thin seams.

4. STRUCTURE

4.1 *Faulting*

Nearly all the faults in the area follow one of two broad trends. The dominant trend is approximately north-westerly, the subordinate trend is northnortheasterly to north-easterly.

The Roeburn Fault throws approximately 205 m of strata down to the south-west in the Roeburn valley, and has the largest throw of any single fault in the area. Brecciated sandstones and siltstones on the right bank of the River Roeburn [6185 6098], 900 m north-east of Mallowdale Pike, indicate the position of the Roeburn Fault where it crosses the river.

Three faults with a similar trend occur to the south-west of the Roeburn Fault. The first, on the north-east facing flank of Mallowdale Pike [61 60], throws an unknown thickness down to the south-west. The second two, in the extreme south-western corner of the sheet [60 60], throw unknown amounts down to the north-east and south-west.

Two, sub-parallel, north-west trending faults occur in the area of High Salter Close [62 61], north-east of the Roeburn Fault. The first of these, the Hawkshead Fault, throws down approximately 8 m to the north-east, and is seen in a zone of brecciation in the upper reaches of Goodber Beck [6302 6058]. The second, to the north-east of the Hawkshead Fault, has a maximum throw of approximately 45 m in the east, decreasing to approximately 12 m in the west. Brecciation and intense jointing associated with this fault are present in ganister sandstones at the top of the Ward's Stone Sandstone in Goodber Beck [6274 6136].

Two, north-west trending faults displace the outcrop of the Ward's Stone Sandstone in the area to the south-east of Higher Thrushgill Plantation [64 61]. Both faults throw down to the south-west, the northern one by 18 m, the southern one by 25 m.

In the northern half of the area, three, sub-parallel, north-west trending faults are present in the River Hindburn and its tributaries. The northernmost of these, the Hollinhurst Fault (named after a locality on sheet SD 66 SE), has a throw of approximately 25 m down to the south-east. The position of this fault can be narrowed down to a 3 m interval in a locality [6487 6424] on the left bank of the Hindburn: Caton Shales are thrown against the Ward's Stone Sandstone here, but the fault plane is not exposed. The middle fault of the three throws down approximately 40 m to the south-west: this fault is exposed in the left bank of the Hindburn [6496 6504] on sheet SD 66 SE. The southernmost fault throws down approximately 20 m to the north-east: this fault is exposed in Mill Beck [6488 6391].

There are no signs of the Well Beck Fault [64 63] in the field, but a fault must be present here to explain the differences between the sequences along strike in Well Beck and Helks Brow. The throw on this fault is approximately 25 m down to the south-west.

Two, minor, north-west trending faults are present on the highest parts of Goodber Common [63 63], north of Grey Stone. These faults displace the base of a topographical feature produced by a sandstone bed, and both throw less than 5 m.

Five, northnortheast trending faults have been mapped on High Salter Close [62 61], west of Salter Fell. The largest throw of any of these faults is 18 m. South of the River Roeburn, the throw of the northnortheast trending fault which crosses Bushy Clough is down to the east, but is not quantifiable.

The north-east trending fault on Greenbank Fell, the Lordset Syke Fault, has a throw down to the north-west of 7.5 m or less. In Hawkshead Gill [64 61], north of the Lordset Syke Fault, are two, northerly trending faults with throws of less than 2 m.

4.2 *Folding*

Apart from local, minor flexures, such as the one exposed in the River Hindburn [6486 6441] in the north-east, folding is remarkable for its absence from the area. The only large fold is the broad, shallow, north-east trending syncline which has folded the Hawkshead Sandstone on Hawkshead [63 64]. Folding associated with syn-depositional deformation has been described in section 3.7 above.

5. QUATERNARY

Some aspects of the Quaternary history of the area have been discussed in Moseley and Walker (1952) and Moseley (1961).

5.1 *Head*

Head covers most of the steepest slopes in the area, and consists of material which has moved downslope under the influence of gravity, perhaps initially under the influence of freeze-thaw conditions. The material which comprises the head is of local origin, and in some areas (for example the steep slopes east of Summersgill [64 63]) the head contains soliflucted glacial till. Where there is no till cover, such as on the north-east bank of the River Roeburn [61 61] south-east of High Salter, the head consists entirely of locally derived, unsorted sandstone blocks in a matrix of sandy clay.

5.2 *Peat*

Peat deposits are widespread throughout the area, and have been mapped where their thickness exceeds 1 m. Thin peat is almost ubiquitous on Goodber Common [62 63], Goodber Fell [63 61], Summersgill Fell [63 61] and Thrushgill Fell [64 61]. Upland peat and basin peat have not been distinguished because on Goodber Common the distinction betweeen the two is imperceptible. On the highest and most exposed ground, such as at Hawkshead [634 603] and on Goodber Fell [63 61], the peat blanket is being actively eroded: the dissected peat hags here are up to 2 m thick. The peat present in enclosed basins, such as in the area south-east of Stauvin [62 64], is not being eroded. To the east of the forestry plantation on Thrushgill Fell [636 616], peat has been dug in recent times.

5.3 *Alluvium and river terrace deposits*

Extensive alluvial deposits are present along the courses of the rivers Hindburn and Roeburn. Thinner and more discontinuous deposits are present along the valleys of the minor streams and rivers, notably Goodber Beck [61 63, 61 62, 62 62, and 62 61], and Thrushgill [64 62 and 64 63]. The rivers are the agents of deposition, but some of the deposits may be glacio-fluvial rather than alluvial.

Older alluvial deposits form terraces along the length of the River Roeburn in the present area. Upstream of the point [602 638] where the river is crossed by the public road to Wray the terraces are very discontinuous and cannot be correlated for any distance. Downstream from here the terraces are more continuous, but are still difficult to correlate. On the left bank of the river south-east of Barkin Gate Wood [60 64] are two terraces above the present day alluvium. The top of the lower terrace is aproximately 7 m above the present river level, and the upper terrace is another 1 m higher. Where exposed along the course of the river, these deposits consist of well sorted, coarse gravels in a matrix of sandy clay.

Upstream of the point where the River Roeburn is joined by Salter Beck [606 622], the clasts within these deposits are entirely of local origin: downstream of here the gravels contain glacial erratics. The origin of the terrace deposits is not clear.

The alluvial deposits of the Hindburn valley do not form such well-defined terraces as those present along the course of the River Roeburn. Two weak and discontinuous terrace features are present on the right bank of the river [648 646] south of Bull Gill. The deposits are poorly exposed, but consist of gravels in a matrix of sandy clay.

The deposits of the minor streams are less extensive and thinner than those along Roeburndale and the Hindburn valley. The deposits along Goodber Beck and Thrushgill, for example, consist of thin spreads of sandy clays and gravels.

5.4 *Alluvial fan deposits*

Alluvial fans are present in Roeburndale where high energy tributary streams join the main valley. The largest fan is present where Bushy Clough joins the River Roeburn [622 605]: the deposits consist of poorly sorted, coarse gravels, sands and clays, with some woody material. The fan itself is braided, and sections through the deposits show them to be imbricated. Smaller alluvial fans occur south-east of Mallowdale Bridge [6096 6181], where the River

Roeburn is joined by an un-named, south-westerly flowing stream, at the mouth of Middle Salter Gill [6009 6310], and at the mouth of the un-named stream which flows through Bowskill Wood [6116 6489].

5.5 *Glacial sand and gravel*

Five, small areas of sand and gravel have been mapped on the western margin of the area [62 60, 63 60]. Exposures of these deposits are limited to animal "scrapings" and ejecta from rabbit burrows: they consist of well sorted silty sands and fine gravels. The till itself is sandy in these areas, and it is likely that the mapped areas of sand and gravel were deposited within the till.

5.6 *Till*

Till deposits are most extensive in the northern part of the sheet, and are present at almost 300 m A.O.D. on Summersgill Fell [638 618], and above 290 m to the east of the Hornby Road [617 623], south-east of Salter Farm. Exposures of till are numerous throughout the area, but most are weathered and slipped. The best exposures are in the banks of Thrushgill [64 62] around its confluence with the un-named, east flowing tributary south of Summersgill. Several sections in the back-scars of small landslips here expose up to 5 m of dark grey, sandy clays with abundant erratics of varying sizes. The erratics include igneous rocks and cleaved sedimentary rocks, with a probable Lake District source. Further good exposures of till are present in the banks of Goodber Beck [614 634], upstream of the waterfalls south of Harterbeck Farm, and in the banks of Hunt's Gill Beck [62 64].

On the steepest slopes, till moves downslope under the influence of gravity and is mapped as head (see below). On the less steep slopes of, for example, Roeburndale north and south of Middle Salter, only the topmost 0.5 m or less has undergone solifluction. This material is not distinguished from the underlying till.

5.7 *Glacial drainage channels*

Glacial drainage channels are present throughout the area but are most common in the till covered ground of the north. Nearly all have an approximate east-west trend, but flow directions are uncertain. The most spectacular of these is undoubtedly the channel now occupied by the misfit stream Salter Clough Beck [60 62], which has incised the valley side to a depth of approximately 30 m. The eastnortheast trending channel east of Harterbeck [61 63] is also well developed.

5.8 *Landslip*

Landslip is common and extensive throughout the area. The larger slips such as the area north of High Stephen's Head in the south-west [60 60], the east-facing side of the Hindburn valley in the north-east [64 64], the left bank of the River Roeburn [61 61] north-east of Mallowdale Pike, the left bank of the River Roeburn around its confluence with Mallow Gill [603 623], the left bank of the River Roeburn [610 647] between Bottom Wood and Barkin Gate Wood, the left bank of Pedder's Gill [60 63] as far downstream as the River Roeburn, and the right bank of the un-named tributary of Thrushgill [64 62] north-west of Higher Thrushgill Plantation, all involve movement of the bedrock and are rotational. The less common minor slips such as those within Higher Thrushgill Plantation [6439 6235 and 6400 6194], those on the right bank of Thrushgill at the northern end of Thrushgill Plantation [64 62], and the slip north-east of Summersgill Farm [645 636], affect the superficial deposits only, and appear to be non-rotational.

6. REFERENCES

BISAT, W.S., AND HUDSON, R.G.S. 1943. The Lower *Reticuloceras* goniatite succession in the Namurian of the north of England. Proceedings of the Yorkshire Geological Society, **24**, 383-440.

BRANDON, A. 1992. Geology of the Littledale area. *British Geological Survey Technical Report* WA/92/16.

MOSELEY, F. 1954. The Namurian of the Lancaster Fells. Quarterly Journal of the Geological Society of London, **109**, 423-454.

_____, _. 1956. The geology of the Keasden area. Proceedings of the Yorkshire Geological Society, **30, 331-352.**

_____, _. 1961. Erosion surfaces in the Bowland Fells, North-west England. Proceedings of the Yorkshire Geological Society, **33**, 173-196.

_____, _. and WALKER, D. 1952. Some aspects of the Quaternary Period in North Lancashire. The Naturalist, **841**, 41-54.

SLINGER, F.C. 1936. The Millstone Grit and glacial geology of Caton Moor, near Lancaster. Report of the British Association, Blackpool, 345.

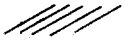
APPENDIX 1

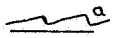
The symbols used in the graphical logs in this appendix are explained below. A symbol next to a log indicates that the feature represented by that symbol is present throughout the bed, and not just in the part of the bed immediately adjacent to the symbol.

 - parallel-lamination

 - cross-lamination

 - trough cross bedding

 - low angle cross bedding

 - asymmetrical ripples

 - flame structures

 - flute casts

 - goniatites

 - bivalves

 - orthocone nautiloids

 - nodules

 - siderite nodules

 - coal

 - limestone

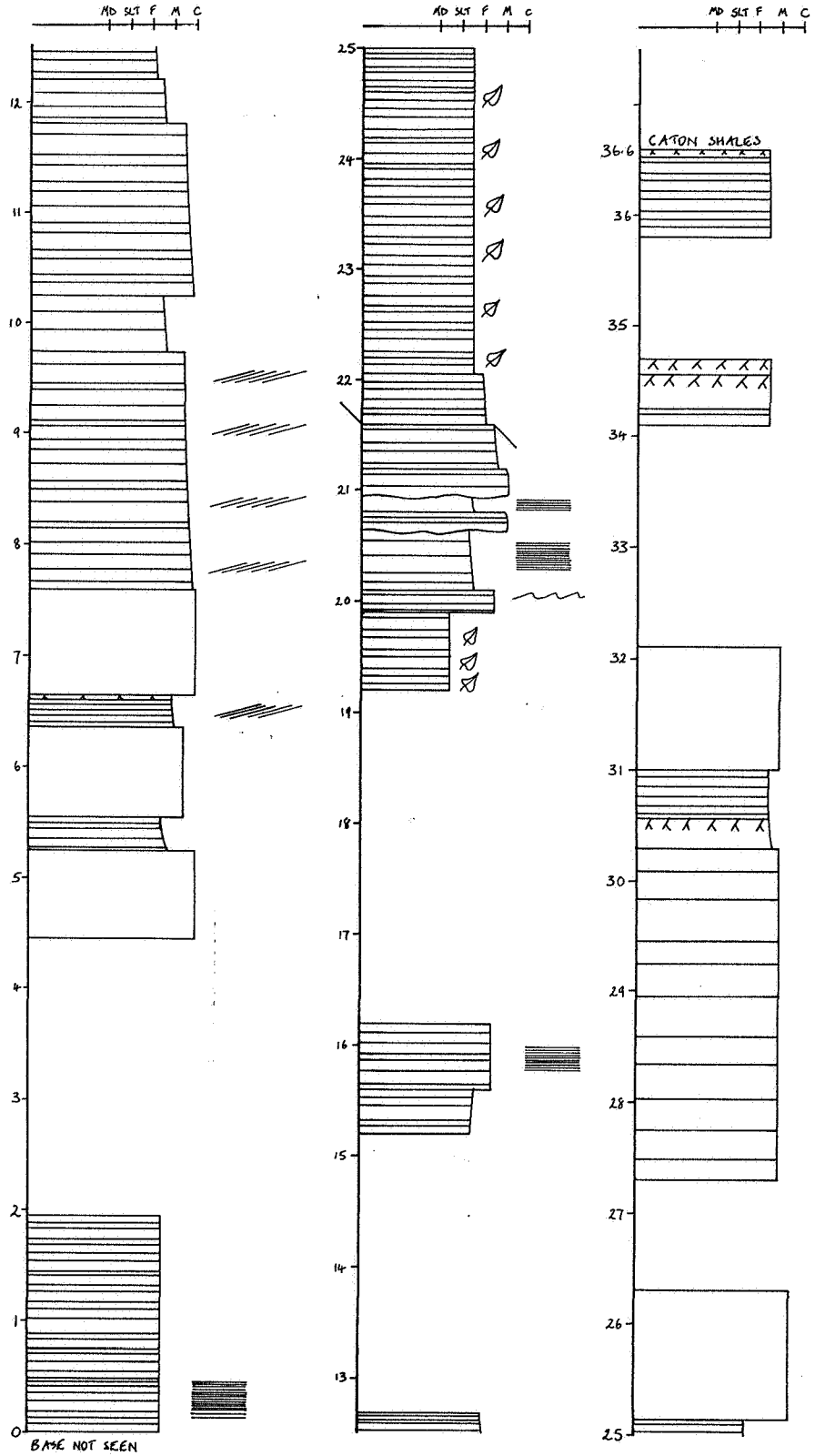


FIGURE 2: SECTION THROUGH THE WARD'S STONE SANDSTONE IN BOWSKILL WOOD. SCALE IN METRES (1:50)

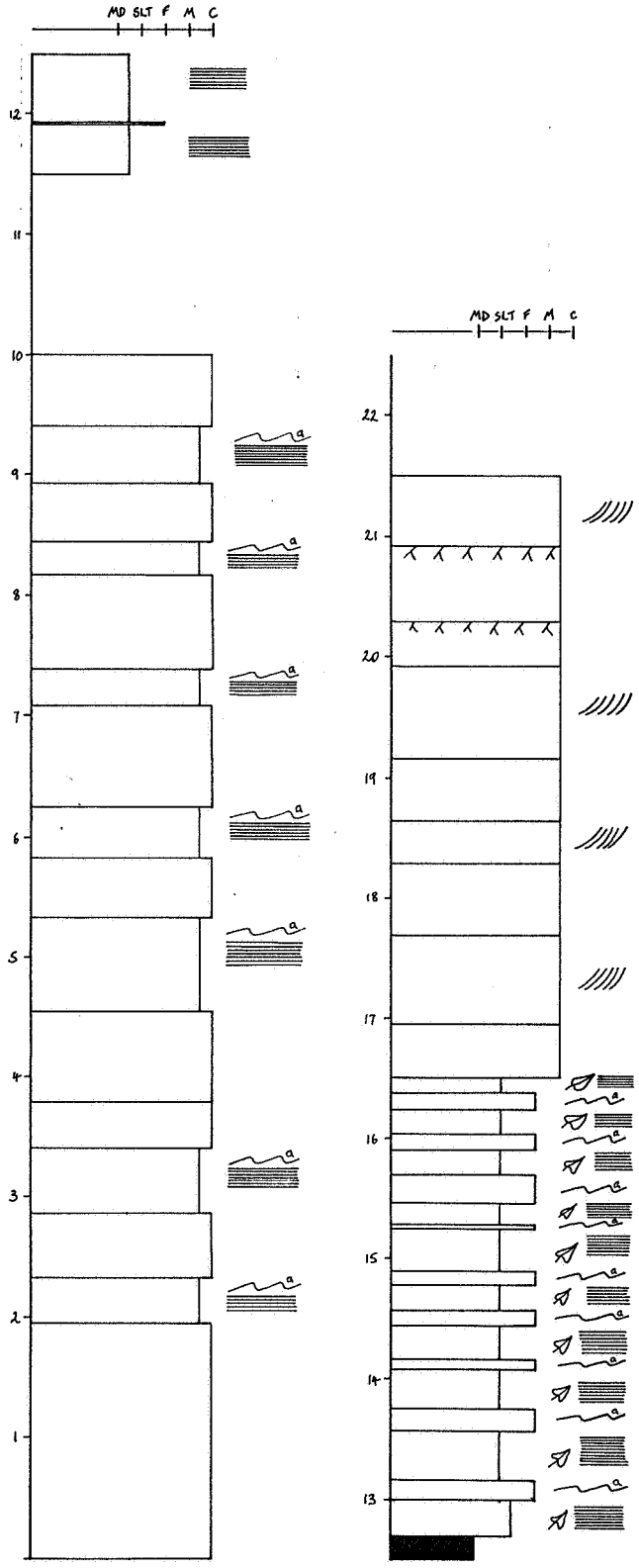


FIGURE 3: SECTION THROUGH THE WARD'S STONE SANDSTONE IN PEDDER GILL [61 63]. SCALE IN METRES (1:50)

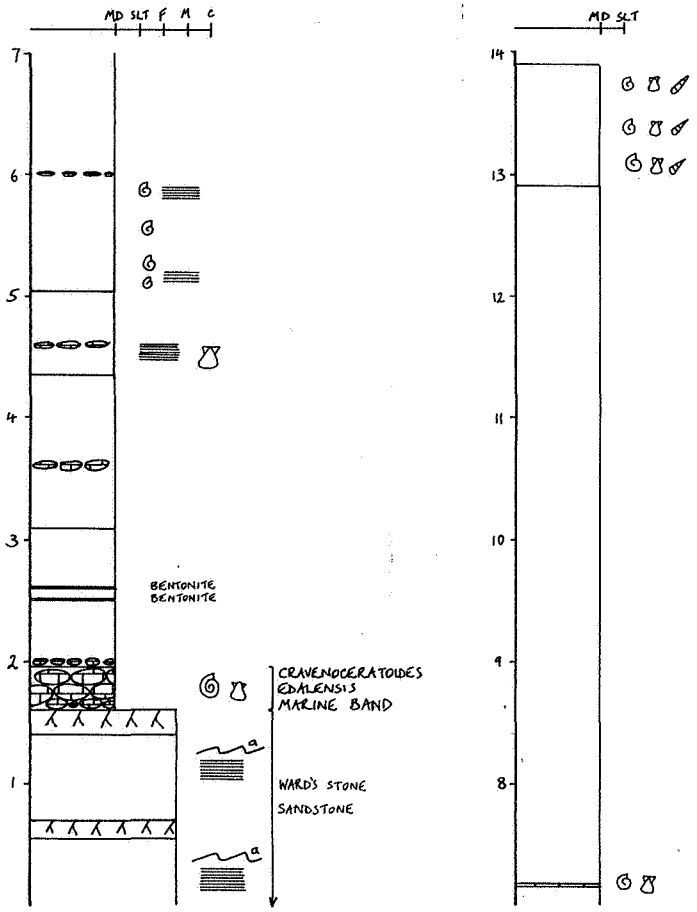


FIGURE 4: SECTION THROUGH UPPERMOST WARD'S STONE SANDSTONE AND CATON SHALES IN GOODBER BECK [630 607], NORTH-WEST OF HAWKSHEAD. SCALE IN METRES (1:50).

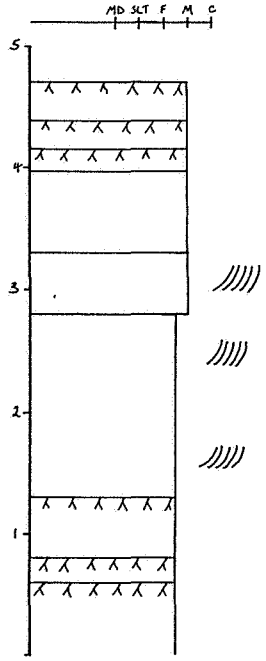


FIGURE 5: SECTION THROUGH UPPER PART OF WARD'S STONE SANDSTONE IN RIVER ROEBURN [621 607], NORTH-EAST OF MALLOWDALE PIKE. SCALE IN METRES (1:50).

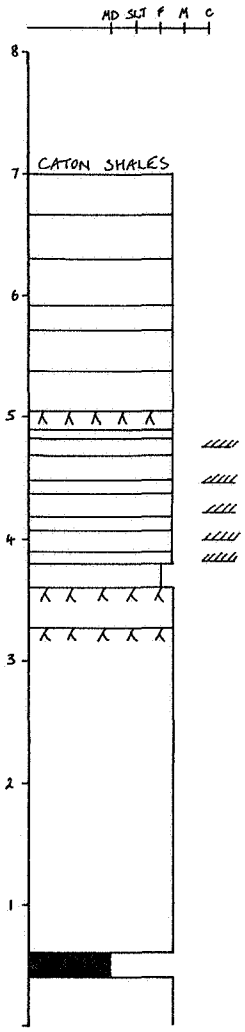


FIGURE 6: SECTION THROUGH UPPER PART OF WARD'S STONE SANDSTONE IN RIVER ROEBURN [619 608]. SCALE IN METRES (1:50).

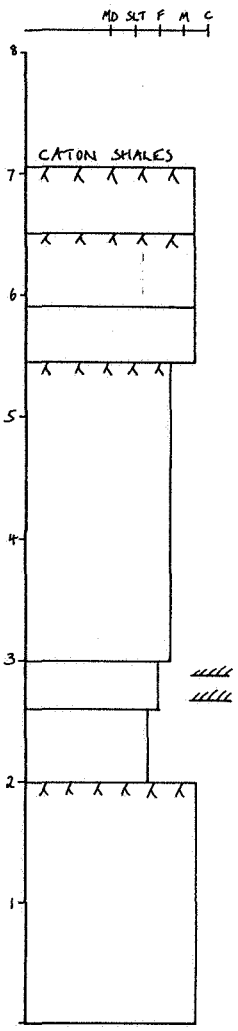


FIGURE 7: SECTION THROUGH WARD'S STONE SANDSTONE AT CONFLUENCE OF HAWKSHEAD GILL AND LORDSET SYKE [646 612]. SCALE IN METRES (1:50).

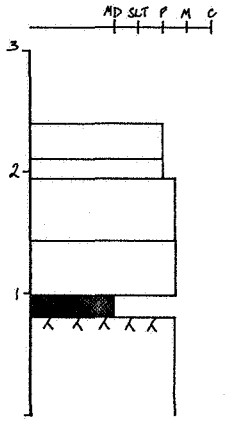


FIGURE 8: SECTION THROUGH UPPER PART OF WARD'S STONE SANDSTONE IN RIVER HINDBURN [6492 6429]. SCALE IN METRES (1:50).

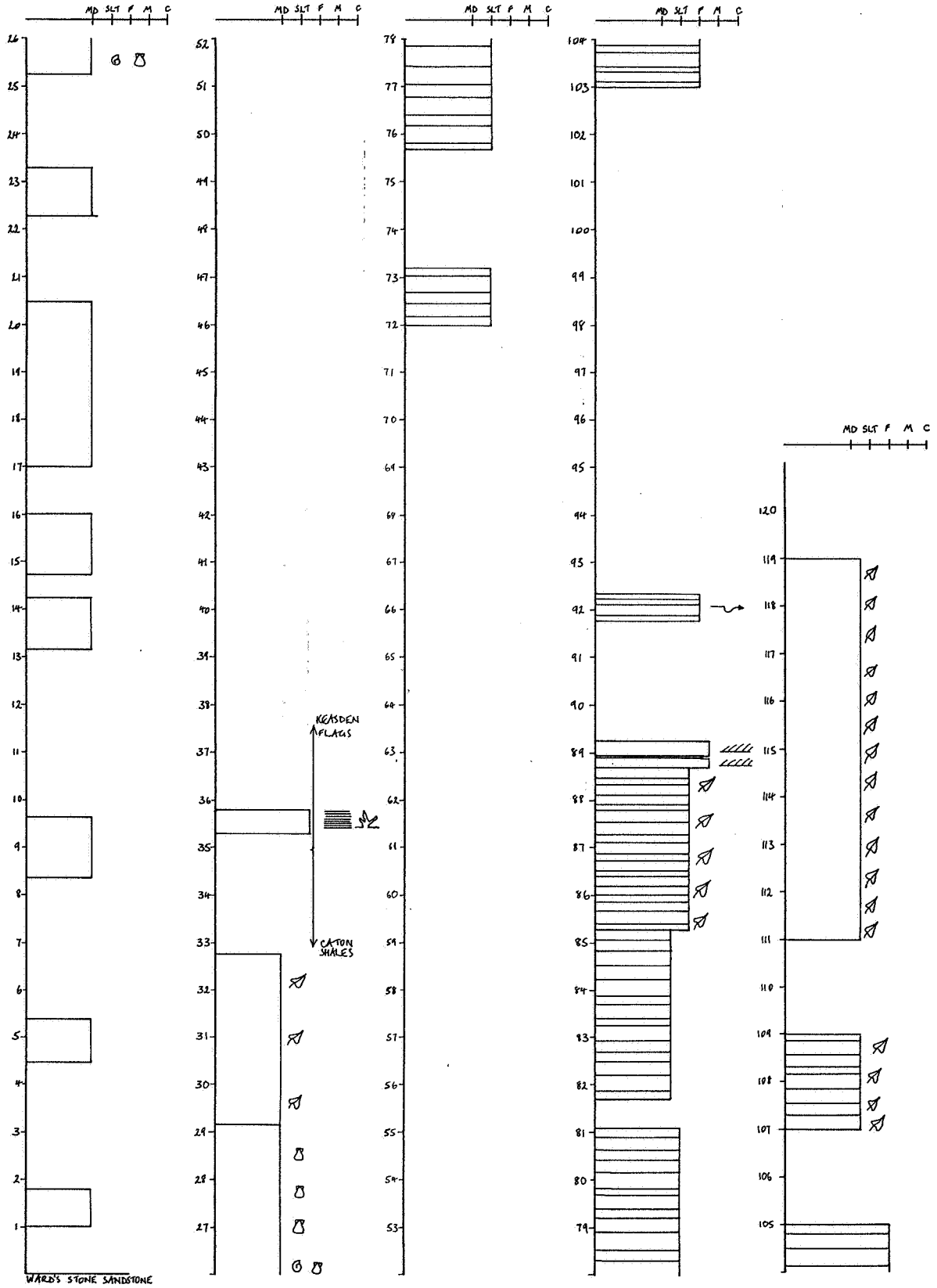


FIGURE 9: SECTION THROUGH CATON SHALES AND CLAUGHTON FORMATION EXPOSED IN HELKS BROW [64 63].
SCALE IN METRES (1:100)

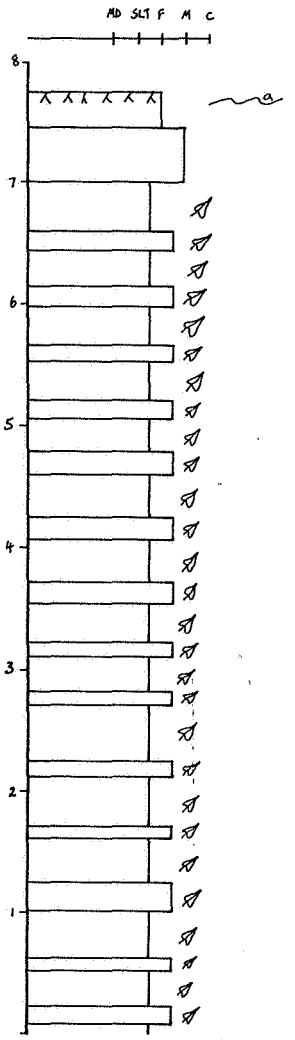


FIGURE 10: SECTION THROUGH THE PART OF THE SILVER HILLS SANDSTONE EXPOSED IN WELL BECK [641 636]. SCALE IN METRES (1:50).

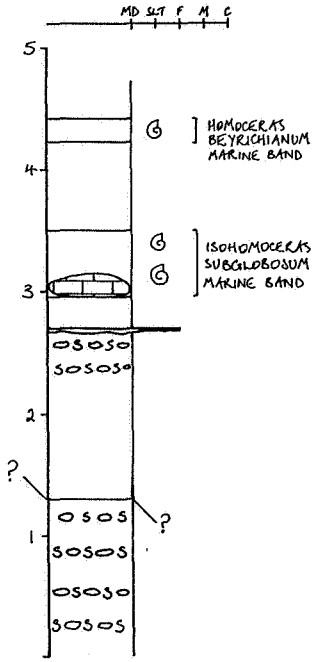


FIGURE 11: SECTION THROUGH PART OF CROSSDALE MUDSTONES IN WELL BECK [641 636]. SCALE IN METRES (1:50). LOG MADE BY DR N.J. RILEY.