The stratigraphy and structure of the, middleton tyas - sleightholme anticline and the development of chert between the underset and crow limestones in North Yorkshire

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Frontispiece

"Far sweeping to the east, he sees
Down his deep woods the course of Tees,
And tracks his wanderings by the steam
Of summer vapours from the stream;"
Sir Walter Scott

THE STRATIGRAPHY AND STRUCTURE OF THE MIDDLETON TYAS - SLEIGHTHOLME ANTICLINE AND THE DEVELOPMENT OF CHERT BETWEEN THE UNDERSET AND CROW LIMESTONES IN NORTH YORKSHIRE

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Thesis submitted for the degree of Doctor of Philosophy in the University of Durham, 1955

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PREFACE AND ACKNOWLEDGEMENTS

The research work for this thesis was carried out between November 1952 and March 1955, under the supervision of Professor K.C. Dunham, Ph.D.,S.D.,F.R.S.,M.Inst.M.M.,F.G.S. Of this time, approximately 12 months (the periods November-December 1952, April-December 1953 and April-June 1954) were spent in the field in North Yorkshire, based in Gilling and Reeth. In July 1954 the author led an excursion of the Yorkshire Geological Society over some of the ground in the vicinity of Richmond, and he is indebted to the members present for helpful discussions in the field. Problems have also been discussed in the field on various occasions with Dr. H.G. Reading (who has re-mapped the Stainmore syncline), Dr. R.W. Hey (who has studied the Crow Series between Richmond and Leyburn) and Mr. J.E. Scanlon (who is engaged in a re-survey of parts of upper Swaledale and upper Wensleydale). Thanks are due to the very large number of land-owners, farmers, quarry managers, institutions and house-holders who readily gave permission for access to their grounds; in particular to the quarry managers of G. Hodsman Ltd. (Kilmond quarry) and the East Layton Limestone Co. (East Layton quarry) for supplying the analyses which are reproduced in Chapter 6, and to the staff and management of J.T. Hymas (Water Engineers) for co-operation during the examination of bore-hole cores.

The author is much indebted to Mr. W. Anderson of H.M.Geological Survey, for access to the official maps and records held at the Newcastle office, and he is grateful to the Geology Department of Leeds University (and particularly to Mr. J. Selwyn Turner) for access to the thesis of Dr. A.J. Rowell. Thanks are due to

Mr. G. O'Neill for preparing the text figures from original diagrams, for taking the photomicrographs and for photographing a number of rock specimens; a grant from the Durham Colleges Research Fund towards the cost of preparing some of the maps and diagrams for publication is acknowledged.

The author is most grateful to Dr. G.A.L. Johnson for help and advice in the preparation of faunal lists, and to Dr. G.Kohnstam and Dr. R.A. Chalmers for physico-chemical advice. He is also indebted to members of the staff and other research students at the Department of Geology, Durham, and indeed to all those who have readily discussed problems associated with this work. Finally he wishes to record his sincere gratitude to Professor K.C. Dunham, who originally suggested the course of research, who has followed its progress both in the field and in the laboratory, and who has been always ready to give advice, criticism, suggestions and encouragement.

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The area surveyed is covered by the following six-inch quarter-sheets (32 in number) published by the Ordnance Survey:-

Yorkshire (North Riding) - Sheet 11, SE
12, SW, SE
13, SW, SE
14, SW, SE
22, NE, SE
23, full sheet
24, full sheet
25, full sheet
37, NW, NE, SE
38, full sheet
39, full sheet

The area is covered by the following geological maps published by the Geological Survey:-

1" sheet 32 (New Series)
1" sheet 41 (New Series)

Cover is provided on a scale of 1:25,000 by the following 8 sheets:-

35/91, 45/01, 45/11, 45/21, 35/90, 45/00, 45/10, 45/20.

The relevant sheets on the scale of 1:63,360 are:-

84, Teesdale
85, Durham
90, Askrigg and Settle
91, Ripon

CHAPTER 1

INTRODUCTION

The Middleton Tyas-Sleightholme anticline is an E-W structure lying across some 130 square miles of country between the towns of Barnard Castle in County Durham and Richmond in the North Riding of Yorkshire. It occupies ground which gradually rises from 200' O.D. in the east to over 1800' O.D. on hill tops in the west. This easterly slope is general over the Northern Pennines as a whole, and may be regarded as a gently tilted plateau surface across which all the major rivers flow in an easterly direction. The area to be described lies between two of these major rivers, the Tees and the Swale, and thus lies entirely within the North Riding of Yorkshire. Much of the eastern part of the structure is covered by relatively low-lying arable and pasture land, and the underlying rock is rarely seen (except in quarry sections) because of the heavy blanket of boulder clay. It is a pleasant, rolling countryside, however, with the high fells visible to the west, and when James was called to the throne of England by the death of Elizabeth he is said (Gilpin, 1786) to have stopped on Gatherley Moor to take a look at the view, with which he was greatly delighted. But whether or not this was for its scenic value we do not know. Further west, particularly in the region of the watershed between the Tees and the Swale, the ground is largely open moorland, heather-covered and inhabited by grouse, which are joined during the summer months by curlew, snipe, golden plover and lapwing. These moors often bear thick deposits of peat, which are generally dissected to a greater or lesser extent into haggs. The moorland is itself

Plate 5

Marske Moor, from the south, with Marske Beck in the foreground, as an illustration of the relatively flat upland surface dissected by tributary valleys. The cliff in the middle distance is of Main Limestone, and is faulted against the Richmond Chert Series in the wood to the right. The lower slopes of the valley are typically obscured by landslips.

dissected by deep narrow valleys (in which run tributaries of the main rivers), the sides of which are often covered with thick woodland (Plate 5, p. 2). The average annual rainfall here is about 55", but this decreases eastwards to be no more than 35" over the low ground to the east. It is in the moorland regions that the characteristic flat-topped peat-covered fells are found, along the sides of which run prominent features formed by differential weathering of alternating beds of sandstone, limestone and shale.

The axis of the anticline is breached by a broad physiographic trough which runs through Bowes, along the line of the River Greta as far as Brignall Banks, and continues ESE past Gilling (carrying very little water in this part) to join Swaledale 2 miles east of Richmond. This depression, here referred to as the Gilling valley, affords an excellent view of the lowest beds exposed in the anticline, which make fine features along the sides of the valley near Gilling.

Most of the settlements are to be found in the main valleys. Apart from the towns and villages in Teesdale and Swaledale, the population is mainly concentrated in the villages along the Gilling valley, and in Bowes. Most of these people have various agricultural pursuits, while higher up on the fells there are widely scattered and often very isolated sheep farms. In the region around Arkengarthdale many of the inhabitants made their living in the lead mines until about 50 years ago, but in addition they often farmed on a small scale. Some of these mines had been worked from at least Roman times, pigs of lead having been found at Hurst which bear the mark of Emperor Augustus. There are now many derelict houses and several almost abandoned villages in this part, as the population fell sharply when the mines closed down, and the present inhabitants are nearly all connected in some way or another with sheep farming. A large stretch of ground north of the village of Marske, some 5 square miles in extent, is now used as a multi-purpose range by the Army units stationed at Catterick Camp, and 6 of the 8 farms in that area have been partially or completely demolished as the result of manoeuvres. The remaining two are still inhabited, however, and carry a sheep population which leads a somewhat precarious existence.

Communications within the area are in general good. A branch railway line serves Richmond, and another branch (now used only as a mineral line) runs south from the Darlington-Barnard Castle railway to Forcett, and has been extended into the very large East Layton limestone quarries. On the other hand there are many roads, the most important of these being the Great North Road (A.1.). This Roman road is joined at Scotch Corner by another from Penrith (A.66.), along which Roman camps are found at intervals. Two of these are within the surveyed area. That at Bowes was called Lavatrae, but the name of the one at Greta Bridge remains unknown. This road, which crosses the Pennines by way of the Stainmore gap, now holds no terrors for the modern traveller, but William Gilpin in 1786 described it as "the most unpleasant that can be conceived". There is an important pre-Roman camp in Stanwick Park (4 miles N.W. of Scotch Corner) which is still being actively excavated. Its presence suggests that these two major lines of communication were in existence before the Roman occupation, the camp being at or near their point of intersection.

The Middleton Tyas-Sleightholme anticline is bounded by a closed outcrop of the Main Limestone, marking the base of the Upper Limestone Group of the Carboniferous Limestone Series. Within this is exposed the upper part of the Middle Limestone Group. The anticlinal structure is complicated by a number of subsidiary domes along its axis, by far the most important of which is the Gilling dome, and it is round this that the Middle Limestone Group is best seen. The north flank of the anticline passes directly into the important Stainmore syncline, but the south flank is less well-defined, and passes, through much-faulted ground, into a shallow synclinal area along Swaledale. Eastwards the structure plunges beneath the Permian Magnesian Limestone, which overlies it with unconformity, and westwards it gradually fades out, further folds developing en echelon and to the south of it.

The beds up to and including the Main Limestone fall into the regular rhythmic pattern of the Yoredale Series, which consists essentially of repetitions of the sequence sandstone on shale on limestone. Of these, the limestone member is generally the most constant and best exposed, while the shale is not often seen. The sandstone member is usually a feature-forming horizon, and is easily followed where the drift cover is not too thick. But lateral facies variations are very rapid in these predominantly fresh-water beds, and mapping of individual horizons is often difficult. Above the Main Limestone the simple Yoredale rhythm is considerably complicated by the development of thick cherty deposits and rapid lateral variations from and within this facies. The essential rhythmic character is still present, however, even if in much modified form.

GEOLOGICAL SUCCESSION

The geological succession established during the present survey is summarised in the following table. The generalised thicknesses are compiled from sections throughout the area.

	Superficial deposits	Thickness in feet
Recent -	Hill Peat River Alluvium Low Level Peat	up to 12
Pleistocene -	Fluvioglacial sand and gravel	at least 30
	Glacial moraines and boulder clay	at least 100
	Solid formations	**Thickness in feet**
Permian -	Magnesian Limestone	over 50
	Basal conglomerate and breccia	0 to 48
	unconformity	
Carboniferous -	Millstone Grit: coarse grit, pebbly in part, with interbedded sandstones, shales and thin coals	over 100
	unconformity	
	Carboniferous Limestone Series:	
Upper Limestone Group		
	CROW Limestone and chert	8 to 60
	Ten Fathom Grit	0 to 80
	Shale	2 to over 50
	Richmond Chert Series	12 to 130
	LITTLE Limestone	0 to 8
	Coal Sills Group	0 to 150
	Main Chert	0 to 30
	Shale	0 to 18
	MAIN Limestone	30 to 85

Middle Limestone Group

Sandstone and shale	45 to 120
Underset Chert	0 to 26
Shale	0 to 20
UNDERSET Limestone	12 to 65
Sandstone and shale	105 to 165
3 YARD Limestone	0 to 15
Sandstone and shale	30 to 120
5 YARD Limestone	24 to 30
Sandstone and shale	100 to over 145
MIDDLE Limestone	48
Sandstone and shale	70
GILLINGWOOD Limestone	7
Sandstone and shale	120
SIMONSTONE Limestone	at least 15
base not seen	

HISTORY OF RESEARCH

The geology of the region covered by the present survey has been sadly neglected since the time of its original mapping by officers of the Geological Survey prior to 1890. The first published information on the geology of this part of the Pennines is to be found in Volume 2 of John Phillips' Illustrations of the Geology of Yorkshire (1836), a masterly account which touched on many aspects of the subject. It was Phillips who named the rhythmic succession in the Middle Limestone Group after the valley of the River Ure (in the upper part of which the series is at its maximum development), although, of course, the rhythmic nature of the beds had long been appreciated by the lead miners. Westgarth Forster first published a succession for the Pennines north of Stainmore in 1809, and Phillips was quick to appreciate the fact that a similar succession could be made out to the south of Stainmore, and recognised the continuity of the limestones in particular. He remarked on the nature of features formed by the Yoredale Series, with the limestones always projecting, and noted that the profiles of the Alston Moor hills followed the same law. Nowhere else are the features so excellently developed as in Wensleydale, but they remain the most characteristic part of the landscape (and of prime importance from the geological point of view) in all areas where the Yoredale Series is exposed. Phillips' name for these beds was adopted by the Geological Survey when the primary mapping was done on a six-inch scale during the penultimate decade of the 19th century. Unfortunately no accompanying memoir was published with Sheet 41 (New Series), within which falls most of the ground covered by the present survey. The extreme S.W corner of the map was described, however, in the Mallenstang memoir (Dakyns et al., 1891), which was issued in explanation of the adjoining Sheet 40. The scattered references in this valuable work to various problems in and around lower Swaledale have provided much of the information known about the geology of this region, and it is to the Mallerstang memoir that many of the views expressed by subsequent writers on lower Swaledale stratigraphical problems can be traced.

Although the rhythmic succession in Wensleydale had been described by Phillips in 1836, it was left to Miller in 1887 to realise the significance of the rhythmic character of this type of sedimentation in his description of the Upper Limestone Series of part of Northumberland. Subsequently Hudson (1924) amplified Miller's views in a description of the rhythmic series in Wensleydale which was the first really detailed account to be published on Yoredale sedimentation. Also in 1924 Kendall and Wroot completed their book on The Geology of Yorkshire, in which are to be found (as well as many interesting anecdotes) a number of original observations relating to the geology of the Middleton Tyas anticline (as it was known by the authors), and in particular to the understanding of some of the important glacial features. These latter were described by Raistrick (1926) in an account of the glaciation of the region, which has been further amplified by the glacial work carried out during the present investigation. After this, no work relating directly to the area was published until Raistrick (1936) gave an historical account of the copper deposits of Middleton Tyas. These deposits, together with those to the north and NW of Richmond, have now been described by Mr. T.Deans (in litt.), who considers them to have been derived from the former Permian cover. Two years after the appearance of Raistrick's later work, Carruthers included a section from Sleightholme Beck (SW of Bowes) in his stratigraphical adventure of 1938, the findings of which (as they affect the present survey) were considerably in error. There followed another long lull which was only broken in 1953 by Rowell's work on the Upper Limestone Group to the west of Arkengarthdale Head, and in 1954 by Reading's account of the stratigraphy and structure of the Stainmore syncline. The ground covered during the present survey overlaps for a short distance (in the vicinity of Bowes) with that mapped by Reading, thus ensuring continuity across this important section.

The view that the northern Pennines acted during Lower Carboniferous times as a rigid block was first put forward by Marr (1921). This block was recognised as being sub-divided into two complementary halves by the Stainmore syncline (which had been detected by Phillips 85 years previously). The northern half was named the Alston Block (Trotter and Hollingworth, 1928), the stratigraphy and structure of which has been admirably summarised by Dunham (1948), while the southern part Hudson (1938) termed the

Askrigg Block. The present survey covers the NE corner of the Askrigg Block, and Reading's recent work is particularly useful in linking the stratigraphy of the two blocks.

Concerning the structure investigated during the course of this work, the first mention of the Middleton Tyas anticline as such is by Kendall (1911, p.54), who considered it to be continuous with the Stowgill anticline described by the authors of the Mallerstang memoir in 1891, and to run eastwards across the Cleveland country to the sea at Robin Hood's Bay. The anticline was first recognised in print (although not named) the previous year by Marr (1910, p.650), who referred to a major E-W anticline, pitching east, and bringing up 'a narrow strip of Lower Carboniferous beds between Richmond and Barnard Castle'. He also saw that the structure was pre-Permian. Whether or not the primary surveyors also recognised the anticline is not known because of the lack of any descriptive work to accompany their map, but it seems likely that it did not escape their notice. Versey (1927) disagreed with Kendall's view that the Middleton Tyas and Stowgill (Howgill) anticlines were continuous, and it has subsequently been shown that there are a series of three separate en echelon folds. The two westerly ones have been described by Rowell (1953), and the eastermost one is the subject of the present research.

CHAPTER 2

THE SIMONSTONE CYCLOTHEM

The basal limestone member of this cyclothem, originally named the Simonside by Phillips (1836) in his description of the Yoredale Series in Upper Wensleydale, has been known as the Simonstone since the original mapping of 1" Sheet 40 by the Geological Survey, which covered Phillips' type area. When the primary survey of the area covered by the present work was made, some 80 years ago, the limestones which were mapped as closing round the Gilling dome were named the 3rd, 4th and 5th Set Limestones, no correlation of the beds beneath the Underset Limestone being implied. It can now be shown (Chapter 4) that the 3 Yard Limestone, as mapped by the Geological Survey in upper Swaledale, is not seen in the succession round the Gilling dome, and that the 5th Set Limestone can be correlated with the 6th limestone beneath the Main, i.e. the Simonstone.

The succession in this cyclothem is shown in section (a) of Figure 1 (p.16).

STRATIGRAPHY

The Simonstone Limestone is the lowest horizon mapped in the present survey, and members of the cyclothem are exposed at intervals on the south side of the Gilling valley between Gilling Wood and the Gilling-Richmond road, a distance of about 1½ miles round the south side of the dome, where the radial dip away from the centre is very striking. The limestone here is about 15 feet thick, and is crinoidal, with many foraminifera, and is noticeably bituminous.

No exposures of the cyclothem occur on the north side of the valley due to an offset of the centre of the structure to the south, and also to much drift on the valley floor (see Fig.9, p.170).

Above the limestone some 70 feet of beds are nowhere exposed, but are presumed to be shale. This is followed by 50 feet of current-bedded sandstone, the top of which passes up into a thin limestone (here called the Gillingwood Limestone), to be correlated with that of the minor rhythmic unit of Hudson (1924, p.127) in the Simonstone cyclothem of Wensleydale, and also with the thin limestone of Dakyns et al. (1891, p.110), occurring in part of upper Swaledale about 55 feet below the Middle Limestone. Worthy of mention are the crinoid ossicles up to ¾" in diameter in the sandy passage beds leading up to the Gillingwood Limestone.

The rest of this composite cyclothem is very poorly exposed, and presumed to be mainly shale, but there are several places where a thin sandstone is visible beneath the Middle Limestone.

DETAILS

(i) Simonstone Limestone

This limestone makes the lowest solid feature on the hillside west of Gilling. Exposures occur at the crest of this feature, some 200 yards SW of Crabtree House, at 490' O.D. (165052), about ¼ mile SW of the centre of the dome. The feature drops down on either side, away from the dome, and limestone exposures occur at intervals along it before it disappears into drift to the NW just beyond Crabtree quarry (162055) and to the SE some 200 yards NE of Gillingwood Hall (172050).

The base of the Simonstone Limestone is not seen, but in

Crabtree quarry 15' were measured, and it is probable that this is not far off the full thickness, the base of the feature being very clear-cut. The limestone is dark blue-grey, thinly bedded, knobbly-weathering, rather easily broken, and moderately well jointed. Its odour when struck betrays an unusually high bituminous content, even for a Yoredale limestone, and a small quantity of oil was extracted from a crushed specimen with carbon tetrachloride (but see Chapter 11, section (d)). Apart from small crinoid ossicles, macro-fossils are uncommon, occasional broken brachiopods and rare corals being all that were found. On the other hand, micro-fossils are fairly abundant, and thin sections reveal many foraminifera (particularly Endothyra, Howchinia and Archaediscus) as well as numerous brachiopod fragments.

An interesting feature of this exposure is an erratic of Shap granite which lies directly on the limestone, indicating that although this part of the hillside is now free from drift (as evidenced by the strength of the features), the side of the valley was originally covered by boulder clay, which has since been partially removed by erosion.

(ii) Beds between the Simonstone and Gillingwood Limestones

Above the feature formed by the Simonstone Limestone is a comparatively flat strip of ground, which leads gently up to the next feature. Although there are no exposures anywhere along it, there can be little doubt that this shelf is due to a shale band, whose thickness, when computed from the dips measured in the limestone beneath, comes to some 70'. At the foot of the bold feature at the top of this supposed shale comes a striking change of vegetation, the slope being covered with much bracken and gorse in coarse grass, replacing the good pasture of lower down. This is typical of a sandy soil, and the sandstone which forms this feature (and is estimated to be 50' thick) is exposed in several small quarries. One of these (161051) is just above Crabtree quarry, some 250 yards E of the point where the feature formed by the sandstone disappears into drift on the eastern edge of Gilling Wood. This section shows 25' of yellowish-brown, medium-grained micaceous sandstone, with prominent current-bedding dipping mainly to the NW. There are instances in the same exposure, however, of dips in several other directions, including SE. (This has been found to be the case in many other exposures of current-bedded sandstones higher up in the sequence, and it has been difficult to attach much significance, on a large scale, even to dominant directions of current-bedding in each exposure, as most points of the compass are represented for any given sandstone horizon if there are sufficient exposures). The top of this sandstone is seen in contact with the Gillingwood Limestone at Gillingwood Hall, and also at the base of the small feature made by the Gillingwood Limestone just north of Long Acres quarry. Here, a maximum of 4' of current-bedded sandstone is seen in a little quarry about 1/3 mile west of the Gilling-Richmond road (179045). There is a gradual passage up into the calcareous facies, and occasional microcline grains occur both in the sandstone and in the passage beds.

(iii) Gillingwood Limestone

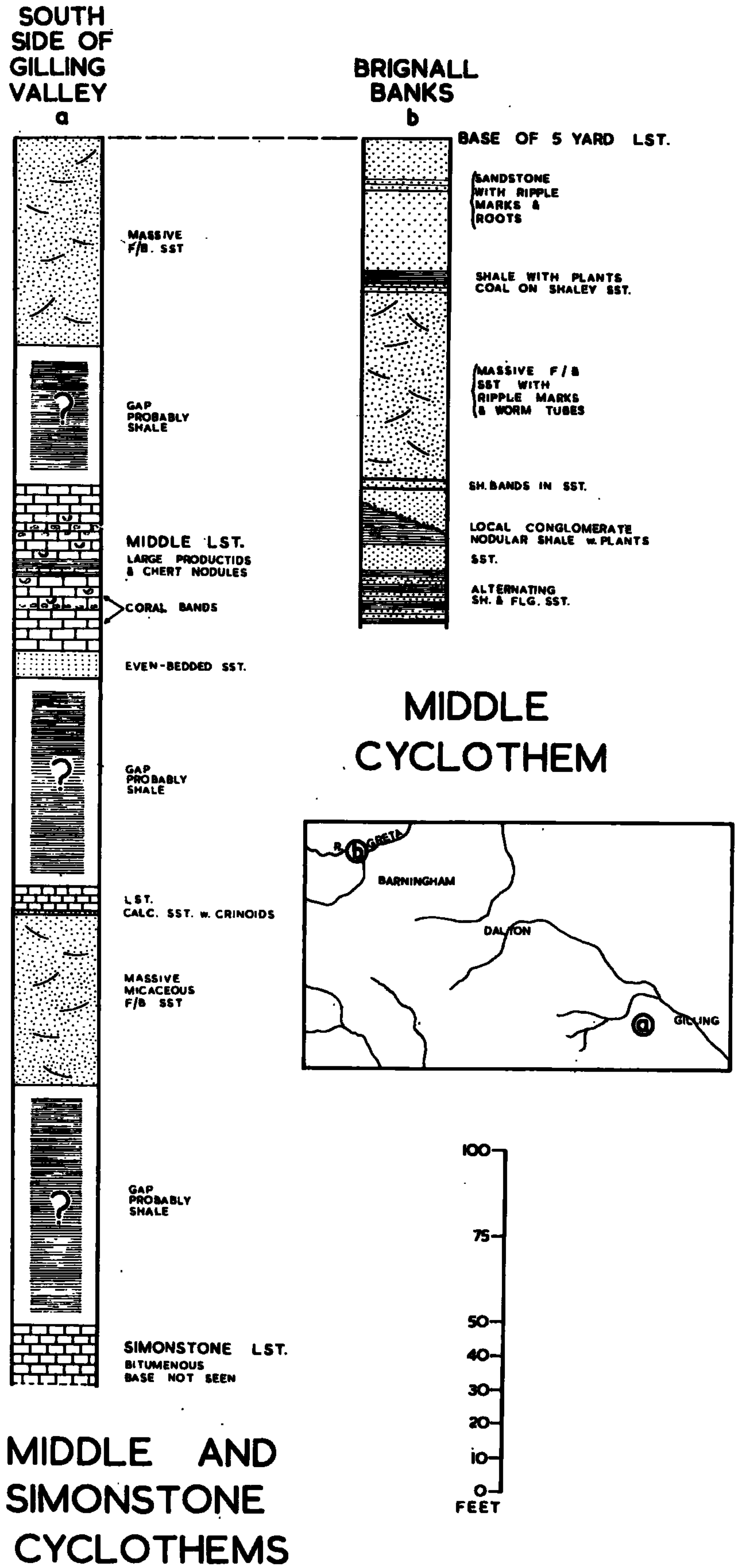
This limestone has been named from an exposure behind Gillingwood Hall, but the greatest thickness seen is 7', a few yards west of the Gilling-Richmond road (183044). It is a grey crinoidal limestone, with variable but small dolomitised patches, thinly-bedded and rather knobbly-weathering. The base is difficult to define precisely, because of the gradual passage from the underlying sandstone, through 8-10" of calcareous sandstone and sandy limestone, to the limestone proper. This shows all transitions from sandstone with a calcareous cement to limestone with a few angular quartz grains, and differential weathering is marked. Examination under the microscope reveals the passage beds as consisting of angular quartz and rare microcline grains, with interstitial calcite. Many of the quartz grains show strain shadows, and a few are of sutured aggregates, suggesting derivation from gneissose country. Occasional ooliths (indicating shallow water deposition) enclose crystalline calcite, which in turn may have a quartz grain in the centre. The ooliths continue up into the limestone, which in addition contains many brachiopod fragments, numerous foraminifera, a few crinoid ossicles and occasional pockets of fragmentary bryozoa.

(iv) Beds between the Gillingwood and Middle Limestones

This horizon is very poorly exposed, but the sandstone beneath the Middle Limestone can be seen at intervals along the south side of the Gilling valley between Kirby Hill and Long Acres quarry, Gilling. A shelf between this sandstone and the Gillingwood Limestone beneath has been mapped as a shale, but it is nowhere exposed. Near Long Acres quarry, the thickness of this supposed shale, as estimated from dips in the limestones above and below it, is approximately 55 feet.

Of the sandstone beneath the Middle Limestone, 6' are exposed in the floor of Long Acres quarry (181042), where it is a pale grey, poorly bedded micaceous sandstone with a few sand-filled vertical pipes, presumably annelid borings. On the hillside south of Gillingwood Hall, up to 8' of well-bedded sandstone are seen at the base of the scar formed by the Middle Limestone. Further west, near the point where the Middle Limestone crosses Jagger Lane (161050), in Gilling Wood, 6' of sandstone are separated from the limestone by 4" of shaley sandstone. Beyond this, drift obscures the ground, but there is evidence of the sandstone again in the centre of the Whashton dome, on the hillside ¼ mile south of Kirby Hill (139061). Here, loose sandstone occurs on a feature in the field, and is surrounded by a closed outcrop of Middle Limestone. In Whashton Waste, just below a small quarry in the Middle Limestone (147061), 7' of current-bedded sandstone are seen forming the roof of a small cave.

FIG. I



SOUTH SIDE OF GILLING VALLEY
a
BRIGNALL BANKS
b
BASE OF 5 YARD LST.
SANDSTONE WITH RIPPLE MARKS & ROOTS
SHALE WITH PLANTS
COAL ON SHALEY SST.
MASSIVE F/B SST WITH RIPPLE MARKS & WORM TUBES
SH. BANDS IN SST.
LOCAL CONGLOMERATE
NODULAR SHALE w. PLANTS
SST.
ALTERNATING SH. & FLG. SST.
MASSIVE F/B. SST
GAP PROBABLY SHALE
MIDDLE LST.
LARGE PRODUCTIDS & CHERT NODULES
CORAL BANDS
EVEN-BEDDED SST.
GAP PROBABLY SHALE
LST.
CALC. SST. w. CRINOIDS
MASSIVE MICACEOUS F/B SST
GAP PROBABLY SHALE
SIMONSTONE LST.
BITUMENOUS
BASE NOT SEEN
MIDDLE CYCLOTHEM
R. GRETA
BARNINGHAM
DALTON
GILLING
100
75
50
40
30
20
10
0
FEET
MIDDLE AND SIMONSTONE CYCLOTHEMS

CHAPTER 3

THE MIDDLE CYCLOTHEM

The beds assigned to the Middle cyclothem which outcrop in the core of the anticline occur in two separate areas, each bounded by a closed outcrop of the 5 Yard Limestone. The larger of these is to be found round the Gilling dome. The authors of the Mallerstang memoir (1891, p. 106), in describing the Middle Limestone of Swaledale, state that it usually occurs in 3 parts, and in places makes 3 separate features, and they have no hesitation in comparing it with the Single Post, Cockle-Shell and Scar Limestones of the Alston Block. Round the Gilling dome, the Middle Limestone occurs in two parts which, in places on the south side of the valley, make separate well-defined features. But the gigantid productids typical of the Cockle-Shell Limestone north of Stainmore occur both above and below the shale band dividing the Middle Limestone, and it is not possible, in this instance, to suggest correlations directly with the Alston equivalents.

Around Brignall Banks, an inlier of the Middle cyclothem is well seen in the Greta, but only the upper part is exposed, the Middle Limestone not being seen.

Comparative sections for the cyclothem are shown in Fig. 1 (p. 16).

STRATIGRAPHY

The Middle Limestone round the Gilling dome is exposed on both sides of the valley. On the north side the lowest outcrops are in this horizon, which, however, is rather heavily drift-covered. On the other side of the beck, it makes one, and sometimes two, excellent features, which can be traced, apart from a few breaks due to drift cover, for 2½ miles, from the Gilling-Richmond road to Whashton. The best exposure is in Long Acres quarry, near the road, where the full thickness of 48' is seen. It is of the normal dark grey crinoidal type, but there is a shale band near the middle, which effectively divides the limestone into two. Very striking are the large productids (the largest seen being 13" across) and a horizon of chert nodules which have clearly been formed by replacement.

The overlying shale, estimated to be 40 feet thick, is exposed in two places only, where its base is seen resting on the Middle Limestone, and its top is marked in several localities by springs issuing from the base of the overlying sandstone. The sandstone, some 60' thick round the Gilling dome, is largely massive and current-bedded. Dakyns et al. (1891, p. 107), when describing this horizon in Swaledale, had no hesitation in connecting it with the 'Lower Brigstone Hazle' of Alston Moor, the Low Brig Hazle of Dunham (1948, p. 19). But lateral facies variations are so rapid that correlation of individual sandstones over such a distance could be dangerous. In the Brignall Banks inlier, over 140' of often massive and current-bedded sandstone, alternating with shale bands towards the base, are almost continuously exposed. Here, the cyclothem is clearly considerably thicker than in the Gilling region, where there are only 100' of beds above the limestone. And there is no sign in the Greta that the Middle Limestone is even nearly approached, judging by the proportion of clastic material in the lowest exposed horizons. But part of the thickening has evidently taken place in the sandstone at the expense of the underlying shale.

DETAILS

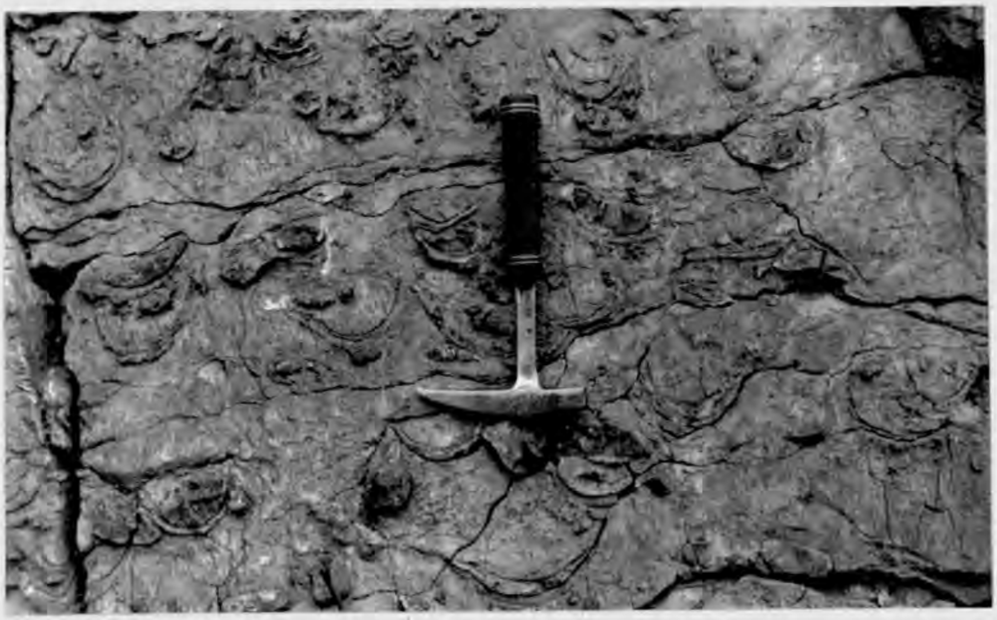
(i) Middle Limestone

Exposures on the north side of the Gilling valley are limited to the stretch between Warrener Lane and Hargill, a distance of a little over 1¼ miles. The limestone forms a feature partly obscured by residual patches of drift on the valley side, but several small outcrops occur a little way north of Hartforth Lane, the lowest exposures on this side of the valley. An old quarry by the side of Forcett Lane (180062) shows 15' of limestone gently dipping eastwards away from the centre of the dome, the lower 9' of which are rich in gigantid productids and chert nodules. West of Warrener Lane, as far as the cross-roads at the top of Stonygate Bank (145064) between Whashton and Kirby Hill, the Middle Limestone is obscured by glacial and post-glacial deposits, the outcrop on the map being conjectural. It has been possible to map it right round the Whashton dome, however, by means of shake holes and exposures in a number of quarries. A small quarry near the summit of the hill south of Kirby Hill (141060) exposes 15' of dark grey limestone with large productids, some corals, and much crinoidal debris, including ossicles up to ¾" in diameter. This quarry, on the south side of the dome, shows the beds to be dipping SSE at 21°. Equally high dips are to be found on the north side of the structure.

The Middle Limestone is well exposed in and around Whashton, and large productids, corals and chert nodules are to be seen in most outcrops. The small quarry on Whashton Waste (147061) which exposes 11' of limestone, shows two small faults. One is along the line of a 10" vein of calcite, and throws 15" to the NW. The other, 10' to the SE, is shown on the map, has a throw in the opposite direction of about 5', and is unmineralised. South of Whashton the continuity of the outcrop is broken by two more small faults, but SE of this, drift covers the ground until the limestone is again seen in Jagger Lane where it passes through Gilling Wood (158049). From this point eastwards, the feature formed by the limestone is continuous as far as the Gilling-Richmond road, except for a stretch of about ¼ mile to the SE of Gillingwood Hall, which is drift-covered. Natural exposures occur most of the way along the feature, which is double for much of its length. Many corals and big productids can be collected along the lower and stronger feature. The continuity of the features is clearly broken to the SW of Gillingwood Hall by two small faults throwing SE between 5' and 10'. But by far the best exposure is in Long Acres quarries (181042) where the following section was measured:-

Limestone with no productids	9'
Limestone with many gigantid productids up to 9" across	3'
Ditto, with chert nodules	4'
Ditto, with shale partings	6'
Shale	2'6"
Limestone with productids	1'
Shale with productids	1'
Limestone, with gigantid productids in upper part, on sandstone	21'6"
	48'

This is considered to be the full thickness of the Middle Limestone, and compares with 45' quoted by Dakyns et al. (1891, p.110) as an average value for Swaledale. Long Acres quarry shows two good coral bands 8' and 16' above the base of the limestone, the dominant genera being Lithostrotion and Diphyphyllum. A band of



A. Middle Limestone, Long Acres quarry, Gilling. A joint-plane section of Gigantoproductid shells lying concave side upwards, many of which enclose chert nodules.

B. Edge of a chert nodule, Long Acres quarry. x 47. The irregular dark line marks the limit of silicification, below which replacement by microcrystalline radial aggregates of silica is complete. (Separate radial aggregates show as small round patches in the photograph). Above the dark line, veinlets of clear silica run through the carbonate, illustrating the process of silicification, and grade into the unaltered limestone.

chert nodules occurs 13' above the base, the nodules very often resting inside the upwards-facing concave part of the productid shells (Plate 6A, p. 20), which suggests trapping of silica in solutions percolating from above. But the coral bed described by Hudson (1924, p.131) from the base of the limestone was not seen, neither was the band of Erithrospongia lithoides, described by the same author (1929) from the Single Post Limestone.

Seen in thin section, the Middle Limestone, which is the normal grey crinoidal type, is very rich in foraminifera of numerous genera, brachiopod fragments and productid spines. Occasional small ooliths are present, and a few very small patches of interstitial silica occur here and there. A section across a chert nodule from Long Acres quarry shows an almost complete replacement of calcite by cryptocrystalline chalcedonic silica, the outlines of foraminifera remaining visible. The boundaries along which silicification has proceeded, gradually eating away the calcite, are abundantly clear, silicification having evidently started at a point inside the concavity of the productid shell and gradually worked outwards from there until, due to lack of further silica, the process was suddenly halted at the stage in which it is now seen (Plate 6B, p. 20). It is evident that this silicification took place after the lithification of the rock, as silica is replacing crystalline calcite, but it need not necessarily have been long afterwards.

(ii) Beds between the Middle and 5 Yard Limestones

(a) Round the Gilling dome.

The shale which rests on the Middle Limestone is seen only twice. One exposure is in a small quarry at the foot of Lythe Wood, beneath Black Hill (168073), where loose shale with ironstone nodules is seen just above the Middle Limestone. A more satisfactory exposure is that on Whashton Waste, where the quarry section shows 10' of soft shale resting on the Middle Limestone. Elsewhere, featureless ground with no exposures occupies this horizon.

Around the Gilling dome, the sandstone beneath the 5 Yard Limestone is well developed, and averages 60 feet in thickness. It is exposed in a number of places on the north side of the Gilling valley between Warrener Lane and Forcett Lane, where it is seen to be pale brown, medium-grained, false-bedded, slightly micaceous and with many small brown limonite patches giving it the speckled appearance so common in Yoredale sandstones. Very striking in a small quarry SW of Blackhill House (168074) are a number of haematite concretions in the sandstone. They average 2-3" in diameter and their formation was evidently prior to lithification, a thin section showing the nodules to contain only scattered quartz grains of the same character as those of the enclosing sandstone, sub-angular and often showing strain shadows. In this respect, they are unlike the 'Red Horses' of Yorkshire and Northumberland, which have evidently formed subsequent to lithification. Also present in the sandstone are scattered plagioclase grains and a few muscovite flakes. In Dalton Beck, ¼ mile below the outcrop of the 5 Yard Limestone, 20' of highly false-bedded sandstone are seen. There are good exposures SE of Gayles, and the bank on the top of which the village of Kirby Hill stands, is littered with many large blocks of the massive sandstone which forms this bold feature. These Blocks also occur to the S and SW of Kirby Hill, where the outcrop of the sandstone sweeps round the Whashton dome. On Whashton Green (144059), 8' of this sandstone are seen within 200 yards of an outcrop of Middle Limestone some 60' higher up on the hill, and the Feldom fault is continued between these two exposures from its last known position ¾ mile to the SW. The best exposure of this horizon, however, is at Stony Kirks (160048) near High Scales Farm, where a cliff of massive and false-bedded sandstone some 25 feet high makes an impressive feature, which continues for ¾ mile to the SE as far as Low Scales Plantation, before being lost again in drift. The sandstone is picked up again near the Low Lodge to Aske Hall, in a small quarry (182038), where a fault throwing SE brings it in contact with the 5 Yard Limestone.

(b) The Brignall Banks inlier.

The closed outcrop of the 5 Yard Limestone around Scargill encloses a section of some 140' of sandstone and shale, excellently exposed in Brignall Banks. To the south of the valley of the River Greta, the only exposures of this horizon are near Cowclose House (064095), where 3' of sandstone on sandy shale underly the limestone, and in Primrose Gill (072102), where the limestone-sandstone junction is well seen. In the Greta itself, sandstone is continuously exposed between the base of the 5 Yard Limestone above Rutherford Bridge, and Mill Scar fault, which crosses the river about a mile further downstream. This sandstone is mainly massive, often false-bedded, sometimes with ripple-marked surfaces, horizontal worm-trails and roots, and thin shaley partings here and there. The river runs in a narrow gorge, some 50 feet deep, beneath Brignall quarries (042115), where the sandstone was extensively quarried many years ago. In Mill Scar (044113) the fault is clearly seen, with sandstone beneath 40' of boulder clay thrown against the following section on the NE, or upthrow side of the fault:-

Sandstone, massive and false-bedded	
Conglomeratic sandstone, coarse, with clay gall and a few large crinoid ossicles	1'
Shale, slightly micaceous, with much plant debris	3'
Sandstone, massive	8'
Shale	

while in the opposite bank, on the north side of the river, 150 yards away, the section is:-

Boulder clay	20'
Sandstone, massive and false-bedded	25'
Shale parting	1'
Sandstone	3'
Shale parting	1'
Sandstone	12'
Shale, with ironstone nodules	12'
Sandstone	7'
Shale and flaggy sandstone, rapid alternations	15'

The conglomerate is definitely absent here, and it appears that lateral facies variations in these beds are very rapid. In Black Scar (057113) a lenticular sandstone band can be seen to increase its thickness from 6' to over 20' in about as many yards. Some 600 yards downstream from Gillbeck Foot, the succession is further complicated by the following section in the north bank:-

Gap to 5 Yard Limestone	23'
Shale with plant debris	3'
Coal	1"
Shaley sandstone	2'6"
Sandstone	24'

There are many places further upstream where the beds for at least 50' immediately beneath the 5 Yard Limestone can be seen to contain nothing but massive sandstone with very minor shaley partings, so this fresh-water shale overlying coal must be of purely local occurrence. But Dunham (1948, p.19) mentions two reports of coal within the Low Brig Hazle of Alston Moor, with which the authors of the Mallerstang memoir connect this sandstone.

In the Swale, east of Marske, some 6' of non-marine sandstone are exposed beneath a limestone thought to be the 5 Yard (see p. 37). It is medium-grained and compact, the small brown limonite spots so characteristic of many Yoredale sandstones being particularly prominent. The upper 18" are devoid of these spots, however, and partly assume the appearance of a gannister.

CHAPTER 4

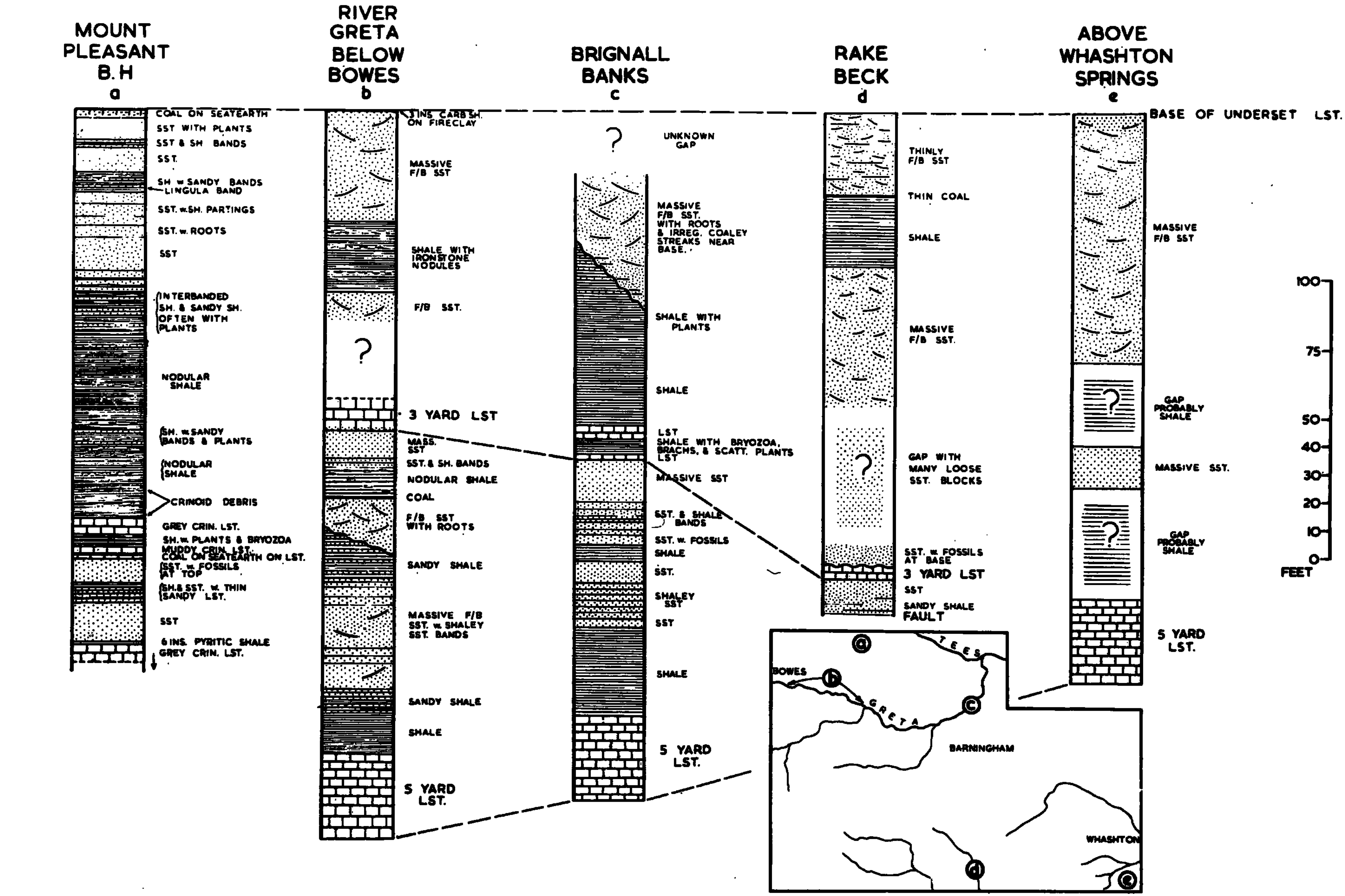
THE 5 YARD AND 3 YARD CYCLOTHEMS

The 5 Yard and 3 Yard cyclothems are dealt with in a single chapter because over the eastern half of the mapped area the 3 Yard Limestone is not seen, and is thought to have been cut out, there being no consistent marine horizon with which to separate the beds between the 5 Yard and Underset Limestones.

The 5 Yard Limestone is the Impure Productal Limestone of Phillips (1836), but he did not recognise the thinner limestone between it and the Underset Limestone. The names now applied to these two horizons originated as miners' terms, and were adopted by Dakyns et al. (1891) during the Primary Survey of 1" sheet 40. As they point out (p.10), the 5 Yard Limestone has been called both the Third Set and Fourth Set by some Swaledale miners, depending on whether or not the 3 Yard Limestone was recognised, which led to some confusion. When the Primary Survey of the area covered by the present survey was made, the 3 Yard Limestone was seen in two places, but not recognised as such, and the limestones closing round the anticline were numbered in 'Sets', counting down from the Main Limestone. Thus the 5 Yard Limestone was everywhere called the Third Set, while the 3 Yard went un-named. One of the clues to the identity of the horizons inside the outcrop of the Underset Limestone lies on the south side of Swaledale, in the section up Greenseat Beck (899972), which meets the Swale between Thwaite and Muker. The limestone at about 1200' O.D., the Middle Limestone of the Survey, contains common gigantid productids and some corals, and lithologically is very similar to the limestone seen in Long Acres quarry (and called the Fourth Set by the Survey). In addition the 3 Yard Limestone, as mapped by the Survey, is here seen to be in two parts, the upper one containing ill-defined "tubes" running down from its upper surface, and the lower one resting on fossiliferous sandstone. It is so similar to two small and unusual limestones seen and mapped near Barningham, which occur between the Underset and 'Third Set' Limestones, that there is no hesitation in assigning the Barningham limestones to the 3 Yard horizon, which will make the Third Set of the Survey correspond to the 5 Yard, and the Fourth Set correspond to the Middle, a correlation already suspected by the presence of abundant gigantid productids. From this, it follows that the Fifth Set will correspond to the Simonstone, as was noted in Chapter 2. Examination of the 3 Yard Limestone of the Survey in Gunnerside Gill (939005, on the north side of Swaledale) and in Punchard Gill (969047, near the head of Arkengarthdale) lent further support for the above correlation.

Among the most abundant and most easily recognisable fossils in the Middle Limestone Group, due to their commonly complete preservation, are the Foraminifera, and one of the most characteristic of these is Howchinia Bradyana (Howchin), which in vertical section looks like an old-fashioned bee hive. Its distribution in the Lower Carboniferous of Northern England was described by Davis (1951), who concluded that it is known only between D_1 limestones and high in P_2. The youngest specimen from a definite horizon recorded by him was from a quarry in the 'Third Set Limestone' near Gilling, the position given being in the middle of the garden of Aske Hall. The nearest locality from which this specimen

FIG. 2



COMPARATIVE SECTIONS OF THE 3 YARD & 5 YARD CYCLOTHEMS is likely to have come is some 2/3 mile to the NW of the position given, where the 'Third Set' or 5 Yard Limestone has been quarried in Low Scales Plantation (168042). Howchinia has now been recognised in every limestone closing round the Gilling dome, and also in the Underset Limestone, being present in most of the slides examined, often in considerable numbers. Its range can therefore be extended to include both the 5 Yard and 3 Yard cyclothems.

Comparative sections for the 5 Yard and 3 Yard cyclothems are shown in Fig. 2 (p. 27).

STRATIGRAPHY

The 5 Yard Limestone round the Gilling dome is not well exposed, only making an occasional appearance through the drift, when it is usually well seen in old quarry sections. It is normally a dark grey crinoidal limestone, with brachiopods usually in fragments, but sometimes occurring complete. It makes a broken feature along the north side of the Gilling valley between Warrener Lane and Gilling Bank, but on the south side it is easily traceable between Aske Park and Whashton Springs. The dip, always away from the centre of the dome, varies between 5° and 16°. At Whashton Springs (152047), 30 feet of the limestone are exposed in a quarry which must show very nearly the full thickness. It is here comparatively rich in productids and their spines. The 5 Yard Limestone is better seen, however, in and around Brignall Banks, where it makes another closed outcrop. Its full thickness is seen to vary between 24' and 30'. Dakyns et al. (1891, p.107) give 20' as an average thickness for upper Swaledale, but state that it may sometimes attain 30'. Northwards, on the Alston Block, however, the average thickness of the sections quoted by Dunham (1948, p.21) is definitely less than 20', while in Wensleydale, to the south, it is only 10' (Dakyns et al. 1891, p.95), so the 5 Yard Limestone can be considered, in the area of the present survey, to be at about its maximum development. When seen in thin section, scattered small ooliths are nearly always present, and these, combined with the fragmentary brachiopod and bryozoan remains, would imply deposition in very shallow water, a conclusion which holds equally for the three underlying limestones. A noteworthy feature of this horizon is the occasional occurrence of quartz-filled cavities, of very variable size, which suggests that a certain amount of silica is normally present in the limestone (but see Chapter 6).

The 3 Yard Limestone is seen only in 4 widely separated localities, and no attempt has been made to join up these scattered outcrops on the map across great tracts of drift-covered ground with so little evidence. In the two best exposures, at Scotchman's Stone (081125, near the eastern end of Brignall Banks) and in an un-named beck ½ mile SW of Barningham (078099), the limestone is seen to be in two parts, separated by a thin non-marine horizon. The former shows the total thickness to be 12'4", the latter about 15', and in both cases there is a gradual passage up into the lower Limestone from the underlying arenaceous horizon. A decalcified sample of the upper leaf at Barningham yielded much glauconite, also pyrite, fluorite and a little sphalerite, together with a small conodont fragment. A bore-hole at Mount Pleasant (033151, 1½ miles SW of Barnard Castle) penetrated the 3 Yard Limestone, where it is 12'6" thick and also divided by a non-marine horizon. These occurrences can be compared with those in upper Swaledale, described by the authors of the Mallerstang memoir (p.108), where the thickness is stated to be generally about 10'. They remark that in Cliff Beck and Ivelet Beck, the 3 Yard Limestone is overlain by sandstone. But it is suggested that it is only the lower leaf that is exposed, the overlying sandstone belonging to the non-marine horizon within the limestone. This is not the case, however, with an outcrop in Waitgate Gill (083047), on the north side of the Faggergill-Waitgate fault. Here, 5' of the 3 Yard Limestone are overlain unconformably by a massive sandstone which has clearly cut out the rest of this horizon. As there is no further sign of the 3 Yard anywhere east of Waitgate Gill, this is taken as evidence for its complete absence in that area due to transgression by the overlying sandstone. It is possible, of course, that it is present and merely not exposed. But in places on the south side of the Gilling valley the beds between the 5 Yard and Underset Limestones make excellent features, and if the 3 Yard Limestone were present there, it would certainly be expected to show itself. Non-deposition is another possibility, but as there is no evidence for this, and there is positive evidence for removal by erosion, the latter is preferred as an explanation of its absence.

The beds between the 5 Yard and 3 Yard Limestones are best seen in Brignall Banks, where the limestones are separated by 91'6" of shales and sandstones, including a marine sandstone with gigantid productids 26' beneath the upper limestone. This compares with only 33' in the Mount Pleasant bore, and it may be that the limestone which has there been taken as the 5 Yard (which was only penetrated to a depth of 6'6") is not that horizon at all, but an intermediate marine band particularly well developed. The sandstone underlying the 3 Yard Limestone is not strong, and is only 14' thick in Brignall Banks. This is less than half the average for the High Brig Hazle of Teesdale, which occurs at the same horizon (Dunham, 1948, p.20). On the other hand, the 5 Yard cyclothem here is over half as thick again as the average value over the Alston Block.

Above the 3 Yard Limestone, a thick shale is visible in Brignall Banks, and is overlain with slight unconformity by a massive non-marine sandstone, the base of which is seen to vary between 66' and 40' above the top of the limestone. At least part of this transgressive sandstone is in the form of a wash-out, running roughly NW-SE. The thickness of this sandstone remains unknown, due to drift cover, but at least 50' of it are actually seen. The Mount Pleasant bore proved about 70' of dominantly arenaceous beds on about 80' of shale, the Underset and 3 Yard Limestones being separated by 150'. Once more, this is over half as much again as the average of the sections quoted by Dunham for the Alston Block (1948, p.22). The sandstone equivalent in horizon to the Natrass Gill Hazle of Teesdale and further north is about 25' thick along the north side of Swaledale, but it is inconsistent, and reaches as much as 90' on Aske Moor. However, a horizon that has proved to be remarkably constant is a band of virtually unconsolidated sand, found usually between 2' and 4' below the base of the Underset Limestone.

Around the Gilling dome, where the 3 Yard Limestone is nowhere seen and thought to be absent, it has been possible to map parts of several sandstone bands in certain places between the 5 Yard and Underset Limestones. Of these, the one underlying the Underset is best seen, particularly SW of Gilling. In this area it is called the "27 Fathom Grit and Plate" on the maps of the Primary Survey, but it certainly never attains a thickness of 27 fathoms. It does become fairly coarse towards the top, and is extremely false-bedded in part. It is composed of quartz grains with strong strain shadows, which are accompanied by plagioclase, zircon and, in one instance, sphene, this material almost certainly being originally derived from regionally metamorphosed acid igneous rocks.

DETAILS

(i) <u>5 Yard Limestone</u>

(a) Round the Gilling dome

West of Hartforth, the mapped outcrop of the 5 Yard Limestone on the north side of the Gilling valley is conjectural. The most westerly exposure is in Blackhill quarry (169075), but the limestone makes a solid feature for about ¼ mile to the NW of this, after emerging from the boulder clay. In this quarry, 16' of limestone beneath 8' of drift dip at 4^{o} down the north side of the Gilling dome. The feature can be followed SE, dropping down into the valley for 1¼ miles, the limestone having been quarried where it crosses Forcett Lane (178068), revealing 20' of grey crinoidal limestone, and at Rock Castle (186062), where 14' are seen. The little beck E of Gilling Bank has two limestone exposures, a small one at 410' O.D. and the other, which has been quarried, at 475' O.D. The latter is certainly the 5 Yard Limestone, and is a buff-coloured crinoidal limestone, with many brachiopod fragments. A thin section shows common foraminifera, occasional ooliths around crystalline calcite, and many very small ankerite rhombs occurring interstitially, which are at least partly responsible for the colour of the rock. There has also been patchy recrystallisation to a fine calcite matrix, but outlines of organic remains are still just visible. The little exposure 65' lower down in the same beck is on the line of continuation of the 5 Yard Limestone from the NW, and a fault has been mapped between the two outcrops. The only other evidence for the limestone on this side of the valley is nearly a mile further SE, in a quarry near Sedbury Park Farm (194044), where 12' of the limestone are seen beneath 4' of drift. It is here the more normal pale grey type, with very many small crinoid ossicles. From this point, the outcrop must continue beneath the alluvial belt (which is ½ mile wide in this part of the valley) to emerge near Low Lodge, where it is faulted against the sandstone beneath the 5 Yard Limestone in a little quarry (182038). On the NW side of the fault, the feature of the 5 Yard Limestone can be picked up again on the northern edge of Aske Park, and followed with only one break (due to drift cover) as far as the Whashton Springs fault. It is well exposed in quarries above Low Scales Plantation (168042), where the base is seen, together with 22' of well-bedded greyish-brown crinoidal limestone, now rich in spiny productids. At the highest point of the feature, above High Scales Plantation, where it approaches nearest to the centre of the Gilling dome, 21' of limestone have been quarried. The dip here is between 9° and 16° away from the dome, which is much higher than the dips on the north side (see Fig. 9, p.170). In Whashton Springs quarry (152047), 8' of drift overlie 30' of limestone, which, although the base is not actually seen, must be almost the full thickness. The limestone is pale grey, crinoidal, and rather thickly bedded, some posts being 4'-5' thick. Spiny productids are plentiful. A cavity some 2" in diameter (lined with calcite) was found, inside which were a number of perfectly formed little crystals of quartz. Grown onto these, in turn, were several patches of pale brown ankerite crystals. The $FeCO_3$ content of the ankerite must be small, about 5%, but N_ω was measurably above 1.682, the figure for pure dolomite. Despite this occurrence of silica, no chert nodules have been observed in this limestone.

West of Whashton Springs quarry, there is no further evidence for the 5 Yard Limestone as far as the little beck near Douthwaite Folly (131054), where there is a small outcrop of the normal crinoidal type, with foraminifera, brachiopod fragments and occasional small ooliths. The limestone's position is next fixed by a shake hole south-west of Grove Gill House (128060); it is well seen in two quarries above Kirby Hill, where it is dipping strongly northwards off the Whashton dome. It makes a separate feature above the sandstone which forms Kirby Hill bank, but this is interrupted 350 yards NW of the village by a wide gully, which undoubtedly marks the line of a fault, the limestone feature continuing beyond it some 30' lower down. The feature, with occasional exposures, is easily traced along the hillside towards Gayles, and a section of 20' is seen in Priest Gill (133070). The beck which crosses the road 250 yards E of East Street, Gayles, has a double exposure of the 5 Yard Limestone. The upper one, between 675' and 725' O.D., is continuous with that in Priest Gill, and shows about 12', dipping at 2° downstream, the top of which is very rich in foraminifera. But at 600' O.D. what can only be the 5 Yard Limestone again, is exposed, to explain which an E-W fault has been mapped just above the lower exposure. On Gayles Common, a good quarry section (122073) shows 16' of well-bedded crinoidal limestone, the 5 Yard again, which has been dropped down from the upper section above by another fault. NW of Gayles, the limestone is completely obscured by drift for over a mile, except for an exposure in Dalton Beck, beneath Castle Steads (112076), where 16' of it (here containing bryozoan fragments) are seen beneath a section of over 100' of boulder clay. Dalton Hall quarry (111088), where 15' of the limestone are seen, shows boulder clay not only covering the solid rock, but filling up a 2' wide gap between joint surfaces. The limestone is finally seen again just beneath Dalton Hall, where a spring issues from its base, and in Burdey's Gill (106091), beyond which the conjectured outcrop joins that on the north side of the valley.

(b) Round the Brignall Banks inlier.

The most westerly exposure of the 5 Yard Limestone round the Brignall Banks inlier is in the River Greta, between 150 and 500 yards above Rutherford Bridge. Its base emerges just above the waterfall (033122) formed by the underlying sandstone, and about 200 yards below the bridge, the full thickness of 24' is seen in a scar on the left bank of the river, both the shale above and the sandstone beneath being exposed. The limestone is the normal grey crinoidal type in hand specimen, but in thin section is seen to consist, apart from the crinoid remains, entirely of recrystallised granular calcite. All traces of organic remains, apart from the crinoids and outlines of the larger brachiopod fragments, have gone.

The limestone base can be traced, by occasional outcrops, along the north side of Brignall Banks as far as the old Brignall sandstone quarries, some 150 yards NE of which the base is again seen, 25' higher up. The fault responsible for this shift is seen very clearly in the right bank of the river, in the Mill Scar section already described on p. 23 . On the east side of the fault, the feature made by the limestone swings round on meeting the fault, and can be traced along the line of it for several hundred yards. Where this happens, the limestone is exposed in an old quarry, a specimen from which shows a thin calcite vein in the limestone, containing a very small crystal of sphalerite less than 1 mm across. Eastwards the limestone is traceable past Moor House Farm, and over the edge of the bank opposite Bank Hill (054113). Outcrops occur at intervals as far as the old quarry south of Lily Hill (067117), the dip varying between 2° and 12° to the NNE. The greatest thickness seen is 30' opposite Black Scar. East of the quarry, landslips have obscured the solid rock for about ¼ mile, but the limestone is exposed again in the Greta below Tebb Wood (074118) for about 350 yards, disappearing beneath the overlying shale.

South of the Greta, the 5 Yard Limestone is less well exposed. Two outliers occur above the south bank, one small one bordering the Mill Scar fault on its SW side, and another forming Bank Hill. Numerous small outcrops of grey crinoidal limestone occur on the latter. A scar on the right bank of the river 500 yards below Gillbeck Foot shows 21' of limestone, but neither the top nor bottom are seen. South of this, the mapped outcrop is conjectural as far as Primrose Gill Plantation (072103), where the lower 22' of the limestone are well seen. A quarry on the north side of the road shows joint surfaces which are very noticeably curved, a fact that has been noted from a number of localities. A thin section from the western end of this exposure shows, as well as crinoidal and brachiopod debris, some complex bryozoan structures and a small calcite-lined cavity filled with quartz. SW from here, the limestone makes a feature below Moorcock Hall, as far as some old quarries near Cowclose House (064095), where the lower 25' are exposed. Specimens from a quarry below Moorcock Hall contain many bryozoa, and thin sections reveal a few ooliths, several small quartz-filled cavities and irregular areas of very small brown ankerite rhombs which impart a patchy appearance to the hand specimen. Westwards from here, the outcrop is obscured by drift as far as Eller Beck, except for exposures in Cowclose Gill, which is dry for nearly 350' where it crosses over the limestone. At and above the ford (054090) the upper 10' are exposed, part of which consist of very coarse crinoidal debris. In Eller Beck (028116), SE of High Barn, isolated exposures continue down to the confluence with the Greta.

(c) Inliers in the Swale

About 1½ miles W of Richmond, in a little quarry just above the level of river alluvium at the foot of Whitcliffe Wood (145012), 9' of grey crinoidal limestone have been exposed. In thin section this is so similar to parts of the 5 Yard Limestone that it is thought to belong to that horizon. But proof is impossible stratigraphically, as the exposure is entirely isolated, and the nearest outcrop is that of the Main Limestone at the top of the wood, nearly 350' higher up, landslips covering the intervening slope.

Another limestone exposure in the Swale, east of Marske (115006), is thought to be the 5 Yard Limestone. Here, 10' of grey crinoidal limestone, lithologically quite unlike the 3 Yard Limestone, dip northwards away from the Marske fault. If this is the 5 Yard, there is no sign of the 3 Yard Limestone above it, in West Wood. But that is thought to have been cut out here (see section (iii)), and the evidence is in favour of this being the lower horizon.

(ii) <u>Beds between the 5 Yard and 3 Yard limestones - western part of area</u>

The 3 Yard Limestone is not seen east of a roughly N-S line through Greta Bridge and Barningham, and is thought to have been cut out in that area. So this section will be confined to those beds seen west of the line, where the 3 Yard is known to be present.

Upstream from the 5 Yard Limestone exposures in the Greta, for about 1000 yards, various members of this horizon are exposed as far as the scar on the north bank, 300 yards west of Thackholme (022128), where the following section is seen:-

Massive sandstone, passage up into 3 Yard Limestone	10'
Sandstone and shale, 12 alternations	3'
Shale, with scattered ironstone nodules	10'
Coal and carbonaceous shale	12"
Lenticular sandstone, with <u>Stigmaria</u>	0-3'
Shaley sandstone, micaceous, carbonaceous in part	4'+

100 yards below this scar, the western side of a wash-out is seen in the left bank of the river, where current-bedded sandstone

is seen cutting down eastwards into sandy shale. Downstream from here, fairly frequent exposures of sandstone are seen, the current-bedding in which dips between ENE and NW, through north. Ripple marks are sometimes seen. The sandstone is mainly medium-grained, light brown, sometimes with small limonite spots, with small mica flakes and carbonaceous material on the bedding planes (which presumably represent relatively quiet periods during deposition). Thin bands of shaley sandstone and sandy shale are also seen in many places, and the whole of this horizon is clearly very variable laterally. For the most part, it is only possible to map it as one unit. 150 yards east of Rutherford Bridge, 8' of sandstone on 8' of sandy shale are exposed in a little gully within 10' of the top of the 5 Yard Limestone, so just here, the shale which is seen overlying the limestone 200 yards below the bridge must be quite thin.

Along the north side of Brignall Banks, part of the sandstone band which underlies the 3 Yard Limestone has been mapped. It is exposed in small quarries near Moor House Cottages (052118), where current-bedding with an easterly dip was observed. East of this, it is not seen again, due to drift and landslips, until it enters the Greta below Brignall (077121), where it contains a number of sandy shale bands. East of Brignall, in a left-bank scar at a right-angle bend in the Greta (078124), 21' of sandstone are seen underlying the 3 Yard Limestone, and 200 yards further downstream, where the limestone enters the river, 5" of gannister cap the sandstone. The following section is seen in the right bank of the Greta, in North Wood (077119), where the 5 Yard Limestone disappears into the river:-

Massive sandstone, with 3 Yard Limestone over	14'
Gap	12'
Fossiliferous sandstone	2'
Current-bedded unfossiliferous sandstone	1'6"
Shale	6'
Sandstone	8'
Shaley sandstone	13'
Sandstone	3'
Gap, almost certainly shale in lower part	32'
5 Yard Limestone	91'6"

The fossiliferous sandstone contains gigantid productids over 6" across, which is a feature not recorded anywhere else during the present survey. This section is the only one, apart from the bore record at Mount Pleasant, where an accurate measurement of the separation of the 5 Yard and 3 Yard Limestones is possible. At Mount Pleasant (033151), this interval, of only 33 feet, is occupied mainly by sandstone, with some shale bands, and is capped by a 7" coal, with seatearth. Marine fossils occur in two narrow bands towards the top (fuller details are given in Appendix II, p. 263). As this interval of 33' is so much less than the section quoted from the Greta, however, it is possible that the horizon which was taken to be the 5 Yard (and in which the bore finished) is not that limestone at all, but some intermediate marine band, particularly well developed. Any further evidence on this point is unfortunately lacking.

South of the Greta, the un-named beck which flows off Barningham Moor to join Primrose Gill in Ladysmith Plantation provides further exposures. Just north of the road (075103), half a dozen separate exposures of sandstone with shale partings are seen, while south of the road, 15" of decalcified fossiliferous sandstone on 2'6" of pale grey micaceous sandstone are seen underlying the 3 Yard

Limestone. South-westwards from here, the sandstone is mapped along a feature, and exposures occur on Rowley Intake (068094), where sandstone is seen several times in the two small becks. A short distance further west, drift covers the feature, but two further outcrops of sandstone are seen. One is in Scale Knoll Gill (055088), where 30' of massive and false-bedded sandstone are separated from the 5 Yard Limestone beneath by a gap of 6'. The other exposure is in the little beck flowing down through East Hope, ¼ mile below the farm (041091) where a glimpse of the sandstone is seen beneath thick boulder clay. W and NW from here, as far as the Greta, this horizon is nowhere exposed, and all the features are superficial.

Two small outcrops of beds beneath the 3 Yard Limestone occur in connection with the Faggergill-Waitgate fault, both on the north or upthrow side, and both in deep valleys. One is in Waitgate Gill (083047), where 10' of sandstone with sandy shale at the base underlies the 3 Yard Limestone. The other is in Holgate Beck (063044), where some 15' of sandstone are seen dipping northwards under the 3 Yard Limestone.

(iii) <u>3 Yard Limestone</u>

The most westerly exposure occurs at the top of a scar on the north bank of the River Greta, 300 yards west of Thackholme (022128), where 10' of the 3 Yard Limestone, overlain by drift, pass down through 10" of passage beds (sandy limestone and calcareous sandstone) into the sandstone beneath. The passage beds, in thin section, are seen to consist of angular quartz grains (many with strain shadows), rare grains of plagioclase, a little muscovite and occasional small zircons, set in a variable proportion of calcareous matrix, the latter including some brachiopod fragments and crinoid ossicles. The hand specimen gives the impression of limestone spots in sandstone, increasing in frequency upwards. A section from 1' above the passage beds still shows scattered quartz grains in the limestone, and deposition of clastic material evidently overlapped to a considerable degree with the onset of marine conditions, this not normally being the case with the major Yoredale limestones. Small brown ankerite rhombs replace calcite here and there, and brachiopod fragments, foraminifera (including Howchinia) and ooliths can all be distinguished, although their original material has all recrystallized to very finely granular calcite. The same has happened to much of the matrix, but crinoid ossicles have successfully resisted recrystallisation. The main bulk of the limestone is the normal dark grey crinoidal type.

Loose blocks of limestone are seen in the wood below Hundah Farm (126028), marking the position of the 3 Yard, but the next place to the east where it is seen in situ is in Brignall Banks, in the little beck running eastwards through Brignall itself (076123). Here, the lowest 18" is seen, passing down through 6" of sandy limestone to sandstone, of which only 18" is visible. In thin section, the sandstone and passage beds are similar to those described above, except that zircon is somewhat more plentiful here. The limestone, however, still has considerable numbers of quartz grains in it 18" from the base, the highest part of this exposure, and the evidence of recrystallisation from the previous exposure is lacking. The full thickness of the 3 Yard Limestone is exposed at Scotchman's Stone (081125), however, where it closes in the Greta, dipping 4° NE beneath the overlying shale. This is the only place covered by the present survey where the whole of this horizon is visible. The section is:-

Limestone, weathering pale brown, shale over	5'
Shale, with brachiopods and bryozoa, also plants in lower part	5'6"
Dark grey limestone	1'6"
Mottled sandy limestone, passing downwards to	4"
Gannister	12'4"

In thin section, the passage beds are similar to those further upstream, but the lower limestone is devoid of all clastic material. It is very rich in foraminifera, and also contains brachiopod and crinoid fragments. The upper limestone, on the other hand, is almost entirely recrystallised to a mozaic of small pale brown interlocking rhombs of ankerite, only the crinoid ossicles and stouter brachiopod fragments having resisted alteration.

On the right bank of the Greta, the limestone rises again to the SW, and is seen resting on sandstone above Parson's Island (078123) and also in North Wood (075118), beyond which it is entirely drift-covered as far as the un-named beck to the west of Barningham. Here it is seen (078099) in a section drawn out over 350 yards, the northerly dip being almost equal to the slope of the stream bed. The section is in 3 separate parts, but can be pieced together as follows:-

Limestone with "pipes", boulder clay over	8"
Brown-weathering grey crinoidal limestone	4'6"
Shale, with many bryozoa	2'
Gap probably less than	4'
Gannister	8"
Sandstone, soft and carbonaceous	2'6"-8"
Irregular erosion surface	
Sandy limestone	0-2'6"
Decalcified fossiliferous sandstone on sandstone	1'3"
About	15'

The sandy limestone is pale grey, with irregular patches which are more lime-rich than others. This leads to differential weathering, which gives the rock a knobbly appearance. Under the microscope, the bulk of the rock is seen to consist of about 75% angular quartz grains with strain shadows, with a few grains of twinned plagioclase, occasional small zircons and muscovite leaves. The remaining 25% is entirely of crystalline calcite acting as a matrix for the detrital material, individual crystals being up to 4 mm in length. The detrital grains are ill-sorted, all sizes below 0.2 mm being present. Parts of the rock have the composition of a calcareous sandstone. But sections of the lime-rich patches (which have the appearance of calcite-mudstone in hand specimen, and account for about 1/3 of the total volume) show only 20-40% of detrital material, the matrix being a very fine-grained mozaic of recrystallised calcite, with round patches free from quartz grains which were evidently once crinoid ossicles. The erosion surface above this is well seen, and in one place cuts down to the base of the sandy limestone. The soft sandstone above moulds itself on to the irregularities of the eroded surface, and is similar lithologically to the overlying gannister, differing from it only through lack of cementation. Above the gap, the shale (whose base is not seen) is exceptionally rich in bryozoa, and also contains crinoid ossicles. The overlying limestone is similar to that already described from Scotchman's Stone, apart from the upper 8", which contain more or less vertical tubes, about ¾" in diameter, and of uncertain origin. A thin section shows the rock to consist almost entirely of organic debris, comprising crinoid ossicles, brachiopod fragments, bryozoa and foraminifera, but with a few small ooliths, and a pale green cryptocrystalline mineral, probably glauconite, which occurs both as rounded grains and as replacement of bryozoa, foraminifera, etc. Under the microscope, the tubes, in contrast, are seen to consist largely of crystalline calcite, with none of the pale green mineral (suggesting that they were formed later than the rest of the rock), and only scattered fossil fragments, mainly of brachiopods and bryozoa, and a few foraminifera, including Howchinia. Pyrites in aggregates of very small cubes is common. A sample of this "tubular" limestone was treated with hot dilute HCl, to remove both calcite and dolomite, and the residual material was found to contain common pyrite and amber-coloured, euhedral fluorite, occasional quartz grains, a few crystals of sphalerite (confirmed by a micro-chemical test), a small conodont fragment and much of the pale green mineral. This was found to have an average refractive index of 1.578, making collophane as well as glauconite a possibility. But another micro-chemical test for phosphate gave a negative result, and it is concluded that the mineral is probably glauconite. According to Winchell (1951, p.377), glauconite with an R.I. as low as this is a variety rich in Mg or Al, and poor in iron.

Further westward, along Barningham Moor, there is no further evidence for the 3 Yard Limestone, and its mapping is not attempted. But southwards, over the watershed, the 3 Yard Limestone is seen along the Faggergill-Waitgate fault. In Holgate Beck, an exposure occurs 200 yards north of the fault (063045), where 15' of limestone dip northwards into the beck. It is seen immediately to the north of the fault on the east bank, 125' above the beck, while on the south side it is down in the water dipping southwards at 24°, showing the fault to throw 125' down to the south. In the latter exposure it is a dark grey compact limestone, rather muddy, with small crinoid ossicles and also, in thin section, brachiopod fragments, scattered foraminifera and ooliths. In Waitgate Gill, just to the north of the fault (083047), 5' of the limestone are seen. It is here grey-brown, compact, crinoidal and contains spiny productids and a bed of Diphyphyllum. Thin sections show scattered quartz grains to be present, with foraminifera and a few ooliths. The limestone is overlain by a sandstone (of which 7' are seen) fossiliferous at the very base, which moulds itself onto the eroded surface of the limestone beneath. A thin section from a few inches above the base showed about 80% angular quartz grains, with rare plagioclase and zircons, cemented by calcite, and enclosing brachiopod fragments up to 2 mm. in length.

Finally, the record of the 3 Yard Limestone from the Mount Pleasant bore (033151) is:-

Limestone, grey and crinoidal, underlying shale	6'
Shale, dark, with some plants and coal smuts	1'
Shale, dark, with many bryozoa	6"
Shale, dark and highly pyritic	2'
Shale, dark and calcareous, passing down to	1'
Limestone, muddy, with some crinoids and shell fragments, on coal	2'
	12'6"

This section bears a striking resemblance to that measured at Scotchman's Stone, and is also similar to the Barningham exposure in showing the 3 Yard to be in two distinct parts.

(iv) <u>Beds between the 3 Yard and Underset Limestones - western half of area</u>

(a) North of the Swaledale-Gilling valley watershed.

This horizon is seen in the Greta between Gilmonby Bridge and Rutherford Bridge, where a number of isolated exposures rise through the drift. ½ mile upstream from the outcrop of the 3 Yard Limestone (013128), 6' of sandstone are seen in the south bank of the river. It is thickly false-bedded, slightly micaceous, with carbonaceous material picking out the bedding. In thin section, the sub-angular quartz grains are of metamorphic type, and small zircons are not uncommon. The mica is muscovite. ¼ mile further west (009130), there is a glimpse of shale beneath alluvium in the north bank, which contains bands of ironstone nodules, and 150 yards north-west of this, 40' higher up the bank, 12' of shaley sandstone and sandy shale (the latter yielding both plants and brachiopods), are seen in a very small beck, where the dip is 5° NE. The next exposure upstream is in Robin Hood's Scar (003132) where 30' of false-bedded sandstone, becoming ganisteroid with <u>Stigmaria</u> towards the top, underlies the Underset Limestone. And 70 yards below Gilmonby Bridge, where the limestone enters the river, a thin seat earth overlain by 3" of carbonaceous shale and coal can be seen on the sandstone in the north bank when the river is low.

North of the Greta, this horizon is seen only 3 times. ½ mile north of Rutherford Bridge there is an area about 1 mile E-W and ¼ mile N-S, which is free of drift, and inside which numerous outcrops of sandstone, mainly massive and current-bedded, sometimes with plant remains, are to be seen. In a small quarry 75 yards north of Ox Pasture Farm (037129), the sandstone contains casts of small crinoid ossicles, and the current-bedding dips NW. The best exposures of the beds above the 3 Yard Limestone occur in the Greta, SW of Greta Bridge. At Scotchman's Stone (081125), the limestone is overlain by 66' of shale, the upper part being somewhat sandy, with scattered plants. This is overlain unconformably by current-bedded sandstone, with Stigmaria and coal streaks in the lower part, which cuts down northwards into the shale. The erosion surface is seen in several places in Mill Wood, and is at its most spectacular in the left bank, 1/3 mile above Greta Bridge (084127), where it is seen to cut out 12' of shale in a lateral distance of 30'. But here it is cutting down southwards, the lowest horizon reached by the sandstone being some 50 yards to the south, which is presumably the centre of a washout. The channel is apparently running roughly NW-SE, and is filled by at least 50' of highly current-bedded sandstone, which makes vertical walls in Mill Wood, but which is carried down into the river northwards by the regional dip, and through which a narrow gorge has been cut between the north end of Mill Wood and Hell Cauldron (084129). Further downstream, the rest of this horizon is obscured, as is most of the Underset cyclothem, so it is not possible to estimate the interval between the sandstone of Hell Cauldron and the Underset Limestone, as the latter is not exposed. The nearest comparable information comes from the bores at Wycliffe (2½ miles E) and Mount Pleasant (3½ miles WNW). The former (121134) proved at least 73'6" of non-marine beds beneath the Underset Limestone, which consisted of many alternations of sandstone and sandy shale, it not being possible to recognise any of the horizons seen in the Greta. The Mount Pleasant bore (033151), on the other hand, proved the following:-

4. Coal on seat earth on gannister, underlying the Underset Limestone	5'2"
3. Alternating bands of sandstone and shale, with plants	39'7"
2. Mainly sandstone, non-marine	23'3"
1. Mainly shale, with plants in upper part, marine fossils towards base, on 3 Yard Limestone	82'
	150'0"

It may be that the unconformity seen in the Greta lies between the shale (1) and the sandstone (2) of the above section. It would be dangerous to suggest more than this, due to the great lateral variations that these non-marine beds can and do show, both in thickness and in facies.

South of the Greta, exposures (mainly of sandstone) occur in Barningham Park and on Barningham Moor. A series of overflow channels running through Barningham Park have cut down through a thick sandstone, and have left 3 outliers, much of which are littered with loose blocks of the sandstone, which is massive and slightly micaceous, and must be at least 60' thick. The beds beneath the sandstone are not seen, but the junction is marked by occasional springs. The sandstone makes a strong feature westwards from Barningham Park, and is exposed in the un-named beck 200 yards above the top of the 3 Yard Limestone (077095), where it is overlain by alternating shales and sandstones. The feature continues along East and West Langbrough, with springs issuing from its base, and onto Barningham Moor, where it dies out in drift just after crossing Woodclose Gill (044083), in which 8' of false-bedded sandstone are seen. ¾ mile SW of Barningham, two relatively thin sandstone bands have been mapped on the north side of Cathaw Stoop (078092), where they make good features some 20' high for about ½ mile across an area where the drift cover is quite thin. The features are littered with loose sandstone blocks at intervals.

Westwards from Barningham Moor, extensive boulder clay obscures the whole of the 3 Yard cyclothem except for a few places where the sandstone beneath the Underset is seen. The best of these is 200 yards north of Spanham (016103), where there is a section in the side of an overflow channel which shows:-

Carbonaceous shale underlying Underset Limestone	1"
Soft carbonaceous sandstone	1'6"
Massive white sandstone	8'6"
Gap	10'
Spring, presumably top of a shale band.	

There are remains of a number of shallow pits in the side of the channel on a level with the spring, from which coal is said to have once been obtained, but nothing can now be seen of a seam. Drift covers this horizon again as far as an old quarry ¼ mile south of Plover Hall (007121). This is full of water, but a sample from the edge is a massive compact well-cemented pale brown medium-grained sandstone, with a few small limonite spots. At Plover Hall itself (006125), flaggy sandstone has been worked in shallow pits, and in How Low Gill (000127) flaggy sandstone is seen about 10' below the base of the Underset Limestone.

(b) South of the Swaledale-Gilling valley watershed

South of the watershed, parts of the 3 Yard cyclothem are exposed sporadically in Holgate Beck. South of the Faggergill-Waitgate fault, an outcrop on the east bank 250 yards above Goat's Bridge (064041) shows 12' of fossiliferous sandstone on shale dipping 10° SE. The sandstone is brown, rather fine-grained and compact, with brachiopods (mainly spirifers) preserved in limonite.

North of the fault, isolated sandstone exposures occur upstream from the 3 Yard Limestone as far as Kexwith (053051), where 6' of alternating sandstone and sandy shale are seen. 350 yards west of the confluence of Moresdale Gill with Arndale Beck (051049) the following section is seen:-

Gannister passing up into cherty base of Underset Limestone	2'6"
Almost unconsolidated pale brown micaceous sand	2'
Sandstone with shaley sandstone bands, scattered brachiopod casts	20'

while 250 yards north of Kexwith, the section in an excavation for a water-wheel is:-

Gannister passing up into cherty base of Underset Limestone	4"
Micaceous seat earth	6"
Friable coal	6"
Sandy seat earth	1'
Gap	1'6"
Sandstone	

In the bank south of Kexwith, coal fragments were found in the soil some 40' below the base of the Underset Limestone, which may correspond with the seam formerly worked at Spanham. South-eastwards from Kexwith, the NE side of the valley is covered by very extensive landslips for ¾ mile, but south of West House the sandstone beneath the Underset Limestone starts a very good feature which runs up onto the south side of Holgate How, and is covered with large blocks of massive sandstone. East of Holgate How there are no exposures, due to peat cover, until the section in Waitgate Gill is reached. Here, a sandstone rests on an erosion surface of the attenuated 3 Yard Limestone just north of the big fault (083047). The sandstone contains brachiopod fragments and about 20% of calcareous cement at its base. Only 7' of it are seen, however, and the next 50' in the succession are not seen in situ, but are probably of sandstone, judging from the number of loose sandstone blocks. Above this, 50' of massive and current-bedded sandstone are well seen in a side waterfall west of High Waitgate (082051), and this is overlain by 25' of shale, the top of which is well marked by lines of springs along both sides of the valley below Rake Gate. 300 yards NW of High Waitgate (082052), where a small beck enters from the east, this shale is seen to be capped by about 8" of moderate coal, which has been worked nearby from a vertical shaft through the overlying sandstone. This sandstone, well seen at Rake Gate (080056) underlying the Underset Limestone, is 25' thick, and has an almost unconsolidated horizon some 4' from the top, similar to that seen in Moresdale Gill.

South of the fault, the upper few feet of the 3 Yard cyclothem are well seen in Buzzard Scar (085042), where the section is:-

Calcareous sandstone, underlying cherty base of Underset Limestone	1"-9"
Coal	0 -1"
Seat earth, with carbonaceous shaley streaks	6"-9"
Gannister	3'
Soft sandstone, poorly consolidated	1'6"
Coal	0-1"
Gannister	9"
Soft white sandstone with plants	1'
Current-bedded, ripple-marked sandstone, to beck	8'
	15'

About a mile further downstream, south of the fault crossing the valley near Telfit, sandstone is exposed on both sides of the beck beneath the Underset Limestone. It is well seen above Orgate (093019), where it is probably in excess of 50' in thickness, although no more than 15' are seen in any single outcrop.

Sandstone, often current-bedded, is exposed at intervals down to the beck, where 14' of it form Orgate Force. There are probably many shaley bands in the succession, but they are not seen.

The upper part of the 3 Yard cyclothem is also seen in Clapgate Beck 200 yards below the junction with Hey Gill (114027), the Underset Limestone is underlain by 2' of soft sandstone, on 7' of well-consolidated sandstone, on 5' of shaley sandstone. Below the bridge, in Otterington Plantation (112015) 20' of sandstone, all well-consolidated, are seen to directly underly the Underset Limestone, in marked contrast to the more complex sections further to the NW. The dip of the current-bedding in this sandstone is mainly to the south-west.

(v) Beds between the 5 Yard and Underset Limestones - eastern half of area

This section deals with the area where the 3 Yard Limestone is not seen, and is thought to have been cut out by the overlying sandstone as demonstrated in Waitgate Gill.

Along the north side of the Gilling valley, outcrops are very scattered, and no satisfactory succession can be determined as they are mostly isolated by drift. The most westerly exposures are in Browson Bank (128102), where 10' of pale brown medium-grained slightly micaceous false-bedded sandstone underly the Underset Limestone. A lower horizon is seen in a small drift-free area on Dunsa Bank (133094), where 30' of false-bedded sandstone are seen. Sandstone comes to the surface again ¼ mile SE of Carkin Moor Farm (168082), where it has been quarried. 25' were measured, and the current-bedding was seen to dip in all directions of the compass in different parts of the quarry. Diddersley Hill, a further 1/3 mile SE, is a striking sandstone peak rising 75' out of the surrounding drift. Black Hill (just across the road) is another, and old quarries into the hill show the sandstone to be exceptionally false-bedded here. A bore-hole was sunk for water by W. Coulson Ltd. in 1946 on the east side of Black Hill, and the driller's log gave the succession as:-

Sandstone	16'6"
Grey shale	14'2"
Sandstone and shale alternations	24'1"
Dark grey shale with ironstone nodules on 5 Yard Limestone	23'6"
	78'3"

The beds beneath the upper sandstone are nowhere exposed on this side of the valley, due to drift cover, and this is the only information available. The upper sandstone is well seen again in Gatherley Moor quarry (192067), where 8' of drift overlie 25' of pale brown current-bedded sandstone, with much white mica and carbonaceous material covering the bedding planes. The false-bedding slopes in all directions, the highest dip recorded being 38°. 300 yards NE, a small roadside quarry (partly full of water) gave this section:-

Sandstone, poorly flaggy in part	7'
Shale, traces of coal in soil near top	5'
Shaley sandstone	2'
Massive and current-bedded sandstone	15'+
	29'

Northwards from this quarry for about ¼ mile, the drift cover is very thin or absent, and solid sandstone is sometimes reached in deep ploughing. NE towards Melsonby, the surface must be almost a dip slope. In Sedbury Park, the quarry 350 yards NE of the Hall (201053) shows 16' of sandstone, in which strongly developed current bedding dips mainly SE. A mile NW of Gatherley Moor, the floor of a large quarry in the Underset Limestone (186080) is of gannister, and ¼ mile east of this (191078) an old quarry shows 20' of sandstone covered by drift, between 3' and 15' thick. SW of Low Merrybent (208075), a beck section between 250 and 350 yards from the farm shows a dip slope of sandstone overlain by shale. ½ mile north of Middleton Tyas (228067) a small inlier of carbonaceous sandstone surrounded by Underset Limestone is seen in a little wood. The sandstone, of which only 2' are seen, is very slightly calcareous, and bears traces of malachite.

South of Gilling Beck there are many exposures of sandstone, mostly just beneath the Underset Limestone. In an outcrop 400 yards east of Olliver (188031) 9' of sandstone are seen passing up through 9" passage beds into the limestone above. To the west this horizon is next seen in the old quarry near The Temple, in Aske Park (174035), where 15' of pale brown medium-coarse well jointed massive sandstone has been used for building on the Marquis of Zetland's estate. In Mouldron Plantation (167037) it has also been quarried, and westwards from there its base makes a good feature round the north side of Black Plantation as far as the Whashton Springs fault. 700 yards north of Aske Moor Farm (151044), a quarry into this feature exposes 25' of massive and false-bedded sandstone, and in the Plantation itself there are numerous small areas where the drift has gone, revealing the sandstone in pavements. ¼ mile NW of Aske Moor (148040), the top of the sandstone is seen to be rather coarse, and a pale purple-brown colour. It contains scattered fossil casts, and glacial striae are preserved on its upper surface. In thin section, sub-angular quartz grains up to 0.4 mm in diameter contain many very small zircon crystals, and many have strong strain shadows. Several sphene grains were seen, and some of the quartz grains are of sutured aggregates. Between the Whashton Springs and Feldom faults, there are only two exposures. One is in Lowne Wood (137046) where 8' of sandstone are seen in Springs Beck. The other is at Sturdy House (135052) where many large blocks of sandstone occur just below the springs issuing from the base of the Underset Limestone. West of the Kirby Hill fault, the sandstone beneath the Underset is picked up in patches where the drift has gone. One of these is ¼ mile south of Pace's House (116063) where 3' of massive sandstone is seen in an old shallow quarry. Just north of this, old shafts have been sunk to work a coal seam which occurs beneath the sandstone. The seam is said to have been 7" thick, and probably corresponds with that seen in Waitgate Gill. ½ mile SW of Pace's House, sandstone blocks are seen beneath an isolated outcrop of the Underset Limestone, and ¼ mile SE of Hornbriggs (096063), where two mineralised faults have been worked, sandstone is seen immediately beneath the limestone in several places. A temporary excavation in a spring at the base of the limestone revealed

Sandstone, limestone over	1'
Pale yellow sand	2'6"
Clay	2"
Sandstone	

The sand is at the same level as that seen at Rake Gate and in Clapgate Beck. North-westwards this horizon is obscured as far as the head of Dous Gill (083075), where 3' of flaggy sandstone is seen above a small spring. Another drift-free patch straddles the road from Newsham between 200 and 400 yards south of Carter House

(080079), where several exposures of a pale well-cemented medium-coarse sandstone with scattered plant remains are seen.

It has proved possible to map another sandstone band about mid-way between the 5 Yard and Underset Limestones, for about 1½ miles along the hillside south of Gayles, which may be the same as that seen on Dunsa Bank, across the valley. The best exposure is in Gayles quarry (128066) where a number of sections bear little resemblance to one another. Lenticular beds of massive sandstone are separated by very variable bands of shaley sandstone and sandy shale, about 25' being seen beneath a drift cover of up to 18'. Along the north face of the quarry, percolation of iron-rich waters through the massive sandstone has led to bizarre patterns of limonite staining, which at first sight might be mistaken for extraordinary false-bedding. Eastwards this sandstone is cut off by the Kirby Hill fault, but westwards it makes a strong feature through Park Wood as far as Jenny's Plantation (118069), with sandstone blocks on the slope. Beyond that it is lost in boulder clay except for an exposure in the beck on the SE side of Castle Steads (112072). Here, some 12' of sandstone with false-bedding dipping WSW is seen beneath at least 50' of boulder clay. And in Chapel Gill, 200 yards NW of High Dalton Hall (102088), an isolated exposure, possibly of the same horizon, shows 16' of mainly flaggy sandstone, split up with shaley partings of 1"-2" in thickness, beneath thick drift. Another thin band of sandstone has been mapped for ½ mile along the hillside south of Gayles Hall (122071) on the strength of a feature with sandstone blocks on it, which is well marked round The Clump, 200 yards west of the hall.

In the north bank of the Swale, 1/3 mile above the old mill west of Richmond (153007), the Underset Limestone is seen resting on 18" gannister, 2' beneath which is a massive sandstone, exposed as far downstream as the bathing steps. The 2' gap between gannister and sandstone is seen in the south bank to be the horizon of soft sand already mentioned from a number of localities further north-west.

CHAPTER 5

THE UNDERSET CYCLOTHEM

The Underset cyclothem is one of the best known of the rhythmic units comprising the Middle Limestone Group to the south of Stainmore, and the Underset Limestone, which marks its base, is easily recognisable in most places by its proximity to the thick overlying Main Limestone. Over the Alston Block (where the limestone at the base is known as the Four Fathom Limestone) this interval has been penetrated by many mine workings, and in nearly every case is seen to be a double cyclothem, a thin limestone known as the Iron Post, complete with underlying sandstone (the Quarry Hazle), occurring between the Four Fathom and Great Limestones (Dunham, 1948, p.23). The Great Limestone, traced round the Stainmore syncline, is equivalent to the Main Limestone of the Askrigg Block, as was shown by Turner (1935), and when Reading (1954) re-mapped the syncline, he found that the Iron Post horizon was recognisable over most of that area also. But he could find no trace either of it or the underlying Quarry Hazle in the Bowes region, where outcrops are separated from their nearest equivalents to the west by 8 miles, and to the north by 6 miles. Somewhere within this interval the Iron Post Limestone as such has died out, and it is significant that no evidence for its existence has been discovered anywhere during the present survey of the ground to the SE of Stainmore. Certainly in the region of Bowes the lower half of the interval between the Underset and Main Limestones (including the Underset Chert) is of marine beds, and Reading's conclusion that here there was continuous marine deposition contemporaneous with the formation of a normal cyclothem to the north and west is no doubt correct. But to the south and east the thickness of marine beds above the Underset is no greater than usual, and the interval between the bases of the Underset and Main Limestones is a single normal rhythmic unit, apart from the development of chert in places. Southwards, in Swaledale and Wensleydale, the Survey found no evidence of the Iron Post either, although it was apparently picked up in places on Winton and Kaber Fells, some 10 miles WSW of Bowes (Dakyns et al. 1891, p.133).

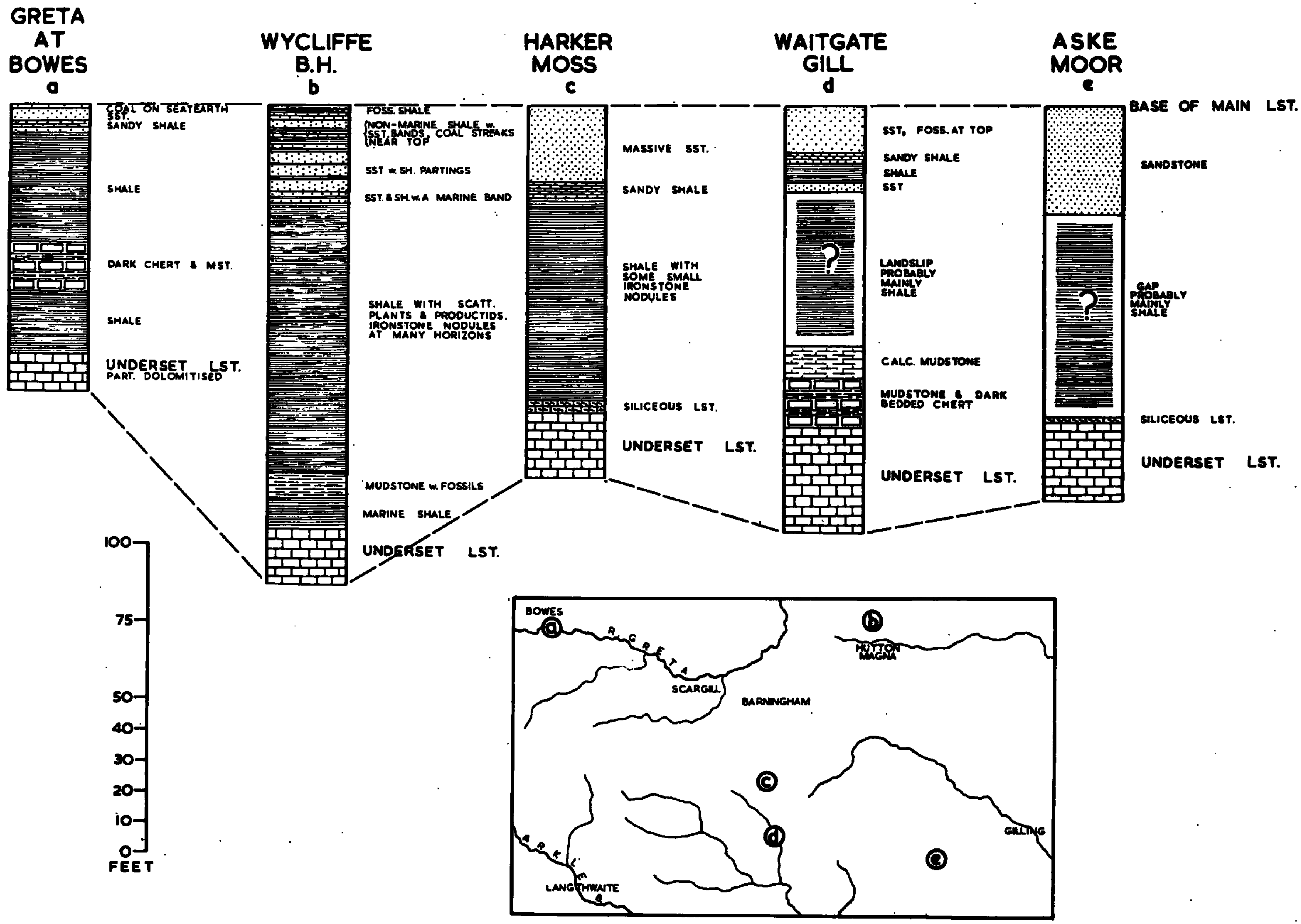
Dr. G.A.L. Johnson made a most important find when he collected several goniatites, referrable to Girtyoceras, from the lower part of the shale separating the Underset Limestone and Chert, in the core of the Mount Pleasant bore (2½ miles NE of Bowes). These indicate a high P_2 horizon, and as the base of the Main Limestone is generally agreed to lie within the Eumorphoceras Zone, the boundary between the Lower and Upper Carboniferous would appear to lie between the Underset and Main Limestones, although Trotter (1952) prefers to draw it lower down, near the Middle Limestone. The present position is admirably summarised by Rayner (1953, pp.285-290), who inclines to the former view.

Comparative sections of the Underset cyclothem are shown in Fig. 3 (p. 60).

STRATIGRAPHY

The Underset Limestone has been mapped as a closed outcrop all the way round the anticline, and in general is well exposed except along the north flank of the structure, where, over a distance of 12 miles, there is only one series of outcrops in a small

FIG. 3



COMPARATIVE SECTIONS OF THE UNDERSET CYCLOTHEM drift-free patch. For the most part, it is a compact crinoidal limestone, but somewhat lighter in colour than the other Yoredale limestones seen in this area, normally being a creamy-grey colour. It varies greatly in thickness, being only 12' in its most westerly exposure at Gilmonby Bridge (995133), below Bowes, but 25' thick in the bore-hole at Mount Pleasant 2½ miles to the NE, which is the more normal thickness. East of a line running roughly N-S through Richmond, however, the upper part of the Underset has a very different lithology, and is composed almost entirely of coarse crinoidal debris, strikingly current-bedded, which must have been deposited rapidly by strong currents (which came from a northerly direction). In this area, at the eastern end of the structure, the Underset is at least 65' thick, which is the highest recorded figure north of Wensleydale, although the authors of the Ingleborough Memoir (Dakyns et al., 1890) measured greater thicknesses than this in several places further south. Miller and Turner (1931) described a bed of rolled corals from near the base of the Underset Limestone along the Dent fault, which has since been recognised in much of upper Swaledale, and Reading (1954) has recorded it everywhere round the Stainmore syncline except in the Bowes region. This coral bed was not seen anywhere during the present survey, it being apparently absent to the east of Arkengarthdale.

In places north of Stainmore, and also in upper Swaledale, the Underset Limestone is sometimes characterised by *Saccamina carteri*, and often by chert nodules. The former has here been recorded from only one locality, but the latter occur commonly throughout the limestone, sometimes in well defined bands. There is evidence that the Underset Limestone contains a certain amount of silica as a depositional constituent, and that it is the subsequent concentration of this which has led to the formation of the chert nodules. The base of the limestone normally has a sharp junction with the underlying beds, but in several cases there is a gradual transition upwards from sandstone. The bottom few feet, over much of the area, have been recrystallised and dolomitised, now being a characteristic buff colour, and over about 8 square miles to the north of Marske, the lowest few inches of the limestone have been silicified to a thin black chert band.

In many places south of Stainmore, a cherty series is developed on, or a little above, the Underset Limestone. There is no record of it on the Alston Block, and Reading (1954) found it to be absent across most of the Stainmore syncline, only making its appearance on the south side, in the Bowes region, where outcrops are limited to the vicinity of the village. There, it consists of up to 16' of hard fossiliferous mudstone and dark chert bands, which are separated from the Underset Limestone by 20' of shale, and which Reading considered to be the lateral equivalent, in part, to the Iron Post Limestone. Along the south side of the anticline, however, outcrops of chert occur, separated from those near Bowes by at least 7 miles, which lie directly on the Underset Limestone. This is the normal occurrence throughout much of Swaledale and Wensleydale, and it is most probable that the chert series at Bowes is at a different horizon to that found further south and SE. The occurrence of chert is very sporadic, however, and in upper Swaledale and Arkengarthdale its thickness varies rapidly between zero and 36', the maximum occurring near Reeth (Dakyns et al. 1891, pp.110 and 116). The greatest thickness of chert encountered during the present survey was 26', north of Marske. Through a combination of surface outcrops and sub-surface information, it is known to thin towards, and be absent north and east of a line drawn roughly from Barnard Castle to Barningham Moor, along the south side of the Gilling valley and across to Middleton Tyas. On the south side of the Swaledale-Gilling valley watershed it becomes well-developed, and generally takes the form of a banded series of siliceous mudstones and dark cherts, which commonly contain calcareous sponge spicules (Plate 7B, p. 70). There is no evidence of organic origin for the silica, which was probably chemically precipitated at the time of deposition (but see Chapter 9).

The shale between the Underset Limestone and Chert, from which the goniatites were obtained in the Mount Pleasant bore, is exposed in one place only, at Gilmonby Bridge (near Bowes). Diligent searching here by a number of people has failed to find any goniatites, but Posidonia membranacea (M'Coy), which occurs with the goniatites at Mount Pleasant, has been obtained. In the beds overlying the Underset Chert in the Bowes area, clastic material makes only a very small proportion of the cyclothem, and in places is virtually absent. Around Bowes, and westwards at least as far as God's Bridge (956127), a thin coal underlies the Main Limestone, beneath which a very thin and variable sandstone rests on shale, which continues down to the Underset Chert. Thus the Tuft Sandstone of Stainmore and further north is hardly represented. But further SE, along the south side of the Gilling valley, a very strong sandstone develops beneath the Main, although on the north flank of the anticline it remains thin and broken up by shale bands. An interesting exposure occurs in East Layton quarry (155106), where it contains a suite of copper-bearing minerals, including bornite and chalcanthite. High on Barningham Moor, near the watershed between the Greta and the Swale, the sandstone is at least 60' thick, which is considerably greater than any record for the complete Iron Post cyclothem north of Stainmore (Dunham, 1948, p.25). It is unusual to find coal capping this sandstone, which often becomes coarse near its top, and although a gradual passage up into the overlying Main Limestone has been recorded from several localities, a sharp junction is much more common. In the Richmond area, this sandstone contains about 20% feldspars, and is properly described as arkosic.

The separation of the Underset and Main Limestones averages 100' over the area, although in the west, where the equivalent of the Tuft is almost unrepresented, it falls to about 80', and in the extreme east, around Middleton Tyas, it is apparently as little as 50'. This compares with between 40' and 70' for upper Swaledale, and up to 150' in parts of Wensleydale (Dakyns et al. 1891, pp.92 and 110). On the Alston Block, the comparable interval is less variable, being generally about 100', despite the presence of the double cyclothem.

DETAILS

(i) Underset Limestone

(a) Round the anticline, north of the Swaledale-Gilling valley watershed.

The Underset Limestone is very poorly exposed along the northern flank of the anticline. The outcrop closes at its western end in the Greta, at Gilmonby Bridge, below Bowes (995133). Here it is a creamy-grey crinoidal limestone, noticeably paler than the other limestones of the Middle Limestone Group, and the full thickness of only 12' is seen. Due to a low northerly dip nearly at right angles to the bank, the outcrop extends on either side of the bridge for 150 yards. The limestone is evidently dolomitic in part, and beneath the bridge has been laced by a network of thin calcite veins. Eastwards, along the north bank of the river, the limestone can be traced for about 1/3 mile, where it is seen in the bank beneath the Bowes Sewage Works, and at the top of Robin Hood Scar (003132), it is seen in contact with the underlying sandstone. Eastwards from this exposure, the limestone is completely lost beneath drift cover for 7½ miles, its position on the map being inserted relative to the Main Limestone above. The Underset has been proved in both the Mount Pleasant and Wycliffe bore-holes to the north. In the former it was 25' thick, grey and crinoidal, with a 9" band of limestone conglomerate 7' above the base, while the latter proved it to be only 18' thick, slightly argillaceous in the upper part. The next exposure on the north side of the Gilling valley occurs in a very small drift-free patch half way up Stephen Bank, on road A.66 (122107), where 5' are seen in an old quarry. 250 yards further SE, however, the drift becomes sufficiently thin for the limestone to form a feature, which can be followed for some 700 yards along the top of the valley, just south of Watling Street. There are a number of old quarries along the length of this feature, in which a maximum of 16' of limestone have been exposed, the upper 4' beneath the drift being rather broken up, due to a combination of pre-glacial weathering and ice action. Some chert nodules occur in the more massive limestone beneath this zone.

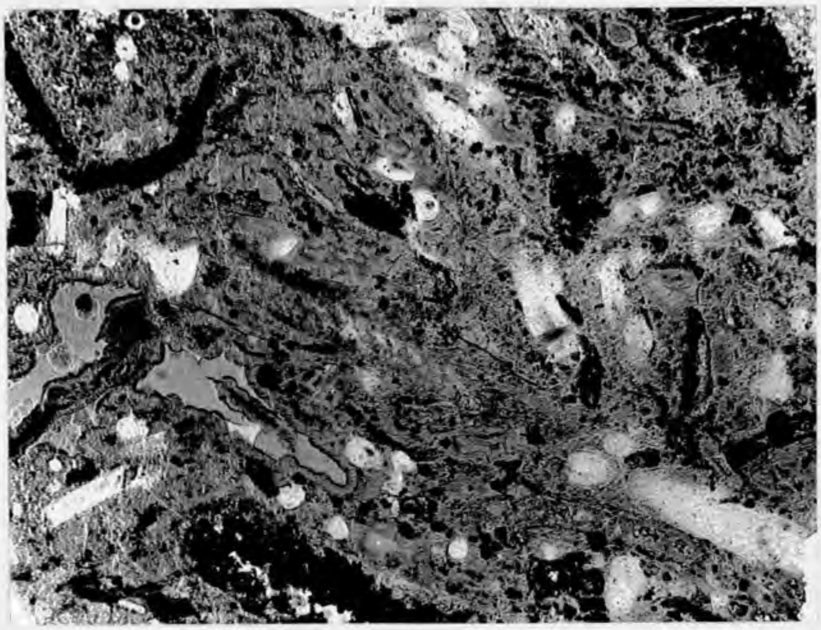
Further east, the Underset completely disappears into drift again for another 3½ miles, and is next seen in a quarry on the south side of West Lane, ¾ mile west of Melsonby (186087), where the drift cover is only 5'. The pre-glacial surface must have been very uneven, however, because a bore-hole in the orchard of Brecon House (300 yards north of this quarry, and level with it) entered the Underset Limestone beneath 47' of boulder clay. The quarry section is of 45' of limestone, in part of quite different lithology to that seen further west. The lower 25' are of the grey crinoidal type usually associated with the Underset horizon, and are even-bedded. But the upper 20' are coarsely crinoidal and strikingly current-bedded, the dip of which is 15° to the south, in opposition to the gentle northerly dip of the even-bedded lower part. This current-bedded limestone is virtually composed of crinoid debris, but in the upper part of it chert nodules and some productids are present.

SW from here, limestone is glimpsed in an old quarry 300 yards east of High Grange Farm (182082), 30' lower than (and 1/3 mile up-dip from) the West Lane quarry, and a fault (downthrowing SE) has been inserted on the map between the two exposures. ½ mile ESE from High Grange (186080), an excellent section in the lower, even-bedded part of the Underset Limestone exists in a worked quarry. Here, 25' of crinoidal limestone are seen beneath thin drift, resting on gannister in the floor of the quarry. The lower 2-3 feet are brown and cavernous, and have been altered to a rock consisting essentially of an interlocking mass of dolomite-ankerite rhombs. Some of the cavities are filled with quartz (individual crystals reaching 5 mm. in length), the presence of which antedates the alteration, and suggests that this limestone may contain a certain amount of silica as a depositional constituent (but see Chapter 6). The rest of the limestone is blue-grey and even-bedded, with dark argillaceous streaks appearing about 20' above the base, and with a band of chert nodules (average size 6" x 4") between 5' and 7' above the base. These nodules are composite, having a pale rim, and a dark glassy core. In thin section, the pale rim, which has a sharp margin against the limestone, and generally constitutes the bulk of the nodule, is seen to be of about 75% microcrystalline silica, much of it in radial aggregates, in which are embedded numerous small brown rhombs of ankerite, the rest of the rock being of corroded calcareous remnants of brachiopod and crinoid fragments. The only differences seen in the dark core are in the silica aggregates, which are about twice the size, and in the ankerite rhombs, which are not quite so numerous. It is evident that complete recrystallisation of all except the larger calcareous fragments had taken place after an initial concentration of silica, the carbonate which was not displaced in the process having recrystallised within the new siliceous matrix. Some 250 yards east of this is another smaller quarry section, which exposes 20' of limestone, complete with chert nodules and recrystallised base, the dip of which is 3^{o} west, as opposed to 3^{o} east in the western quarry. There has been ponding between the two quarries, due to the converging dips and the impervious gannister underlying the limestone, evidence of this being seen at the eastern end of the larger, worked quarry. Here, joints have been opened up into small caverns up to 6' above the limestone base, in which stalactites are common. The lower 2' are in many instances filled with a brown clay, embedded in which are lumps of the surrounding dolomitised limestone, and also water-worn pebbles of chert (from the nodule band) and gannister (from the floor). In one widened joint, this material has been lithified by carbonate to a conglomerate, the pebbles in which are up to ¾" in diameter. Eastwards, the limestone is next seen in small drift-free patches in and around Melsonby. In an old roadside quarry 250 yards south of the village centre (197082), 22' of even-bedded, well jointed limestone underlie 8' of highly crinoidal, slightly current-bedded limestone, the joint surfaces bearing traces of chalcopyrite and malachite. In the beck and by the roadside for ¼ mile east of the village cross-roads, there are numerous exposures of the upper current-bedded part of the limestone (sometimes with irregular silicified patches) which is composed largely of crinoid ossicles, commonly reaching 1 cm. or more in diameter. ½ mile further east, the Underset is again seen in Barton Old quarry (211081), where some 15' of the lower even-bedded part have been exposed. It is the rather pale creamy-grey colour normally associated with this horizon further westwards, and contains occasional small chert nodules. An unusual feature is the presence of a coating (up to 1 cm. thick) on some of the joint surfaces of radial aggregates of very finely fibrous, dead-white aragonite ($N_x = 1.530$, $N_z = 1.685$), which is probably of comparatively recent origin. On the other side of the Roman road, the largest single exposure of the Underset Limestone occurs in Barton quarry, where there is over a mile of quarry face. Drift cover is between 2' and 20' thick, noticeably red-brown along the eastern side (Triassic material), and the quarry is entirely in the upper coarsely crinoidal part of this horizon, at least 42' of which are seen. It may well be more than this, but estimation of the thickness across the quarry is difficult due to the large-scale current-bedding. The limestone is made up almost entirely of crinoidal debris, including columnals up to 10" in length. A few productids are present, and chert nodules occur in bands which, under the microscope, are seen to consist largely of silica in radial aggregates up to 0.1 mm. across, in which are set many pale brown ankerite rhombs of all sizes up to 0.5 mm. across. The remaining part is taken up by calcite, in the form of crinoid ossicles, corroded both inside and out. Here again, the whole nodule (apart from the resistant calcareous remnants) has recrystallised after an initial concentration of silica, the undisplaced carbonate coming out as euhedral ankerite embedded in the silica.

The Underset Limestone proved to be only 34' thick in the Newton Morrell bore-hole (237093), the lower 26' being a hard blue-grey slightly argillaceous crinoidal limestone. This was capped by only 8' of pale coarsely crinoidal material, in strong contrast to the very much greater thickness in Barton quarry, only 1-1/3 miles to the SW.

A quarry 150 yards north of Low Merrybent Farm (211077), in a small drift-free patch, shows 32' of lithified current-bedded crinoidal debris, also with bands of chert nodules, resting on 6' of limestone with normal lithology. The farm itself is built on solid limestone, but southwards the ground is drift-covered for 1/3 mile as far as Kneeton Hall, 200 yards west of which (211069) limestone (on which are traces of chalcopyrite and malachite) has been brought up from an old shaft. The same minerals, together with azurite and chalcocite, have come from another shaft 200 yards NW of the Hall, where they are also associated with galena. In Kneeton Hall quarry (214072), a section of 44' of Underset Limestone is covered by up to 15' of drift (containing boulders, mainly of limestone, up to 5' across), and has a well-striated and polished upper surface. The dip varies between 4° and 9° away from the centre of the Gilling dome, here some 3 miles distant. The limestone section shows 30' of normal limestone (with chert nodules at intervals) overlain by 14' of highly crinoidal limestone, slightly current-bedded, with a few productids. In the SE corner of the quarry, 21' above the base of the section, a lenticular band of <u>Aulophyllum</u> up to 8" thick is well seen. Across the Great North Road, coarse crinoidal limestone emerges from the drift for about 100 yards in the field to the NE of Kneeton Cottages (217069), and ¼ mile north of Middleton Lodge, in Acre Howden Plantation (223072), 20' of coarsely crinoidal limestone (with a horizon of chert nodules) has been quarried in another small drift-free patch. Crinoidal limestone is seen by the side of Lodge Gill Wood, 300 yards SE of Middleton Lodge, and again in small exposures in another drift-free patch straddling Five Hills Lane, between ¼ and ½ mile north of Middleton Tyas. A good section occurs in Leyberry Plantation, on the eastern outskirts of Middleton Tyas (232059), where there are many small old quarries. The large quarry shows 50' of current-bedded coarsely crinoidal limestone with chert nodules, overlain by the Underset Chert, all dipping SE. But 80 yards SE is another quarry section showing 20' of current-bedded limestone, also dipping SE, the two quarries being separated by a branch of the main Middleton Tyas fault, south of which the Underset Limestone occurs as an inlier. It is well seen in Lamberry Bank Plantation, just north of the Vicarage (230057), where 35' of limestone, very variable both in lithology and dip, are exposed. Large lenticles

A. Underset Limestone, Black Scar quarry. The current-bedded upper part of this horizon is truncated by an erosion surface, on which lies the thin Underset Chert (overlain by boulder clay).



B. Underset Chert, Marske Beck. x 42. Patchy areas of carbonate and small rhombs of dolomite (both dark) in brown microcrystalline silica, outlined by which are spicules replaced by clear secondary silica with relatively high refractive index. A cluster of very small hexagonal quartz crystals has developed in the centre of the photograph (see Chapter 9).

of current-bedded crinoidal limestone are enclosed in the normal pale grey limestone, and it would appear that this was near the fringe of the area of disturbed deposition. Outcrops occur at intervals along both sides of the valley as far south as Black Scar quarry (231052), the most southerly exposure of the inlier. Here, in the most spectacular of all the Underset exposures (Plate 7A, p. 70), 46' of limestone are seen in the northern end of the quarry. The lower 13' are of the normal pale grey even-bedded type, above which are 24' of strikingly current-bedded coarsely crinoidal limestone, with isolated cherty patches. This in turn is overlain by 9' of less coarsely crinoidal limestone, glauconitic towards the top, with occasional productids and Aulophyllum, and from which came the lowest specimen of Hyalostelia recorded in the area. On this rests the Underset Chert. In the south end of the quarry, however, 4' of argillaceous limestone on 3' shale are additionally present beneath the chert, the base of which is clearly an erosion surface cutting down to the north. The current-bedding in the main bulk of the limestone is dipping SW. Another striking feature of this quarry is the sporadic occurrence of malachite and azurite at all levels, particularly on bedding planes and joint surfaces, and at the north end, a joint gap (filled with brown clay) was found to contain a vertical slab of chalcocite up to 1" thick and nearly 1 square foot in area. It has been suggested (see chapter 11) that copper mineralisation was by deposition from downward-percolating solutions. Certainly there is no evidence for a fault within ¼ mile of Black Scar quarry.

In the south-eastern corner of Sedbury Park, the Underset Limestone is exposed immediately to the east of the Sedbury fault at

'The Rock' (200047), where 38' of grey crinoidal wavy-bedded limestone is seen dipping away from the fault at 25°. The dip soon flattens out, however, and the limestone makes a feature for some 250 yards SE before being lost in drift. It is next seen in Skeeby, 1¼ miles to the south, where a small quarry in the yard of Hall Farm (200025) exposes 12' of pale creamy-grey even-bedded crinoidal limestone. Opposite this, on the north side of the road, a larger quarry exposes 23' of it, here with occasional chert nodules. Between Skeeby and the Gilling-Richmond road, drift cover on the outcrop of the Underset Limestone is thin or absent, and it makes a good northward-facing feature for much of this distance. Limestone occurs abundantly in the soil above the feature, and small shallow quarries are numerous. 400 yards east of Olliver (188031), the base of the limestone and the underlying sandstone are seen to be separated by 9" of passage beds, through which the change from rather coarse sandstone to limestone is entirely gradual. The lower few feet of the limestone have been dolomitised, and are largely recrystallised. Numerous small cavities in the rock, mainly no more than 1-2 mm. across, are lined with tiny rhombs of dolomite-ankerite. 300 yards SW of Olliver (183029) a quarry into the feature has opened up a very good section of the Underset Limestone. 27' are exposed, of which the lower 12' are even-bedded, with massive posts several feet thick, and from which a small but complete crinoid calyx was collected (an unusual find not repeated anywhere else in the area). Above this are 15' of strikingly current-bedded crinoidal limestone, coarse at several horizons, with abundant chert nodules in the lower 8'. The dip of the current-bedding is between SSE and SW.

A short distance west of Olliver quarry, the limestone disappears into the drift again, to be next seen ¾ mile away on the western edge of Aske Park, 200 yards SW of 'The Temple' (173035), in a small and very shallow quarry. Drift again obscures it as far as the Richmond-Ravensworth road, where 18' of limestone have been exposed in a roadside quarry (162035). There is no evidence anywhere in Aske Beck for the Underset, but on the south side of Black Plantation the base of the limestone makes a low NE-facing feature for about 750 yards, which is clearly displaced by a fault about ¼ mile north of Low Coalsgarth (154038). 100 yards west of Aske Moor Farm (150037), an isolated and restricted exposure in the bank of the overflow channel shows the very top of the limestone beneath a thin bed of siliceous limestone, the Underset Chert. 300 yards NW from here, a limestone outcrop occurs adjacent to an old quarry in the underlying sandstone. As so commonly happens near the base, this limestone is pale brown, with small cavities, and is seen in thin section to be recrystallised (except for some crinoid ossicles) into an interlocking mosaic of brown dolomite-ankerite rhombs, all other traces of organic remains having been obliterated. Across the Whashton Springs fault, the top of the limestone is seen in a shake-hole (144039) about 30' below the previous outcrop, where 5' of crinoidal limestone underly the Underset Chert. At Sturdy House (135051) it emerges from the drift to make a bold feature for 200 yards, as far as the Feldom fault. Strong springs issue from the base of the feature, and a quarry into it has revealed 15' of pale creamy-grey crinoidal limestone. NW of the fault, a prominent feature some 25' high, which runs for ½ mile inside and parallel to the Feldom moraine, may have a solid foundation even though it is drift-covered. The Underset is next seen below Feldom Rigg where, in an old quarry 1000 yards south of Pace's House (115058), 10' of pale crinoidal limestone are seen underlying the Underset Chert. 30 yards to the south there is an isolated limestone outcrop, and a fault (of throw at least 15' north) separates the two exposures. A little way NW, a series of swallow-holes (in one of which the limestone is seen beneath 8' of boulder clay) at a level some 40' below the quarry necessitate the insertion of another northerly-throwing fault north of the quarry. ½ mile SW of Pace's House (109062), the limestone emerges from the drift for about 100 yards, where its lower part (together with the underlying sandstone) is recognised. This locality is 25' higher than the swallow-holes marking the limestone top only a short distance to the SE, and another fault must be drawn between the two exposures.

Beyond this, the outcrop is obscured for another ¾ mile, to be seen again ¼ mile SE of Hornbriggs (097063), where two mineralised faults through the limestone have been worked. The NE-SW branch has a throw NW of 10', and has brecciated and dolomitised the limestone, which is veined by calcite. The main N-S fault has carried an outlier of limestone across to the NW side of the little beck, which originates at a strong spring at the base of the limestone just east of the main fault, now (1954) being harnessed for the public water supply. Shake holes occur just north and south of Crumma House (093071), and from the top of Moor Lane (092075) ½ mile westwards to Windsor Lodge (084074) a series of swallow holes (in one of which limestone is seen beneath 7' of drift) clearly mark the top of the Underset. In another swallow hole at the northern end of Harker Moss (081072) 4' of pale grey crinoidal limestone are seen beneath the overlying shale and drift. Further swallow holes occur in an overflow channel between Low House (078072) and Byers Hill (068074), in several of which southerly-dipping limestone, grey and crinoidal, is seen overlain by shale. In one hole 50 yards west of the road from Newsham, galena occurs as an extremely thin patchy film on a joint surface. The nearest known fault is 450 yards away to the west, beyond which the limestone is again seen in a large shake-hole into the floor of the overflow channel. 1/3 mile north of Low House a roadside quarry (078078) has exposed 12' of partially dolomitised crinoidal limestone near the base of the Underset, which is overlain by 5' of boulder clay containing a Shap granite erratic. Westwards for 1½ miles scattered shake holes marking the top of the limestone comprise the only evidence for the Underset. In Osmaril Gill (054079) limestone comes to the surface in either bank at 1250' O.D., and west of this for 2/3 mile the drift is only thin, occasional springs marking the base, and an almost continuous line of shake holes marking the top of the band, which is apparently about 25' thick. 3 large swallow holes into the drift are seen at 1270' O.D., 1/3 mile NW of White Fell, but beyond this the Forestry Commission's plantation is so thick that penetration is exceedingly difficult, and estimation of position with any accuracy virtually impossible. Only thick drift was seen, and the Underset Limestone has been mapped in relationship to the overlying Main Limestone, and also (where present) on the shake holes and springs plotted by the Ordnance Survey previous to afforestation.

North of the North Spanham fault, the limestone comes out of drift at the farm (017101) and makes a feature for ¼ mile round the south side of the overflow channel. There are numerous outcrops on the feature, and a section of the lower 16' is seen, dipping north at 3°, in an old quarry some 200 yards north of Spanham. North of the North Spanham fault, the top of the limestone is marked by frequent shake holes for about a mile, as far as Long Side (008106), at the SE end of which a shake hole in the overflow channel (which drained the glacial lake beneath Spanham West Hill) exposes 7' of partially dolomitised limestone (veined by calcite) beneath the Underset Chert. North of this, at Seley spring (008107), the limestone makes a solid feature for some 300 yards, and is exposed in a small hollow. It is seen again ¼ mile to the west, at a spring, where it is grey and crinoidal, and 200 yards NW of Farewell Farm (002119) the first of a series of shake holes extending as far as the road to Plover Hall marks the top of the limestone. The base makes a feature round the east side of Quarry Hill, on the top of which grey crinoidal limestone (in part dolomitised) has been quarried. The next exposures are in How Low Gill (999126) which is dry for 150 yards, and in a spring at the southern end of Tom Gill Plantation (999128) the base of the limestone is seen. 500 yards south of Gilmonby Bridge, in a small drift-free patch, both the limestone and the overlying shale are seen in adjacent exposures by the side of the road, but are separated from the Gilmonby Bridge exposure, already described, by a tract of superficial deposits.

(b) South of the Swaledale-Gilling valley watershed.

The Underset Limestone is seen in the valleys running south into the Swale. In Arndale Beck, 350 yards north of the confluence with Moresdale Gill (053050), the base is seen to consist of 4" of dark glassy fossiliferous chert passing down into the underlying gannister, above which 10' of northly-dipping limestone are exposed. Further upstream the rest of the Underset is obscured by landslips, but 500 yards up Moresdale Beck (050049), the fossiliferous chert band (dark and glassy in the upper 2") is again seen grading up from the underlying gannister through 4" of passage beds, and is overlain by limestone. In thin section, the passage beds are seen to be a normal transition from sandstone to limestone, with fragmentary fossils, and the overlying chert band to be a fossiliferous limestone with scattered quartz grains, the matrix of which is of recrystallised dolomite, in which most of the fossils (including stout brachiopod fragments) have been altered to microcrystalline silica. There are numerous small sponge spicules, averaging 0.05 mm. in diameter, but there is no reason to suppose that they were originally siliceous, since they are now composed of the same type of silica as that which has replaced the originally calcareous organisms. In the dark glassy part of the chert band the groundmass has also been partly eaten away by silica, but 25-40% of dolomite still remains. As the structure of some of the silicified fossils, particularly foraminifera, remains perfectly clear in many instances, silicification must have taken place earlier than recrystallisation of the matrix, because the latter process invariably obliterates the finer organic structures.

South of Moresdale Beck, the only evidence of the Underset is near Moresdale itself. 50 yards north of the building (054058) the base of the limestone is seen at a spring, from which a feature can be followed for 250 yards to the SE. And 150 yards SW of Moresdale, several swallow-holes mark the top of the limestone.

Beyond this, to the Faggergill-Waitgate fault, the mapped outcrop is conjectural. Along the north side of Holgate Beck, the limestone has been quarried 100 yards east of Kexwith, but beyond this, as far as a point 150 yards south of West House (063046), a very extensive landslip covers everything beneath the Main Limestone. South of West House, the Underset emerges from beneath the landslip and makes an excellent feature, on which are many small outcrops, all the way round the south side of Holgate How for a distance of ¾ mile before being lost in an expanse of peat east of the Newsham-Richmond road.

South of the Faggergill-Waitgate fault the Underset is seen dipping 20° southwards by a barn 350 yards north of Schoolmaster Pasture (059041), and on the east side of Holgate Beck it outcrops on Hollin Brow (065040). At intervals between these points it makes a sufficiently good feature to enable the horizon to be mapped with confidence. In the thin strip of ground north of the cross-fault through Rispey Wood, a single outcrop of brecciated limestone (overlain by dark chert) dipping NE at 27° marks the Underset west of the beck.

The Underset Limestone emerges from the peat cover east of Holgate How in Rake Beck, and enters the stream bed 200 yards above Rake Gate (079057), where a scar on the north bank shows a full section of 25' of pale grey crinoidal limestone, overlain by the Underset Chert. The beck is dry for 200 yards above this section, to where the chert enters the stream. Northwards from Rake Gate, a broad dry valley (the Harker Moss overflow channel) affords several glimpses of the top of the limestone in swallow holes. 350 yards north of the bridge (080058), shale is seen overlying limestone with a 5° northerly dip, and between 250 and 600 yards further north the limestone is seen again in several more shake holes, brought up by a reversal of dip. East of Long Green Farm a small transverse fault brings the limestone up again in a shake hole, and all the way across Harker Moss it must be only a short distance beneath the surface, joining up with the series of shake-holes along the northern margin, on the watershed. On the east side of Rake Beck, the base of the Underset can be fixed by occasional outcrops of limestone resting on the underlying sandstone for 350 yards below Rake Gate, but beyond this it is not seen as far as a point 130 yards SW of the remains of High Waitgate (084050), where a good feature (along which are several outcrops) emerges and can be followed as far as the main fault. The top of the limestone is well marked SE of High Waitgate by a series of shake holes, in some of which chert is exposed. East of Rake Gate, a N-S feature some 250 yards long carries a number of outcrops of creamy-grey crinoidal limestone, the Underset again. This is some 40' higher than the limestone base seen in the right bank of the beck, and an up-faulted block has been mapped to explain this occurrence. Between the two branches of the Waitgate fault, where it crosses the gill, the Underset is well seen on the eastern side of the valley, where a steep limestone-covered feature is truncated to the south, and runs into sandstone northwards, clearly defining the faults.

South of the Waitgate fault, the Underset Limestone is dropped down near to the beck, and 30' of it are seen in a scar 80 yards SW of Waitgate (085046). But the best exposure is in Buzzard Scar (086042), where the full thickness of 34' is seen beneath the Underset chert, the lower 2"-4" being of fossiliferous chert passing down into gannister (as in Arndale and Moresdale Becks). Immediately downstream from the southerly of the two Dickey Edge faults, the top of the Underset Limestone is seen (084038) dipping SW into the beck beneath the chert, and is not visible again until it is seen on the east side of the valley at 870' O.D. (091025), between the two faults which straddle Telfit, where 20' of crinoidal limestone (overlain by dark chert) are exposed. South of the faults, the limestone outcrops on both sides of the valley. On the east side, 16' are seen on the underlying sandstone ¼ mile SE of Telfit, at 900' O.D. (090023), and above Orgate, at 825' O.D. (093021) the base is seen to be brown and dolomitic, with many small cavities. On the west side of the valley, the Underset is in contact, at the fault, with the top of the Richmond Chert Series, and the throw at this point, ¼ mile SW of Telfit (084024), must be about 250' to the north. The limestone is exposed at intervals for 350 yards south of the fault, both the top and the bottom being visible, and giving a total thickness of 27'. It is creamy-grey and crinoidal, dolomitic at the base, and here contains the highest recorded specimens of Howchinia (see p. 27). There are irregular silicified patches in the upper 4' which, in thin section, are seen to consist largely of relatively coarse radial aggregates of fibrous silica (individual fibres being up to as much as ½ mm. in length), in which are embedded small rhombs of dolomite. All except the stoutest crinoid ossicles have been replaced in the centres of these patches. The most likely origin for the silica in this instance would seem to be from the overlying cherts.

Southwards, both sides of the valley are obscured by landslips, but the limestone is exposed at Pillimire Bridge (100007), where it is seen coming out from beneath the chert. There is no further evidence for it until it is seen again in Clapgate Beck, where isolated exposures occur on the east side of the valley ¼-1/3 mile south of Low Feldom (113035), and 200 yards south of the confluence with Hey Gill, where 8' of limestone are seen overlying sandstone. Just below Clapgate Bridge (112017), 12' of limestone are seen overlying sandstone, with a gap of 4' beneath the lowest exposure of the chert. The limestone cannot therefore be more than 16' thick at this point.

For 2¾ miles eastwards, along the north side of Swaledale, the Underset is completely obscured by landslips. But several stream sections expose this horizon on the south side of the river, in one of which it is 36' thick. Limestone is seen in the Swale beneath Hudswell Banks, ¼ mile downstream from Lownethwaite Bridge (149005), and also ¼ mile above the old mill, where 6' are underlain by gannister. 15' of limestone are exposed in a quarry on the south bank, at the end of the weir (156008), a short distance east of which the outcrop must close because eastwards the scar of the Main Limestone along the south bank drops down rapidly towards river level.

(ii) <u>Beds between the Underset and Main Limestones</u>

This section includes stratigraphical descriptions of the Underset Chert, which is only present in part of the area, and then not at a constant horizon, so this arrangement is considered to be more satisfactory than devoting a separate section to it. The petrography of the Underset Chert, however, is dealt with separately in section (a) of Chapter 9.

(a) North flank of the anticline

The Main Limestone closes in both the River Greta and Sleightholme Beck a short distance above their confluence 1¼ miles west of Bowes, and in the latter a gorge continues for nearly ½ mile downstream from the point of closure. At the bottom of this gorge, the top of the beds underlying the Main are seen in places, the best of these being beneath Barney Scar (966124), where the section is:-

Carboniferous shale underlying Main Limestone	6"
Coal	2"
Sandy seat-earth, with roots	4'
Massive sandstone	3'
Flaggy sandstone	8'
	15'8"

At a point ¼ mile upstream from the confluence with the River Greta, the top of the Underset Chert appears in Sleightholme Beck, underlying shale which occurs beneath the beds seen in Barney Scar. It is a siliceous sandstone, calcareous in part, and is seen at intervals as far as 250 yards below the confluence. 150 yards above the weir west of Swinholme (981131), the Underset Chert comes up again, and is exposed in the river as far as the old Mill Race beneath Bowes, in which it is seen to overly shale. In the south bank, beneath Gilmonby Hall, 12' of hard fossiliferous mudstone (some bands in which are siliceous with dark flinty cores) is both overlain and underlain by shale, while in the north bank, near Gilmonby Bridge, this horizon is 16' thick and includes nearly 50% of dark flinty chert. 100 yards above the bridge, 20' of shale (the lower 10' of which are exposed) separate the chert from the Underset Limestone. Eastwards from Gilmonby Bridge, there are no further exposures of the Underset Chert on the north flank of the anticline as far as Middleton Tyas.

The beds above the chert are seen at intervals in the north bank of the Greta just above Bowes. Some 35' of shale, nodular and fossiliferous in the lower part, pass up into a thin sandstone, which is overlain by a foot of sandy seat-earth, capped by a thin coal (poor and shaley), pieces of which occur in the soil beneath the Main Limestone scar. Above the coal, and beneath the Main, several exposures show 6"-9" of shale, which is rich in small spiny productids. Beneath Kilmond Scar (1¾ miles east of Bowes) flaggy sandstone is seen at intervals, and is 20' thick at the eastern end of the scar, at Kilmond Wood Farm (036136). Above the scar, where the Main Limestone is worked in Kilmond quarry (023136), an excavation for the foundations of a crusher revealed 12" of shale on 3' of pale grey sandy seat-earth on 13' of sandstone underlying the Main. There is no coal in this section, but the shale band is dark and extremely fossiliferous, being crowded with spiny productids and bryozoa.

A mile north of Kilmond Scar, the Mount Pleasant bore has proved 125' of beds between the Main and Underset Limestones, some 15' more than the estimated separation at Bowes. A condensed version of the section there is as follows:-

Fossiliferous shale underlying Main Limestone	6"
Sandy seat-earth, coal smut over	1'6"
Sandstones, with thin shale bands, mainly non-marine	41'
Shale, mainly marine, but some plants near top	37'
Hard fossiliferous chert, calcareous and argillaceous	7'3"
Calcareous shales and dark argillaceous limestones	25'9"
Shale, partly pyritic and nodular, on Underset Limestone	12'

As compared with the Bowes section 3 miles away, the arenaceous beds beneath the Main are very much thicker, and those assigned to the Underset Chert, which must include the calcareous shales and argillaceous limestones, are over twice as thick.

The next exposures of this horizon eastwards from Kilmond Scar are 2½ miles away, in the Tees. The Main Limestone rises above the level of the river at the eastern end of Rokeby Gorge, and for 2/3 mile over the crest of a small northward-pitching anticline, before the limestone again enters the Tees north of Rokeby Park (083144), the beds beneath the Main are continuously exposed in the south bank. A composite section, built up over this distance, is as follows:-

Carbonaceous sandstone, underlying Main Limestone	8'
Sandstone, partly flaggy, partly false-bedded	17'
Carbonaceous micaceous sandstone	4"
Coal, seen only on E. flank of anticline	5"
Seat-earth	8"
Sandstone	11'
Shaley sandstone and sandy shale	2'
Shale	18'+
	57'2"

A distance of 300 yards up the Greta from its confluence with the Tees, the Main rises out of the river, and for ¼ mile further upstream the underlying beds are exposed in the east bank at the base of Mortham Wood. Here, the section is:-

Shaley sandstone with irregular coaley streaks, Main Limestone over	6"
Poorly bedded sandstone, with carbonaceous partings	6'
Shaley sandstone, micaceous, with slight current-bedding	3'6"
Sandstone, massive and current-bedded	6'
	16'

Most of Mortham Wood is on the drift overlying the above section, however, and eastwards glacial deposits entirely obscure these beds as far as the little quarry 1/3 mile NE of West Layton (147104), where a glimpse of sandstone is obtained at the base of an outlier of Main Limestone. 2 miles east of Mortham Wood, however, the Wycliffe bore proved 138' of beds between the Main and Underset Limestones, a condensed version of the section reading:-

Dark fossiliferous shale underlying Main Limestone	1'8"
Sandy shale, with irregular coaley streaks	1'6"
Non-marine shales and shaley sandstones	11'10"
Mainly sandstone, shaley partings	13'
Shale and sandstone bands, fossiliferous	4'
Shale, with productids and scattered plant debris	87'6"
Mudstone, with scattered productids	7'6"
Shale, good marine fauna, overlying Underset Limestone	10'
	138'

In this section, the only part bearing any resemblance to any part of the Underset Chert is the 7'6" band of mudstone 10' above the Underset Limestone. It is thought that this compact horizon, similar to some of the mudstones seen west of Bowes, is the lateral equivalent of part of the chert, but there is here no sign of silicification. The core of the shale overlying the Underset (the same horizon as that in the Mount Pleasant bore from which Johnson's Girtyoceras specimens were obtained) was very carefully searched, but yielded no goniatites. This dark shale was also searched at its outcrop near Gilmonby Bridge, but again no goniatites were found.

The beds immediately underlying the Main Limestone are well seen in East Layton quarry, on the SE or upthrow side of the mineralised Sorrowful Hill fault (155106), where the following section is seen in contact with Main Limestone to the NW:-

Carbonaceous shaley sandstone, underlying Main Limestone	1"
Sandstone	1'3"
Finely banded shaley sandstones and sandy shales	7'
Coal, 0-6", enclosing lenticular sandstone, 0-2'	0-2'6"
Soft carbonaceous sandstone	3'6"
Shale	1"
Sandstone	5'
	17'7"

Enclosed in the shaley sandstone at the top of this section are common nodules of bornite, about 1" across, which are also occasionally found in the sandy shale about 18" below the limestone base. Malachite and azurite occur abundantly throughout the section (in the vicinity of the fault), the former in both fibrous and botryoidal form, and the latter sometimes in crystals big enough to be easily resolved by the naked eye. A pale sky-blue mineral aggregate encrusting the soft carbonaceous sandstone, thought to be much too pale in colour for azurite, was separated and found to have refractive indices between 1.510 and 1.540. A test for sulphate was positive, and a tentative identification as chalcanthite ($CuSO_4.5H_2O$) was confirmed by an X-ray powder photograph.

This mineral has only been previously recorded in England from Cornwall and from the Parys Mine, Anglesey (A.G.W.Kingsbury, personal communication), and is likely to be of very restricted occurrence due to its high solubility. More basic sulphates such as langite and brochantite are by no means rare on decomposing copper ores, but chalcanthite is only present where conditions are comparatively dry. In East Layton quarry, the locality (in a temporary cavity in the fault zone) was overhung and consequently protected, and was evidently sealed off from percolating waters by the impervious beds between it and the overlying Main Limestone.

SE from East Layton quarry, these beds are drift-covered as far as Middleton Tyas, but a section from the Newton Morrell borehole (237093), beneath 135' of drift, reads:-

Basal Permian beds	
unconformity	
Purple-stained sandstone, abundant white mica	2'
Shale, slightly sandy with reddened patches towards top	14'
Shale, with horizons of small flattened crinoid ossicles	6'
Calc. shale, with thin irregular shaley limestone bands and abundant flattened crinoid ossicles, traces of malachite	13'
Underset Limestone	35'

Black Scar quarry (231052) exposes the beds overlying the Underset. A section from the south end of the quarry is as follows:-

Shale, boulder clay over	18'
Siliceous limestone	4'
Dark chert	4"
Siliceous limestone	1'3"
Dark chert	10"
Streaky impure limestone	4'
Shale, fossiliferous, with traces of malachite, on Underset Limestone	3'
	31'5"

The top shale (the 'Black Scar'), extremely difficult to reach, is apparently unfossiliferous, and contains numerous pretty white rosettes of gypsum, about 2 mm. in diameter, on the bedding planes. The underlying beds, down to the base of the lower dark chert band, comprise the Underset Chert (here 6'5" thick), and the shale separating it from the limestone contains brachiopods and bryozoa. Bornite nodules (which can be found on the dump in the centre of this part of the quarry) are presumed to have come from this shale. But towards the northern end of the quarry, the base of the chert cuts down to remove the two lower members of the above section, so that the chert lies directly on an eroded surface of current-bedded Underset Limestone (Plate 7A, p. 70). The chert is fossiliferous throughout, with many crinoid ossicles and a rich brachiopod band 1' above the base. 200 yards NE of Black Scar quarry, another small quarry has proved 6'6" of Underset Chert as follows:-

Siliceous limestone	4'
Dark chert	6"
Streaky siliceous limestone, with traces of malachite and azurite	2'
Current-bedded Underset Limestone	

Whether or not this chert is equivalent in horizon to that seen near Bowes is unknown, because there is no evidence for the length of interval represented by the erosion surface between the top of the limestone and the base of the chert. The nearest exposure of chert is over 5 miles away to the west, where it appears to rest normally on the Underset Limestone.

A mile west of Black Scar quarry, a bore hole sunk behind Scotch Corner Hotel in 1939 proved the following:-

Red and grey sandstone underlying Main Limestone	36'
Black shale	6'
Red sandstone	1'
Black shale	10'
	53'

The only member of this horizon exposed at the surface anywhere near is 18" of gannister underlying the Main Limestone by the side of the drive through Sedbury Park (on the eastern side of the Sedbury fault (202050), where it contains traces of malachite.

(b) South flank of the anticline, north side of the Swaledale-Gilling valley watershed.

The most easterly exposure of this horizon on the south side of the Gilling valley is on Rasp Bank, south of High Coalsgarth (148029), where sandstone blocks occur on the slope beneath the base of the Main Limestone. Across Aske Beck, on the east side of the hill surmounted by the Jockey Cap Clump (a landmark for many miles around), the sandstone is better seen in an old quarry which proves this facies down to 35' beneath the base of the Main. Round the north side of the Jockey Cap Clump this sandstone makes an excellent feature (on which are loose blocks) for ¼ mile beneath the equally excellent one formed by the Main Limestone.

About 150 yards west of Aske Moor Farm (150038), 18" of siliceous limestone are seen overlying the Underset Limestone, and in a shake hole 1/3 mile further west the Underset is again capped by 18" of siliceous limestone with argillaceous streaks and much crinoid and brachiopod debris. Along the Feldom fault, shale and sandstone from beneath the Main Limestone have been brought up from some old shafts, and can still be examined. Most striking is some rather coarse limonite-spotted sandstone, probably from close beneath the Main, which is comparatively heavily impregnated with malachite, commonly in the form of radial fibrous aggregates.
A small drift-free patch ¼ mile NW of Feldom Nick (113056) reveals sandstone blocks just below the base of the Main, and 1000 yards south of Pace's House (115058), chert is seen in the Underset Limestone quarry as follows:-

Platey siliceous limestone, with brachiopods and bryozoa	12"
Dark flinty chert	10"
Siliceous shale and mudstone, with productids	4"
Underset Limestone	2'2"

Westwards, just beneath the outcrop of the Main Limestone, small isolated outcrops of sandstone occur at the spring 400 yards SW of Hornbriggs (092062), in Crumma Gill (090068) and beneath the old quarry 270 yards south of the remains of Windsor Lodge (085072). SW from the last-mentioned quarry, the outcrop of the Main sweeps round to the south, over the watershed, but westwards drift cover continues as far as the overflow channel west of Byers Hill. Above this channel, sandstone blocks litter the ground up to the base of the Main Limestone, and 400 yards NE from How Tallon (060076) a scree consisting of blocks of massive and false-bedded sandstone reaches down to the ice-edge channel. The sandstone is well seen in situ in Osmaril Gill (052077), where it is about 60' thick. It gets coarser towards the top, and at the western end of Eel Hill (048080), where the Main Limestone overlies an irregular erosion surface, it is better described as a grit. In Woodclose Gill, below Hush Head (041076), massive sandstone is picked up again, and is of about the same thickness. But westwards drift creeps up to the base of the Main, and obscures the underlying beds except in a small quarry at the northern end of Hud Scar (037083), where several feet of coarse limonite-spotted sandstone are seen beneath the limestone.

For 2½ miles W and NW from here, nothing whatsoever is seen of the beds between the Main and Underset Limestones due to thick boulder clay cover. But along the north side of Spanham East Hill

(012101), 4' of flaggy sandstone are seen underlying the Main, while on Spanham West Hill (006100), up to 10' were measured, very different from the grit at the same horizon 2½ miles to the SE. Where the North Spanham fault crosses Eller Beck (991103), 1½ miles west of Spanham, 7' of flaggy sandstone underlie the Main south of the fault, while north of it (in West Black Sike) 8' of flaggy sandstone on 20' of nodular shale are seen. The throw of the fault is here small, as it is in the process of reversing its direction of movement, and the flaggy sandstone is probably little more than 10' in total thickness. In Eller Beck, 1000 yards downstream from the fault, a crag of brecciated banded chert, 6' high, is thrown up on the north bank. This outcrop is quite isolated, and lithologically is more similar to the Main Chert of Chert Gill (a mile to the NW) than to any known type in the Underset Chert. There is evidence, however, that the Main Limestone is present all the way along the north bank of the beck, above this outcrop, and unless a complicated system of faults is invoked (for which there is no evidence), this chert must be mapped above the Underset Limestone, and taken as another of the lithological types belonging to the Underset Chert.

Northwards, along the west side of The Combs (the site of a glacial lake), flaggy sandstone is seen underlying the Main Limestone at intervals. Below Low Green Fell (998113) this section was seen:-

Spring in limestone debris	
Seat-earth	1'6"
Gap	5'
Flaggy sandstone	9'
Sandy shale	

This horizon is next exposed in Chert Gill (989125), practically a mile to the NW, where the section is:-

Grey clay underlying Main Limestone	6"
Poor coal and carbonaceous shale	12"
Sandy shale	4'
Shale, slightly micaceous, very scarce fragments of marine fossils	20'+

This is in striking contrast to the massive sandstone, up to 60' thick, seen underlying the Main less than 4½ miles away to the SE. A similar section is seen in Huggill, ¾ mile westwards, but with the sandy shale up to 10' thick.

Below High Green Fell, on the edge of Hong Kong Plantation (994118), banded chert is exposed some 40' beneath a scar of Main Limestone, and is lithologically similar both to that tentatively assigned to the Underset Chert in Eller Beck, and to the Main Chert seen nearby. As there is no reason to suppose that this exposure is separated from the Main Limestone by faulting, this can be taken as further evidence that just here, the Main and Underset Cherts are similar in lithology. ½ mile NE of this, however, in Low Gill (997124), the Underset Chert is merely a fossiliferous siliceous mudstone, which is again exposed in Craddock's Plantation (995127) where it is underlain by shale. But it may be added here, in support of the two isolated outcrops of banded chert belonging to the Underset horizon, that the same facies, above the Main Limestone, can be seen to pass laterally into mudstone with extraordinary rapidity (see Chapter 6, section (ii)). The Underset Chert is well seen in Chert Gill Plantation (991128), where sharp flexures fold siliceous mudstone into two E-W synclines and an anticline within a distance of 50 yards, the dip into the folds being as steep as 45°. Exposures are sufficiently good, however, to show that faulting is unlikely. The next outcrops beyond Chert Gill are in Sleightholme Beck to the west, and the River Greta to the north, and have already been described.

(c) South of the Swaledale-Gilling valley watershed.

The sandstone underlying the Main Limestone is well exposed in the north bank of the Swale opposite the railway station at Richmond (177010), where 15' of pale massive medium-coarse grained sandstone, dipping downstream at 7°, are thrown against the Richmond Chert Series to the NW of the Richmond fault. In thin section this sandstone is seen to be arkosic, with up to 20% of microcline, plagioclase and microperthite grains. The remaining 80% is of angular quartz grains up to 0.5 mm. across, many with strain shadows, some of them sutured aggregates (probably from quartzite), with occasional zircons, a few interstitial muscovite leaves and rare rutile.

The occurrence of microcline and microperthite here is of importance because these minerals have not been previously recorded from Yoredale sandstones, although orthoclase and sodic plagioclase are not uncommon. Butterfield (1939), in a petrological study of 49 Yoredale sandstone specimens obtained from between the Great Scar and Underset Limestones, was unable to find any microcline or microperthite, although in the overlying Millstone Grit these are the dominant feldspars (Gilligan, 1920). It is interesting to note that here they make their first appearance within the Middle Limestone Group. The most easterly record of this sandstone comes from the bore hole in St. Trinians sand quarry, ¾ mile further east, where 16'2" of strong grey sandstone, (containing a 4' shale band) were proved beneath the Main. This horizon outcrops at intervals along the base of Whitcliffe Scar, 1¾ miles west of Richmond, where the junction between massive sandstone and the overlying Main Limestone is sharp to the east of Willance's Leap. At an exposure 200 yards WSW of Willance's Leap (134020), however, the sandstone grades up through 6" of passage beds into the limestone, and ¼ mile west of West Applegarth (122015) a similar section is seen. All along the north side of the valley here, very extensive landslipping has obliterated the rest of the beds between the Main and Underset Limestones, but the Underset Chert is well developed in a little quarry on the south side of the river, the evidence from which has been used in mapping a conjectured outcrop north of the Swale. The quarry, 500 yards below Lownethwaite Bridge (151006), gave this section:-

Calcareous shale and siliceous mudstone, landslip over	9'
Dark flinty chert	3'
Siliceous mudstone	5'
Dark flinty chert	2'
Siliceous mudstone	3'
Shale and siliceous mudstone	4'6"
Dark flinty chert	2"
Limestone	1'6"
Shale on Underset Limestone	1'8"
	18'10"

Also on the south side of the valley, 1¼ miles further west, in Scarcote Gill (129008), the Underset Limestone is overlain by 7' of chert and siliceous mudstone, above which is a gap of 97' to the Main Limestone, giving the horizon under consideration a total thickness of 104'.

In Clapgate Beck, beneath the bridge (112017), 14' of alternating bands of dark flinty chert and poorly fossiliferous calcareous mudstone overlie the Underset Limestone and near the head of Hey Gill (120032) the beds beneath the Main Limestone are exposed in the beck, where shale underlies some 30' of massive sandstone. Further up Clapgate Beck, on the east side of the valley, the rather coarse top of the sandstone is seen in several places, and 250 yards south of Low Feldom (113036), 11' of massive sandstone on at least 20' of alternating shale and sandstone bands underlie the Main. An isolated exposure of the Underset Chert in the beck 350 yards SW of Low Feldom (111036) shows similar lithology to that beneath Clapgate Bridge.

Drift and landslips obscure the beds between the Main and Underset Limestones down the west side of Clapgate, and beneath Marske Edge, as far as an exposure of the Underset Chert just above Pillimire Bridge (099008), where 14' of banded mudstones, fossiliferous argillaceous siliceous limestones and dark cherts overlie the Underset Limestone, while above this, behind Clints Cottage, a foot of calcareous sandstone is seen at the base of a cliff of Main Limestone. There is an exposure of Underset Chert on the west side of the valley 1/3 mile SW of Telfit (083022), where 14" of strong pale grey flinty chert (in which are embedded small crinoid ossicles) overlie the Underset Limestone, and above which are 18" of dark chert on 3' of siliceous mudstone. In Marske Beck, 100 yards above its confluence with Throstle Gill (085028), an isolated exposure comprising 8' of dark chert and mudstone also belongs to the Underset Chert, and 1½ miles further upstream Shaw Vein brings up an inlier of Main Limestone at Shaw (059026), where the top of the sandstone beneath the Main is seen. In Throstle Gill, beneath Thringill Hill (084038), no less than 25' of alternating mudstone and dark chert bands are seen resting on an inlier of Underset Limestone which borders the fault to the north. An interesting feature of this facies of the Underset Chert is an abundance of calcareous sponge spicules (but see Chapter 9, section (a)). Within the uplifted wedge between the two Dickey Edge faults, 10' of dark chert and mudstone are exposed on the east side of the valley, while above this the top of the beds underlying the Main Limestone are seen at intervals. About mid-way between the faults, limestone on 12' of sandstone on 12' of shale on a further 12' of sandstone were observed. North of the faults, one of the best exposures of the Underset Chert occurs in Buzzard Scar (086043), where 10' of tough calcareous mudstone on 16' of mudstone and dark bedded chert in thin alternating bands rest on the Underset Limestone. Opposite this, on the west side of the valley, chert and mudstone outcrops can be followed round beneath Kersey Green Scar, in which the Main Limestone overlies the following:-

Sandstone, calcareous (with fossil fragments) at the top	15'
Sandy shale	3'
Shale	6'
Sandstone	

This section is cut off abruptly by the southern branch of the Waitgate fault, but across the valley, just beneath the base of the feature made by the Main Limestone east and north of High Waitgate, sandstone outcrops occur at intervals, and these continue up the eastern side of the overflow channel leading up to Harker Moss, and over the watershed. In only one outcrop is the sandstone not in sharp contact with the Main, and there 4" of underclay with traces of coal come between the two. In a shake hole beneath Weather Hill

(079067), 4' of siliceous limestone overlain by shale are all that remain of the Underset Chert (26' thick only 1½ miles to the south), while further shake holes ¼ mile to the north, on the edge of Harker Moss, show only shale on the Underset Limestone. This shale is well seen in the lower reaches of the overflow channel, NW of Snaiza, where it is about 65' thick with some horizons of ironstone nodules. It is mainly through this soft material that the spectacular Harker Moss channel has been cut. The upper 5' of the shale are sandy, and grade up into the sandstone which underlies the Main Limestone, here 25' thick.

On the west side of the Harker Moss channel, the section is similar, except that on Byers Hill, by the side of the farm (071074), 9" of coal on a seat-earth are separated from the Main by 3' of sandstone, which is unusual. And 200 yards NE of Long Green Farm (074067), the top of the sandstone underlying the Main is a definite grit. In thin section, the angular quartz grains, up to 1.5 mm. across, occur both as single crystals (sometimes enclosing small green pleochroic tourmaline laths), and as sutured quartzitic aggregates, and are accompanied by common microcline and microperthite grains. Interstitially, a little muscovite, sericite and hydro-biotite, together with a few small zircons and some limonite, are cemented by microcrystalline silica. West of Rake Gate, these beds are obscured by hill peat as far as the Newsham-Richmond road, by the west side of which 6' of Underset Chert have been quarried on Strappan Hill (071047). Round the south side of Holgate How, sandstone blocks are seen beneath the Main Limestone at intervals, but NW of the wall crossing over the How a very extensive landslip obliterates all further exposures of this horizon on the east side of the valley as far as Arndale Hole (053058), where the following section was measured 50 yards below the confluence:-

Fossiliferous calcareous shale passing up into Main Limestone	3"
Sandstone, calcareous and carbonaceous	6"
Gap	3'
Sandstone, hard and compact	2'
Sandstone, current-bedded and limonite-spotted	3'+
	8'9"

However, in the west bank, 250 yards below the confluence, the section is:-

Sandstone underlying Main Limestone	8'
Shaley sandstone	1'
Shale	1'3"
Shaley sandstone	1'3"
Shale	6'
Shaley sandstone	

In the former section, the junction between the limestone and the underlying beds is gradual, whereas the latter (although only 200 yards away) shows a sharp junction, implying a break in sedimentation which would account for the differences in the beds immediately underlying the limestone.

In Moresdale Gill the sandstone beneath the Main is well developed, and is seen as loose blocks for some 450 yards downstream from the junction, the latter being marked in the south bank by a line of strong springs. South of the gill, the junction rises rapidly up towards the Faggergill-Waitgate fault, and on Fair Seat Hill (047045) the Main Limestone is seen dipping northwards at 24°, underlain by grit. The Underset Chert is nowhere exposed north of the fault in this valley, but south of it, near the foot of Hollin Brow (065039), 18' of banded siliceous mudstone and chert dip downstream away from the fault at 21°.

CHAPTER 6

THE MAIN AND LITTLE CYCLOTHEMS

The Main and Little cyclothems are dealt with together in one chapter because over long stretches of ground in the south and SE part of the mapped area the Little Limestone, although presumably present, is unrecognisable as such, and the two cyclothems cannot therefore be everywhere differentiated.

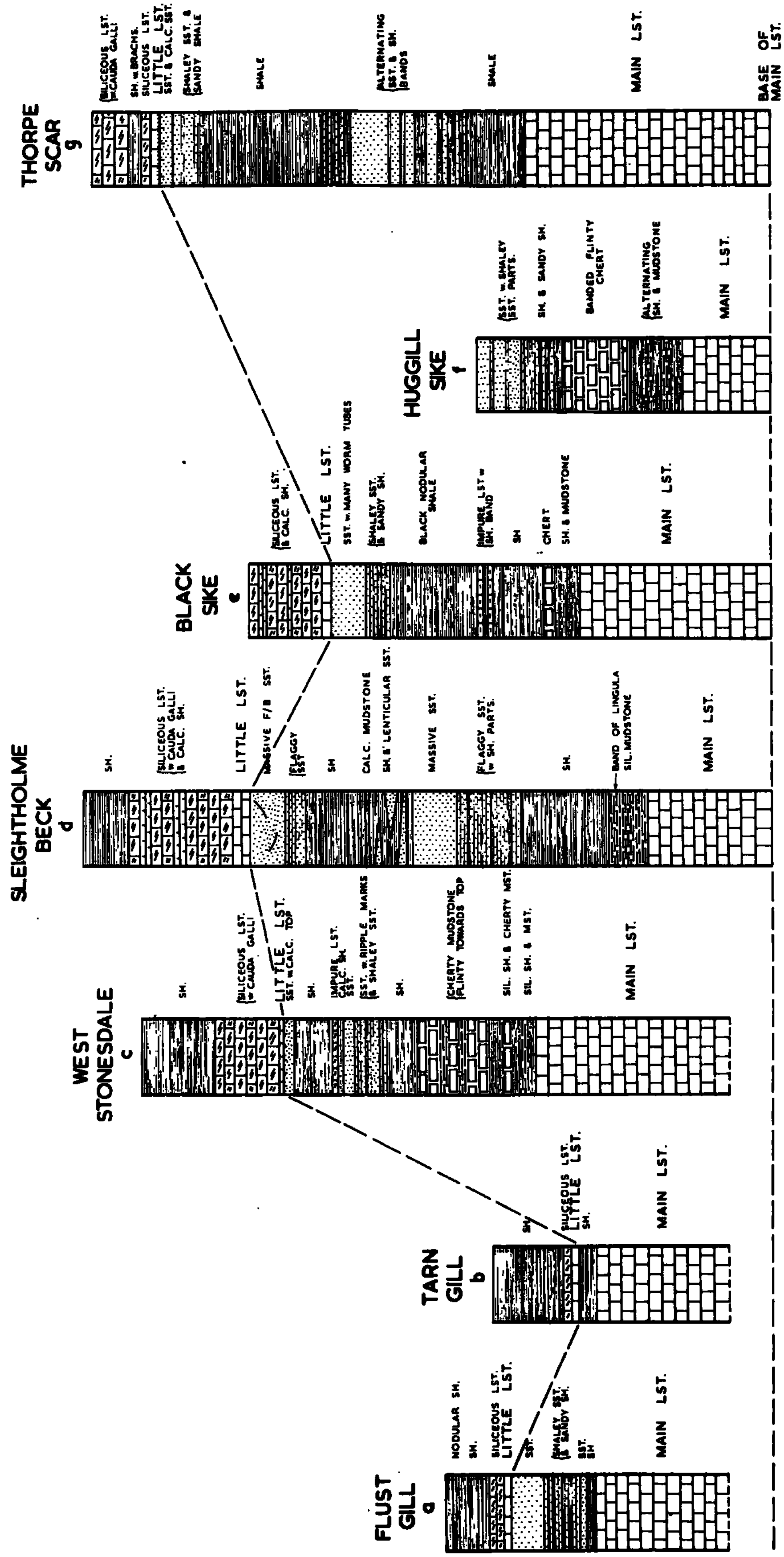
Of particular interest are the variations in the beds above the relatively very constant Main Limestone, and the development of chert within them (the petrography of which is dealt with separately in Chapter 9). The stratigraphy of these beds has been very imperfectly understood in the past, and a number of different versions have been presented. Phillips (1836, p.66) clearly correlated the Little Limestone with the Red Beds, a series of crinoidal limestones above the Main which are well developed in the lower parts of Swaledale. When the Geological Survey covered the area, they used the Red Beds as a mapping horizon, and were under the impression (Dakyns et al., 1891, p.10) that they, together with the cherty Black Beds, passed laterally into the Coal Sills, a series of sandstones and shales well developed to the north and NW. Hudson, in 1924 and again in 1941(p.266), also considered the Red and Black Beds to be lateral equivalents of the Coal Sills, and to underlie the Little Limestone. Carruthers (1938, p.252), on the other hand, stated that "there can be no doubt at all that the Ten Fathom Grit is the Upper Coal Sill (possibly the Lower one also)", and that in Swaledale the Little Limestone comes below the Coal Sills. The Ten Fathom Grit of Swaledale is overlain by the Crow Limestone, which he considered to be the equivalent of the Little Limestone of the Alston Block, although the Primary Survey had mapped the limestone on the Coal Sills as the Little. And more recently Dunham (1950, p.55) correlated the pale coarsely crinoidal limestones around Richmond with the Main, and thought that the muddy and siliceous marine beds in the same area passed northwards into the Coal Sills.

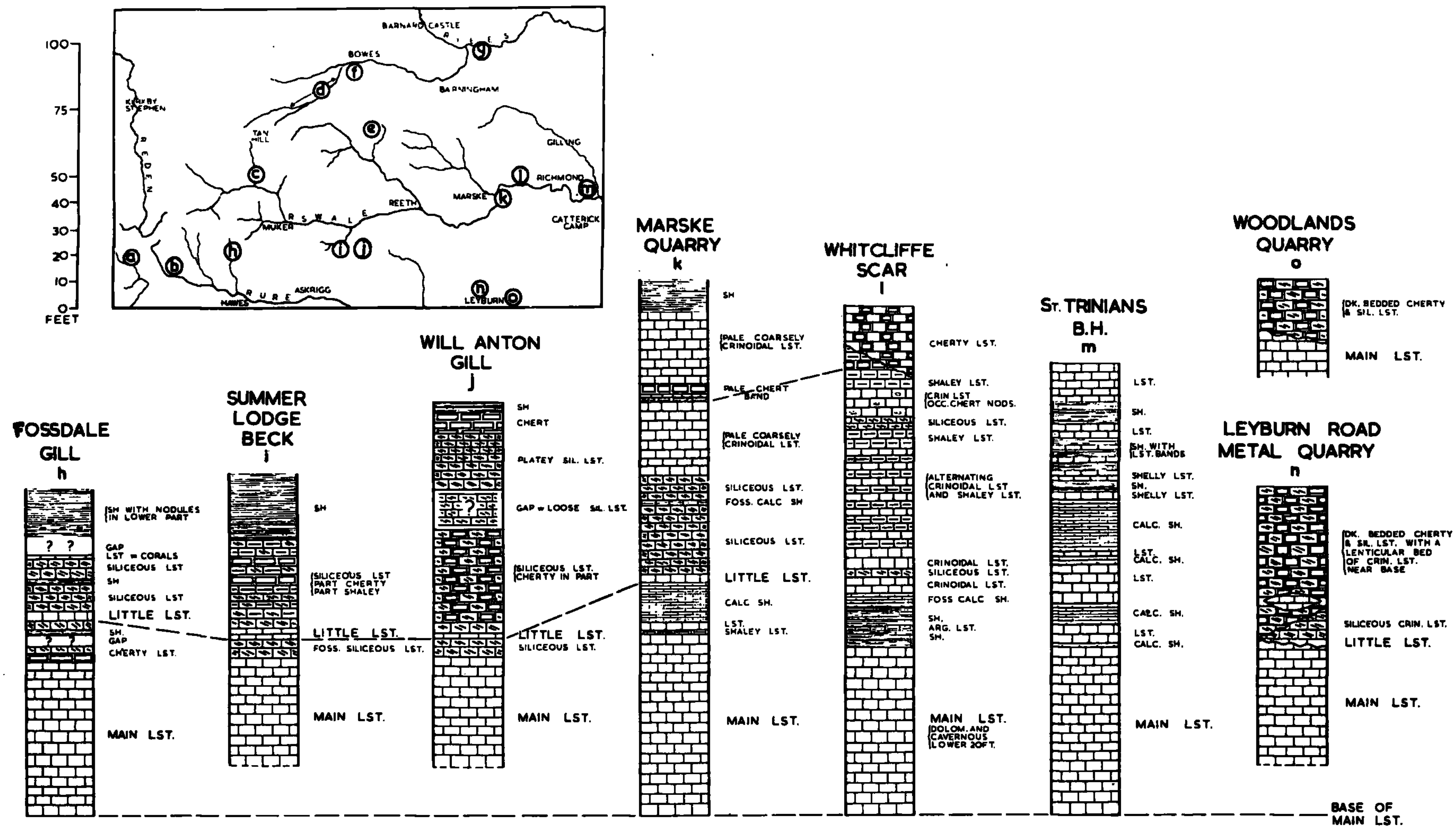
Of the views so far presented, that of Carruthers is the easiest to prove wrong. Turner (1935) and later Reading (1954) have confirmed the view of the Primary Survey that the Coal Sills and the overlying Little Limestone can be followed round the Stainmore syncline, and straightforward mapping during the present work has shown that the Coal Sills underlie and are entirely separate from the Ten Fathom Grit, this having always been the generally accepted idea. Over parts of the western side of the map a series of cherty beds, the Main Chert, overlie the Main Limestone, above which come the Coal Sills, capped by the Little Limestone. This is a thin relatively pure limestone, and is overlain by a very variable series of siliceous limestones and mudstones which it is proposed to name the Richmond Chert Series, but which have previously (particularly in the north) been incorporated into the Little Limestone. When these beds are traced eastwards towards Richmond, the Coal Sills die out and the interval between the Main and Little Limestones is much reduced. The feather edge of the Coal Sills is clearly defined between Teesdale and Swaledale, and to the east and SE of this line the Main Chert is separated from the Richmond Chert Series only by the Little Limestone, which comes right down to rest on the former. Because of a change of facies in the Main Chert near the margin of the Coal Sills, however, which leaves the siliceous beds both above and below the Little Limestone with very similar lithology, it is only possible to distinguish between the Main Chert and the Richmond Chert Series in much of this region when the Little Limestone can be recognised. Fortunately it has a very characteristic lithology which, although not always present, is seen sufficiently often to show that towards Richmond the interval between the Main and Little Limestones gets progressively smaller until at Richmond itself it is apparently no more than 7'. Further evidence from within the mapped area is not available, but it can be shown from a combination of sections taken further up Swaledale and in Wensleydale (see Chapter 7) that an unconformity has developed beneath the Little Limestone, the latter apparently progressively transgressing over the lower beds until it is resting on the Main Limestone.

In lower Swaledale, lenticular bodies of coarse crinoidal limestone are developed in the Richmond Chert Series, and it is these to which the term Red Beds has been applied. But the Black Beds were taken as the more argillaceous horizons in the same series in this region, while further west and NW the term was applied to the Main Chert, beneath the Little Limestone, and it is hardly surprising that the authors of the Mallerstang memoir were sometimes uncertain (p.110) about the relative ages of their Red and Black Beds. The original correlation made by Phillips when he equated the Red Beds with the Little Limestone is thus closer to the results of the present survey than any of the succeeding views, and in fact differs from it mainly by a detail of nomenclature.

Comparative sections of the Main and Little cyclothems are shown in Fig. 4 (p.101).

FIG. 4a


FLUST GILL
a
TARN GILL
b
WEST STONESDALE
c
SLEIGHTHOLME BECK
d
BLACK SIKE
e
HUGGILL SIKE
f
THORPE SCAR
g
NODULAR SH.
SH.
SILICEOUS LST.
LITTLE LST.
SST.
SHALEY SST. & SANDY SH.
MAIN LST.
SILICEOUS LST.
LITTLE LST.
LITTLE LST.
SST. w CALC. TOP
IMPURE LST.
CHERTY MUDSTONE FLINTY TOWARDS TOP
SIL. SH. & CHERTY MST.
SIL. SH. & MST.
MASSIVE F/B SST.
FLAGGY SST.
CALC. MUDSTONE
SH. & LENTICULAR SST.
MASSIVE SST.
FLAGGY SST. w SH. PARTS.
BAND OF LINGULA
SIL. MUDSTONE
SST. w MANY WORM TUBES
SHALEY SST. & SANDY SH.
BLACK NODULAR SHALE
CHERT
SH. & MUDSTONE
SH. & SANDY SH.
BANDED FLINTY CHERT
ALTERNATING SH. & MUDSTONE
SHALE
ALTERNATING SST. & SH. BANDS
BASE OF MAIN LST.



COMPARATIVE SECTIONS OF THE MAIN AND PART OF THE LITTLE CYCLOTHEMS

FIG. 4b

STRATIGRAPHY

The Main Limestone (known as the Great north of Stainmore) is by far the thickest and most constant of the Yoredale Limestones mapped during this survey. It is well bedded, often in posts up to 4'-5' thick, and is normally a characteristic pale grey colour. It is crinoidal, but relatively poor in other macrofossils, although thin sections generally reveal an abundance of shell debris among which foraminifera are common. The thickness varies between 30' and 85', with 60' as a more normal figure, the latter being a fair average for the Alston Block also (Dunham 1948). Variation is rapid, however, the maximum and minimum thicknesses occurring on the north flank of the anticline within 2½ miles of one another. It is usual for the bottom few feet to be brown and dolomitised, as is also the case with the Underset Limestone, and it is suggested that this was caused by percolation of magnesium-rich ground waters, probably during the time when the area was overlain by the Permian Magnesian Limestone (see Chapter 8). The main bulk of the limestone has been shown by analyses to have a silica content as high at 10%. Chert nodules occur, but are less common than in the Underset Limestone, and silica is very rarely seen in thin sections, although occasional quartz crystals up to 2 cms. in length have been recorded. This suggests that a considerable proportion of silica can be present in a limestone without being obvious, even under the microscope. The rich coral-brachiopod band of Weardale, known as the Frosterley Marble, was shown by Reading (1954) to die out across Stainmore, but in places thin and impersistent coral bands, mainly of *Dibunophyllum*, are seen at several levels, and a bed of *Chaetetes* and *Lonsdaleia* occurs just above the base near Richmond.

In the Bowes region, the Main Limestone is overlain by alternating shales and calcareous mudstones (correlated by Reading with the Tumbler Beds of the Alston Block), above which comes the Main Chert, here a series of banded well-bedded flinty cherts of very local occurrence, but up to 26' thick in Chert Gill. The Main Chert dies out to the NE and SW with extraordinary rapidity, apparently passing laterally from its maximum development (in no more than a mile) into black shale which overlies the so-called Tumbler Beds beyond the limits of the chert. But SE from the Bowes region the Main Chert persists, although it changes in facies from a banded chert to a series of siliceous mudstones, calcareous shales and impure limestones.

Above the Main Chert over the western part of the mapped area are the Coal Sills. These are a variable series of sandstones and shales, well known on the Alston Block, and which there commonly carry coal seams (locally workable) above the sandstone members, normally 3 in number. South of Stainmore, however, only two sandstones are developed, which are here called the Upper and Lower Coal Sills without implying exact correlation with those further north. But Reading (1954) found the Upper Coal Sill in the Bowes area to be a continuous mappable horizon which he equated with the White Hazle of Dunham (1948, p.27). Here, the two Coal Sills are separated by shale in which a thin un-named marine limestone occurs, but which passes westwards into fossiliferous sandstone. In the northern part of the Stainmore area, Reading recorded 3 impersistent marine bands within the Coal Sills, and used the supposed equivalence of the marine Red and Black Beds of Swaledale with the Coal Sills (a correlation here shown to be incorrect) as evidence of the proximity of the sea during that time. No coal is seen in situ in connection with the Coal Sills south of Stainmore, but loose fragments in the banks of Sleightholme Beck suggest a seam at or near the top of the lower leaf. Traced SE from the Bowes region, the Lower Coal Sill first dies out. The upper one persists for about a mile further, characterised by abundant worm casts (Plate 8A, p. 135) (the "wormy grits" of the Mallerstang memoir), until it also dies, leaving the Little Limestone (which normally overlies the Upper Coal Sill) resting either on the Main Chert or on black shale, depending on whether or not the former is developed.

The Little Limestone (or Upper Little, to distinguish it from a limestone of the same name low in the Middle Limestone Group) is a grey crinoidal bed, often containing small sand grains visible in thin section, and has been seen up to 7' in thickness. It is characterised by more or less vertical tubes, up to 18" long, partly chert-filled and running down into the limestone from a thin cherty bed at the top, which are often very well seen on weathered surfaces. These tubes, together with the cherty top (commonly slightly glauconitic), are developed over a very wide area in North Yorkshire and parts of Westmorland, and were first described by Rowell (1953) from Kaber Fell, and subsequently found, quite independently, through much of Swaledale, Wensleydale and adjoining areas during the present survey, where they were used as an aid to identification of the Little Limestone. It was Rowell's view that these tubes were infilled polychaete borings. If this is the explanation, as seems likely, the top of the Little Limestone will mark a short depositional break.

The Little Limestone is overlain by a very variable series of fossiliferous siliceous limestones and mudstones which, although not for the most part strictly cherts, are sufficiently siliceous to be called a chert series, and have been named after the town of Richmond, in the vicinity of which they reach their maximum development of about 130'. In the west the series is no more than 20' thick in places, the overlying shale being equivalent to the higher siliceous beds further east. Rowell (1953) kept these cherts separate from the underlying Little, but Reading (1954) preferred to regard the Little as a marine series which varied in thickness across Stainmore between 20' and 30', and with an upper boundary which was often indistinct. The term Little Limestone here refers only to the thin relatively pure and constant limestone band at the base, as it is clearly unsuitable for use with a series whose top is so strongly diachronic as that of the proposed Richmond Chert Series. In lower Swaledale lenticular crinoidal limestones enter into this series, and are so strongly developed around Richmond that the proportion of silica within the series is substantially reduced. These limestones sometimes weather a pale yellow-orange colour, which led to the adoption of the term Red Beds by the old miners. But due to lenticularity and minor erosion surfaces within these beds (some of which can be seen, but many of which must go un-noticed), sections through the series show wild variations over quite short distances. It is suspected, however, that one of the factors contributing to these variations is the mode of weathering of the siliceous argillaceous limestones, which seem to break up into platey, apparently somewhat shaley fossiliferous bands during the process of decomposition, and are often difficult to distinguish from the fossiliferous calcareous shale partings which occur throughout the series. But despite all these striking variations, one band of white chert, about 4' thick, which is developed towards the top of the series, is remarkably constant and has been used as a mapping horizon, being an invaluable marker for position within this variable series. It outcrops just beneath the top of the valley sides in lower Swaledale, and has been named the Marske Chert Band, after the village around which it is so well seen. It has been traced as far west as Little Punchard Gill (957033), on the west side of Arkengarthdale, and is known to exist over an area of more than 30 square miles on the north side of Swaledale.

The Richmond Chert Series is succeeded by shale, substantially thicker in the west than in the east, which is overlain by the Ten Fathom Grit. In upper Swaledale the "Grit" is commonly in two parts which are separated by a thin limestone (named the Faraday House Limestone by Rowell (1953), and followed by Reading into Stainmore) and sometimes by a coal. It is particularly well developed west of Reeth and in Arkengarthdale, where it often exceeds 60' in thickness (Dakyns et al., p.111), and is overlain by the Crow Limestone. It has been mapped between the head of Arkengarthdale and the moors west of Marske, and although of considerable thickness, it is never coarse enough to be comparable with true Millstone Grit facies. The Faraday House Limestone, if developed, is nowhere exposed within this area. East of Marske, however, sections in the south side of Swaledale show very rapid thinning of the Ten Fathom Grit, and half way to Richmond it is represented merely by a few thin sandstone bands in shale, while a mile SE of Richmond it has gone altogether, the Richmond Chert Series being separated from the Crow Limestone by only a few feet of shale.

DETAILS

(i) Main Limestone

(a) North flank of the anticline

The Main Limestone closes in Sleightholme Beck a mile above its confluence with the Greta, at the head of a gorge lined on either side for ½ mile by cliffs of limestone. The outcrop in the beck extends upstream for some 400 yards, to the foot of Black Scar (965113), the total thickness being 42'. Scattered corals, largely Dibunophyllum, occur over about 5' in the middle of the section, and small chert nodules weather out at intervals. Traced downstream towards Bowes, the limestone rapidly thins and in Huggill (976127) there is only 30', both the top and bottom being well-defined. It can be followed along the south side of the valley (dipping north at 4° and overlying a thin coal) as far as Chert Gill, where a dip slope forms the bed of the beck for ¼ mile. Along the north side of the Greta valley, the base of the limestone is picked up at intervals just above the river as far east as Chapel Bank, below Bowes (993133), while the top is seen only in Seal Gill (974132) between the railway and the main road (A.66). The limestone is grey and crinoidal, never the creamy colour characteristic of the Underset, and generally lighter grey than those limestones underlying the Underset. It is well-bedded, occurring in posts often 4'-5' thick, and generally with excellent jointing. Macrofossils are not common (except locally) and the limestone is pure in its lower part, but towards the top argillaceous partings are usually present. It is very well exposed in Kilmond Scar, and on the dip slope for up to ½ mile north of it, where there has been extensive quarrying. The old L.N.E.R. quarry at Hulands (015138) exposes 60' of undulating crinoidal limestone, the shaley partings towards the top (which is beautifully polished and striated by ice action) being up to 1' thick. Just behind the crusher, a bore hole was once sunk to prove the thickness of limestone, and is said by one of the quarry-men present at the time to have reached the underlying shale at 60'. There are a further 25' of limestone exposed in the quarry above the spot where the hole was drilled, making the alleged thickness of the Main Limestone 85'. This compares with the known thickness of 30' in Huggill, 2½ miles WSW.

Another excellent section is that in Kilmond quarry, ½ mile to the SE (023135), where 50' of grey, thickly-bedded crinoidal limestone are seen, bearing traces of chalcopyrite in calcite-filled cavities. A specimen 1' above the base of the limestone is unusually dark, hard and fine-grained, and in thin section is seen to be partially recrystallised, with stout brachiopod fragments and productid spines (associated with which are many small pyrite cubes), and many foraminifera, particularly Endothyra and Tetrataxis, with Howchinia conspicuous by its absence. The bulk of the limestone is grey and crinoidal, with much organic debris (mainly brachiopod fragments, but with some bryozoa and occasional small foraminifera) and a band of corals 45' above the base. A compound analysis made on a number of representative specimens from the face for George Hodsman and Sons Ltd. gave the following result:-

$CaCO_3$	84.30%
$MgCO_3$	2.52%
SiO_2 + insoluble	10.31%
FeO, Fe_2O_3, Al_2O_3	1.23%
H_2O + organic	1.64%
	100.00%

The most striking part of this analysis is the high silica value, and although the only silica seen in the thin sections was a solitary partially replaced brachiopod shell, there must be a considerable quantity disseminated throughout the limestone, probably as a depositional constituent, which has subsequently become concentrated locally into chert nodules.

Many outcrops of the Main Limestone occur in small quarries on either side of the road A.66 as far east as the Cross Keys (038138), but north of the road it dips northwards into drift. Limestone is seen in several places in Thorsgill Beck, where it is rather argillaceous, and must be near the top of the Main. A short way north of the beck, the Mount Pleasant bore proved only 55' of Main Limestone, which contained shale bands near the top, and the main bulk of which was rather unfossiliferous, apart from small crinoid ossicles throughout and a few corals and brachiopods near the base. Eastwards, the next exposures are in the Tees where, between Egglestone Abbey and a point 2/3 mile downstream, 83' of thickly bedded grey crinoidal limestone are exposed in Rokeby Gorge (see Frontispiece). This is practically the same thickness as that alleged in Hulands quarry. The only macrofossils seen were occasional corals, apart from the abundant crinoid ossicles. Downstream, the limestone is seen at intervals resting on the underlying carbonaceous sandstone, and north of Rokeby Park (083144) the dip again brings it into the river, where it makes a continuous outcrop (dipping downstream at about 5°) as far as the confluence with the Greta (085145). There is another continuous section up the Greta for 300 yards, exposing the full thickness of the Main again, beyond which limestone is seen for some 500 yards further upstream in Mortham Wood. The next exposures to the SE are in a drift-free patch around Lane Head (125117), where a quarry section by the cross-roads shows 36' of limestone dipping northwards at between 3° and 5°. Just over a mile north of this, the Wycliffe bore (122134) proved the Main to be 57' thick, shaley with fine shell fragments and bryozoa at the top, mainly the normal grey crinoidal type below, with argillaceous streaks becoming less common with depth. The bottom 6' had been partially dolomitised, and a small dolomite-lined cavity was brought up some 4'6" above the base. ¼ mile north of West Layton, in another drift-free patch (143104), a quarry has exposed 34' of the Main. 7' of brown recrystallised and dolomitised limestone with many small dolomite-lined cavities form the lower part of the quarry, and are overlain by 27' of the normal grey crinoidal type. Two small residual outliers of limestone also occur near here, one being about 600 yards NE of West Layton (146104), and the other on the ridge 350 yards south of Telfit Hall (130107). Old quarries in both of them reveal the lowest dolomitised level in the Main.

Eastwards, in East Layton and Forcett quarries, where there are something like 2 miles of almost continuous quarry face, one of the largest single exposures of the Main Limestone is to be seen. There are in fact 3 quarries, extending over ¾ mile, the easternmost being Forcett quarry, west of which are North and South East Layton quarries, both the latter being actively worked. Forcett quarry, now no longer used, exposes 43' of well-bedded grey crinoidal limestone, apparently homogeneous and rather unfossiliferous, which is covered by up to 20' of boulder clay (containing a high proportion of material from west of the Pennines). The top of the limestone has been polished and striated by ice action, as in the two other parts of the quarry. The jointing is well developed, but in the adjacent northern part of East Layton quarry the jointing is quite spectacular, two major sets cutting the limestone up into huge blocks, which are traversed by a minor set between the other two (Plate 13B, p.179) (but see Chapter 8 section (c)). In this part of the quarry up to 49' of the Main are seen, the upper part containing dark irregular argillaceous streaks. The limestone apparently contains remarkably few fossils apart from crinoid ossicles, but in thin section the upper part is seen to consist largely of fragmentary brachiopods and bryozoa, with much crinoid debris, among which is disseminated a variable proportion of argillaceous material. There are traces of malachite in calcite on the joint surfaces here, but in the southern part of East Layton quarry a whole suite of copper-bearing minerals has been identified. There are two faults (both downthrowing NW) crossing this quarry in a NE-SW direction, the one to the NW throwing at least 20', the other only 9'. Associated with the former, which brings nearly 20' of beds underlying the Main into contact with the limestone, are much malachite and azurite, with bornite nodules and chalcanthite in the beds beneath the limestone, and chalcopyrite (+ goethite) with a little covellite higher up, in the limestone, which also contains quantities of barytes, witherite and calcite in the fault zone. These minerals are found elsewhere throughout the quarry (but in very much smaller quantities) in the limestone and particularly on joint surfaces, and are certainly not associated exclusively with the fault zone. The smaller fault includes a zone of breccia which has been cemented largely by barytes, with some calcite and dolomite, on which have grown little clusters of radiating malachite fibres. Small specks of chalcopyrite are present in the barytes. The quarry section shows a maximum of 45' of limestone, the lower few feet of which have been dolomitised as elsewhere. It is noteworthy that none of the three quarries show any chert nodules in the limestone. The owners of the quarries had a series of analyses made in 1922 of the limestone in the southern part of East Layton quarry, with the following results:-

Distance of sample above base of limestone	%$CaCO_3$	%$MgCO_3$	%FeO + Fe_2O_3	%SiO_2	Sum
41'9"	94.01	0.87	0.60	4.50	99.98
38'5"	97.01	1.13	0.35	1.50	99.99
37'7"	94.93	1.36	0.55	3.20	100.04
34'7"	96.05	1.09	0.35	2.50	99.99
32'1"	95.18	1.17	0.90	2.85	100.10
30'1"	92.26	4.35	0.75	2.50	99.86
28'10"	94.68	1.36	0.55	3.30	99.89
27'7"	95.41	1.21	0.40	2.95	99.97
23'4"	95.04	1.02	0.40	3.50	99.96
21'10"	96.51	1.14	0.40	1.95	100.00
20'2"	92.61	5.29	0.85	1.15	99.90
18'2"	91.10	4.46	0.75	3.55	99.86
15'6"	93.76	3.85	0.55	1.70	99.86
14'6"	97.46	0.99	0.75	0.70	99.90
13'6"	98.25	0.75	0.40	0.45	99.85
12'3"	97.81	0.98	0.60	0.55	99.94
11'9"	90.24	6.20	1.05	2.25	99.74
10'9"	91.17	6.13	1.30	1.20	99.80
10'	94.78	3.40	0.90	0.95	100.03
8'	91.49	6.12	1.65	0.70	99.96

These analyses show that the lower 12' have a much higher MgO content than most of the rest of the face, and presumably in the lowest 8' the dolomite content was known to be too high to be of use, and the rock was not analysed. The figures leave no room for any argillaceous impurities, and these are only seen in the upper part of the limestone, in the quarry to the north. The silica content, up to 4½%, is significant because here there is no evidence of it either in hand specimen or in thin section, which again lends support to the view that it is disseminated throughout the rock as a depositional constituent, although in this case evidently rather a variable one, and not apparently high enough for concentration into chert nodules. Many dip readings were taken in these 3 quarries, and also in old Forcett quarry (¼ mile SE of the one described above), where up to 33' of limestone have been exposed beneath up to 25' of boulder clay. These showed how little use isolated readings can be for projecting a horizon over any distance, because the beds undulate considerably and dip, within this restricted area, in every direction of the compass up to as much as 7°. It is only when an idea of the regional dip can be obtained that it is possible to construct outcrops of these undulating beds beneath the drift with any accuracy.

The village of East Layton is built on a small drift-free patch of Main Limestone (a pre-glacial hill), the interval between there and the quarry (between ½ and ¾ mile away) affording an estimate of the regional northerly dip. Eastwards the limestone is seen in an old quarry to the east of the Forcett-East Layton road (168103), where 25' dip NE at between 10° and 14°, while ¼ mile further SE it is seen dipping ENE at 11° in a quarry on the edge of Gill Wells Plantation (172101). Beyond this the Main Limestone is not seen again as far as Middleton Tyas, nearly 5 miles away, and the only evidence for its position is a depression in the drift (possibly a shake hole) beneath Suddels Farm (181101), 900 yards to the east of the last exposure.

In Middleton Tyas, the Main Limestone is seen in small exposures just south of St. Michael's Church (235055), where it has been dropped down by the Middleton Tyas fault. ½ mile south of this, a quarry between Kirk and Ludburn Becks shows 7' of it covered by reddish drift, but one of the best exposures in this neighbourhood is in Southfields quarry (228049), now a rubbish dump, where the following section was measured:-

Limestone, 7' drift over	2'
Calcareous shale, with flattened crinoid ossicles	10"
Grey crinoidal limestone, even-bedded with 3 shaley partings of 2"-4" thickness	8'
Limestone, as above	20'
	30'10"

The Main Limestone is also seen in and around Moulton (235038), where it is affected by an E-W fault. On the west side of the beck (a few yards above the bridge) some 60' of limestone are exposed dipping NNE at 20° away from the fault, while in a road-side quarry 250 yards to the west it is pale brown and dolomitic, with many small cavities, and bears signs of current-bedding. The dolomitisation is evidently associated with the fault, south of which more dolomitised limestone is seen dipping south at 18°. West of Moulton, the Main Limestone was reached in a bore hole at Morris Grange Sanatorium (223042) beneath 89' of drift, and behind Scotch Corner Hotel 48' were proved beneath 71' of drift. ¼ mile north of Scotch Corner (213057), a quarry in a small wood beside the old Great North Road exposes some 15' of the Main, which was also reached beneath 23' of boulder clay in a deep well near Violet Grange (208057). On the north side of the road A.66, ¾ mile from Scotch Corner, grey crinoidal limestone is seen dipping NW at 6^{o} into the Sedbury fault. A quarry 500 yards east of Sedbury Hall (202050), through which the drive to the Hall passes, has been worked in 29' of well-jointed Main Limestone, the lower 9' of which have been dolomitised (as is so commonly the case). SE from here, a feature marks the base of the limestone for a mile, but it becomes progressively fainter, and is finally lost beneath drift at Abbey Close.

(b) South flank of the anticline

The most easterly sign of the Main Limestone on the south side of the Gilling valley is at Olliver Ducket (183022), where it outcrops on the north side of Pilmoor Hill, and is brown and dolomitic due (in part) to the proximity of the Bend Hagg fault. An old shallow quarry 150 yards SE of St. Osythe shows the normal grey lithology, but ½ mile west, at Bend Hagg (173023), the limestone appears on the south side of the fault, where it is brown and dolomitic near the dislocation. But 70 yards away in the old quarry, 27' of grey crinoidal limestone have been worked, and the well-developed joints bear traces of malachite and azurite. Along the north side of the race-course, old north-facing quarries expose up to 20' of limestone also bearing traces of malachite and azurite, these minerals being seen again in a quarry 350 yards WSW of Gingerfield Farm (162025), but here the limestone has been dolomitised in addition. The Main is seen at intervals along Rasp Bank, where it is affected by several faults, and traces of copper are seen again above High Coalsgarth. South of this, a faulted outcrop forms Beacon Hill (145025), 150 yards east of which a quarry section shows 46' of grey limestone (also with traces of malachite and azurite on the joint surfaces) dipping north at 18° to join the exposures in Rasp Bank. Along Coalsgarth Edge and opposite, in Randell Wood, the Main outcrops at intervals and the base makes an excellent feature round 3 sides of the Jockey Cap Clump to the north. North-eastwards as far as the Feldom fault, however, a combination of glacial drift and peat obscure the limestone except for sporadic exposures in shake holes (which are fairly numerous), but the base makes a feature for some 750 yards to the SE of Buddle House (133044). Just SE of the fault, the limestone surmounts the watershed, and the outcrop continues down towards Clapgate Beck where 30' are exposed at the springs where the beck rises (109036). Down the east side of the valley the limestone is well seen in a number of scars, where it has a rather variable dip. The lower 20' bear signs of dolomitisation here. Near the confluence with Hey Gill there has been considerable alteration of the limestone due to faulting, and it is now almost entirely recrystallised to a brown dolomite-calcite rock, all traces of organic remains having disappeared, and it is intimately veined by threads of dolomite-ankerite, giving it the appearance of a breccia. South of this, the base of the Main is brought right down into the beck by the Hey Gill syncline, but south of the Marske Moor fault it is up again at about 800' O.D., and is seen at intervals down both sides of the valley towards the Swale.

Above the spring on the side of Clapgate Bank (121024) the limestone is seen to contain chert nodules in its upper part. Round

Applegarth Scar, and eastwards along Whitcliffe Scar, the Main is well exposed in many places, but the lower part is not often seen, it being generally obscured by debris fallen from above. ¼ mile west of West Applegarth (122015), however, the full thickness of 60' is visible, and there is a gradual passage through 6" from the underlying sandstone. There is a good band of Chaetetes depressus between 18" and 2' above the base, but this is the only place where it has been seen. Johnson (personal communication) has found a similar band in many places in the Tyne valley, one lenticular mass extending over several acres. In Whitcliffe Scar the Main is 63' thick, the lower 20' being dolomitised and cavernous to a greater or lesser extent, with Lonsdaleia floriformis some 3' above the base. At the eastern end of the scar, the base is in sharp contact with the underlying sandstone. On the south side of the valley, the Main Limestone in Scarcote Gill is only 55' thick. North of the Richmond fault its top enters the Swale in Temple Grounds (166007), where levels have been driven into the limestone for copper. Between the two branches of the fault, 35' of partly dolomitised limestone are exposed in the wood south of the Temple, and on the south side of the river two levels have been driven into the bank at the base of Billy Bank Wood (165006) to work deposits of copper which were evidently associated with the northern branch of the fault. The Main disappears into the river 150 yards above Richmond Bridge, dipping downstream at 10^{o}, but it reappears again 1/3 mile further down at the base of the weir, dipping SE, a small syncline covering the intervening part. On the south side of the fault, opposite the Station (177010), some 40' of the limestone are seen resting on sandstone and covered by thick boulder clay. It is the normal grey crinoidal type except near the fault, where it has been dolomitised and is rather cavernous. The limestone soon disappears into the river dipping SE at 5°, but a further record comes from the bore in St. Trinian's quarry (189008), where the Main was proved to be 62'4" thick. Shale bands 27'6" and 33'9" above the base yielded several fish scales and a few small <u>Lingula</u>.

On Feldom Moor, at the head of Clapgate Beck, the Main Limestone forms an extensive SW-facing drift-free dip slope, through which the Feldom fault runs. This fault has been much worked in the past through a series of bell-pits (for lead and copper) on either side of Feldom Lane, and galena, chalcopyrite, malachite, azurite, goethite, barytes, dolomite and calcite have been collected from the tips. In addition, chalcopyrite, malachite and goethite were obtained from old 'flats' workings 400 yards north of the fault, which suggests that the copper-bearing minerals are not necessarily associated primarily with the fault (but see Chapter 11, section (c)). Much of this dip slope is in the lower buff-coloured, recrystallised and partly dolomitised part of the limestone, in which all traces of microfossils have gone, but round the western edge the top of the limestone is well marked by swallow holes, in many of which the top few feet of the limestone are visible. A specimen from one of these, SSE of the remains of West Feldom (104040), shows the top of the Main to be sandy, containing up to 10% of small angular quartz grains (about 0.05 mm. in diameter) in a matrix of organic debris, mainly of crinoids and brachiopods, with a little interstitial argillaceous material. A few bryozoan fragments and a single <u>Tetrataxis</u> were seen in the section, which also contained some glauconite grains about 0.1 mm. in diameter, and a little glauconite replacing crinoid ossicles.

Just south of Feldom Nick (116052) the base of the Main makes a feature for about 200 yards to the SE of the lateral moraine, but to the NW peat obscures it for about 1¼ miles, the only exposures being in swallow holes. Along this stretch the position of the Feldom moraine coincides with the outcrop of the lower part of the Main, the base of which is consequently rarely seen. There are many outcrops along the south side of the Snaiza Gill overflow channel, on Gayles Moor, near the western end of which (084059) the full 60' of limestone are seen. At the spring ¼ mile SW of Hornbriggs (092062) the base of the Main is dolomitic and unusually cavernous, the cavities being partially filled by large crystals of calcite. The dip here is 9° SW, taking the limestone beneath an outlier of the overlying chert series, the latter occupying the centre of a small basin. North of this outlier is another dip surface, the NE corner of which is crossed by the Feldom moraine. Outcrops occur in many shallow quarries where the limestone has been worked largely for walling material, and the base is easily traced (except on the eastern side), by means of an excellent feature a little way beneath the top of the slope, round into Snaiza Gill again. South of the gill, numerous outcrops occur in shake holes and little shallow quarries, and the base can be traced round from the gill and along the north and east sides of an area of bog NE of High Waitgate, where the limestone rests directly on massive sandstone. Here, the lower 7' are brown and dolomitised, the only parts not to have recrystallised being the stouter crinoid fragments, but above this the normal grey crinoidal lithology persists. Just to the north of the

High Waitgate fault the base and the top of the limestone (both well defined) are brought to within 80 yards of one another by a dip along the fault of 12°, which is in striking contrast to the extensive outcrops to the north and east.

South of the Waitgate fault system there has been much landslipping over the outcrop of the Main, but the lower 45' of it are well seen in Kersey Green Scar (083045), while the top is marked by shake holes in the slope behind. The base (in sharp contact with the underlying sandstone) is seen in a number of outcrops as far south as Thrin Gill (083037), beyond which the limestone is obscured as far as the springs at the base of Helwith Bank (082029). 80' above Telfit Farm (086026) the top of the Main has been quarried, and it is seen dipping SW in several places between there and the fault. Down the east side of Waitgate Gill up to 55' of limestone are seen between the Dickey Edge faults, where the base is well exposed, but southwards as far as the little gill entering from Marske Moor to the east, only isolated exposures emerge through slipped material, one of which shows 6' of grey crinoidal limestone with chert nodules. A section of one of these shows, unlike those in the Underset, a gradual transition from crinoidal limestone with brachiopod and bryozoan fragments, and a few foraminifera (particularly _Endothyra_ and _Tetrataxis_) with small patches of interstitial microcrystalline silica, into a rock mainly formed of minute radial aggregates of chalcedonic silica in which are tattered calcite remnants. The latter show no signs of recrystallisation, again unlike those nodules sectioned from the Underset.

A small faulted inlier of Main Limestone has been worked on Marske Moor, where a quarry on the north side of Limekiln Hill

(103027) exposes 30' dipping south at 6°, the lower part being brown and dolomitised, as is usual. South of the fault the Main is exposed on both sides of Marske Beck, forming a dip slope above the eastern bank to the north of Orgate Vein. The base is easily traced round the natural boundaries of this outcrop as far as the vein. A quarry on the northern side (098023) exposes the lower 28', with a band of chert nodules 25' above the base, while along the SW side excellently developed joints have led to the formation of a 52' vertical cliff of limestone, brown and dolomitic at the base, which dips SE at about 6° into Orgate Vein (Plate 5, p. 2). An old shaft on the vein, 400 yards beyond the valley edge, has brought up galena and barytes associated with dolomitised limestone. South of the vein, the Main is dropped right down into Limekiln Wood, but is covered over by landslips as far as Clints Wood, where a section of 58' is seen. Just above Clints Cottage (100009) the full thickness of 76' was measured. To the west of the beck exposures are poor. On the north side of Skelton Moor 40' of grey crinoidal limestone have been quarried close to the old lead mines (078024), and on Telfit Bank the top is visible in several places (overlain by the chert series), but around Skelton itself the outcrop is conjectural.

Shaw Vein has thrown up a faulted inlier of Main Limestone in Shaw Beck which is seen as far upstream as the Green Dragon Inn (054027). The greatest thickness exposed is 45' (on the SW side of the vein) and a row of shake holes along the top of the south bank marks the top of the limestone. Where the outcrop closes in the beck near the Inn, the top is seen to be the normal grey crinoidal type, but in addition contains siliceous patches of irregular outline which are only visible on a weathered surface. A decalcified specimen showed some of these patches to be cylindrical in shape, some 5-7 mm. in diameter and several centimetres long. These siliceous patches contain very small quartz grains, and are evidently of later origin than the rest of the rock, possibly being infilled borings. The residue from the treatment was found to contain (apart from quartz sand) aggregates of very small pyrite cubes, a few glauconite grains and glauconite casts of tiny gasteropods, together with several hexactinellid sponge body spicules referrable to Hyalostelia (Hinde, 1888).

The Main Limestone is well seen in Holgate Beck (065039), where it dips 14° SSE away from the Faggergill-Waitgate fault, the base making a good sweeping feature down Hollin Brow. North of the fault it has been quarried on Fair Seat Hill (046046), where it dips at 24° to the north. The dip soon flattens out, and in Moresdale Gill it is to the south. The base of the limestone is exposed in many places on both sides of the gill, showing a sharp junction with the underlying sandstone. The lower part is brown and dolomitic, and chert nodules occur up Low Easegill Beck, a north-bank tributary. ¼ mile west of Kexwith there are apparently two scars formed by the Main Limestone, but the lower one is not in place, having slipped for 75'-100' down the hillside. North of Kexwith there are many excellent and full sections of the Main Limestone in the region of Arndale Hole, where the outcrop is largely bare in the steep sides of the valley. The Main is 60' thick 250 yards south of the confluence, while immediately above it 62' were measured, and several hundred yards further upstream the thickness has risen to 65'. In the first section the limestone lies directly on sandstone, but upstream some 3"-6" of fossiliferous shale intervenes. The limestone base is only partly recrystallised, the unaltered patches consisting of much shell debris with many foraminifera and numerous pyrite cubes up to 0.3 mm. across. The limestone is totally recrystallised 3' above the base (all organic traces having been obliterated) and consists almost entirely of dolomite-ankerite, cold HCl having little effect on it. Higher up, the crinoid ossicles have escaped alteration, and over 12' above the base the normal grey lithology is present. Some of the few fossils (particularly spiny productids) have been silicified and stand out strikingly on water-worn surfaces. Embedded in the limestone 300 yards upstream from Arndale Hole was a prismatic crystal of quartz some 2 cms. in length which indicates a high (if only local) silica content. The limestone outcrops in Arndale Beck, dipping alternately up- and down-stream for 600 yards above the confluence, before the overlying chert series enters the water.

Down the east side of Arndale Beck, south of Arndale Hole, and along the NE side of the valley as far as West House (063048), landslips cover most of the Main, but the upper part is seen at intervals. In a crag 100 yards NW of West House, chert nodules up to 20" in length occur in a 6" band some 14' below the top of the limestone. Eastwards, Holgate How is formed by the Main, its base making a most excellent feature round its south and east sides, while to the north a dip slope drops down to a series of swallow holes along the east side of Holgate Moor. The faulted outcrop of the Main Limestone on Long Green is studded with small shallow quarries, and round the north side the base makes a good feature.

The beck from Frankinshaw Well sinks into the limestone on crossing the Long Green-Byers Hill fault (071063) and reappears again 250 yards further on in a strong spring at its base. Byers Hill is capped by an outlier of Main Limestone some 20' thick which makes a feature all round the hill, and is well exposed in a quarry on the north side (072075). The bottom 7' are not seen, but between 7' and 10' above the base the limestone is brown and dolomitised, with many little cavities. Above this, the normal grey limestone is seen, but it is practically devoid of macrofossils apart from the ubiquitous crinoid remains.

The Main Limestone on Newsham Moor has a wide outcrop, and is seen in many small exposures and swallow holes in the thin peat covering. The base is easily followed from the NE side of Frankinshaw How (063065) all the way round to Woodclose Gill (041076), where there is everywhere a sharp junction with the thick underlying sandstone. Individual dips are very variable, but the regional dip is SSE. At Spring Head (055066) the base appears again on the edge of a little faulted inlier of the underlying sandstone, NW of which the limestone dips at 30° into the fault. All over this part of the moor, exposures are very shallow, no more than 7' being seen in any one place. The lithology is very constant, and the grey crinoidal limestone has well-developed joints. Above Osmaril Gill (052076) the lower 22' form a bare scar on the underlying sandstone, and round the north side of Eel Hill the partially dolomitised lower part of the limestone contains <u>Lonsdaleia floriformis</u> at the base. Where the Main crosses the head of Woodclose Gill (dipping SE at 5°) a dry V-shaped gorge affords a section of the full 50' of limestone. South of White Fell, very many shake holes occur in this horizon, but northwards in Hud Scar (037081) the temporary northerly dip down the slope has led to a long limestone scree in Hudscar Holes, beneath the outcrop. Hope Scar (033076) exposes 35' of the Main (brown, dolomitic and recrystallised (except for the crinoid ossicles) in its lower part), above which the only outcrops are in shake holes. These sweep round over the watershed to a point some 650 yards south of Hope Scar (034070), where the limestone has been mineralised towards the end of an ESE-WNW fault. Much galena (with calcite) is present on the tips from the old lead mines. Nearby, some old coal pits have been mapped by the Ordnance Survey, but there is no evidence for any coal here, and it is thought that these pits belong to some of the earliest workings for the galena.

Along the north side of Arndale Hill, swallow holes and small exposures mark the Main Limestone across to the west side of the Stang road, by the side of which Stang quarry (023076) shows 8' of limestone with strikingly regular wavy bedding planes in vertical section. The amplitude of the waves is about 2" and their length some 2'. It may be that this is a form of ripple-marking, but is not thought likely because of the vertical as well as horizontal regularity in the section (the same pattern being repeated many times), and also because (as far as can be made out) the crests of the waves do not extend for any great distance, making the bedding somewhat nodular in form. NW from Stang, the drift creeps up over the lower part of the Main, but the upper part is seen in numerous shake holes, in some of which as much as 20' are visible. There is a very sharp flexure in the limestone 650 yards SE of Jinglepot Hole (013083), dips to the NE as high as 40^{o} being recorded. But this is purely a local phenomenon, and there is no evidence for any faulting. Many shake holes and small outcrops mark the Main as far as the South Spanham fault. At the head of Scargill Beck (009092) the lower part of the limestone has been worked from a level heading SSW from the spring, and galena in quantity was obtained. But here again there is no evidence of any faulting. Between the two Spanham faults the Main is marked merely by several springs at its base, but along the north side of Spanham East Hill it forms a bare scar in which 54' of limestone (with chert nodules in the lower part) were measured. Spanham Hush, at the western end of the hill (009099), has laid bare the mineralised North Spanham fault in a most excellent exposure. Along the line of the fault the limestone is much disturbed, vertical beds being recorded, and it is completely dolomitised, with many caverns, some of which contain clusters of nail head spar, individual crystals being up to 3½ cms. across. Goethite is common, usually in massive form, but in some cases occurring in little curved rhombohedra as pseudomorphs after dolomite or ankerite. Around Spanham West Hill the Main is well seen again, particularly along the north face where 45' were measured. The limestone forms the whole of this hill, so the full thickness is not present. On the south side, the North Spanham fault (here in two parts) is again well seen, several feet of breccia marking the northern branch.

A small inlier of Main Limestone occurs in East Black Sike, upstream from the South Spanham fault (996098), where the top few feet are exposed over about 100 yards. The limestone is rather argillaceous, but is still grey and crinoidal. A thin section reveals many bryozoan and fine brachiopod fragments set in a fine mozaic of calcite, apparently recrystallised. The Main Limestone borders the North Spanham fault on its south side for some 2½ miles, from West Black Sike to Sleightholme Beck. In the former (994103), the limestone (much brecciated and dipping at 60° to the south) is thrown against the flaggy sandstone and shale beneath the Main (Plate 13A, p. 179). The dip rapidly flattens out, and a reversal exposes a small inlier between 100 and 250 yards further upstream; 400 yards to the west (in Eller Beck Hush) the throw of the fault is reduced to zero as it reverses its direction of movement, the limestone merely dipping away from it on either side at up to 12°. But there has been considerable fracturing and horizontal slickensiding in the limestone. South of the fault, a complete section in Eller Beck shows the Main to be 60' thick. It contains a well-defined coral band 45' above the base, while 35' up a bed of partly silicified spiny productids have weathered out. For two miles to the west the outcrop of the Main is covered by morainic drift, apart from two isolated exposures, one on the north side of Hazel Bush Hill (985103) and the other on the north side of Citron Seat (978104). A line of sink holes marks its top ¼ mile west of Redmire Hills (962101), and ¼ mile east of Sleightholme (960100) the top is exposed in an old quarry, where it dips 4° SW beneath the overlying calcareous shale. Grey crinoidal limestone, thinly bedded, is seen in a shallow quarry 200 yards south of Bar Gap, while 180 yards west of the farm, in the east bank of Sleightholme Beck (957106), the upper 30' of the Main limestone are exposed, thrown against the Upper Coal Sill to the north of the fault.

North of the North Spanham fault the Main Limestone is seen at intervals through the drift on Eller Beck Rigg, at the NE end of which (000112) 40' of horizontal limestone are exposed. From here as far as Hong Kong Plantation the base makes a well-defined feature on which scattered outcrops occur. A short north-facing scar in Green Fell Plantation exposes 25' of well-jointed limestone, while up above, on Low Green Fell, the top is marked by swallow holes into the peat cover (here up to 8' thick in places). The up-faulted wedge at the southern end of Hong Kong Plantation (993117) exposes 42' of the Main dipping WSW at 10°, and at the northern end of High Green Fell (250 yards to the north) 32' of well bedded and jointed grey crinoidal limestone in an old quarry are cut off abruptly at the western side by the westernmost of the High Green Fell faults. A swallow hole a few yards west of the quarry indicates that the throw of the fault is approximately equal to the thickness of the limestone. By means of further swallow holes the Main is followed round into Chert Gill and back into Sleightholme Beck.

South of the watershed, the Main Limestone has been traced round the head of Arkengarthdale. To the west of the road, swallow holes mark its top between Roe Beck (954055) and the NE end of Leading Stead (954064), and it is well seen (dipping NW at 4°) in Swanasit quarry (956061). But across Leadingstead Bottom and in Mud Beck peat on very thick boulder clay obliterates all solid rock. At the head of Mud Beck (959085) Dakyns et al. (1891, p.118) noted the presence of a powerful spring which deposited much tufa. There is no spring there now (1954), but a 5' high green mossy mound may have a foundation of tufa. Similarly Robin Dub (961088), described then as another spring, is now a stagnant hollow. In Crook Sike Gill, 250 yards NE of Robin Dub, 8' of shale are seen beneath thick boulder clay, and the top of the Main Limestone must lie beneath this exposure. So it must be assumed (if Robin Dub and the mossy mound are on the outcrop of the limestone) that during the past 75 years the water flowing in the Main has worked its way down to a lower level. The Crook Sike Gill exposure leaves no doubt that the limestone does not continue across the watershed beneath the peat, a point on which the Primary Surveyors were unsure. Some 500 yards SE of Robin Dub an isolated outcrop occurs in Limestone Hill (65085), where a west-facing 15' crag of the Main is entirely surrounded by peat. It may be that this exposure has been thrown up by a fault, as the limestone is here rather higher than would have been expected. But with absolutely no further evidence the exposure has been mapped normally. South of this, for 1000 yards, drift and peat obscure the outcrop, but above Seavy Hill they thin sufficiently for swallow holes to develop into the top of the Main. At the head of Roughton Keld the limestone is exposed at a strong spring, which is directly in line with very well-marked dislocations in the features formed by the beds above the Main Limestone on the west side of Cleasby Hill. There is no doubt that this spring is on the fault, the water issuing from the base of the limestone on the downthrow side. Just south of the fault (on the upthrow side) a small drift-free patch reveals the base of the limestone some 20' higher than the level of the spring. Near Ravens Park, the upper limit of the drift drops down below the level of the Main, and eastwards from there the limestone is very well exposed as far as the Faggergill fault, shake holes marking the top for the whole distance. The base makes an unmistakable feature all the way, but the outcrop is covered in places by peat, particularly to the west of the old lead mine.

Ovening Nick (988073) affords a good exposure of the upper part of the limestone in a narrow gully ending in a swallow hole. It is grey, crinoidal, very compact, with many foraminifera, and contains fragmentary brachiopods and bryozoa.

At the foot of Stang Pass a faulted inlier of Main Limestone occurs around the old Stang Lead Mine (010059). On the east side of the valley the top is exposed in a hush SE of Stang House, and also in Dry Gill (on the north side of the Faggergill fault), shake holes occurring at intervals between the two. In Dry Gill (008053) the limestone immediately adjacent to this major fault dips north at 35°, and is dolomitised. On the west side of Shaw Beck there are no outcrops, and the limestone is marked only by shake holes along its upper boundary.

(ii) <u>Beds between the Main and Little Limestones</u>

(a) South side of the anticline, west of Stang

The section in Sleightholme Beck upstream of the Stainmore Summit-North Spanham fault exposes the beds between the Main and Little Limestones over a distance of 2 miles, the dip for the most part being similar to that of the stream bed. Immediately overlying the Main, a series of calcareous and siliceous fossiliferous mudstones form the bed of the beck for 450 yards above the fault. These are also seen in Hound Beck for 500 yards above its confluence with Sleightholme Beck. These flat-lying mudstones are no more than 20' thick, however, and are succeeded by some 20' of shale which is exposed in the banks of Hound Beck south of Sleightholme Farm. Above this, the Coal Sills come in and the lower part is continuously exposed in Sleightholme Beck for a mile upstream from the farm.

As the section is so long and the beds so variable laterally, it is difficult to measure the thickness accurately, but the Lower Coal Sill is probably about 50' thick here. There is loose coal in the banks, but it could not be found in situ. Just above the confluence of Dry Gill and Frumming Beck, the Upper Coal Sill is exposed in both streams where it overlies 26' of shale and is no more than 20' thick, the junction with the Little Limestone being well seen. But it is very massive, and in part current bedded. These beds are drift-covered round the eastern end of Sleightholme Moor, but reappear north of Beck Crooks, where the Upper Coal Sill makes a good feature (littered with blocks of massive sandstone) for ½ mile. The overlying Little Limestone is inferred from a small quarry section at the SW end of the feature (942074), where the massive sandstone becomes fossiliferous at its very top. South of the road, Annaside Beck exposes 8' of massive sandstone (with a few worm casts) underlying the Little Limestone (941065), while in its right-bank tributary, Lad Gill, this bed is seen dipping downstream over a distance of 110 yards. It is a medium-grained sandstone, and here the worm casts are quite plentiful, with occasional casts of fragmentary brachiopods in addition towards the top. Cherts above the Little Limestone are next seen, but the top 4' of the Upper Coal Sill are repeated some 200 yards further upstream by a fault, being easily recognised by the worm casts which (in this area) are so characteristic of this horizon, and also by the presence of the overlying Little Limestone. Eastwards across Leading Stead drift covers the hillside, but at its eastern end (955062) 5' of wormy sandstone are exposed beneath the Little Limestone. Southwards from this point the sandstone horizon is not seen again, and probably dies out north of Roe Beck.

NE of Arkle Beck, good exposures occur round Cleasby Hill and Hoove. Just to the south of the North Spanham fault, West Black Sike shows 7' of fossiliferous shale overlying a little inlier of Main Limestone, above which come 25' of banded flinty chert (including some thinly bedded siliceous mudstones in the lower 7'). The chert (which is also very well seen in Eller Beck and East Black Sike) continues upstream for a considerable distance due to its low northerly dip, to be lost eventually beneath the peat. South of Spanham East and West Hills, beds up to the Little Limestone have been faulted against the Main Limestone. In the south wall of Spanham Hush (009098) the section on the downthrow side of the fault is:-

Little Limestone and overlying cherts	
Massive sandstone	16'
Flaggy sandstone	25'
Sandy shale grading up into shaley sandstone	7'
Shale with bands of ironstone nodules	15'
Flinty chert	7'
	70'

The Lower Coal Sill has died out between here and the upper reaches of Eller Beck, where it is seen beneath the western end of White Crag. The Upper Coal Sill is still well developed, however, and can be mapped beneath the Little Limestone between the two main faults, being exposed at intervals between East Black Sike and Scargill Beck. South of the South Spanham fault, the chert overlying the Main Limestone is exposed in many swallow holes SE towards Stang, and in Black Gutter (009086) 2' of siliceous mudstone on 4' of shale separate the chert from the limestone. A similar section is seen in Doorgill Head (015078), but in the shake hole called Priestwife Pool (019075) 11' of fossiliferous shale and mudstone overlie the Main Limestone. Just to the west of the Stang road (¼ mile SW of Stang quarry) the most easterly exposure of flinty banded chert at this horizon occurs in a shake hole, where 3' of it overlie siliceous mudstone. To the east of this, the Main Chert is mainly comprised of siliceous limestone and mudstone.

The Upper Coal Sill, which forms the bold north-facing scarp of White Crag, is very well exposed eastwards from Bleak How. The sandstone itself (massive, medium grained, very pale and in places current-bedded) is no more than 25' thick, although it holds up a feature between 3 and 4 times that height. It is fossiliferous at the very top, with casts of brachiopod fragments and little crinoid ossicles. The feature almost dies out into drift east of East Black Sike, but reappears beyond Black Gutter (where it is covered with loose somewhat flaggy sandstone), and although not so strong, sweeps round Cold Brow. 300 yards NW of Doorgill Head (013080) the feature dies out again (this time not in drift) and a section 200 yards SW of the swallow hole (014073) reveals only 3' of fossiliferous carbonaceous micaceous sandstone. This is the lateral equivalent of part of the massive sandstone which formed White Crag, and marks the feather edge of the Upper Coal Sill, the lower one having died out further NW. South of the watershed, another interesting exposure occurs in Hurr Gill, on the SE or upthrow side of the fault (011066), where 15' of dark fossiliferous shale (very slightly sandy and micaceous in part) underlie the Little Limestone. This is virtually beyond the limit of the Coal Sills delta, the arenaceous material being barely detectable in hand specimen.

Across the south side of Hoove there is no solid rock, but in the Faggergill valley further interesting exposures occur. Along the east side, and across the head of the valley as far as a shake hole 300 yards NE of Ovening Nick, the chert horizon overlying the Main Limestone can be traced. It is between 2' and 4' thick, and is of the flinty banded type seen further north. It is separated from the limestone by at least 7' of shale and mudstone. Across the head of the valley, the Upper Coal Sill shows well in Carkin Bank and Faggergill Scar. A section in the latter (993077) showed the sandstone to be 30' thick, including the flags at the base. But 400 yards SE, in Black Sike, the section is:-

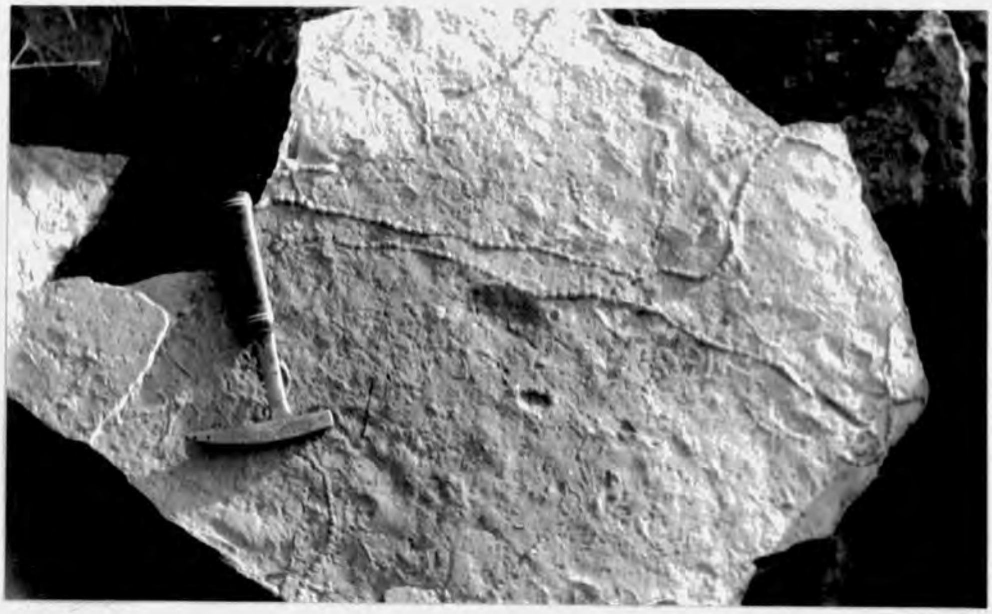
Sandstone, flaggy in part, with many worm casts up to 5' in length (Plate 8A, p.135), Little Limestone over	12'
Sandy shale grading up into shaley sandstone	8'
Black shale, with bands of ironstone nodules	30'
	50'

The sandstone has thinned rapidly and (as can be seen from the features) continues to do so south of this section, so that at the south end of Shivery Scar (250 yards away) it has gone altogether and the Little Limestone rests on shale as in Hurr Gill.

On the west side of the Faggergill valley, the most easterly exposure of the Coal Sills Marine Band occurs in Blind Gill (986076), where it is 5' thick (including a 2' shale band in the middle). It overlies a thick shale, this point being beyond the limit of the Lower Coal Sill, and is a very muddy fossiliferous limestone. In thin section it is seen to consist of many brachiopod fragments set in a matrix of dark brown, somewhat calcareous, argillaceous material, in which is a very variable proportion of small angular quartz grains, as high as 15% in parts of the slide. The only other exposure of this band (apart from that in Sleightholme Beck) is on High Seavy Rigg, to the north of Cleasby Hill (974089), where 12" of the same rusty-weathering argillaceous limestone is seen resting on shale in a little gutter. Westwards from Blind Gill, up to 10' of shale overlying the Main Limestone are seen in swallow holes, with the exception of one behind Ravens Park (972069), where a thin calcareous mudstone band has developed some 3' above the top of the limestone. The authors of the Mallerstang memoir record 5 or 6 feet of chert here, separated from the Main by a foot of shale (p.118), but no sign of chert could be found anywhere near Ravens Park.

The Upper Coal Sill can be traced SW from the head of the Faggergill valley by means of an intermittent feature and scattered massive sandstone blocks as far as Seavy Hole, about ¾ mile away. Beyond this, round Baxton Knab (980068), there is no sign of it for some 500 yards (apart from an isolated outcrop of flaggy sandstone), but it becomes prominent again due south of the top of Cleasby Hill to make an excellent feature (on which are many outcrops) round onto the west side of the hill. So on Baxton Knab there is yet another position for the edge of the delta which deposited the Upper Coal Sill. Above Ravens Park the sandstone is massive (coarse towards the top) and about 25' thick. ¼ mile to the NW the feature is dropped down 30' by the fault running through Roughton Keld, north of which there is no difficulty in following the sandstone along Brown Edge and Bleakhow Edge into White Crag. In Long Gutter, beneath Brown Edge (969085), the most southerly exposure of the

Plate 8



A. Worm trails on a bedding surface of the Upper Coal Sill, Black Sike (Faggergill).

B. Black Scar, Sleightholme Beck. The top of the Main Limestone is in the foreground, and is overlain by the "Tumbler Beds". The bottom of the Lower Coal Sill appears at the top of the scar to the left.

Lower Coal Sill occurs, where it is flaggy and interbedded with shale. To the north and NE it forms a low feature round Garded Hill and Low Seavy Rigg (on which are scattered sandstone blocks), and is exposed again beneath Redwell Springs, in the upper reaches of Eller Beck (982092), where it is flaggy and ripple-marked. Eastwards from there it is not seen again, and is definitely absent 1½ miles away in Spanham Hush.

(b) North flank of the anticline

North of the Stainmore Summit-North Spanham fault, Sleightholme Beck affords excellent exposures of the Main Limestone-Little Limestone interval. In Black Scar, 1¼ miles upstream from the confluence with the Greta (965113, Plate 8B, p.135), the section is:-

Massive sandstone of the Lower Coal Sill, drift over	10'
Flaggy sandstone with shaley partings	22'
Shale	30'
Fossiliferous siliceous mudstone, good band of <u>Lingula squamiformis</u> near top	7'6"
Shale	1'6"
Dark siliceous mudstone, with shale partings	6'
	77'

The upper siliceous mudstone band also contains plant remains, small lamellibranchs, and occasional orthocone nautiloids and spirifers, so the lower part of this section is probably an estuarine deposit, with alternations between just marine and just fresh-water conditions. From a point ¼ mile further upstream, the Lower Coal Sill is well exposed in the river for some 350 yards and is seen to be largely current-bedded with some shaley partings. Above this come some 40' of shale with lenticular sandstone beds in its lower part, and containing a 14" fossiliferous calcareous mudstone (the Coal Sills Marine Band) some 15' above its base, which is exposed in the banks to the NW of Bar Gap (958108). In Bog Scar, nearby, the section is:-

Massive sandstone, current-bedded	15'
Flaggy sandstone	17'
Dark shale	20'
	52'

The sandstone members of this section constitute the Upper Coal Sill, which is overlain by the Little Limestone (well exposed at the top of the scar). No coal is seen in situ anywhere in this section, but 400 yards NE of Bar Gap coal is present in the loose material in the sides of a little gill flowing north into Sleightholme Beck, and this may have come from the top of the Lower Coal Sill.

When these beds are traced round from Black Scar towards Bowes, striking changes take place. 600 yards north of Black Scar, in the east bank of the beck (966118), 3'6" of banded flinty chert are seen overlying the siliceous mudstone, and in Huggill, 1500 yards further NE (977125), the section is:-

Sandstone, with shaley sandstone partings	15'
Non-marine shale and sandy shale	15'
Banded flinty chert	22'
Alternating shale and mudstones on Main Limestone	18'
	70'

The upper part of this section is undoubtedly the Lower Coal Sill and its underlying shale. The shale and mudstones at the base are similar to those in Black Scar, and can readily be correlated with them. This leaves the chert, totally unrepresented in Black Scar (only 1 mile away), to be fitted in, and as its feather edge is actually seen resting on siliceous mudstone to the north of the scar, it must be supposed that it overlies that horizon and passes laterally into the lower part of the shale which underlies the Lower Coal Sill in Black Scar. The best exposure of this very hard banded flinty chert (the petrography of which is described in Chapter 9) is in Chert Gill (987118, Plate 9A, p. 139), where 26' of it are well seen. It overlies alternating shale and mudstones (quite distinct from the limestone proper) as in Huggill, but the beds above it are obscured by hill peat. A steep north-facing feature runs across the south side of Gilmonby Moor for about ½ mile (disappearing into drift either end) on which are many large blocks of massive sandstone. This is thought to be an outlier of the Upper Coal Sill, the sandstone being very similar lithologically to that in White Crag, a mile to the south.

On the north side of the River Greta the chert is seen in several sections near the confluence with Sleightholme Beck. In Sealgill (974132) the succession is:-

Sandstone with shaley sandstone partings, the Lower Coal Sill	15'
Shale grading up into sandy shale	7'
Gap	7'
Banded flinty chert	19'
Alternating shale and mudstones, on Main Limestone	

Eastwards from here the chert is not seen again, and must die out as quickly as it came in. The Upper Coal Sill is excellently exposed in Clint quarries (above the road ½ mile west of Bowes) where it is capped by the Little Limestone. But drift cover obscures the beds above the Main Limestone everywhere between there and the Tees except for isolated non-marine shale and sandy shale exposures in the upper reaches of Thorsgill Beck. Fortunately the Mount Pleasant bore has supplied a section for this part, which reads as follows:-

Coarse uniform light-brown grit, thick boulder clay over	43'
Banded sandy shale with plants	8'
Finely laminated blue shale with plants	29'6"
Soft dark shale on Main Limestone	25'6"
	106'

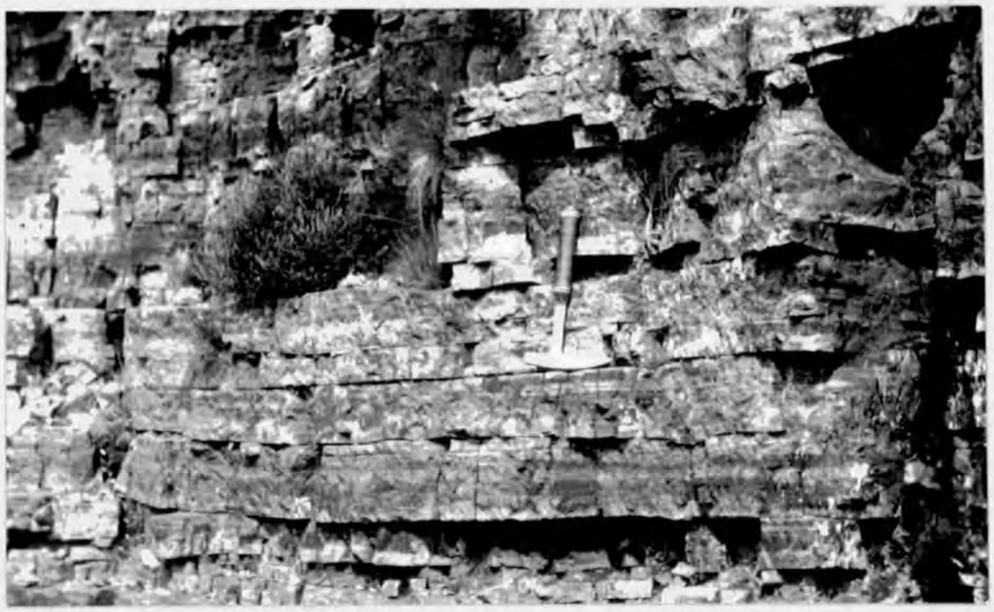
It is noticeable that here both the alternating shales and mudstones and the banded cherts of further west and SW are represented only by shale, illustrating the rapid lateral changes which take place in these beds immediately overlying the Main Limestone. This is further emphasised by the section in the Tees at Egglestone Abbey (062152), where only a thin shale separates the Main Limestone from a series of alternating flaggy sandstones and sandy shales which outcrop upstream towards Barnard Castle.

The beds overlying the Main Limestone are again seen immediately downstream from the Tees-Greta confluence, where a combined section from Cross Berry Plantation and the opposite bank shows the succession to be:-

Calcareous sandstone passing up into the Little Limestone, river gravel over	4'
Shaley and partly carbonaceous sandstone	9'
Mainly shale	40'
Very rapidly alternating non-marine sandy shales and shaley sandstones	50'
Shales	19'
Mudstone	4"
Shale on Main Limestone	8"
	123'

It is evident that here the Coal Sills are very much broken up by shale bands, and are in the process of dying out. And in Thorpe Scar (½ mile further east) there is a similar section. But 1¾ miles ESE from Thorpe Scar the Wycliffe bore has proved 94' of soft dark grey and very uniform shale lying on the Main Limestone without any sign of arenaceous material. The shale is generally

Plate 9



A. The Main Chert in Chert Gill. The bedding is unusually clear in this section.

B. The top of the Little Limestone in White Stone Gill, Sleightholme Moor. The partially chert-filled tubes (probably annelid borings) and the thin chert capping weather out strongly.

poorly fossiliferous, but is marine and, unlike that at Mount Pleasant, must all have been deposited beyond the limits of the Coal Sills delta. SE from here, there is no further evidence of any of the beds between the Main and Little Limestone on the north side of the anticline.

(iii) <u>The Little Limestone and overlying beds</u>

(a) South side of the anticline, west of Stang

The type exposure of the Little Limestone for the purpose of the present work is in Dry Gill or White Stone Gill (929090), where its full thickness of 7' is seen 750 yards upstream from the confluence with Frumming Beck. It is a compact grey limestone, slightly sandy in its lower part (noticeable on weathered surfaces), with small but numerous crinoid fragments. The upper part is characterised by numerous irregular cherty tubes, more or less vertical, which coalesce in the top 4" or so to form a band of chert, and which continue downwards for as far as 18" into the limestone, getting progressively less siliceous with depth (Plate 9B, p.139). The tubes are somewhat variable in diameter, but ½"-¾" is quite typical. A thin section of one of these tubes revealed up to 20% of angular quartz grains of all sizes up to 2/3 mm. across, with scattered plagioclase and zircon grains, set in a matrix of finely crystalline calcite (with crinoid and brachiopod fragments) and isotropic pale brown opaline silica in which occasional very small rhombs of recrystallised carbonate occur. Pyrite is disseminated throughout the slide in small patches. These tubes, which weather out quite strongly, must have been formed soon after deposition of the limestone (probably by some boring organism such as an annelid) and filled up by the succeeding siliceous sediment. The cherty tubes are very constantly developed at this horizon over an area of several hundred square miles, and have been used as a clue to the identity of the Little Limestone as far south as Wensleydale (but see Chapter 7).

In both Dry Gill and Frumming Beck the Little Limestone is succeeded by a series of platey siliceous mudstones, calcareous shales and siliceous limestones (all of them fossiliferous to a greater or lesser extent) about 35' in thickness, and above which come some 50' of shale (with two thin siliceous limestone bands in the lower 20') below the Ten Fathom Grit. The series of siliceous deposits overlying the Little Limestone has been named the Richmond Chert Series, after the very well developed cherty limestones of lower Swaledale at that horizon, and these beds on Sleightholme Moor are therefore members of that series. Very characteristic of the series are Cauda Galli markings on the partings, which generally take the form of low concentric ridges running across the surface, very variable in size and extent, at first sight similar to the traces which seaweed swirled by a current might make on a soft surface. These markings are caused by complicated sedimentary structures of unknown origin (described in Chapter 9) which have not been observed during the present survey in any quantity beneath the Little Limestone. Cauda Galli markings are particularly well developed in the Richmond Cherts in Dry Gill.

SE from Frumming Beck the beds above the Little are peat-covered over the watershed, but loose pieces of siliceous limestone were found above the feature of the Upper Coal Sill north of Beck

Crooks, although the Little itself is not seen. In Lad Gill to the south (943063), the lowest 5' of the Richmond Cherts are separated from the Upper Coal Sill by a 4' gap. But 200 yards further upstream a fault repeats this part of the section, which now reads:-

Massive false-bedded sandstone of the Ten Fathom Grit	
Shale, becoming sandy towards the top	16'
Fossiliferous siliceous limestone, with Cauda Galli	27'
Little Limestone, sandy lower part, cherty top 2"	1'10"
Upper Coal Sill	

Eastwards across Leading Stead, drift covers the hillside, but at its eastern end the Ten Fathom Grit (which must be well over 50' thick) makes a feature which is followed round to Roe Beck. An isolated exposure 250 yards WNW of Swanasit quarry (954062) shows 8" of sandy limestone (the Little) overlain by loose siliceous limestone and resting on an attenuated Upper Coal Sill.

On the east side of Arkengarthdale Head, the Little Limestone has been mapped most of the way round Cleasby Hill and Hoove. It is exposed on the east side of Bleak How, above the western end of White Crag (980090), and makes a small feature about 10 yards back from the top of White Crag for much of its length. SW from Doorgill Head the feather edge of the Upper Coal Sill is overlain by a thin brown clay (probably a fossil soil) and in Hurr Gill (011066) this clay is seen again, overlying shale, but here contains blocks of sandy limestone up to 15" thick which are undoubtedly erosion remnants of the Little (which presumably has been completely removed from the former section). Along the east side of the Faggergill valley the Little Limestone is mapped at the base of a feature formed by the Richmond Cherts (in the absence of the Coal Sills) and is well seen in Black Sike (995073), where it is 3' thick and apparently a good grey crystalline crinoidal limestone. A thin section shows many small foraminifera, together with brachiopod and crinoid fragments, set in crystalline calcite, but includes about 20% of angular quartz grains of all sizes up to 2/3 mm. in diameter, with occasional plagioclase, zircon and mica. Beyond this, round to Bleak How, the Little is not exposed again, but there is no reason to suppose that it is not present.

The Richmond Chert Series forms a wide outcrop on Faggergill Moss (the saddle between Cleasby Hill and Hoove) where siliceous limestone emerges from the peat cover in Great Foster Hill (990084), but all round the south and west sides of Cleasby Hill the peat hides this horizon. To the north, however, there are numerous exposures. A little quarry in the side of Tarnhow Hill (976087) exposes 3' of siliceous limestone with crinoid ossicles, productids and Hyalostelia anchoring spicules on 2' of white chert, beneath which are 3' of streaky siliceous limestone. This white chert band can be followed round Long Rigg and Green Hill to the SW, and is present in many sections in the upper part of the series south-eastwards in the direction of Richmond. It is particularly well seen in the neighbourhood of Marske, and it has proved to be the only bed within the Richmond Cherts which can be followed over any distance, being most useful as a horizon marker. It is very easily recognised by its colour, and has been mapped over many miles of outcrop. Around Hoove, siliceous limestones (some with Cauda Galli) are seen at intervals along the north side, but SE of Doorgill Head (where the Coal Sills die out) the Main Chert and the Richmond Chert Series come together in one thick series between the Main Limestone and the shale underlying the Ten Fathom Grit, and are indivisable except in those sections where the Little Limestone can be recognised within the series. It is these beds which are dealt with in section (iv) of this chapter.

SE of Hoove the Marske white chert band is seen again in Rowantree Gill (012064), where it overlies a series of SE-dipping cherty limestones. In Hurr Gill 10' of calcareous shale and siliceous limestone are seen on the erosion surface above the Little, above which are 20' of shale overlain by more siliceous limestone. North of the fault some 50' of shale underlie the Ten Fathom Grit. South of Hoove there are no exposures, but on the west side the Richmond Cherts are well seen, and in Black Sike the Little is overlain by 25' of siliceous limestone, streaky chert and calcareous shale. Isolated outcrops of these beds continue upstream for a considerable distance, however, and the series is probably here over twice this thickness.

Cleasby Hill is capped by the Ten Fathom Grit, which makes a good feature on all sides except the NE (which is peat covered). It is seen as blocks of massive false-bedded sandstone on the feature. Around Hoove the Ten Fathom Grit makes a strong feature on all except the south side, and in Elsey Crag (004080), on the north side, makes a bold scar some 45' high, the massive sandstone becoming coarse towards the top. At various places around Hoove (just below its flat peat-covered top) fragments of fossiliferous cherty limestone can be picked up at the top of a feature formed by the upper part of the Ten Fathom Grit, indicating that the Crow Limestone is present. The limestone itself is seen once only, in a little gutter on the NW side.

Elsewhere loose pieces of the overlying chert series (very similar to the Richmond Chert Series) are the only evidence for it.

(b) North Flank of the anticline.

Immediately north of the Stainmore Summit-North Spanham fault, the Little Limestone is well seen in both banks of Sleightholme Beck. The east bank section (958107) shows 5' of grey slightly sandy Little Limestone (with moderately well developed tubes running down from its cherty top) resting on the massive Upper Coal Sill. Above this some 8' of the Richmond Chert Series are present in the top of the bank. North of the Greta there are traces of the Little Limestone at the top of Clint quarries (NW of Bowes) and in Thornberry quarry, 1¾ miles ENE of Bowes, very weathered siliceous limestones and calcareous shales of the Richmond Chert Series are seen. The next exposure of the Little Limestone east of this is in Thorpe Scar (096144), nearly 5 miles away, in the south bank of the Tees. Here the Little is 3' thick, and its base is a passage through calcareous sandstone from the top of the Coal Sills. The limestone is crinoidal, but rather sandy, and is brown, having been partly dolomitised. It is overlain by at least 20' of calcareous shales and siliceous limestones with Cauda Galli, which are carried down into the river by the northerly dip but which, beyond the bend, outcrop in the bed of the river for 1½ miles downstream as far as the base of Howbury Scar (121144) due to the dip then being predominantly across the stream. The dip is very variable, however, and the beds undulate considerably, but the same horizon is constantly reappearing. Most of the exposures are in the south bank, and across the river up to 54' of shale overlying the chert series are seen. This shale is partly marine, flattened crinoid ossicles being abundant in the lower 15', occasionally accompanied by productids and spirifers. The base of the overlying Ten Fathom Grit is seen above Whorlton Bridge (106146), and also in Howbury Scar. Beyond the limits of the map, the Tees section exposes the Ten Fathom Grit as far downstream as Ovington (132149), where it is overlain by the Crow Limestone and Chert.

The Thorpe Scar exposure is the most easterly one on the north flank of the anticline where the Little Limestone itself is visible, but the overlying chert series can be traced some way further east. On either side of the Vicarage cross-roads, north of Hutton Magna (127128), quarry sections reveal up to 15' of cherty limestone with irregular argillaceous streaks, in a small drift-free patch. And ¾ mile SE a small quarry at Hutton Fields (135117) exposes 9' of siliceous limestone and calcareous shale. There is a comparatively large drift-free patch on the hill north of East Layton quarry, where up to 32'6" of similar beds were measured, all of which belong to the Richmond Chert Series. They are highly fossiliferous, containing many flattened crinoid ossicles, bundles of _Hyalostelia_ anchoring spicules, and many fragments of brachiopods. The dips are very variable, and east of this patch only occasional outcrops, widely separated, appear from beneath the drift, it not being possible to continue the mapped outcrop of the series with any accuracy. SW of the Forcett fault 18' of siliceous limestone in Hergill quarry (176110) can definitely be assigned to this horizon, however. A striking feature here are the lenticles of coarse crinoidal limestone (up to 1' thick and many yards long) which occur interbedded with the cherty limestones, and which are so much more common on the south side of the anticline. Two quarries into siliceous limestone in

Stanwick Park are probably in the Richmond Cherts, but eastwards, in and around Aldbrough, chert exposures may belong either to that series or to the one above the Crow Limestone (which is very similar in lithology).

(iv) Beds above the Main Limestone on the south side of the anticline, east of Stang

Along the southern part of the map, east of Stang, the Richmond Chert Series reaches its maximum development, and except in those sections where the Little Limestone is identifiable, is inseparable from the underlying Main Chert (here of similar lithology) because of the total absence of the Coal Sills.

On the west side of the road north of Stang Pass, the most easterly exposure of flinty chert in the Main Chert is seen. East of the road this horizon is comprised of mudstones, calcareous shales and siliceous limestones, the lower 10' of which are exposed in Rowantree Hole (023071). Siliceous streaky limestones are seen in shake holes eastwards and over the watershed as far as the head of Black Sike (032071). Southwards, in Arndale Beck, the Ten Fathom Grit is seen near the confluence with Black Hag (025063) as blocks of massive sandstone, which also occur on Arndale Hill. An exposure of 2' of decomposing streaky siliceous limestone of the Richmond Chert Series 500 yards further downstream is faulted against more massive sandstone of the Ten Fathom Grit, the latter being seen for a further 600 yards. A thin shale band about 5' thick then separates the sandstone from the underlying chert series, which is almost continuously exposed in the beck over the next ¾ mile as far as its base on the Main Limestone, the Little Limestone not being identified. The

Marske band was picked up on both sides of the valley at intervals, not far below the top of the series. The beds are extremely variable in lithology, and are all more or less siliceous apart from pale coarse crinoidal limestones (common in the upper part) which are undoubtedly lenticular bodies. Fossils, mainly fragmentary, are abundant throughout, bundles of Hyalostelia anchoring spicules (often exceeding 2' in length) being very common, particularly in the upper part, where they are characteristic of the Richmond Chert Series. Above Arndale Hole (053060) these beds are very well seen in the following section:-

Siliceous shaley limestone with abundant Hyalostelia and occasional pyrite nodules, enclosing many small limestone lenticles (Plate 10A, p. 157)	16'
Mainly siliceous shaley limestone, Hyalostelia in upper 10'	50'
Siliceous limestone and mudstone, some dark chert bands, probably Main Chert	20'
	86'

but again the Little Limestone is not distinguishable. Away from the slopes of the valley, hill peat is very widespread and exposures very poor. But there is enough evidence from loose material in gutters in the peat to be able to map the chert series right over Holgate Moor and all except the western end of Kexwith Moor, to the south of which Moresdale Gill provides a useful section. Here, immediately overlying the Main Limestone (038047), come a series of siliceous mudstones, calcareous shales and siliceous limestones in a section spread over a distance of 750 yards. 4' of grey limestone with a cherty top (from which a few differentially-weathering tubes run down into the limestone) overlie these beds, some 30' above the Main. This is probably the Little Limestone, which would here give the Main Chert a thickness of 30'. The siliceous limestones of the Richmond Chert Series overlying this show well developed Cauda Galli, and probably exceed 75' in thickness. The Marske Band, underlain by a thin bed of corals, was seen a short distance from the top at Moresdale Head (027051), where a tough 4' chert band caps the series, and is separated from the massive false-bedded sandstone of the Ten Fathom Grit by no more than 2' of shale.

South of the Faggergill-Waitgate fault there is a very good section in Holgate Beck which, between Goat's Bridge and Helwith, exposes the full thickness of the chert series, here about 100'. The dip is variable, but predominantly southerly, and the Marske Band, easily followed along both sides of the valley, is carried down from a height of 1050' O.D. above Holgate (067040) into the bed of the beck at 750' O.D. by the confluence of Holgate and Shaw Becks (073028). The band (about 4' thick) is exposed in Helwith Bank and along the eastern side of Pattison Plain as far as the head of Thrin Gill (079038), thus bounding on 3 sides the area of Pattison Plain, largely a dip slope in the beds overlying this chert band. Small shallow quarries into a lenticular coarse pale crinoidal limestone band here have yielded much of the walling material for this slope, and several good specimens of <u>Woodocrinus</u> were obtained from these walls. At the northern end of the Plain, loose sandstone is present in the peat cover on Sail How, and a small outlier of the Ten Fathom Grit has been mapped. A useful section in Holgate Beck, at the eastern end of Shaw Tongue (071032), exposes:-

Ten Fathom Grit, Crow Limestone and Chert over	45'
Mainly shale	20'
Siliceous limestones	25'
Marske white chert band	4'
Siliceous limestones and calcareous shales, to beck	12'

while in a little gully in the north bank of Shaw Beck, just upstream from the fault running up onto Shaw Tongue (069029), the section is:-

Cherty siliceous limestones, peat over	14'
Marske white chert band	2'6"
Shaley siliceous limestones, with irregular crinoidal limestone bands and lenses	32'
Calcareous shale	7'
Crinoidal limestone, irregularly bedded, with chert nodules	11'
Calcareous shale	3'
Streaky siliceous limestone	4'
Thickly bedded impure crinoidal limestone	16'
Gap to Main Limestone	20'
	109'6"

The Marske Chert is here some 95' above the top of the Main Limestone. North of Shaw Tongue the chert band makes a closed outcrop in Skegdale Beck, just below the bridge (where the underlying coral bed is again seen), and in Shaw Beck it is clearly exposed on both sides of the valley as far up as the Shaw Vein. It sometimes splits into two leaves which are separated by as much as 4'6" of siliceous limestone. A good exposure of the underlying coral band occurs north of Prys House (065025), where it is 2' thick and separated from the chert by 3' of siliceous limestone. *Hyalostelia* is abundant in the upper part of the series beneath the Marske band.

In Roan Beck, above the Green Dragon Inn at Hurst, the Ten Fathom Grit is exposed south of Roan House (048029), where it is partly current-bedded. A coal seam in its upper part has been worked, and is still visible in an old level at the north end of Roan Hush

(046030). Upstream from here, only peat is seen as far as Roan Head, where an outlier of pebbly Millstone Grit is exposed. Just north of Roan House, however, a small feature marks the base of the Crow Limestone, and the overlying chert is seen in an old quarry 120 yards NE of the ruin.

South of Shaw Beck the Ten Fathom Grit is seen at intervals skirting the north side of Skelton Moor. ESE of Prys House the Shaw Vein throws it against the Main Limestone along a line of old workings, but NE from the fault its base makes a bold feature on which massive sandstone is exposed. 300 yards ENE of Prys House this sandstone is unusual in that the little spots which commonly give the rock a speckled appearance are here of haematite instead of limonite. On Skelton Moor, south of Shaw Vein, the Marske Band was identified in two isolated exposures, but there is insufficient evidence there on which to map it. To the SE, however, in Moor House Gill (088013), it is well seen again for about 300 yards on either side of the fault. The base of the chert series is exposed along Telfit Bank, where it rests directly on the Main Limestone, but for the most part the exposures of the Richmond Cherts are isolated and dips variable, the Marske Band often providing the only clue as to the position in the series.

To the east of Marske Beck and Waitgate Gill the relatively flat tops between the valleys are all in the Richmond Chert Series. Two small outliers straddle Snaiza Gill (the overflow channel between the head of Dalton Beck and Rake Beck), where they occupy the site of a small shallow basin, the dip being inwards round their margins. South of this a wide outcrop stretches along the hill tops between

Gayles Moor and Marske. Its base over the northern part is marked by a number of shake holes into the Main Limestone, in many of which siliceous limestone and calcareous shale are seen. Bands of more pure limestone occur within the series and may locally form features across the peat-covered moor, but they are all lenticular bodies and no single one can be traced for far. South of Waitgate there are many exposures of the series along the east side of the valley, at least 80' separating the Marske Band from the top of the Main Limestone. The lithology is extremely variable, and here includes thin black chert bands in some of the calcareous shale horizons. In Dickey Edge the Marske Band is picked up, and stands out along the top of the valley as an obvious white streak as far south as the Marske Moor fault. East of Cordilleras Lane white chert is seen in the dry channel west of Low Feldom (106037), and can be traced round the west side of the Clapgate valley as far as the wood opposite Hey Gill (110030), so all outcrops between the two valleys must be in the top part of the Richmond Chert Series above the Marske Band. Exposures here are very poor, however, due to drift cover, and pale crinoidal limestone, siliceous limestone and calcareous shale are only seen in small and widely separated outcrops.

North of Clapgate Bridge the Marske Band is picked up again in Clapgate Spring Plantation (112022) and is easily traced for 2 miles round the spur north of Marske as far as Orgate Vein. It is about 4' in thickness, and a section 500 yards NE of Rubbing House (110020) shows its separation from the top of the Main Limestone to be 96', while above Marske it is 92'. The interval is occupied by streaky, siliceous and crinoidal limestones, with intervening calcareous shale horizons. Near Jingle Pot (099012) 25' of pale crinoidal and streaky limestones are exposed above the Marske Band, and these beds form the featureless south-facing dip slope on the top of this spur. A section down the south side of Orgate Vein, which throws the chert series against the base of the Main Limestone, reads:-

White chert of the Marske Band	4'
Streaky crinoidal limestone with Hyalostelia	6'
Coarse crinoidal limestone	2'
Gap	10'
Impure limestone rich in brachiopods, with calcareous shale bands	21'
Fossiliferous calcareous shale	1'6"
Impure coarsely crinoidal limestone with brachiopod fragments	14'
	58'6"

East of Clapgate Beck there are few exposures of the Richmond Cherts north of the Clapgate Bank road due to extensive peat and drift cover (apart from those in the numerous shake holes into the top of the Main Limestone). But from Clapgate Scar (117024) southwards along the east side of the valley and eastwards along the north side of Swaledale, the Marske Band is almost continuously exposed just beneath the top of the bank for a distance of 2¾ miles, so here again the isolated exposures on the moors at the top must be in the highest part of the Richmond Chert Series. Above Clapgate Spring (121024) the Main Limestone is overlain by siliceous limestones with abundant Hyalostelia no more than 20' from the base. In a little quarry at the top of Clapgate Bank the white chert is again underlain by the coral bed, and in Applegarth Scar, in a small down-faulted wedge (120016), 25' of interbedded streaky siliceous and pale crinoidal limestones overlie the Marske Band.

It is here appropriate to record the section in a roadside quarry ¾ mile SE of Marske (113996), a short distance beyond the southern limit of the map, where the following was measured:-

Mainly crumbly-weathering pale coarse crinoidal limestone, shale over	27'
White chert, upper part of the Marske Band	3'6"
Pale crinoidal limestone with Hyalostelia	1'
White chert, lower part of the Marske Band	1'3"
Mainly pale coarse crinoidal limestone	28'
Impure and streaky limestone	9'
Fossiliferous calcareous shale	1'6"
Streaky cherty limestone	26'
Limestone, with thin cherty top	3'
Fossiliferous calcareous shale	4'
Gap, evidently shaley beds, above Main Limestone	11'
	115'3"

The Marske Band is here about 85' above the top of the Main, but the most important feature of the section is the 3' of limestone above the lowest shale, which resembles the Little Limestone in all respects, although here the tubes running down from the cherty top are poorly developed and are only recognised in one part of the exposure. If, as is considered most probable, this bed is taken as being the Little Limestone, then the Main Limestone-Little Limestone interval, which has decreased progressively from about 130' in the region of Sleightholme to about half this value around Hoove (just beyond the edge of the Coal Sills) and about 30' in Moresdale Beck, would be no more than 15' in this quarry near Marske. Further evidence of this lateral variation will be presented from outside the area of the map in the next chapter.

At the northern end of Red Scar (east of Marske, on the south side of the Swale, 118005), 35' of siliceous limestones overlie the white chert band, which is the greatest thickness encountered above this marker horizon. The Marske Band is followed for ¼ mile east from Red Scar, along Thorpe Edge, but then suddenly dies out. In the Scarcote Gill section (129008) it is not present in 136' of siliceous limestones and calcareous shales which rest on the Main, and above which come no more than 20' of alternating sandstones and shales (the lateral equivalent of the Ten Fathom Grit), overlain by the Crow Limestone and chert series. ¾ mile further east, in Church Gill (142005), 4'6" of dark chert in a 12' band of shale and mudstone overlie the Main Limestone. Above this come 117' of the Richmond Chert Series, at the base of which the Little Limestone is thought to be just recognisable. Near the top of this gill section are broken exposures of shale with thin sandstone bands (overlain by the Crow Limestone), these being all that remain of the Ten Fathom Grit. And a further 2½ miles down the valley to the ESE the Richmond Chert Series and the Crow Limestone are separated by only a few feet of shale, the Ten Fathom Grit being entirely unrepresented. The Crow horizon is exposed ½ mile south of Richmond, in Spring Wood quarry (the section in which has been measured by Dr. R.W. Hey), where it is at least 60' thick, consisting of a series of siliceous, crinoidal and shaley limestones very similar to that overlying the Little Limestone.

Along the north side of Swaledale, 65' of the Richmond Cherts are exposed beneath the Marske Band in Salmon Gill, ESE of Park Top, while east of Deepdale these beds are exposed for a mile along the upper part of Whitcliffe Scar. This is the best single exposure of the series, and a number of sections taken at intervals along the scar bear little resemblance to one another. This fact serves to illustrate the very rapid lateral facies variations which take place within this horizon. A thin band of shale, taken as representing the beds between the Main and Little Limestones, forms a narrow shelf in the scar at the top of the Main, and gives rise to a number of small springs. 350 yards east of Willance's Leap (131020) the section is as follows:-

Streaky siliceous limestone	6'
White chert of the Marske Band	4'
Streaky siliceous limestone, with Hyalostelia	1'6"
Shaley limestone, with Hyalostelia	6'
Crinoidal limestone, with occasional chert nodules	10'
Streaky siliceous limestone	5'
Shaley limestone	7'
Alternating crinoidal and siliceous limestones, with Hyalostelia	28'
Alternating shaley and pale crinoidal limestones	14'6"
Grey and impure crinoidal limestones, supposed horizon of Little Limestone at base	11'6"
Calcareous shale with shell and crinoid fragments	4'
Gap, probably shale	7'
Argillaceous limestone	12"
Shale on Main Limestone	6'
	111'6"

The supposed horizon of the Little Limestone is placed on the evidence from Marske quarry, although here it is not specifically recognisable as such. This places the Marske Band about 80' up in the Richmond Chert Series (and about 100' above the top of the Main Limestone). But it suddenly disappears 50 yards east of this section, and is not seen again further along the edge. Beneath Willance's Leap a 4' band of corals, mainly Dibunophyllum and Chaetetes, is well developed, and on the edge of High Moor (142019) joint surfaces in pale crinoidal limestone near the top of the series have a very thin patchy coating of galena in places, although there is definitely no faulting nearby. A section near Applegarth Vein (131019), at the western end of the scar, reads:-

Pale crinoidal and streaky siliceous limestones	15'
Gap	14'
White chert of the Marske Band	4'
Crinoidal limestone, coarse in part, with interbedded siliceous limestone	27'
Shaley limestone, with much Hyalostelia, enclosing bands, lenticles and nodules of hard crinoidal limestone up to 2' thick	21'
Shaley limestone, with much shell and crinoid debris in part	9'
Siliceous limestone	12'
	102'

while at the top of Whitcliffe Wood (145015), at the other end of the scar, the section in an old quarry reads:-

Loose pale crinoidal limestone	
Streaky siliceous limestone with Cauda Galli	6'
Alternating shaley and siliceous limestones	21'
Impure limestone with some chert nodules, supposed horizon of Little Limestone at base	16'
Siliceous shale, partly calcareous, with scattered productids and very variable lenticles of silicified limestone (in part flinty chert) up to 2' thick, on Main Limestone	8'
	51'

Although the Little Limestone is not recognisable here by its special characteristics, it is considered to come above the siliceous shale at the base of the section, and 1½ miles SE, in Low Bank Wood on the south side of the Swale, a small quarry reveals:-

Richmond Chert Series, much siliceous and crinoidal limestone	
Calcareous shale, with many shell fragments	3'
Shale, with small gypsum needles and traces of pyrite on bedding	2'
Slightly micaceous siltstone with occasional shell fragments	2'
Main Limestone	7'

Here again the Little Limestone is thought to be the lowest post of the overlying chert series, with the 7' of shaley beds representing the interval between the Main and Little Limestones, and

A. Beds of the Richmond Chert Series on the north side of Arndale Hole. Nodules of relatively pure grey limestone are enclosed by platey-weathering siliceous shaley limestone.

B. Beds of the Richmond Chert Series in Hurgill quarry, Richmond. The white Marske Band is about 2/3rds of the way up the face, and is cut out towards the left by the overlying beds.

corresponding to the 15' assigned to that horizon in Marske quarry on more positive evidence.

The Richmond Chert Series is well seen in the Swale between Richmond Bridge and the weir, and also in Castle Bank, immediately beneath the Castle (171006). But the best exposures are on the hillside north of the town, which is in effect a dip slope. Hurgill quarry (165016) provides a most valuable exposure, the section at its north end being:-

12	Limestone, middle part of posts silicified to chert	15'
11	Limestone, streaky with coral bed at base, pale and crinoidal above, with silicified patches	6'
10	Shaley limestone	6"
9	Partly silicified impure limestone	1'8"
8	Streaky siliceous limestone	3"
7	Very prominent hard white chert of the Marske Band	2'
6	Streaky limestone, almost entirely silicified to pale brown chert	7'
5	Impure blocky crinoidal limestone, irregular patches and lenticles of chert, galena on some joint surfaces	15'
4	Pale streaky limestone with flinty chert patches	1'3"
3	Impure crinoidal limestone with partly silicified patches	6'
2	Streaky siliceous limestone	2'6"
1	Impure crinoidal limestone with thin shaley limestone partings containing _Hyalostelia_	5'

Southwards across the quarry, however, an erosion surface at the base of 11 cuts out beds 8-10 inclusive, while another and more striking one at the base of 12 cuts out all the beds down to and including 6 at the southern end of the exposure (Plate 10B, p. 157). Thus the removal of the Marske Band is clearly demonstrated, and the sudden end to the white chert exposures in Thorpe Edge and Whitcliffe Scar is most probably due to removal by this same erosion surface within the upper part of the Richmond Chert Series.

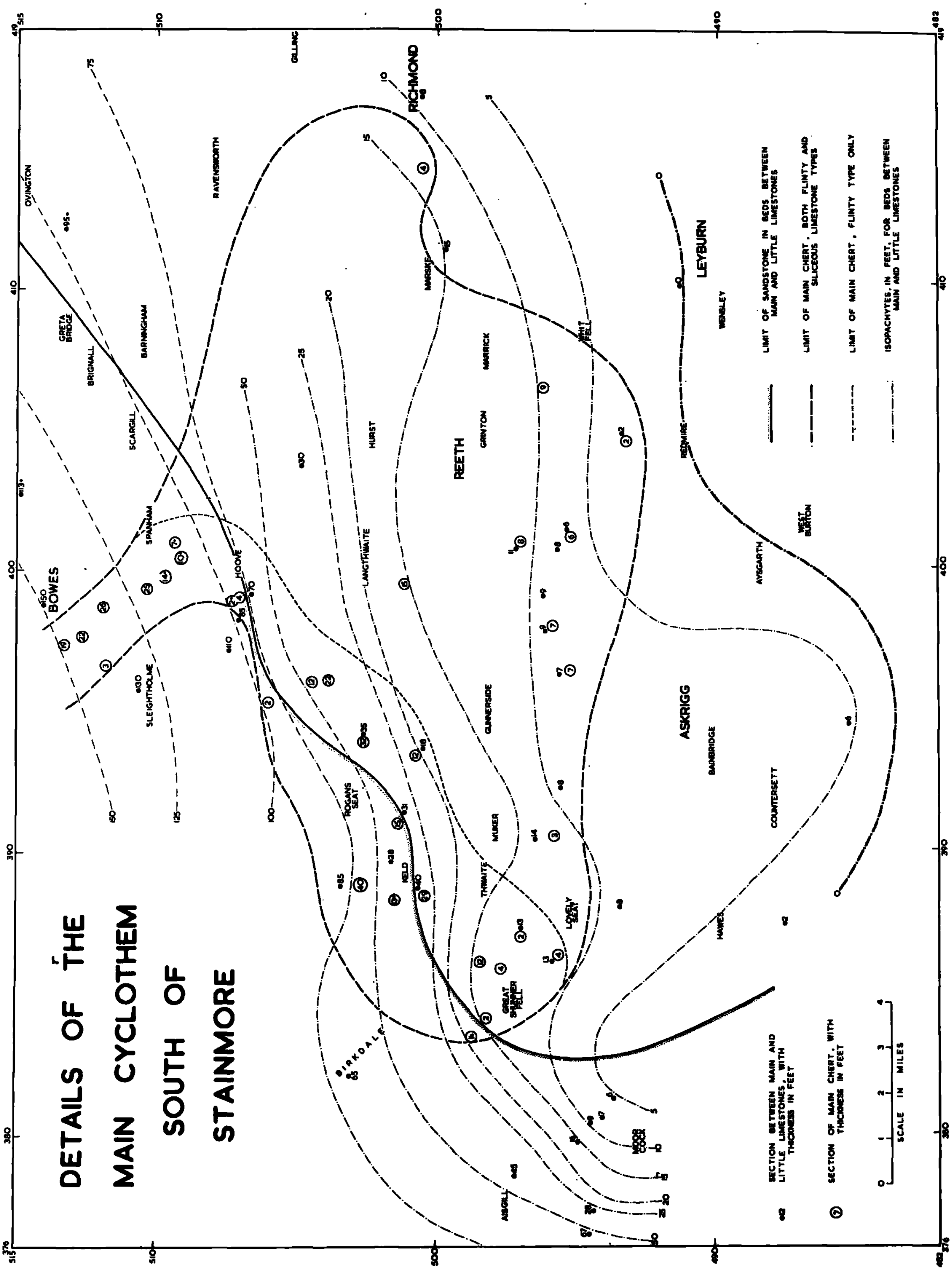
Another interesting section occurs in the quarry behind the Infectious Diseases Hospital (173016), where 2' of silicified limestone with lenticular cores of pale flinty chert are overlain by 25' of streaky siliceous limestone with lenticles of crinoidal limestone up to 2' thick (which make up about ¼ of the bulk). Parts of these lenticles have been removed by solution and replaced to a varying extent by crystalline $CaCO_3$. The section is capped by 8' of crinoidal limestone which encloses many thin beds and lenticles of streaky siliceous limestone up to 4" in thickness, the latter accounting for about 1/10th of the bulk. Traces of chalcopyrite and malachite occur on joint surfaces at the western end of the quarry. East of the Infantry Barracks there is another quarry (177017) which exposes 33' of streaky siliceous limestone with irregular lenticles of pale (in part coarsely crinoidal) limestone, and on the east side of the Gilling Road, on the edge of the new Housing Estate (180017), another erosion surface has been exposed in siliceous limestones, this time cutting across the bedding at an angle of 9°.

East of Richmond a great spread of fluvio-glacial sand and gravel obscures nearly all the solid ground, but a useful section comes from the bore-hole in St Trinian's quarry (189009), which is reproduced in section (m) of Figure 4 (p.101). 103'4" of limestone and calcareous shale on the Main Limestone were proved beneath the superficial deposits. At Crow Hole, opposite Brompton-on-Swale (215994), a section of some 20' of shale overlain by 15' of sandstone (somewhat purple near the top) occurs in the south bank of the Swale, while 600 yards further downstream in the opposite bank, 4' of this purplish sandstone are overlain with an unconformity of 10° by 4' of sandstone breccia. It is not possible to identify the underlying sandstone, except to say that it must be well up in the

Upper Limestone Group, but the breccia (which includes many angular fragments of chert from the thick series exposed further upstream) is certainly basal Permian. It was originally mapped as such by Phillips (1836), and Gunn recorded it as probably Permian during the Primary Survey. Round the next bend in the river undoubted Magnesian Limestone is now exposed in the south bank beneath Thornbrough, confirming Phillips' original mapping.

The Newton Morrell bore (237093), 6 miles NNE of Brompton, proved 48' of basal Permian breccia resting on beds of the Underset cyclothem. The breccia is of very similar composition to that exposed in the Swale, but is considerably coarser, individual fragments of sandstone and chert frequently reaching a length of 4 inches. The cementing material is dolomite, and this horizon is almost a dolomitic limestone near its base, where the foreign fragments are smaller and much less numerous than in the higher parts. It is well known (from evidence beyond the limits of the present area) that this basal breccia was deposited in depressions in the uneven pre-Permian land surface. Great variations in its thickness over quite short distances are therefore to be expected. The important structural implications of the Newton Morrell record are discussed in Chapter 8 (p.172).

FIG. 5


DETAILS OF THE
MAIN CYCLOTHEM
SOUTH OF
STAINMORE
RICHMOND
GILLING
RAVENSWORTH
OVINGTON
GRETA BRIDGE
BRIGNALL
BARNINGHAM
SCARGILL
SPANHAM
BOWES
HOOVE
SLEIGHTHOLME
MARSKE
MARRICK
GRINTON
REETH
HURST
LANGTHWAITE
GUNNERSIDE
MUKER
THWAITE
KELD
ROGANS SEAT
GREAT SHUNNER FELL
LOVELY SEAT
BIRKDALE
AISGILL
MOOR COCK
LEYBURN
WENSLEY
WHIT FELL
REDMIRE
WEST BURTON
AYSGARTH
ASKRIGG
BAINBRIDGE
COUNTERSETT
HAWES
LIMIT OF SANDSTONE IN BEDS BETWEEN MAIN AND LITTLE LIMESTONES
LIMIT OF MAIN CHERT, BOTH FLINTY AND SILICEOUS LIMESTONE TYPES
LIMIT OF MAIN CHERT, FLINTY TYPE ONLY
ISOPACHYTES, IN FEET, FOR BEDS BETWEEN MAIN AND LITTLE LIMESTONES
SECTION BETWEEN MAIN AND LITTLE LIMESTONES, WITH THICKNESS IN FEET
SECTION OF MAIN CHERT, WITH THICKNESS IN FEET
SCALE IN MILES

CHAPTER 7

VARIATIONS WITHIN THE MAIN AND LITTLE CYCLOTHEMS TO THE WEST AND SOUTH OF THE MAPPED AREA

The variations in the beds between the Main and Crow Limestones over the area of the map, described in the previous chapter, were considered to be of sufficient interest to warrant their investigation on a wider scale. Accordingly the position of the top of the Main Limestone was copied from the maps of the Geological Survey, and every available section of these beds over some 450 square miles of the northern part of the Askrigg Block (as far south as the watershed on the south side of Wensleydale) was visited. In all, 83 such sections were measured, the details of which, together with those from the relevant part of the surveyed area, have been summarised in Figures 5 and 6. 41 of these sections have been selected and reproduced (with 10 sections from within the mapped area) in Figure 7 as evidence for, and to add further detail to, these diagrams.

It has proved possible to draw the boundary of the Coal Sills with considerable accuracy south of the River Tees. The Upper Coal Sill reaches further south and east than the lower one, and the boundary in Figure 5 is in general the limit of the upper horizon. Section 5, from the Tees between its confluence with the Greta and Thorpe Scar, shows the Coal Sills moderately well developed, but less than 2 miles away the Wycliffe Bore (section 6) proved at least 95' of uniform dark shale on the Main Limestone, without any trace of the Coal Sills*. From between these sections, the boundary is traced across the area of the map (see Chapter 6) as far as Roe Beck, at the head of Arkengarthdale. There are no arenaceous beds between the Main and Little Limestones in Gunnerside Gill (section 18), but 4' of massive grey micaceous sandstone intervene near the Swinner Gill Mines (sections 14 and 15), which carries the boundary across the south side of Rogans Seat towards Keld. The West Stonesdale and East Gill sections (11 and 12) both show Coal Sills facies, which dies out north of Aygill (section 13). Adam Gill (17), on the NW side of Great Shunner Fell, exposes a 5' bed of sandstone, while an unfigured section in Wavery Gill (½ mile SE) shows the Coal Sills to be absent. This brings the margin round the west side of Great Shunner Fell, and east of section 38 (another Adam Gill) in Cotterdale. The Coal Sills are present in all 5 measured sections on Widdale Fell, but to the east, on Ten End (section 43), thinly bedded fossiliferous micaceous calcareous sandstone overlies 12' of shale on the Main Limestone, and is capped by pebbly grit. This is evidently a transition facies from the Coal Sills to the siliceous limestones of the Main Chert further east, and the boundary has been continued as far as this section. South of the watershed the grits come down onto the Main Limestone and cut out this horizon.

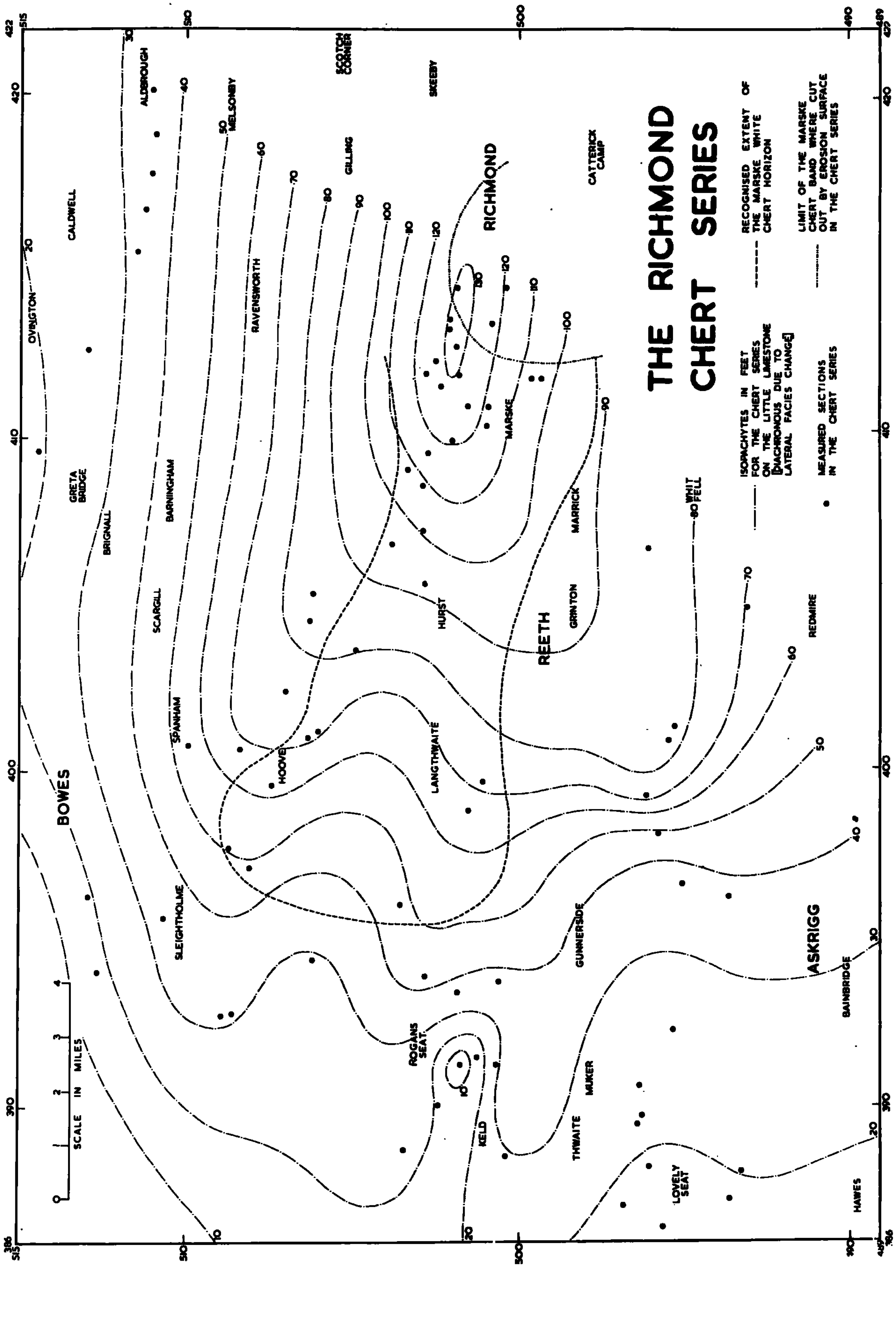
The general trend of the Coal Sills boundary can be continued north of the Tees by means of sub-surface information. The record from a bore-hole near Crook (some 8 miles SW of Durham), which was described by Woolacott (1923), showed undoubted Coal Sills facies between the Main and Little Limestones. On the other hand the record described by Fowler (1944) from a bore near Chop Gate, in the Cleveland Hills, shows beds at this horizon which must be correlated with the cherts around Richmond. A very thick series of siliceous limestones and cherts overlie the limestone taken as the Main, but by their very nature it is not possible to recognise individual beds within this series. What is certain, however, is that the Coal Sills are unrepresented, and that their southern boundary must run between these two positions.

The Main Chert in the region of Bowes is separated from the underlying limestone by a series of shales and mudstones. It is of the banded chalcedonic type, and has been recorded from a narrow zone (see Figure 5) which runs SE as far as Hoove, and from there SW through Rogans Seat and Keld to Great Shunner Fell. Around Bowes this chert passes laterally both east and west into black shale, but south of Spanham it passes westwards into shale, while to the east the passage is into a series of siliceous limestones and calcareous siliceous shales, the boundary of which sweeps round in a great loop along the Swaledale-Wensleydale watershed to Richmond, and thence back to Spanham. In general the thickness of this series decreases southwards, to be less than 10' south of the Swale. But north of Swaledale and east of Arkengarthdale, the facies is so similar to that of the overlying Richmond Chert Series that it is usually impossible to separate the two when the Little Limestone is not recognisable. The boundary of the Main Chert is open in a narrow NW-facing neck near Bowes, where the chert is last seen dipping into the Stainmore syncline. There is no further evidence for it to the north, and somewhere beneath that structure the boundary must close. It must be emphasised that this line in no way represents the edge of a basin of chert deposition, but merely marks the position where chert or siliceous limestone passes laterally into shale.

There is no evidence to suggest any break in deposition along this boundary.

The Little Limestone is thought to have been recognised, resting either on the Coal Sills or the Main Chert, in over half of the measured sections. Its most characteristic feature, cherty tubes running down into the limestone from a thin siliceous capping, is developed almost continuously (to a greater or lesser extent) over an area of at least 300 square miles, and sporadically for some distance beyond that limit. (It should be noted, however, that this feature is not entirely restricted to the Little Limestone, and was recorded in the overlying Crow Limestone in the unfigured Great Punchard Gill section.) The recognition of the Little Limestone has enabled the Main Chert and Richmond Chert Series to be differentiated in many sections, and isopachytes for the Main Limestone-Little Limestone interval have been constructed (see Figure 5). These show that the Little continues to descend progressively towards the Main Limestone south of the boundary of the Coal Sills, until in Wensleydale the two limestones are actually in contact. North of Wensleydale there is no evidence in individual sections for an erosion surface beneath the Little, although comparison of all the sections makes it extremely probable that one is present. In Messers Dorman Long's limestone quarry north of Redmire (section 50), however, up to 18" of sticky red clay with carbonaceous patches are seen between the base of the limestone taken as the Little and the Main Chert (Plate 11A, p. 167), and this would represent the erosion surface which goes unseen further north. In the road metal quarry a mile NW of Leyburn (section 51) the limestone believed to be the Little is separated from the Main by up to 4" of shale in parts, while

FIG. 6


THE RICHMOND CHERT SERIES
ISOPACHYTES IN FEET FOR THE CHERT SERIES ON THE LITTLE LIMESTONE (DIACHRONOUS DUE TO LATERAL FACIES CHANGE)
MEASURED SECTIONS IN THE CHERT SERIES
RECOGNISED EXTENT OF THE MARSKE WHITE CHERT HORIZON
LIMIT OF THE MARSKE CHERT BAND WHERE CUT OUT BY EROSION SURFACE IN THE CHERT SERIES
SCALE IN MILES
0
1
2
3
4
ALDBROUGH
MELSONBY
SCOTCH CORNER
SKEEBY
GILLING
RICHMOND
CATTERICK CAMP
CALDWELL
RAVENSWORTH
OVINGTON
GRETA BRIDGE
BRIGNALL
BARNINGHAM
MARSKE
MARRICK
WHIT FELL
HURST
REETH
GRINTON
REDMIRE
SCARGILL
SPANHAM
HOOVE
LANGTHWAITE
BOWES
SLEIGHTHOLME
GUNNERSIDE
ASKRIGG
BAINBRIDGE
ROGANS SEAT
KELD
MUKER
THWAITE
LOVELY SEAT
HAWES

in others it rests directly on the Main, the top post of which is cut down from 3' to 1' in thickness across the quarry. This erosion surface is thus considered to account for the whole of the time taken for the accumulation of some 150' of beds of Coal Sills facies only 15 miles away in the region of Bowes.

In every measured section except one, the Little Limestone is overlain by a lesser or greater thickness of siliceous platey impure limestones, the Richmond Chert Series. Isopachytes on this facies (the top of which is strongly diachronous) show a roughly concentric arrangement with an elongated centre near Richmond (see Figure 6), with the overlying shale passing inwards into the cherty beds until around Richmond itself the chert series reaches almost to the Ten Fathom Grit. The marked thickening in lower Swaledale is partly due, however, to the incoming of lenticular bodies of coarse crinoidal limestones into the series, which substantially increase the thickness of the Little cyclothem. The only horizon within the series which has proved recognisable over any distance is the Marske Chert Band, described in the previous chapter. Beyond the area of the map, it has been recognised just below the top of the Richmond Chert Series in the unfigured section in Little Punchard Gill, and it is present above a long gap in section 28 in Fore Gill. It is well seen under the bridge near the Old Gang Mines in Hard Level Gill, and a 4' band of pale chert in Howden and Thupton Gills (sections 47 and 48), south of Penhill, probably belongs to this horizon, although this is the only place where white chert is seen at this level south of the Swaledale-Wensleydale watershed. The band is very strong at the top of Downholme quarry, a mile south of section 30.

FIG. 7a

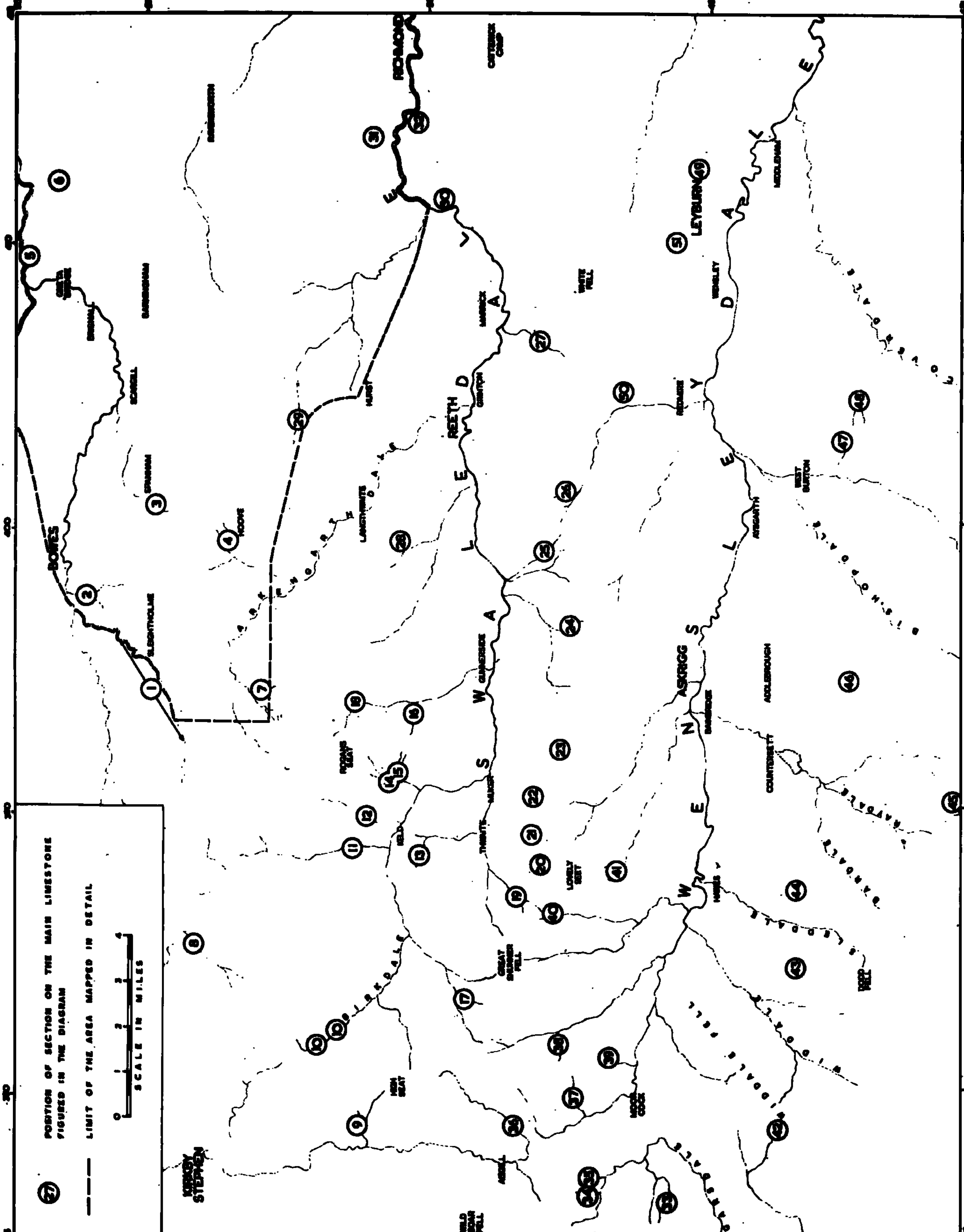
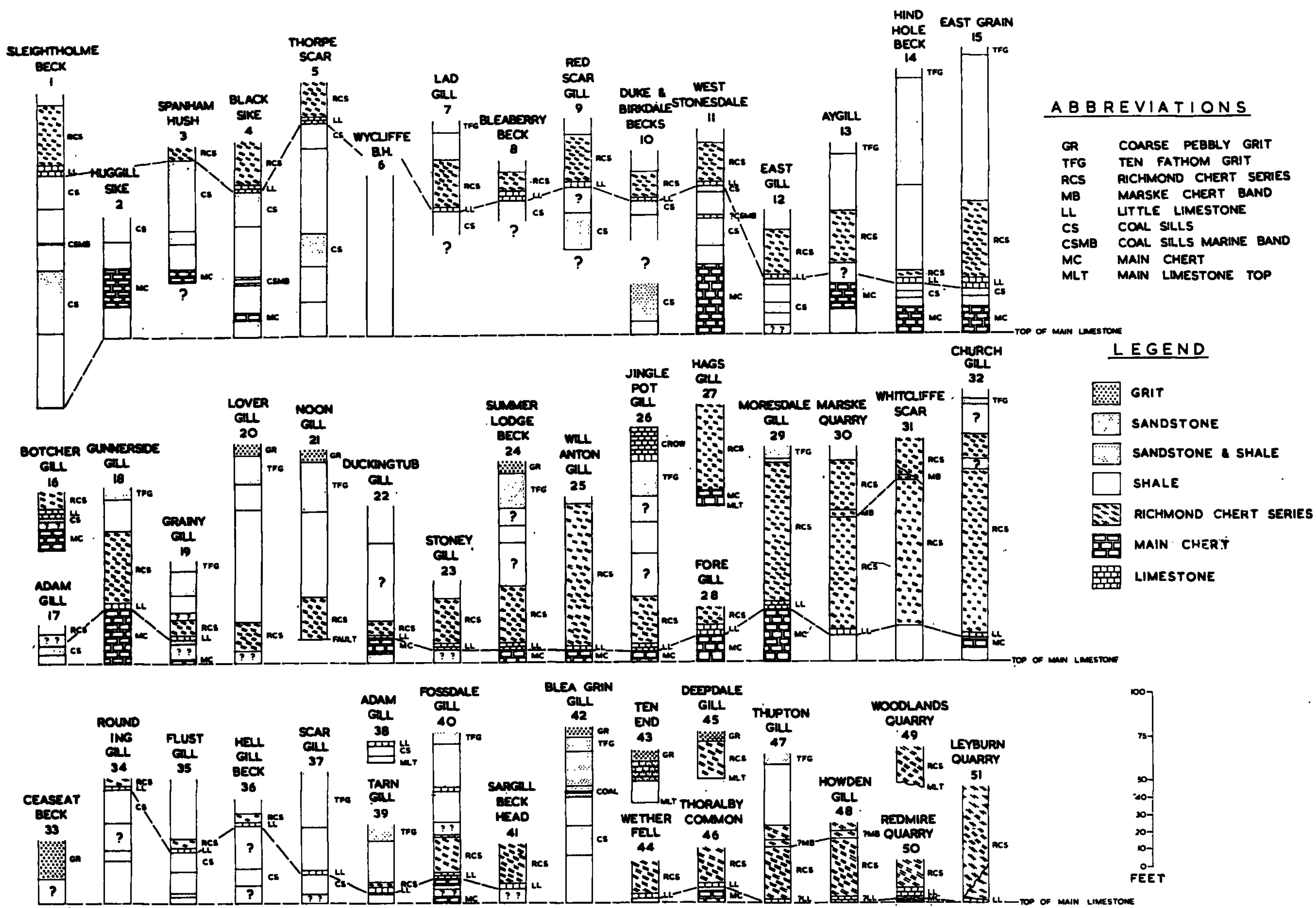

POSITION OF SECTION ON THE MAIN LIMESTONE FIGURED IN THE DIAGRAM
LIMIT OF THE AREA MAPPED IN DETAIL
SCALE IN MILES
0 1 2 3 4
RICHMOND
LEYBURN
REETH
ASKRIGG
HAWES
BOWES
KIRKBY STEPHEN
W E N S L E Y D A L E
S W A L E D A L E
A R K E N G A R T H D A L E
B I S H O P D A L E
C O V E R D A L E
R A Y D A L E
B I R K D A L E
G A R S D A L E
M I D D L E T O N
AYSGARTH
WEST BURTON
ADDLEBROUGH
COUNTERSETT
HIGH SEAT
MOOR COCK
GREAT SHUNNER FELL
LOVELY SEAT
KELD
MUKER
THWAITE
ROGANS SEAT
LANGTHWAITE
HURST
GRINTON
MARRICK
WHITE FELL
WENSLEY
MIDDLEHAM
CATTERICK CAMP
STAINMORE
SLEIGHTHOLME
WILD BOAR FELL
MIDDLETON

FIG. 7b

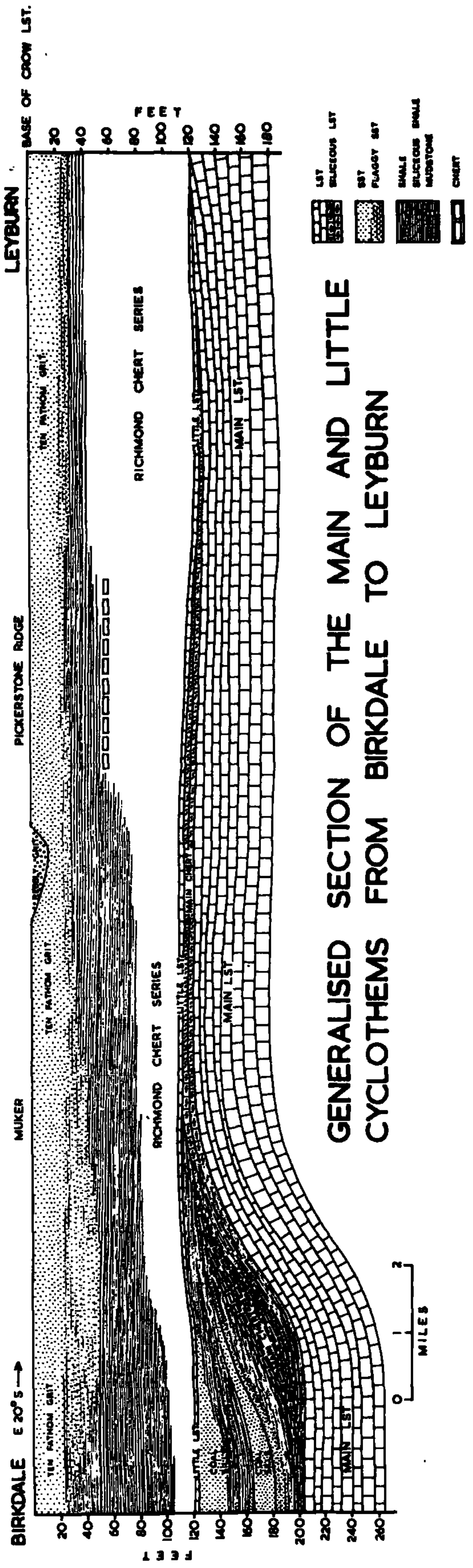


SECTIONS ON THE MAIN LIMESTONE OVER THE NORTHERN PART OF THE ASKRIGG BLOCK

The sections in Hind Hole Beck (14) and East Grain (15) make an interesting comparison. The former shows a mere 4'6" of the Richmond Chert Series overlain by thick shale, while only a few hundred yards away in East Grain there are 11' of well developed cherty beds with Cauda Galli, above which are 34' of siliceous shale containing many thin siliceous limestone bands. These latter strengthen rapidly when traced southwards in the banks of Swinner Gill, and less than ¼ mile south of the old mines the full 45' are good siliceous limestones, East Grain thus affording a good section of the actual transition from shale into the chert series. Another spectacular increase in the thickness of the series takes place on Whitaside Moor, on the south side of Swaledale. In the unfigured section in Hooker Gill 44' were measured, while ¾ mile east in Will Anton Gill (section 25) there are 83' of siliceous limestones above the Little. Generally, however, the thickness increase is gradual and hardly noticeable from section to section. A feature which is particularly associated with the Richmond Chert Series, and which is rarely seen in the similar facies of the Main Chert, is the characteristic Cauda Galli marking. This has been traced to a problematical structure in these beds (see Chapter 9) which, upon weathering, gives rise to concentric 'swirls', and should not be confused with rather similar markings in some arenaceous rocks (which have also been called Cauda Galli) which are due to parting across small-scale current bedding.

There are a number of very fine sections in the tributaries into the Ure from Abbotside Common, north of Moor Cock. In Scar Gill (section 37) the Little Limestone, 16' above the Main, is directly overlain by 25' of shale, this being the only section seen where the

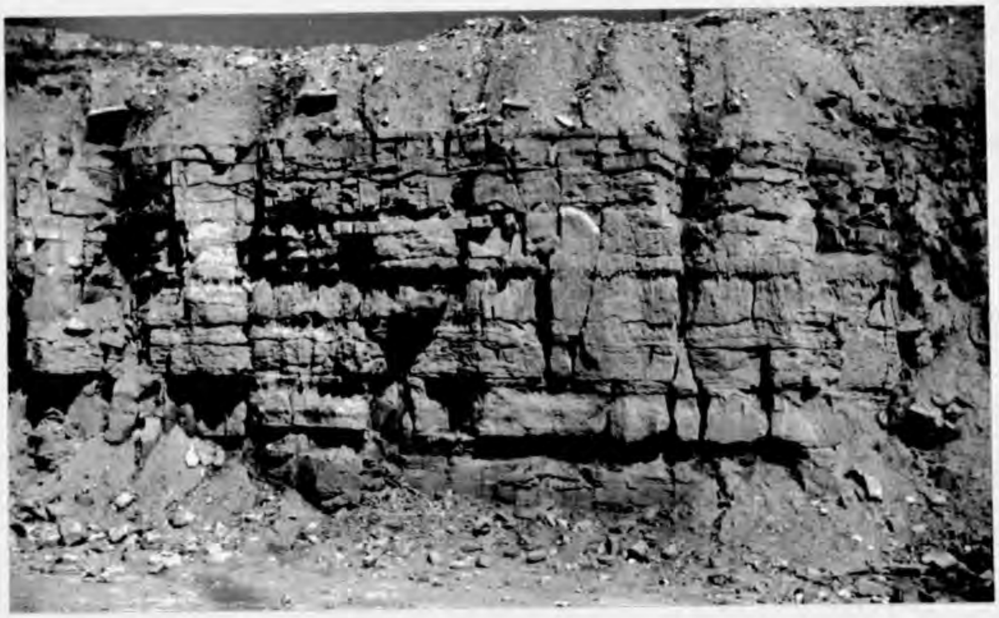
FIG. 8



GENERALISED SECTION OF THE MAIN AND LITTLE CYCLOTHEMS FROM BIRKDALE TO LEYBURN

Richmond Chert Series was absent. The Little is absolutely characteristic here, and there can be no doubt about its identification. 1000 yards to the north, however, in Washer Gill, the section above the Main Limestone (unfigured) consists of 106' of non-marine beds before a thin sandy limestone is reached. It is this horizon that Rowell (1953) called the Little Limestone, and in Scar Gill the same thin sandy limestone was also referred to the Little, an extra cyclothem being invoked in this one section to explain the underlying limestone. There is little doubt, however, that the Little has been faulted out of the Washer Gill section, as the Main Limestone (carrying a 3' vein of quartz, with chalcopyrite, malachite and fragments of dolomitised limestone) is not in normal contact with the overlying shale.

West of Moor Cock, a good section in Flust Gill (35) shows at least 35' of shale overlying no more than 5' of the Richmond Chert Series. Only 1¾ miles to the south, however, in Ceaseat Beck (33), coarse pebbly grit has transgressed to within 14' of the top of the Main Limestone. The intervening beds are not seen, but it can be presumed that those above the Little Limestone are no longer present. In most of the sections along the south side of Wensleydale this coarse grit is present. North of the Ure it is generally above the Crow Limestone, and in only a few sections does it rest on the underlying Ten Fathom Grit. In one of these (Summer Lodge Gill, section 24) this is caused by the infilling of a washout, on either side of which the grit rests on the Crow Cherts. South of the Ure, however, the grit is at a lower horizon. In general it rests on the Richmond Chert Series, but on the south side of Penhill the lower part of the Ten Fathom Grit is apparently present



A. Beds above the Main Limestone in Redmire quarry, Wensleydale. The hammer marks a clay horizon between the Main Chert and the supposed Little Limestone. The "tubes" and chert capping of this Limestone are about 2/3rds of the way up the face, and are overlain by siliceous limestones of the Richmond Chert Series.

B. Section in the north side of Leyburn road metal quarry. A lenticular bed of crinoidal debris in the centre of the far face is enclosed in siliceous limestones of the Richmond Chert Series. In the left foreground is the top of the Main Limestone, overlain by a bored bed taken to be the Little Limestone.

in Thupton Gill (section 47). Southwards, in Coverdale, the grit rests on the Main Limestone in places, and the same is true on Naughtberry Hill to the west.

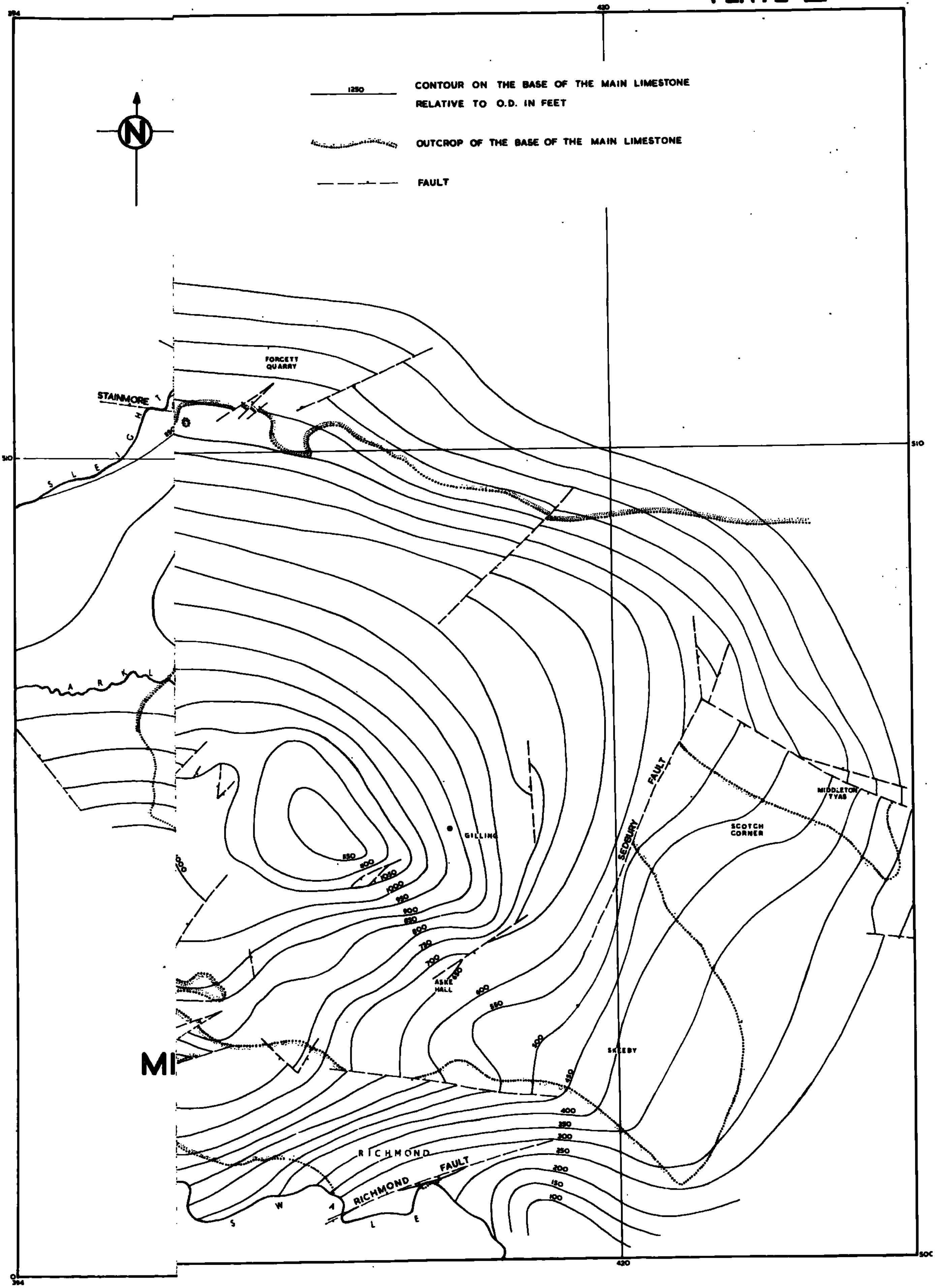
Two quarry sections near Leyburn are of particular interest. The road metal quarry 1 mile NW of the town (section 51) exposes up to 66' of the Richmond Chert Series above the Little Limestone. At the north end of the quarry 12' of siliceous limestones are overlain by a lenticular bed of coarse crinoidal debris, which has a maximum thickness of 7', and which thins out to zero in both directions along about 100' of the quarry face (Plate 11B, p.167). This illustrates (though on a considerably smaller scale) the nature of the coarse crinoidal limestones within the series in the Richmond area. In general these beds are pale in colour, but they often weather a light orange-brown, a feature which led to the adoption of the term 'Red Beds' for parts of this horizon. Above this striking lenticular body in Leyburn quarry come at least 45' of well bedded, hard, rather dark, streaky siliceous limestones, typical of the 'Black Beds' of the Mallerstang Memoir (1891). In the southern part of the quarry they rest directly on the limestone thought to be the Little, the intervening beds having been cut out by one of the minor erosion surfaces which are so common within this series. There are a number of these within the 12' of siliceous limestones overlying the Little along the north side of the quarry, and no single bed can be traced very far without being cut out by another. This is not so with the 45' of cherty beds in the southern part of the quarry, however, which are unusually evenly bedded despite the fact that they enclose a number of spherical bodies of grey limestone up to 3" in diameter. This same horizon is

A. The Main Limestone overlain with unconformity by the Richmond Chert Series in Woodlands quarry, Leyburn.

B. Closer view of the unconformity in Woodlands quarry, showing the cherts moulded onto the uneven eroded surface of the Main Limestone.

immediately recognised a mile east of Leyburn, in Woodlands quarry (section 49). There the chert series rests unconformably on an eroded surface of Main Limestone, the lowest beds of which mould themselves onto the often strikingly uneven surface on which they were deposited (Plates 12A and B, p.168). This unconformity is therefore here taken to represent not only the period of deposition of all the beds between the Main and Little Limestones, but also to account for the lower part of the Richmond Chert Series. It would appear that during the period following deposition of the Main Limestone, a roughly E-W ridge was raised above sea level in the vicinity of what is now Wensleydale, and that later beds were then laid down unconformably with overlap to the south against the north side of this ridge, which was not finally submerged until the coarse pebbly Millstone Grit was being deposited in that area.

PLATE II


1250
CONTOUR ON THE BASE OF THE MAIN LIMESTONE RELATIVE TO O.D. IN FEET
OUTCROP OF THE BASE OF THE MAIN LIMESTONE
FAULT
N
FORCETT QUARRY
STAINMORE
GILLING
SEDBURY FAULT
SCOTCH CORNER
MIDDLETON TYAS
ASKE HALL
SKEEBY
RICHMOND
RICHMOND FAULT
420
510
500

CHAPTER 8

STRUCTURE

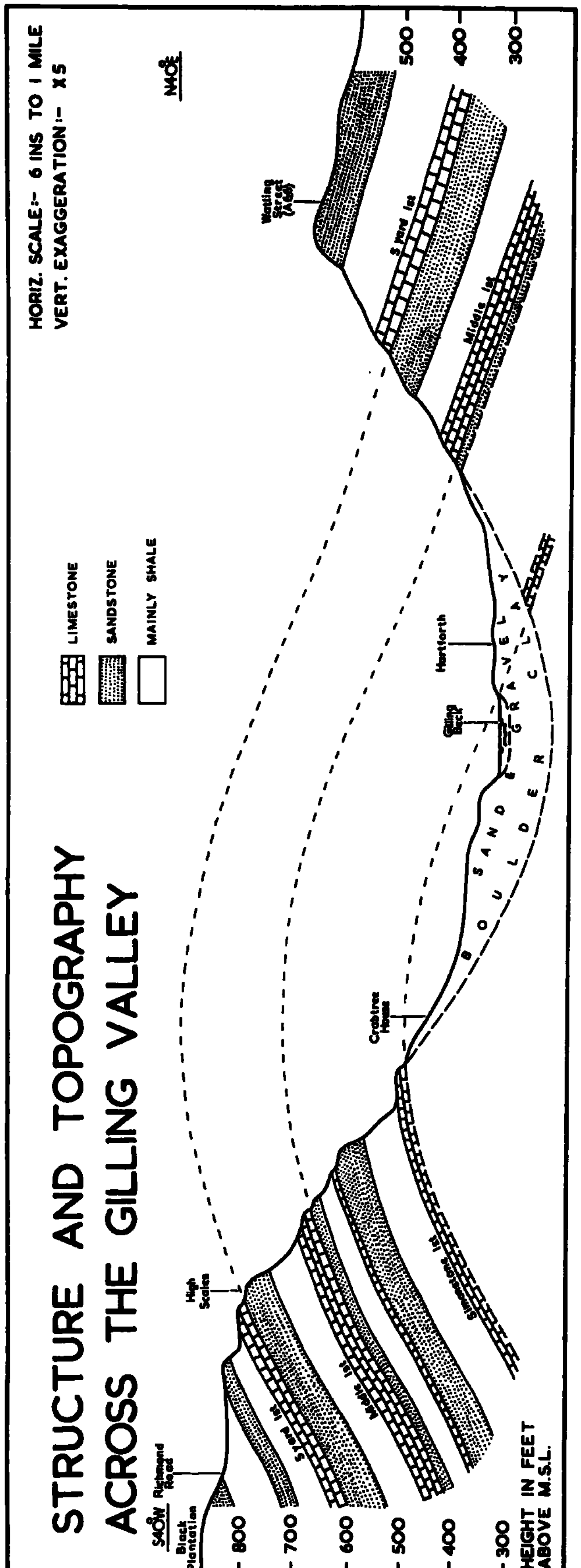
The area under consideration lies immediately to the SE of the Stainmore syncline, in the NE part of the stable Askrigg Block. The structure is summarised in Plate II (p.169), contours being drawn at 50' intervals on the base of the Main Limestone, so that the map is directly comparable with those of Dunham (1948) for the Alston block and Reading (1954) for the intervening Stainmore syncline. It is estimated that the structure contours are accurate to within 100' over the whole of the map, but over much of it, especially in the vicinity of the outcrop of the Main Limestone, the margin of error will be less than 50'.

(a) Folds

The structure is essentially that of a gently easterly-pitching somewhat asymmetrical anticline, the axis of which trends slightly south of east. The north flank of the anticline is simple, and passes without interruption into the southern limb of the Stainmore syncline. The dip of this flank is of the order of 4° or 350' per mile, which is rather less than the average in the syncline itself, the dip decreasing slightly onto the block. The axis of the anticline pitches in a direction 10° south of east at about 100' per mile (slightly more than 1°) and its regularity is interrupted by three subsidiary domes. The easternmost of these, the Gilling dome, is a strong structure, second only to the anticline itself, and the main fold closes rapidly round the north, east and south sides of it, with dips locally in excess of 10°.

This dome is breached by the Gilling valley, which thus affords

FIG. 9


STRUCTURE AND TOPOGRAPHY
ACROSS THE GILLING VALLEY
HORIZ. SCALE:- 6 INS TO 1 MILE
VERT. EXAGGERATION:- X5
LIMESTONE
SANDSTONE
MAINLY SHALE
Black Plantation
Richmond Road
High Scales
Crabtree House
Gilling Beck
Hartforth
5 yard lst
Middle lst
BOULDER CLAY
SAND & GRAVEL
800
700
600
500
400
300
HEIGHT IN FEET
ABOVE M.S.L.
500
400
300

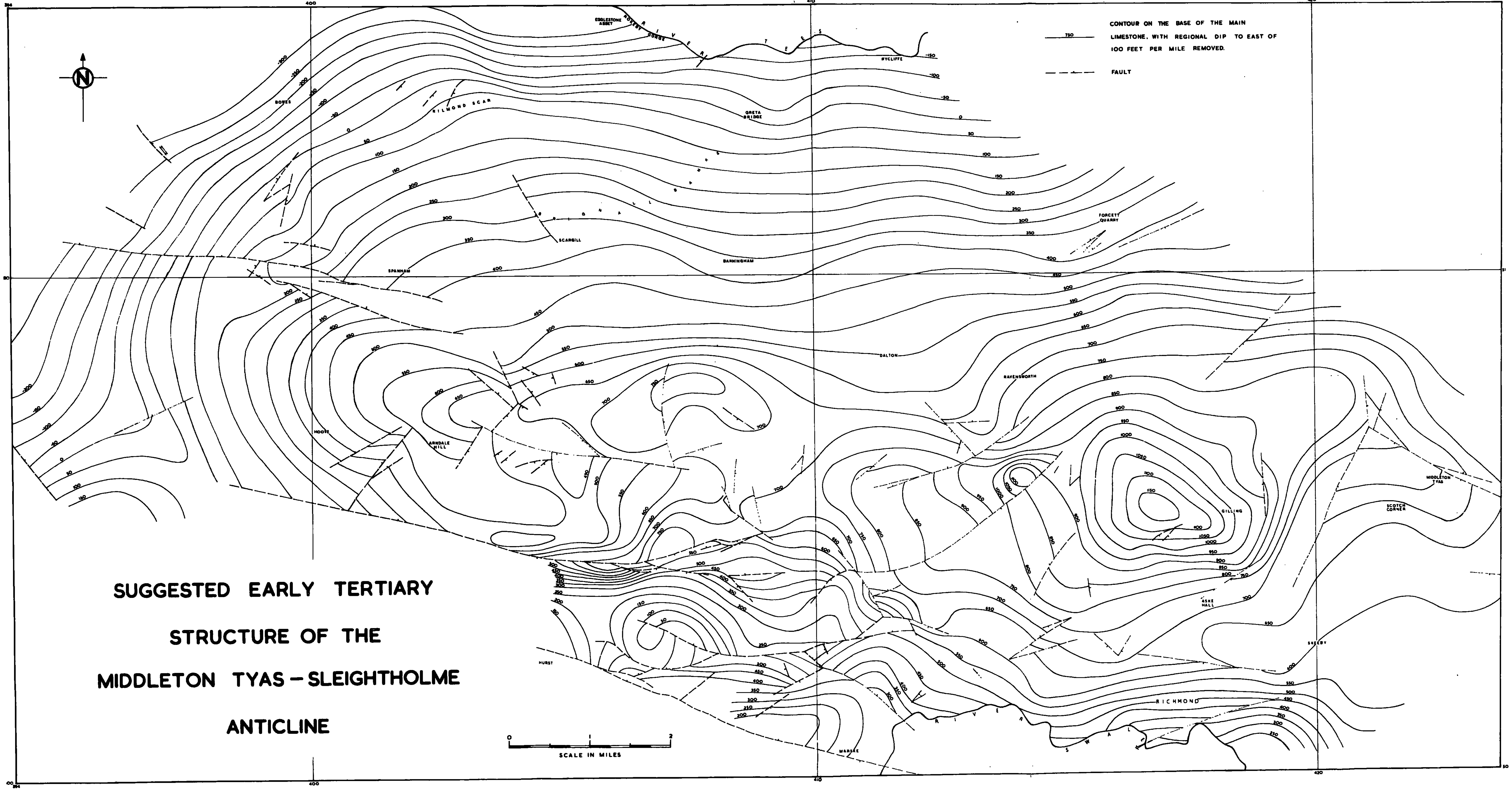
an excellent section through the structure, and the inverse relationship of topography to structure across the dome is illustrated in the section in Fig. 9 (p. 170). It is probable that the original breaching was near the highest point in the structure (as is often the case), and evidently erosion was more rapid on the NE side of the valley (where the dip is lower), the bottom of the valley being slightly displaced towards that side from the centre of the fold. The closure to the west of the Gilling dome is about 100', and it passes, by way of the Feldom fault, into the Whashton dome, a small but comparatively sharp flexure. This is slightly elongated along an E-W axis, and dips off it to the north and south are as high as 20°. The closure round the Whashton dome is a minimum of 125', and it passes westwards along the axis into an elongated open area between Byers Hill (070075) and Stang (015072), along the Teesdale-Swaledale watershed. It is probable that structure contours over this area, if they could be constructed at intervals of 25' or less, would reveal several more very shallow domes. This is suggested by small variations in local dips, but unfortunately thickness estimates in this area of rapidly changing facies are not sufficiently accurate to warrant construction of contours at any smaller intervals. West of Stang, the anticline dies away in the region of Sleightholme (955101), to be replaced en echelon to the south by the small Tan Hill anticline of Rowell (1953). As the main anticline has previously been known only after the village where the most easterly exposures along the axial line are to be found, it was thought desirable to add to the name to define the western as well as the eastern end of the structure. It is therefore proposed that the term Middleton Tyas-Sleightholme anticline be adopted.

The southern limb of the anticline is considerably complicated by faulting, and throws of up to 300' have been measured. A number of these faults have been mineralised, and are associated with the Swaledale-Arkengarthdale system. It is nevertheless possible to estimate the average dip at about 500' per mile, which is somewhat steeper than that of the northern limb. Important subsidiary structures on this flank include a half-dome on the north side of the Faggergill-Waitgate fault south of Holgate How, half-basins just west of Marske and south of Helwith, and an elongated basin open at its eastern end along the line of Moresdale. There is probably another basin to the SE of Richmond, the base of the Main Limestone being only 120' O.D. in the St Trinian's bore-hole (189009) a mile east of the town. But there is only sufficient information to be able to construct part of the north side of this structure.

It has long been considered that the Middleton Tyas-Sleightholme anticline was a pre-Permian structure, and the Primary Survey indicated an unconformable overlap of the Permian across the Upper Limestone Group on the published map. Unfortunately, because of very heavy drift cover, positive proof of this point was not available, and it was not until over 60 years later that convincing evidence was forthcoming from the Scorton bore-hole (251999) (Fowler, 1945). There, the Magnesian Limestone is represented by no more than 2' of dolomite resting on 15' of basement beds, but this horizon rapidly thickens to the north, south and east. In fact the change is so rapid that the only reasonable explanation is one of overlap of the Permian beds onto a pre-existing ridge of Carboniferous rocks. Very recently (1955), further convincing evidence has come from a bore-hole at Newton Morrell (237093), 2 miles north of Middleton Tyas, where a thick basal Permian breccia rests on beds of the Underset cyclothem, yet only a short distance to the west and south there is abundant evidence of the overlying Main Limestone and succeeding cherty horizons. Clearly, considerable erosion must have taken place before the onset of Permian deposition in the area, and this could only have been initiated in such a fashion by the formation of the anticline in Upper Carboniferous times. At what period in the Upper Carboniferous the movement took place is uncertain, but it seems likely that the Coal Measures were never deposited in this area. There is stratigraphical evidence for the formation of an E-W ridge in the Wensleydale district during the time of deposition of the lower part of the Upper Limestone Group (see Chap. 7, p.167). Further evidence of early Upper Carboniferous movement comes from consideration of the beds between the Main and Little Limestones in upper Swaledale, and downwarping associated with movement of the Stainmore syncline must then have extended as far south as this to enable the thick Coal Sills Group to be accommodated (Fig. 8, p.166). So it is suggested, as Hercynian movements appear to have already started by then, that at least part of the Middleton Tyas-Sleightholme anticline was initiated as early as Upper Limestone Group times.

It is generally agreed that the area now occupied by the Northern Pennines had, by early Tertiary times, been reduced to an almost flat surface by erosion, and that the resulting peneplain was subsequently tilted eastwards by very considerable later Tertiary movement along the Outer Pennine fault. This fact was realised as early as 1836 by Phillips (p.139), who noted a universal dip eastwards from the Pennine fault of between 60' and 100' per mile, and it is this tilted peneplain which has been partially dissected to give the

PLATE III



SUGGESTED EARLY TERTIARY STRUCTURE OF THE MIDDLETON TYAS – SLEIGHTHOLME ANTICLINE

topography of today (Plate 5, p. 2). It is of interest to know what form the structure of the area may have taken before this tilting, which is thought to have taken place in comparatively late Tertiary times (Trotter, 1929, p.167), and a modified structure contour map (Plate III, p.173) has been constructed by removing the average topographical dip of the area after the method adopted by Reading (1954). An easterly dip of 100' per mile was found to be a satisfactory figure, and as this is the same as the value used by Reading, the two maps are again directly comparable.

The suggested early Tertiary structure which emerges after this modification is somewhat better defined than that of the present day. The easterly pitch of the anticline has been entirely removed, and the closure at its western end is now as well marked as that at its eastern end. The Gilling and Whashton domes are again dominant features, and the rather open area along the axis between Byers Hill and Stang now becomes a third well-marked dome centred on Byers Hill. The slightly asymmetrical nature of the anticline is more easily noticed because the flanks of the structure are now parallel. There is a striking similarity (only of course in reverse) to the detail of the structure obtained by Reading when he removed the easterly pitch of the Stainmore syncline. This can be taken, along with their complimentary nature, as evidence of the approximately contemporaneous formation of the two structures by N-S compressive forces, although the Stainmore area is known to have been a trough of sedimentation in Lower Carboniferous times long before the Middleton Tyas-Sleightholme anticline could have been initiated.

(b) Faults

Most of the minor faults have already been described in the detailed stratigraphical sections of earlier chapters, and they need not be considered here. But they have been incorporated, along with the major faults, in a statistical analysis of trends, the result of which is reproduced in Fig. 10 (p.178). This shows that there is a marked predominance of faults running between 70° and 85° west of north, and a less well-marked peak at 65°-70° east of north, with a broad minimum between 30° west of north and 25° east of north, and a narrower minimum between 80° east of north and east.

The three most important faults in the area all trend roughly WNW, and two of them serve as the boundary to the SW part of the map over part of their length. An interesting feature about these faults is the fact that although they run remarkably straight for miles, a complete reversal of throw is accomplished along the length of each one, and the reversal is in the same direction in each case. The throw is to the north along the western parts of the faults and to the south along their eastern parts. This state of affairs can arise in a number of ways, but in this instance the most likely mechanism is for faulting combined with a little horizontal movement to have succeeded slight folding. If the axis of the fold makes a large angle with the direction of subsequent faulting, it is only necessary for comparatively small lateral movement to take place to effect a marked reversal of throw along the fault. Certainly most of the indications along these three faults are only those of vertical movement, but then the fault faces themselves are rarely seen. Eller Beck Hush (991103), on the North Spanham fault, has, however, exposed horizontal slickensiding in the region where the throw is in the process of reversal, and this is considered to be positive evidence in favour of the theory. The North Spanham fault (Plate 13A, p.179) is a continuation of the south branch of the Stainmore Summit fault carried as far east as Sleightholme Beck by Reading, and is thus the eastern end of an important dislocation which extends for over 10 miles. The Faggergill-Waitgate fault, followed for some 7 miles, reverses its throw beneath a cover of peat on Booze Moor (020050), near Moresdale Head, and the fault plane is nowhere seen at the present day. Similarly the Marske fault, mapped for over 5 miles, reverses its throw in a heavily drift-covered area just to the west of Marske (096006), but there is little doubt that the faults are all continuous, and that these reversals do take place.

It has been found, with a better understanding of the stratigraphy, that a number of the faults mapped during the Primary Survey are unnecessary and have been omitted. Several new faults have, however, been recognised, but in spite of this it will be found that the total number of faults has been somewhat reduced. Field evidence for most of the faults on the map has already been given, and it is therefore unnecessary to give further consideration to those whose significance is purely local. But there are several faults, apart from the three major WNW dislocations, which call for further comment. One of these is the ENE-trending Richmond fault, which has a NNW downthrow of at least 85', and possibly nearly twice that, in the north bank of the Swale opposite Richmond station. The fault plane itself has been obscured by a deposit of tufa several feet in width, but the regional SSE dip is seen to be disturbed in the immediate vicinity of the fault so that the dip is in towards the fault on both sides. Beds of the Richmond Chert Series are here in contact with the sandstone underlying the Main Limestone, and as is common elsewhere, dolomitisation of the limestone has taken place near the fault. Westwards this fault divides, so that in Temple Grounds (166006) and Billy Bank Wood (164005) a thin wedge of uplifted beds is found between its two branches. But as with the three major WNW faults, all of which divide along part of their length, one branch is very subsidiary to the other.

Two structurally interesting faults are those which bound the Whashton dome. The Feldom fault, on its SE margin, is over 3 miles in length, and its throw to the SE is over 100' for much of that distance. The Kirby Hill fault, running roughly parallel to, and NW of this, has a similar throw to the NW, and the beds between these two faults have been comparatively sharply folded. The striking thing about these faults is the rapidity with which they die out at their NE end. The Feldom fault, where it crosses the western end of Whashton village (147063), drops its throw from about 130' to less than 20' in only 1/3 mile, this being apparently entirely due to the dying out of the fold between the two faults. So it is evident that at the time the Whashton dome was formed, movement must have taken place along the two faults contemporaneously with the folding. The faults may have been in existence prior to doming, but there is no evidence to show that this was the case. It seems likely that most (if not all) of the faults in the area were at least initiated during the Hercynian folding.

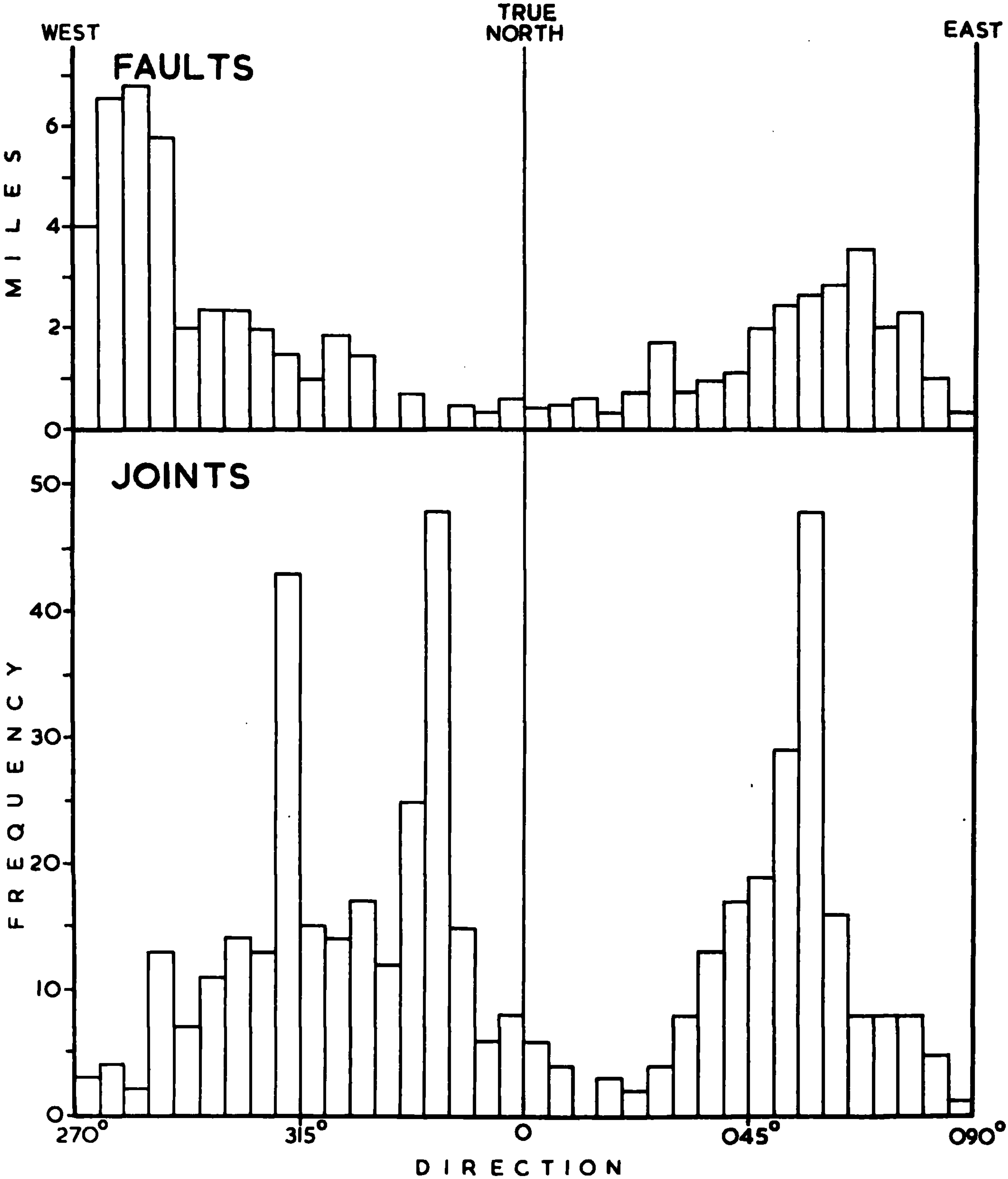
Part of the eastern boundary of the map incorporates the important Darlington fault, which separates the Trias from beds of the Upper Limestone Group in the south and from the Magnesian Limestone further north. It was long supposed that the Permian-Trias boundary beneath the very heavy drift cover between the Tees and the Swale was a normal one, but Fowler (1945) has shown, from consideration of sub-surface records, that the boundary must be the continuation of the well-known Hartlepool fault. He was able to fix its position with considerable accuracy, despite the fact that there are no surface exposures, and the line of the fault has been taken directly from the map reproduced (p.246) in Fowler's paper.

(c) Joints

The first mention of joints and joint directions in the Carboniferous of the Pennines was by Phillips (1836). He published a diagram (p.98) showing the distribution of 89 readings, about ¾ of which were taken on the Carboniferous Limestone Series of the Askrigg Block. This diagram shows a strong broad maximum at NNW, two subsidiary maxima at E and ENE, and minima of zero at NW by W and NE by N. Phillips also recognised that these directions were independent of at least all the minor faults. The only other relevant work to have been done in this country was by Wager (1931) and Dunham (1933). Wager described the joint system in the Great Scar Limestone of the Craven district, two sets of joints at right angles being interpreted as shear fractures. Dunham analysed more than 1000 joint readings on the Great Limestone in the Stanhope-Frosterley area, and obtained maxima at 20°-25° west of north and 60°-70° east of north, similar to those of Phillips. These two sets at right angles he also attributed to shear fractures.

The result of the analysis of some 400 joint readings made during the present survey is shown in Fig. 10 (p.178). These readings

FIG. 10



STATISTICAL ANALYSIS OF STRUCTURAL TRENDS were nearly all taken on limestones, the majority being on the well-exposed and thick Main Limestone. It will be noted that 3 strong maxima occur at 55°-60° east of north, 15°-20° west of north and 45°-50° west of north, with a very low minimum at E and a zero minimum at 10°-15° east of north. These directions evidently bear no relationship to those of the major WNW faults, but the first of the maxima does correspond in direction with many of the minor faults (some of which are also mineral veins) which form the broad peak between NE and ENE. It will also be noted that the first maximum is exactly at right angles to the bisector of the other two, which are separated by 30°. In an important work on the joint system of the Palaeozoic beds of the Allegheny Plateau of New York and Pennsylvania, J.M. Parker (1942) has shown that the joints there can be divided into two sets which intersect approximately at right angles. But he was also able to sub-divide one set into two groups which intersect at a small angle. Both theoretical and experimental work has shown that this double set can be produced by simultaneous compression and tension acting at right angles. Such an arrangement of stresses will result in the tangential components reinforcing one another, while the normal components, acting in opposite directions, will tend to cancel out. Variation in the relative values of these components will serve to modify the angle at which the two groups of joints in the set will intersect. So it is evident, from Parker's work, that the joint system of the NE part of the Askrigg Block could have resulted from simultaneous compression and tension acting at right angles. This interpretation would require compression from directions 35° west of north and 35° east of south, and tension from directions 55° east of north and 55° west of south.

A. View looking west along the North Spanham fault on Scargill High Moor. In West Black Sike (foreground) dolomitised Main Limestone is thrown against nodular shale in the Underset cyclothem. In the background is Eller Beck Hush, where the throw has fallen to zero.

B. Jointing in a small part of East Layton quarry. Three principal directions can be seen.

Such stresses correspond closely with the NW-SE compression proposed by Wager for the formation of the joints of the Craven district, but Dunham considered a N-S compression to be more likely for those of the Alston Block. Reading was unable to find any definitely dominant direction of jointing in the beds of the flexible Stainmore syncline, but there was a marked absence of jointing in a NNE direction, which he took as confirmation of a roughly N-S compression. It is evident that much of the transverse folding in this part of the Pennines was produced by a N-S compression, but in practically every case the jointing is at right angles to the bedding, regardless of dip, implying that the joints were formed before and independently of the folds. So it is not necessary to suppose that the compression which produced the folds was from the same direction as that which gave rise to the joint system.

The statistical analysis of Dunham's results does actually show a subsidiary maximum at 55°-60° west of north, and the bisector of this direction and the peak at 20°-25° west of north trends very nearly NW-SE. If this apparently very minor peak, as well as the other two, could be shown to be of importance over the Alston Block as a whole, there would then be justification in postulating a roughly NW-SE compression (combined with tension at right angles to this) for the formation of the joint system over the Northern Pennines as a whole.

In many of the larger quarries visited during the present survey, the joint surfaces can be followed for considerable distances (Plate 13B, p.179), and it is a striking fact that those in the set at 55°-60° east of north are irregular and often curve away as much as 10° from their average direction, whereas the other two sets are remarkably even and constant in trend. This is precisely what Parker found on the Allegheny Plateau, and it led him to believe that the irregular set (at right angles to the bisector of the other two sets) originated from tension alone. These tensile joints would have been formed somewhat later than the other two sets, but on the Askrigg Block this second stage of joint formation was doubtless connected with the same period of stresses, all joints having been in existence before the pre-Permian folds were initiated.

An attempt was made to detect any possibly significant changes in the joint system across the area of the present survey by plotting frequency diagrams for a number of restricted portions. The largest number of readings came from the southern part of the area, where exposures are good, and over this region there was no detectable change in the three dominant jointing directions. The north side of the anticline yielded relatively few satisfactory measurements (outside quarry sections) because of heavy drift cover, and this is reflected in the wider spread and lower peaks on the diagrams plotted for that area. In spite of this, however, the positions of the peaks remained constant, and it is concluded that the region acted as a single unit during the formation of the joint system.

CHAPTER 9

PETROGRAPHY OF THE CHERTS

(a) The Underset Chert

The series of more or less siliceous beds developed on or a little above the top of the Underset Limestone in parts of the area and collectively known as the Underset Chert, are very variable (as was shown in Chapter 5) and they pass laterally towards the west, north and east into shale immediately overlying the Underset Limestone. These siliceous beds cannot be traced individually over any great distances, and marked variations in lithological type commonly take place over intervals of less than 50 yards. The field relationships of these various types are not easy to follow, and there is a passage, both vertical and lateral, between them all. But one of the most noticeable features in the field (apart from the generally well-developed bedding) is the great variation in the apparent proportion of carbonate in these rocks. There is little to distinguish some beds in the Underset Chert from the fine-grained horizons in the underlying limestone, yet in others there is often no sign in hand specimen of any carbonate. There is considerably less difference between these types when examined in thin section, however, and they all point to the same mode of origin.

The most common lithological type in the Underset Chert is a dark blue-grey siliceous calcite-mudstone which, in hand specimen, often shows little sign of any silica. Bands in this mudstone are fossiliferous, and contain many spiny productids, but the main bulk of it is apparently virtually unfossiliferous. Dark flinty chert bands, commonly between about 1" and 6" (but sometimes several feet) in thickness, occur associated with the mudstone, and these, when traced laterally, pass into the normal mudstone, the field relationships suggesting secondary concentration of silica at these horizons. In thin section, the mudstone is seen to be composed of between 65% and 70% very fine-grained calcite which is set in an apparently isotropic very pale brown matrix, the R.I. of which is 1.530 in a specimen from Marske Beck. Some slides show this matrix just beginning to crystallise in vague very slightly birefringent areas, and others show it as microcrystalline radial aggregates of chalcedony, there being no doubt that the isotropic material is amorphous or cryptocrystalline silica. But even when fully crystalline, it still retains its very pale brown colour in ordinary transmitted light. Organic fragments (mainly bryozoa and brachiopods) are common in these slides, and are often partially replaced by secondary silica (with the exception of crinoid ossicles, which are rarely altered). Calcareous sponge spicules are abundant in a number of slides, and average between 0.05 and 0.2 mm. in diameter. These spicules are often partially, and sometimes completely, replaced by microcrystalline silica with $N_w = 1.541$. There is no evidence that any of them were primarily siliceous as the silica of which some are now formed is in every case clearly secondary, and of a different generation to that which sometimes fills the axial canals.

On approaching a band of dark chert, the silica content gradually rises until the calcite proportion is reduced to less than 25%. But the mode of occurrence is still the same, with very fine-grained carbonate set in either amorphous or cryptocrystalline pale brown silica. Sections from within the chert bands show as much as 95% silica, all of which is fully crystalline, but it is a simple matter to distinguish two generations of chalcedony. The original silica which crystallised from the amorphous state still retains its pale brown colour in transmitted light, but most of the rest of the rock is composed of entirely colourless microcrystalline silica (with R.I's near those of quartz) enclosing small secondary carbonate rhombs, all that is left of the calcite which was in the rock before subsequent enrichment in silica and partial recrystallisation. Ghosts of previously existing organic fragments (particularly brachiopods) are outlined by the original brown silica, and it is evident that prior to secondary silicification the rock was no more than a variety of the mudstone containing a rather higher proportion of original colloidal silica.

The other important lithological type in the Underset Chert has been called "lime plate" by Carruthers (1938). It is a dark streaky siliceous mudstone which, on weathering, parts along the rather irregular bedding into thin but tough "plates" which make a ringing sound when struck (a property found to indicate a considerable silica content). It is normally highly fossiliferous, and hence somewhat calcareous, with many spiny productids and a few spirifers and gasteropods. In some localities secondary silicification has altered the rock to a dark and very hard chert, but the streaks due to irregularities in deposition are still clearly visible. Thin sections reveal the platy material to consist of abundant calcareous organic material set in a matrix of some 60% very fine calcite and 25% nearly isotropic silica, with irregular dark brown streaks of argillaceous material. Alternating with this are very thin and irregular streaks of cherty material containing abundant cross-sections of calcareous productid spines (some partly replaced by silica) set in virtually isotropic pale brown silica. Rare angular grains of quartz up to 0.05 mm. across have been detected, and a few slides contain small honey-brown grains of collophane, often in elongated aggregates, most of which are apparently isotropic. But some, indistinguishable from the rest in ordinary light, are birefringent, showing high first-order colours. Birefringent collophane has been described by Dunham et al. (1948) from the Magnesian Limestone of Durham, and it may be that this property of the mineral is more common than had been supposed. The present occurrences of collophane are fish remains; recognisable scales and teeth are found in these cherty beds from time to time.

Where secondary silica enrichment has taken place, only a few corroded remnants of calcareous brachiopods are left, and micro-crystalline pale brown fibrous radial aggregates of chalcedony enclose productid spines now replaced by colourless silica. Of interest in this secondary material are scattered aggregates of tiny hexagonal quartz crystals (Plate 7B, p.70), conspicuous by their relatively high refractive index, and their presence is taken as indicating a lack of enclosed water in the secondary silica (see section (d), below).

(b) <u>The Main Chert</u>

The Main Chert is a series of siliceous beds developed on or a short distance above the top of the Main Limestone, the strati-graphical relations of which are described in Chapters 6 and 7. This series is confined, roughly speaking, to Swaledale, Arkengarth-dale and the Bowes area, the limit being shown in Fig. 5, p.160 Petrographically these beds fall into three groups. In the northern part of the area, an alternating series of shales and siliceous mudstones are found immediately above the Main Limestone. These may be up to 20' in thickness, and are very dark in colour. The mudstones are very hard, weathering sometimes into paper-thin plates, but often showing conchoidal fracture on fresh specimens. A fine banding is generally (but not always) visible, and the silica content evidently rises towards the top of these beds, black flinty cores being common in the upper part. They grade upwards into the second group in the Main Chert, which is a banded flinty rock, generally dark grey in colour, but often bleached to a dull creamy-white. This chert, which gives the impression in hand specimen of being 100% silica, is much shattered and run through by veins of chalcedony and crystalline quartz, the latter particularly well developed in cavities. The bedding is generally easy to follow, but is often ignored by partings and shatter cracks. No trace of any fossils could be found in hand specimens of this material.

Thin sections of mudstones from the lower series reveal a wide variation in the proportion of silica. In general, they show very fine-grained calcite set in a matrix of virtually isotropic pale brown silica (with microcrystalline patches in part), with a variable but small quantity of argillaceous pigment. Locally the proportion of carbonate is as high as 80%, and brachiopod fragments together with productid spines appear in the lower part. But the mode of occurrence of the carbonate, in very small grains scattered more or less evenly throughout the matrix, suggests that it was chemically precipitated, and that only a small proportion of the carbonate present is of organic origin. There is no evidence of organic origin for any of the silica.

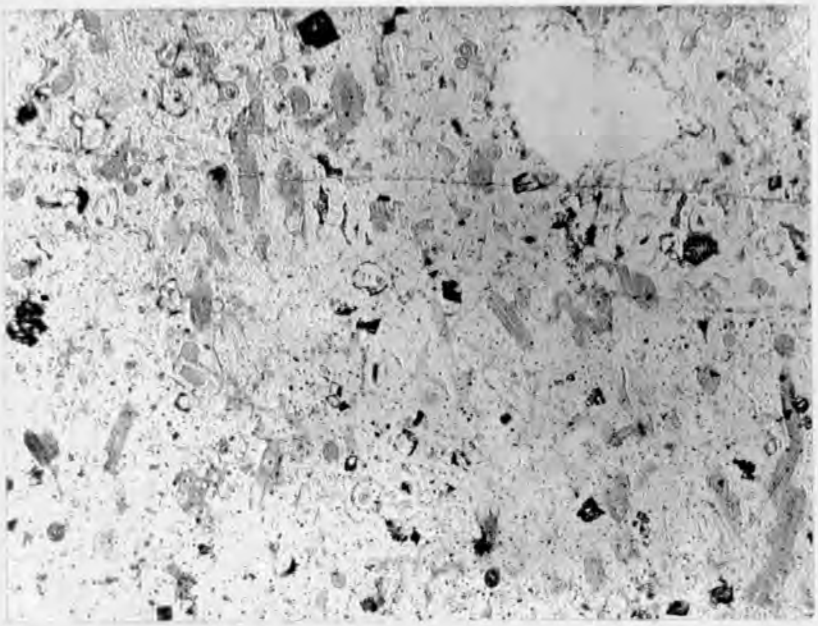
Slides of the overlying banded flinty chert show largely colourless microcrystalline silica (N_w = 1.539) enclosing many very small carbonate rhombs (mainly dolomite, but probably some ankerite, longest diagonal up to 0.08 mm, N_w = 1.679) and a few corroded residual patches of calcite, the two together making no more than 5% of the rock. There are also ragged areas of the original pale brown nearly isotropic chalcedony, but for the most part the rock appears to have recrystallised into a colourless variety. In isolated cases, these relics of original silica outline the forms of fossils, sponge spicules being recognised (Plate 14A, p.188). It appears that the carbonate rhombs are secondary, and have re-crystallised from the material which was not carried away during the process of secondary silicification. As might then be expected, these rhombs are of very variable occurrence, some slides showing them to be entirely absent. That silica was introduced into the rock during the recrystallisation process is most probable because of the very corroded appearance of small remnants of evidently primary carbonate, but so little is left of the original material that it is difficult to tell how much of it was siliceous, and hence how far-reaching were the secondary effects.

The third lithological group in the Main Chert comprises fossiliferous siliceous limestones, which make up the bulk of this horizon in middle and lower Swaledale, and also in lower Arkengarthdale (see Fig. 5, p.160). It is a very variable group, but the different types within it are so similar to those in the equally variable overlying Richmond Chert Series that a separate description is considered unnecessary. In those sections where it was not possible to locate the intervening Little Limestone (see Chapters 6 and 7), it generally proved impossible to separate these two essentially similar cherty horizons.

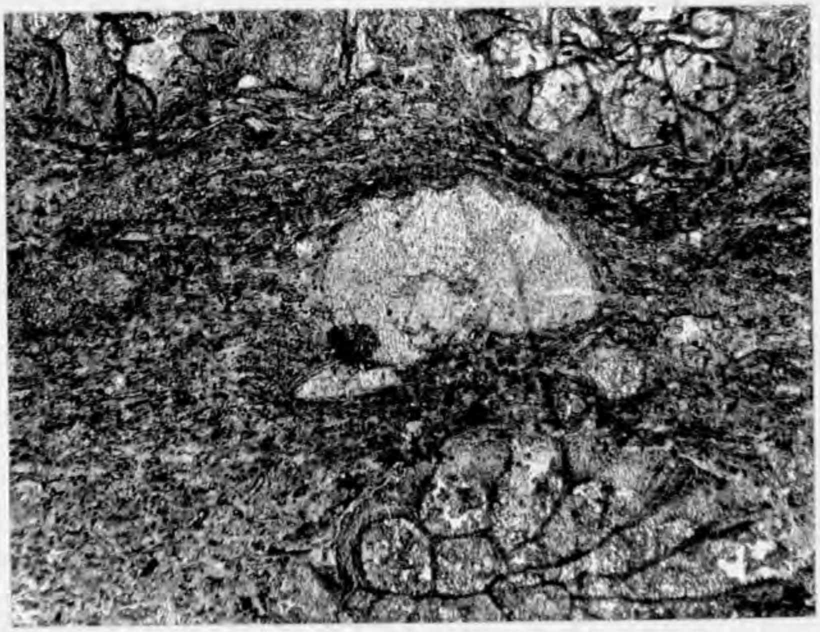
(c) The Richmond Chert Series

The series of siliceous limestones and cherts which overlie the Little Limestone have, for the purposes of this work, been termed the Richmond Chert Series (Chapter 6, p.140), and they comprise by far the largest proportion of the cherts considered in this chapter. The predominant lithological type is a fossiliferous limestone with a variable, sometimes dominant, proportion of silica. Argillaceous material is present in small quantities at some horizons, the rock then being composed of an intimate mixture of carbonate, silica and clay minerals. Lenses of relatively pure crinoidal limestone (generally about 6" thick) occur within this siliceous material (Plate 10A, p.157), and are clearly contemporaneous because the bedding parts to flow round these nodular bodies. The bedding in the siliceous limestones is extremely uneven, with very complex small-scale structures, and deposition would appear to have taken place, for the most part, under rather turbulent conditions, giving these beds their essentially streaky nature. There are fairly numerous horizons at which complete brachiopods are crowded onto the bedding planes, however, and these may have marked periods of relative quiescence. In some places, particularly in lower Swaledale, great lenses of coarse crinoidal reef limestones, often over 20' in thickness, occur within the Richmond Chert Series, and mark periods of particularly rapid local deposition. Secondary silicification has evidently taken place in this series where irregular nodules of flinty chert, sometimes containing recognisable corals and brachiopods, occur within the siliceous limestones.

Weathering can affect these cherty beds in two distinct ways.



A. Main Chert, Huggill. x 50. Scattered dolomite rhombs (dark) in secondary microcrystalline silica. Replaced sponge spicules are outlined in pale brown chalcedony, the refractive index of which is considerably below that of the colourless silica.



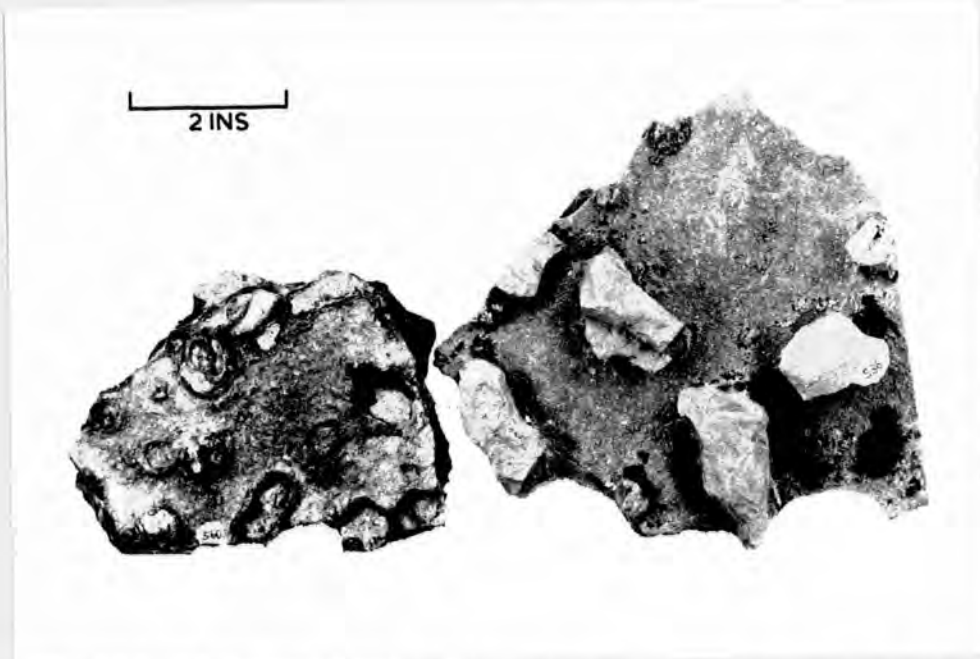
B. Richmond Chert Series, Round Hill, north of Hoove. x 47. Bryozan fragments and part of a crinoid ossicle set in, and distorting the bedding of, a very fine-grained mixture of chemically precipitated carbonate and almost isotropic brown silica.

One is for the rock to part into thin plates (in much the same way as certain horizons in the Underset Chert) and the surfaces of these plates are either crowded with fossil fragments, or else bear the roughly concentric "swirls" which have, since the last century, been known as Cauda Galli markings. Fossils and Cauda Galli markings do not occur together, and the latter are best developed to the west and north of Reeth. The other product of weathering is a pale grey, noticeably light and spongey rock, which retains the structures of the original material but which has been entirely leached of carbonates. This rock is all that can be found on the surface of many of the smaller exposures, and tends to give a false impression of the essentially calcareous nature of this series.

In thin section, the streaky siliceous limestones are seen to consist mainly of an intimate mixture of very fine-grained calcite and cryptocrystalline, in part almost isotropic, pale brown silica (the refractive indices of which vary between 1.530 and 1.541). It is apparently rapid variations in the proportion of these two major constituents which give the rock its streaky appearance, the darker streaks containing generally about 40%-50% silica (but locally as much as 75%), while in the lighter parts calcite is markedly predominant. Set in this carbonate-silica mixture is a variable quantity of organic debris, principally of brachiopods, foraminifera, bryozoa and small crinoid ossicles, which clearly distort the bedding of the matrix (Plate 14B, p.188). Some of the foraminifera contain an infilling of brown isotropic silica, as is also the case with the central canals of some of the crinoid ossicles. This implies that the organic material was deposited into a siliceous environment, which is visualised as being an ooze of chemically precipitated calcite and silica. As before, there is no evidence of any organic origin for the material acting as matrix, and there is often no sign of any secondary alteration having taken place. Bryozoan structures are often beautifully preserved, these generally being among the first to go when recrystallisation takes place. In some sections, however, very small brown rhombs of dolomite or ankerite (with N_w between 1.679 and 1.682, and a long diagonal of no more than 0.05 mm.) have grown in the matrix, which must have partially recrystallised. The colour of these tiny rhombohedra is seen, in reflected light, to be at least partly due to enclosed limonite (presumably from weathered ankerite), and in a few sections limonite has segregated into little patches, sometimes round spines of productids. The hand specimens from which these sections were cut have a definite orange-pink tinge, and this colour is particularly common in the upper part of the series, in description of which the term 'Red Beds' has been used in the past. Also present in these siliceous limestones are common angular grains of detrital quartz (locally making as much as 3-5% of the rock, and mostly less than 0.1 mm. across), occasional grains of cryptocrystalline glauconite (up to 0.4 mm. across), a few very small flakes of white mica and rare occurrences of isotropic yellow-brown collophane. Locally, calcareous rods (about 0.5 mm. in length and 0.05 mm. in diameter) are common, and are probably concentrations of sponge spicules. As before, there is no evidence that these supposed spicules were ever siliceous.

It is interesting to note that the supposed borings into the top of the Little Limestone (Plate 15A, p.190 , and Chapter 6,. p.139) are filled by very similar material to that which occurs in the

Plate 15



A. The top surface of the Little Limestone, illustrating the infilling of supposed borings. The fresh specimen on the left is from Leyburn road metal quarry, and that on the right (with the cherty tubes weathered out strongly) is from White Stone Gill, Sleightholme Moor.

B. Cherty capping to the supposed Little Limestone, Marske quarry. x 38. Brachiopod, bryozoan and crinoid fragments, together with angular quartz grains (clear), microcrystalline glauconite (rounded and sub-angular grey grains) and a short length of organism "α" (left-hand margin, just above large brachiopod fragment) set in an intimate mixture of carbonate and brown silica.

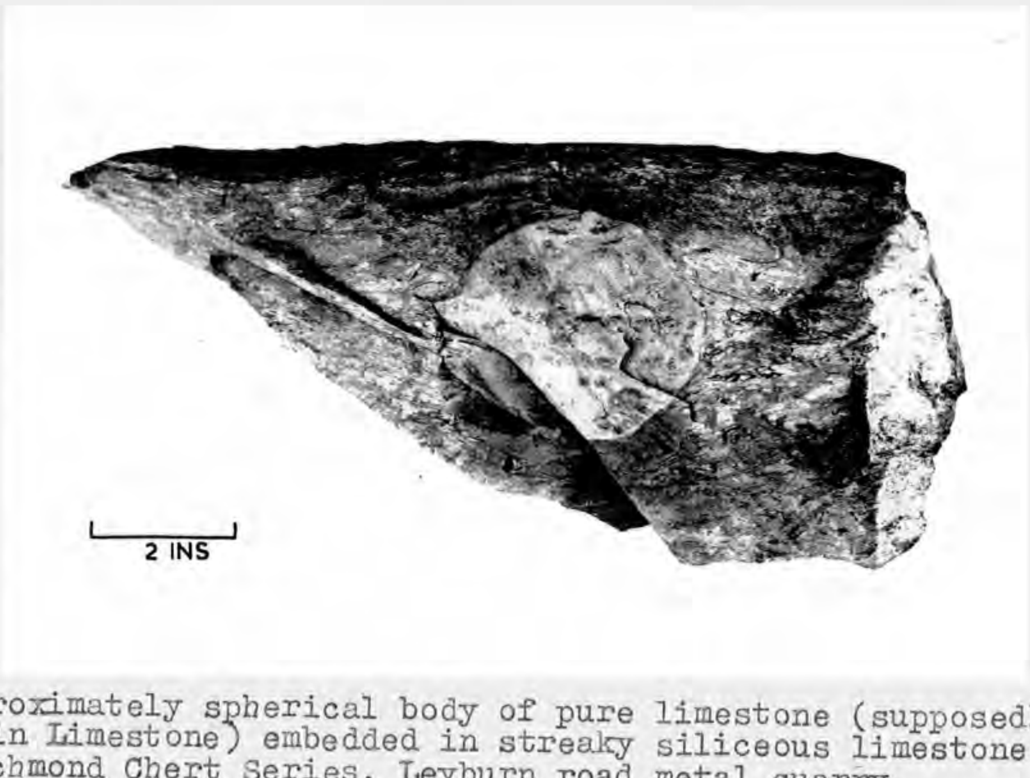
overlying beds. The Little Limestone is often sandy, and contains glauconite, and both detrital quartz and pale green cryptocrystalline glauconite tend to be concentrated in the "pipes". These minerals occur together with organic fragments, set in a matrix consisting of a mixture of very fine-grained calcite and almost isotropic pale brown silica (Plate 15B, p.190). This supports the view that these tubes were formed during a widespread depositional break at the top of the Little Limestone, and that they were subsequently filled during the formation of the lowest part of the Richmond Chert Series.

The lenses of crinoidal reef material which occur in, and are contemporaneous with, the streaky siliceous limestones, must have been laid down very rapidly. As the proposed calcite-silica precipitate was presumably being deposited constantly over a fairly wide area, this material would be expected to occur interstitially to the crinoid debris, although only in small quantities due to the high rate of deposition of the organic carbonate. There is little evidence of this in the field, but thin sections reveal a surprisingly high proportion of finely divided calcite in pale brown silica. There is a wide variation within a single slide, and parts are as rich as 80% in the inorganic mixture. But for the most part, large crinoid ossicles (together with scattered brachiopod fragments) make up 60-70% of the rock, and in places it passes into almost pure limestone (Plate 16A, p.191). Finely disseminated limonite is present in some of the ossicles, and gives a pinkish colour to the hand specimen.

In the Leyburn district of Wensleydale, the normal streaky siliceous limestones of the Richmond Chert Series contain, in their

Plate 16

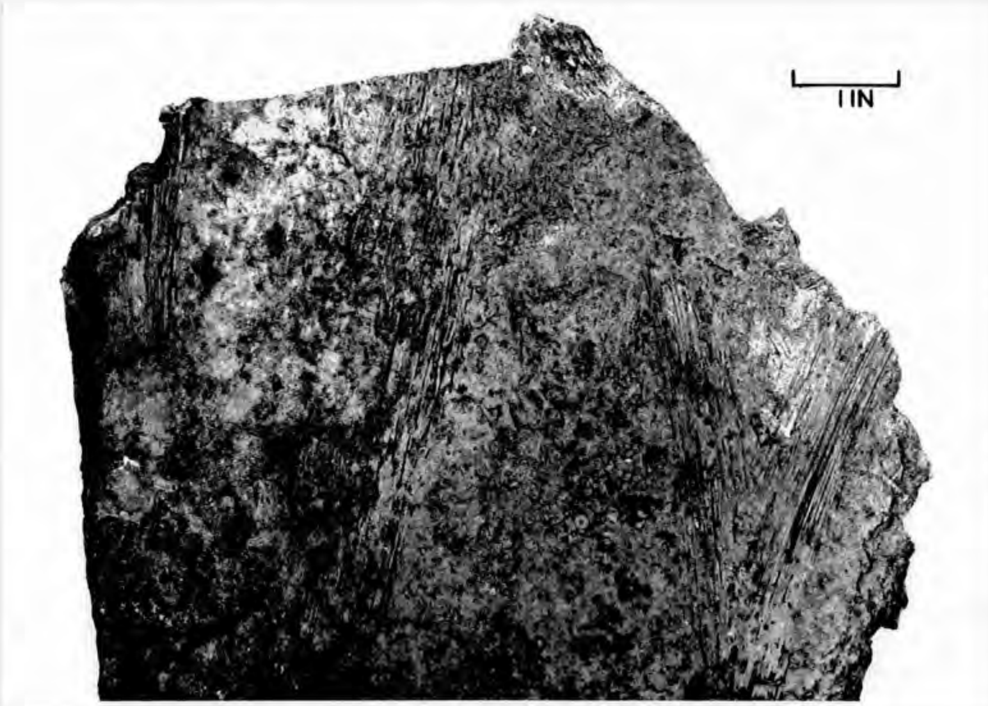
A. Crinoidal limestone, Richmond Chert Series, Leyburn road metal quarry. x 35. Organic debris and a single clear quartz grain (top right) cemented by calcite. Elsewhere in the same slide, the cement is a fine-grained inorganic carbonate-silica mixture.



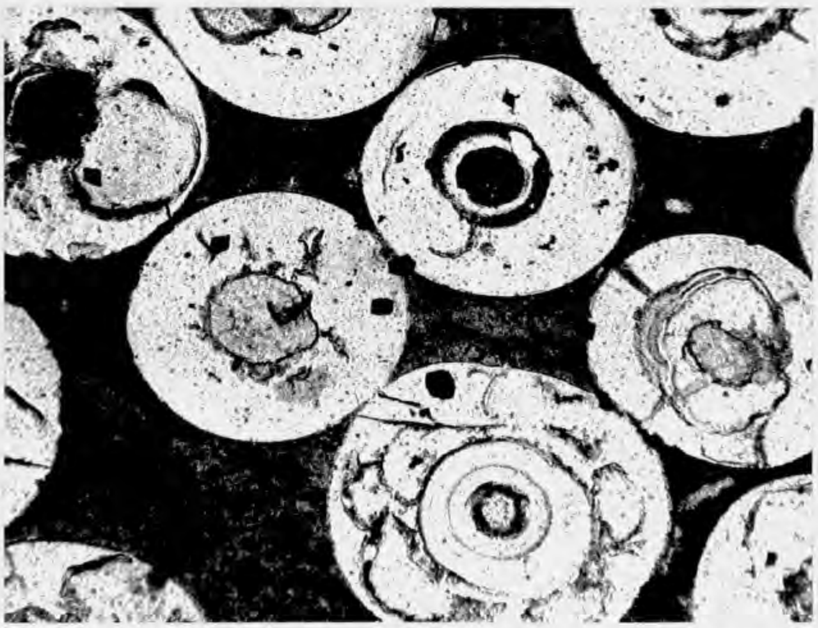
B. An approximately spherical body of pure limestone (supposedly from the Main Limestone) embedded in streaky siliceous limestone of the Richmond Chert Series, Leyburn road metal quarry.

lower part, occasional enclosed nodules of pure grey limestone. These nodules are approximately spherical, and average about 3" in diameter. The bedding beneath them is considerably distorted, but it flows smoothly over the top of the nodules (Plate 16B, p. 191). This could only have happened if the limestone nodules were dropped into the unconsolidated material during its deposition. In this region, the cherts rest with noticeable unconformity on the Main Limestone (see Chapter 7, p. 168), and nearby the Main Limestone was probably being subjected to sub-aerial erosion. As the lithology of the nodules compares directly with that of the underlying Main Limestone, it is suggested that they are pebbles of that limestone which have either rolled or been carried into the sea from the nearby land, and dumped into the calcite-silica mud during the time of deposition of the lower part of the Richmond Chert Series.

A highly characteristic fossil which occurs throughout the Richmond Chert Series, and which is particularly abundant in its upper part, is the supposed siliceous sponge <u>Hyalostelia</u>. Separate body spicules and bundles of anchoring spicules have, by association, been assigned to the same little-understood genus. The bundles of anchoring spicules (as much as 3 feet in length) are by far the most common remains, and occur in very large numbers lying horizontally along the bedding (Plate 17A, p. 192). Thin sections of these spicules show them to be composed mainly of radial fibres of colourless secondary chalcedony (R.I.s near 1.542), which has evidently recrystallised from the original material of which they were formed. Often a central canal is filled by calcite, but sometimes the chalcedony continues right across the section, and the canal is not apparent. A vague concentric structure is commonly visible in



A. Lengths of Hyalostelia anchoring spicules lying along the bedding in siliceous limestone of the Richmond Chert Series, Whitcliffe Scar.

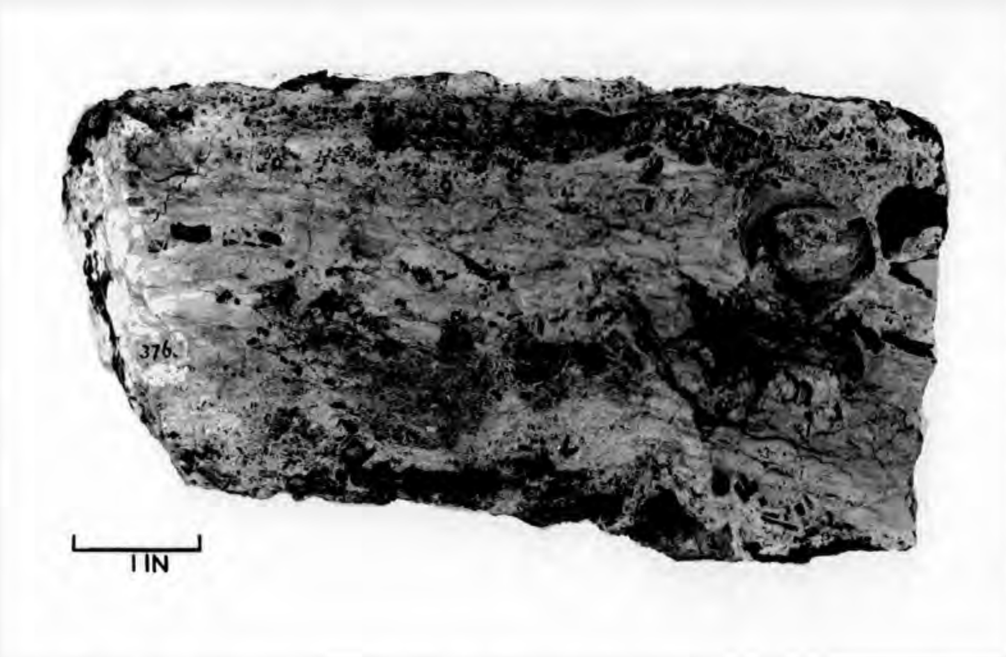


B. Cross-sections of Hyalostelia from the Richmond Chert Series. x 35. Various arrangements of microcrystalline silica and calcite (both apparently secondary) are illustrated. Small dark carbonate rhombs occur throughout the slide, ignoring mineral boundaries. The matrix is of fine-grained carbonate and brown silica.

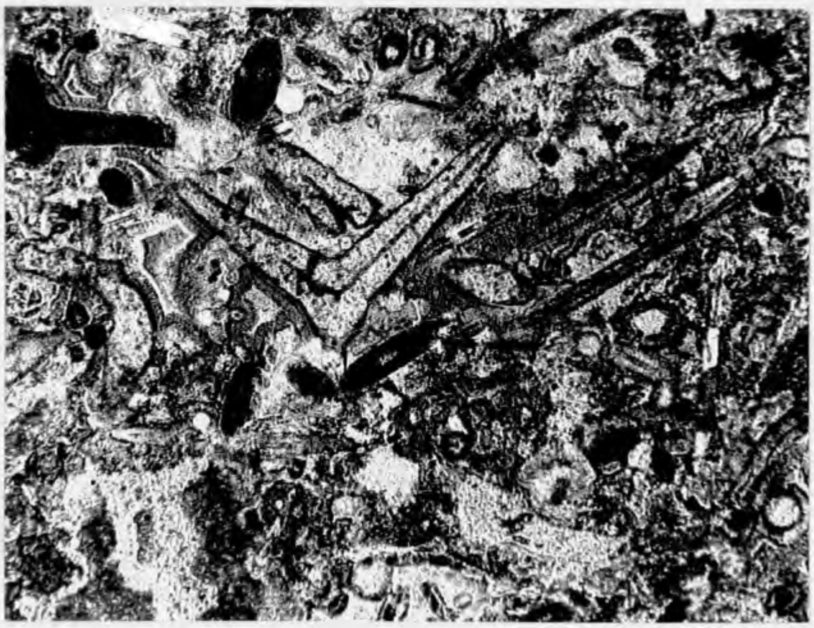
thin section, with irregular arcuate alternations of calcite and chalcedony (Plate 17B, p.192). Close examination of a fractured longitudinal section in hand specimen shows this effect to be due to a globular form adopted by the chalcedony, and not to any true concentric structure in the spicule. The evidence can be taken as pointing to replacement by both calcite and silica, it being difficult to tell what the original composition and structure of these spicules may have been. But the fact that most of them (including those in the relatively pure limestone nodules) are now composed mainly of silica may be taken as indicating a probability that they were originally siliceous.

There is evidence of secondary silicification at some horizons in the Richmond Chert Series, particularly in the lenticular crinoidal reef limestones in the upper part of the series. Nodules and lenticles of pale flinty chert which, by their cross-cutting field relationship, are clearly subsequent, are by no means uncommon. In thin section, these nodules are seen to consist of about 3 parts of colourless chalcedony (in fibrous radial aggregates) to 1 part of carbonate. The carbonate takes the form of ragged residual patches of calcite (including recognisable corroded crinoid ossicles) together with newly-formed brown rhombs of dolomite (up to 0.4 mm. long diagonal). The latter are taken to be secondary after the original carbonate which was not removed during the introduction of secondary silica, the latter presumably being derived by solution from the surrounding material before complete lithification.

A horizon which has proved to be remarkably constant over much of the north side of Swaledale is a band of very pale chert which has been named the Marske Chert Band (see Chapter 6, p.142).



A. White chert of the Marske Band, Hurst. This specimen is crowded with casts of crinoid fragments.

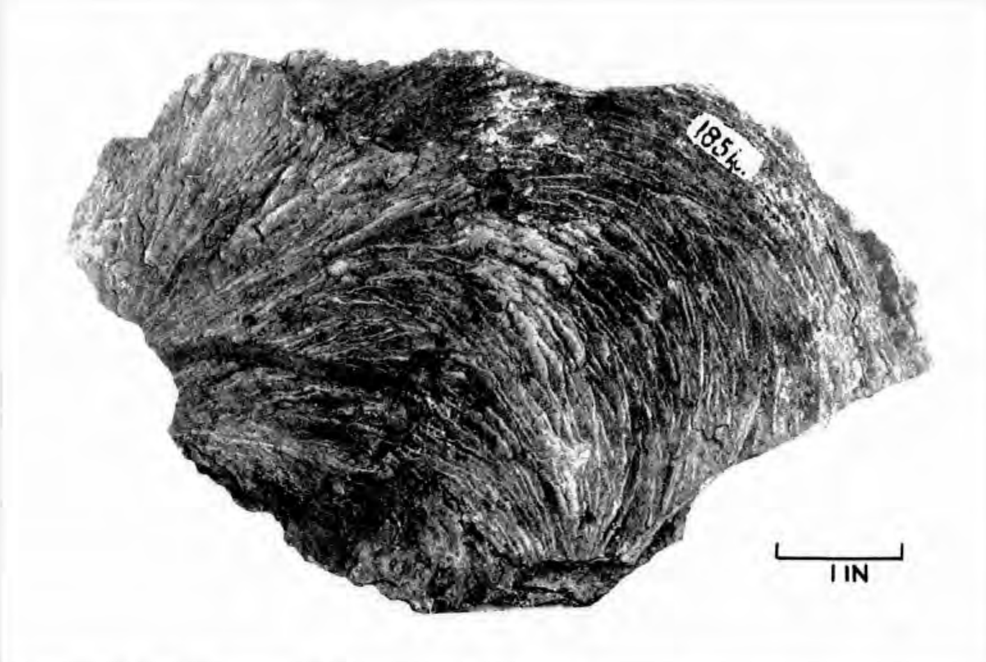


B. Marske Chert Band, Clints Wood, Marske. x 47. Calcareous spicules (clear, high relief) and a few spicules of brown silica (very dark, probably originally calcareous) set in rather variable brown microcrystalline chalcedony with typical colloidal structures.

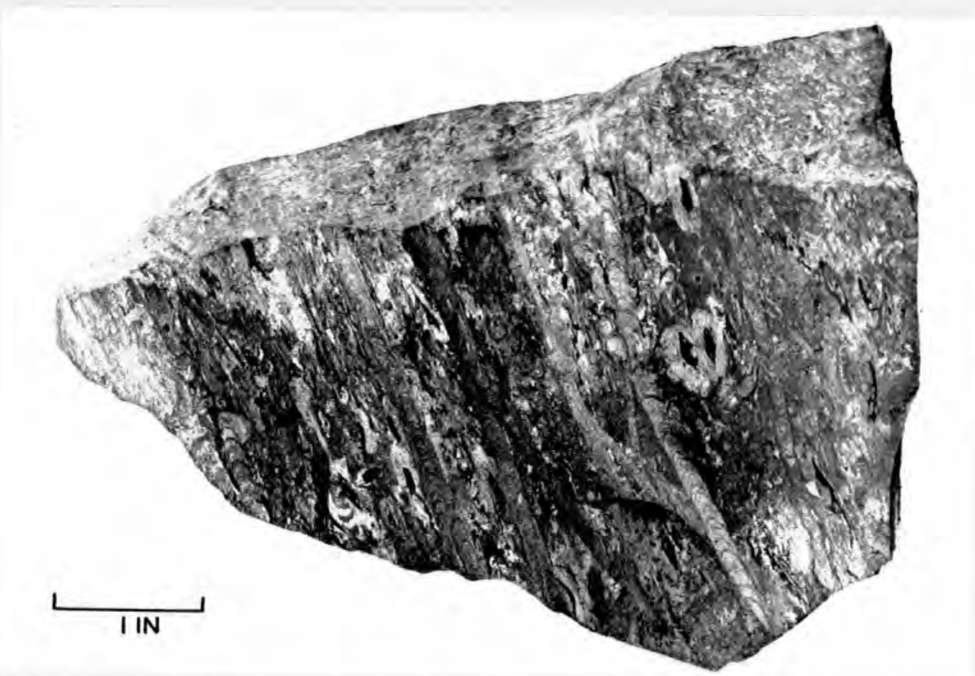
This chert is generally flint-like, extremely hard but brittle, normally dead white on a weathered surface but a pale creamy-pink colour on a fresh surface. It commonly contains casts of calcareous fossils, impressions of crinoid stems up to ¾" in diameter often being present (Plate 18A, p.193). Thin sections show this chert to be partly secondary in origin. Corroded relics of calcareous fossils occur scattered throughout the rock, but most of it is composed of entirely microcrystalline silica in which organic structures can be seen. Calcareous spicules which have resisted silicification are not uncommon, and are locally abundant (Plate 18B, p.193). The degree of silicification varies in different parts of this band, and sometimes the original pale brown almost isotropic silica (R.I.s near 1.536) is still present in part. Some slides show small rhombs of secondary carbonate in the silica. At the top of Downholme quarry, south of Marske (982113), where the band is particularly strong, it is composed entirely of microcrystalline silica, which contains cavities lined with botryoidal fibrous radial aggregates of silica. Much of the silica is pale brown, but clear colourless patches may represent areas where original carbonate has been replaced. In every locality there is evidence of at least some replacement by secondary silica at this horizon, and for this to have taken place in a single bed over such a wide area, it seems necessary to postulate a penecontemporaneous alteration.

The Cauda Galli markings (Plate 19A, p.194) which are so characteristic of the surfaces of partings in siliceous limestones of the Richmond Chert Series in many places have long been supposed to be of organic origin. In Bleaberry Beck (Kaber Fell, 085853) parts of this horizon are in exactly the right state of decomposition

Plate 19



A. Typical Cauda Galli markings on a parting in siliceous limestone, Richmond Chert Series, near Reeth. (Specimen in collection of Geology Dept., Durham).



B. Problematical structures (giving rise on weathering, to Cauda Galli markings) in siliceous limestone, Richmond Chert Series, Sleightholme Beck.

to show that the markings are due to parting along highly problematical structures in the siliceous limestone. These structures (Plate 19B, p. 194), which are particularly well developed in a specimen of massive siliceous limestone from Sleightholme Beck, opposite Bog Scar (957107), consist of more or less horizontal layers, between 1 and 4 mm. thick, which are seen in thin section to be filled with material of similar composition to that of the bulk of the rock. They sometimes extend over an area of at least a square foot, and frequently cross one another at angles of up to 20°, some clearly being later in origin than others. The material inside these layers is disposed (in vertical section) in alternating light and dark cusp-shaped bands like a series of C's, with the direction of the cusp being different in adjacent layers. A horizontal section along these layers, which is displayed by any Cauda Galli marked surface of this rock, shows these alternating bands to be arranged in a roughly concentric pattern, but the paler, more calcareous bands are discontinuous and appear to be set in the darker, more siliceous material. Because of the way in which the layers cut one across the other, they must be of post-depositional origin, and have been formed beneath the surface. They are also almost certain to have been formed before lithification. Because of the lateral area over which individual layers occur, it is difficult to conceive any organism which could have produced such planar structures by burrowing. It is just possible that there may have been a species of alga living at that time which could live and spread laterally in colonies beneath the surface, and thus have pushed the unconsolidated mud aside to form these structures. But it is equally difficult to find a satisfactory sedimentary process which might produce them. They cannot be due to small-scale current-bedding because they must be of post-depositional origin, and the only clastic material present is fragmentary organic debris. They are unlikely to be slump structures because of their regularity. Lateral movement between the top and bottom of the layers would not produce the observed C-shaped bands. Injection of mud into cracks in the semi-consolidated material would also not produce such regular banding. So in spite of the fact that Cauda Galli markings can be seen to be derived from these problematical structures, and are therefore definitely not surface effects such as fucoid markings, there is not yet sufficient evidence to be able to decide on their primary origin, or even to decide whether they are due to an organism or a sedimentary effect.

(d) Origin and transport of the silica

The essential feature which microscopic study of these cherts reveals is that of contemporaneous deposition of silica together with carbonate and argillaceous material in varying proportions. Evidence has earlier been produced for the presence of depositional silica in the Underset and Main Limestones, and the process must have continued for some time after limestone formation ceased. There is no evidence of any organic origin for the silica (apart from the *Hyalostelia* spicules which, if they were originally siliceous, must also have obtained their silica from some outside source), and the only reasonable explanation for the origin of amorphous material of this nature is one of primary deposition, probably as a gel. It is estimated by Clarke (1924) that no less than 319 million tons of silica in colloidal form are taken down to the sea by the rivers of the world every year, this figure being second only to that for $CaCO_3$.

In tropical regions, where lateritic decomposition is taking place, dissolved silica is often a particularly abundant constituent in river waters. The Amazon water, for instance, apparently contains among its dissolved solids over 28% SiO_2, compared with 39% $CaCO_3$. But it is a striking fact that sea water contains practically no silica, and it has been calculated (Rankama and Sahama, 1950) that the concentration of silica in sea water is of the order of 0.02 grams per ton, which compares with an average of over 17 grams per ton for river waters. It follows that precipitation of the silica by sea water must be almost complete, and the process visualised is one of simultaneous deposition of $CaCO_3$ together with colloidal silica as a gel in a shallow epicontinental sea, off the mouth of a large river. This theory was advocated by Sargent in 1923, and later (1929) extended by him to account for many varieties of chert, including those of North Yorkshire.

The method of precipitation, however, can evidently not be a simple one of flocculation by electrolytes, as is sometimes supposed (and as is demonstrably the case with colloidal ferric hydroxide), because silica forms a hydrophilic colloid, and the large proportion of adsorbed water renders it very insensitive to normal electrolytic effects. Correns (1951) has published curves of solubility against changing pH which show that the solubility of silica gel gradually increases with increasing pH, while that of $CaCO_3$ decreases very rapidly with increasing pH. The pH values of average sea water (7.5-8.4) and river water with dissolved $CaCO_3$ (8.0-8.4) are so little different that changes of pH are most unlikely to cause any precipitation of silica. Correns' curves do show, however, that at a pH of 8 the solubility of $CaCO_3$ is about 40 mg/litre, whereas that of SiO_2 gel is about 280 mg/litre. This implies that the concentration of silica must reach a surprisingly high value before it can be precipitated as a gel, whereas $CaCO_3$ can be precipitated from a solution with a relatively low concentration. This could have explained the rarity of deposits of originally colloidal silica, because a sufficiently high concentration for precipitation would not often be reached. But this high solubility of silica at high pH values is not observed in natural sea water, as noted above, and the fact remains that only a trace is normally present, despite the considerable silica content of the incoming river waters. More promising were the results of experiments carried out by Tarr in 1917, who succeeded in showing that calcium bicarbonate is an important precipitant of colloidal silica. He stresses that precipitation in nature is apparently far more complete than was the case in any of his experiments, and there would appear to be further factors affecting the process which he was unable to simulate. But calcium bicarbonate would undoubtedly be present in sea water from which calcium carbonate was being precipitated, and the close association of calcite and silica in nature can thus be at least partially explained.

It is not known if this type of deposition is taking place anywhere today, but the fact that cherts such as those under consideration are uncommon in the stratigraphical column would suggest that if the silica is to be brought into the sea by a large river, there would have to be an unusually rich source of soluble silica somewhere in its catchment area to make its waters more silica-rich than those of other rivers. It may be argued that such an environment of deposition would be totally unsuited to the life which evidently flourished in that sea from time to time. But the actual composition of the sea water would be little different from the normal because it is apparently incapable of taking more than a trace of silica into solution. The silica dissolved in fresh water appears to be precipitated soon after it comes into contact with sea water, and the process of actual deposition of this amorphous material would be the only deterrant to life.

The variations of lithological type within the cherts are explained if deposition of $CaCO_3$ at a constant rate is supposed, but that the rate of influx of silica and argillaceous matter were variable over quite wide limits, as would be the case with river-borne material. It is evident that carbonate was present in varying proportion throughout the period of chert deposition (even though secondary silicification has subsequently removed much of it from certain restricted horizons), and it follows that the most silica-rich beds would be those of most rapid deposition. The pale brown colour which, in transmitted light, characterises the silica here thought to be primary, has often been noticed by previous writers, and Sargent (1929) attributed it to an optical effect. To determine whether or not organic carbon might be a contributory factor to the colour, a thin slice of chert was heated to a temperature estimated to be about 650°C (a dull red heat), which was maintained for 3½ hours. When the slice was subsequently mounted for study under the microscope, no difference could be detected between it and the untreated material, and it is concluded that in this case an optical effect is the most probable cause of the colour.

Recently, Folk and Weaver (1952) have studied fracture surfaces of chert with the aid of the electron microscope, and they have shown that the intensity of the brown colour often associated with these rocks is proportional to the number of minute spherical water-filled cavities which are enclosed in the chalcedony. They show that chalcedony without these bubbles has the same optical properties as normal quartz, and conclude that chalcedony is merely micro-crystalline quartz containing a variable proportion of water in these spherical cavities, the brown colour being probably due to a complex dispersion effect. If the colouration in the cherts under consideration is due to this cause, it follows that the cavities must have been present throughout the whole course of crystallisation of the chalcedony, because the colour is the same, regardless of the stage reached by crystallisation. The separation into discrete phases of silica and water would then have occurred during the process of lithification.

The fact that the secondary silica is always completely colourless suggests, on the evidence of Folk and Weaver, that it is normal quartz and does not contain any water-filled bubbles. Certainly a replacement deposit would not be expected to contain cavities, but the refractive indices of much of this secondary silica are still just below that of balsam, and therefore it has not the optical properties of normal quartz. The mechanism of replacement is not properly understood, but the fact that small subsequent carbonate rhombs are embedded in this silica implies that actual recrystallisation has taken place at certain horizons. This is most likely to have happened shortly after deposition, probably before complete lithification, in which case the source of this secondary material would merely be the fresh deposits of the immediate surroundings. It is known that opal is appreciably soluble, especially in alkaline waters, and presumably the silica would be far more prone to replacement before it had lithified and separated into two distinct phases.

A theory put forward by Wroost (1936) to account for the concentration of silica to form flint nodules in the chalk was considered in connection with this secondary silicification. Wroost visualised the adsorption of free CO_3 ions from atmospheric carbonic acid by siliceous spicules which, by rendering the silica mobile, enabled it to move downwards in colloidal form in ground waters, to be deposited as a gel at a higher pressure level where solubility of the chalk would be increased. There are a number of objections to this mechanism, among which is the fact that the presence of CO_3 ions in solution is most unlikely from a physico-chemical standpoint, hydroxyl ions being much more probable. In such an environment, saturated with respect to carbonate, it is also unlikely that the solution will be acid. To test this, the pH value of lime water containing in solution just enough CO_2 to convert carbonate to bicarbonate was measured and found to be 7.0, indicating a neutral solution. It is therefore concluded that the assumption of an acid solution, on which much of Wroost's theory appears to rest, is unsound, and that secondary transport of silica is unlikely to have taken place by such a mechanism. It is much more probable that in the case of the cherts under consideration, secondary silicification took place penecontemporaneously with deposition.

CHAPTER 10

GLACIAL AND POST-GLACIAL DEPOSITS

During the period of maximum glaciation in the North of England, not only were the Pennine hills ice-covered and the valleys filled by local glaciers, but a stream of ice from a centre in the Lake District was forced up over the Stainmore depression and flowed eastwards between the boundaries of the local Pennine ice-sheets covering the upland areas now termed the Alston and Askrigg blocks. This stream (here called the Stainmore ice) carried with it many boulders of rocks peculiar to the Lake District, and the former extent of the Stainmore ice can be gauged from the area within which these erratic boulders are now found. The ground covered by the present survey is interesting from the glacial point of view because it includes deposits from both the local ice-sheet and the Stainmore ice, and the junction between the two has been followed for over 12 miles, as far east as Richmond. Beyond Swaledale, the Stainmore ice turned and flowed SSE down the Vale of York, and erratics deposited by it have been found south of the Humber.

The first mention of far-travelled erratics in the area is to be found in Phillips' work (1836, p.162), where boulders of Shap granite are recorded from the Stainmore Pass, and further east in Teesdale, the valley of the Greta, and around Richmond. It was not until some time later that the method of transport of these erratics was realised, however, and the first work of importance on the glaciation of this part of the Pennines was done by Goodchild (1875), who extended further north the methods initiated by Tiddemann (1872) in north Lancashire and south Yorkshire. Goodchild traced the southern limit of Shap erratics west of Stainmore, and first recognised the former presence of the ice sheet which was centred on the high ground between the headwaters of the Swale and the Ure. He also produced evidence to show that some of this ice, as well as flowing eastwards down the two major dales, travelled northwards across the upper part of Swaledale and over the Swaledale-Teesdale watershed in the region of Tan Hill, where it left abundant striae. He showed that once over the watershed, this ice flowed eastwards along the northern edge of the high fells, and acted as a barrier to prevent the Stainmore ice from turning SE down Arkengarthdale. H. Carvill Lewis (1894) extended, and added further detail to Goodchild's work, concluding that the ice-sheet was centred on Mallerstang. He was also of the opinion that the Swaledale glacier travelled no further east than Reeth, and left lower Swaledale an ice-free valley. Some of the more striking glacial features in the vicinity of Richmond were subsequently recognised by Kendall and Wroot (1924), whose work was amplified and extended by Raistrick (1926) in a paper on the glaciation of Wensleydale, but he added much detail on the glaciation of the dales themselves, and on the interplay between the Stainmore ice and that from the local centre. It is this work by Raistrick which has been continued by the present contribution.

(i) <u>Deposits of the local ice-sheet</u>

These deposits occur as isolated patches of boulder clay on the high ground, and also as thicker and better preserved masses of drift lower down in the valleys. The former are in an extremely weathered state, and are generally quite thin. On the whole they are very poorly exposed (due to extensive peat cover), but can be seen in the bottom of peat haggs around the fell tops between Arkengarthdale Head and the Harker Moss channel (north of Marske). These deposits consist largely of local material which has not travelled very far, and which is set in a clay matrix of variable proportion, sometimes having been almost entirely leached away. It is likely, as stated by Raistrick, that this high-level drift once formed a more or less continuous sheet of boulder clay, and has since been reduced by weathering and erosion to its present patchy state. East of the Harker Moss channel the drift is, if anything, even more patchy, but there is much less peat. There are large areas (mainly dip slopes) on the Main Limestone and the Richmond Chert Series which are devoid of any superficial cover. But on Marske Moor, between 1 and 2 miles north of Marske, various excavations on the Army Range have revealed glacial drift more than 6' in thickness over an area of about ¾ square mile. This consists largely of sub-angular fragments from the underlying Richmond Chert Series, set in a variable matrix of rather sandy clay.

In marked contrast to this high level drift is that found lower down in the valleys, principally in Swaledale and its north-bank tributaries Marske Beck and Clapgate Beck. In the neighbourhood of Marske, drift covers the sides of Swaledale generally up to about 100' above the level of the river. There is an extensive spread up Marske Beck as far as its confluence with Throstle Gill, and a good section of drift some 30' high occurs in the west bank, to the east of Telfit Farm. Here the section is of true boulder clay, striated boulders (mainly of local Yoredale material) often being over 18" across. Downstream towards Marske the drift boundary rises up the valley sides to be nearly 200' above the beck around Skelton and in Hag Gill (west of Marske). The floor of the valley consists of gently undulating drift-covered ground up to 400 yards wide, which opens out into Swaledale itself where drift extends across the valley for up to 2/3 mile (Plate 20A, p.207). This covering of drift in the valley bottom is breached by the lowest reaches of Clapgate Beck, which affords a good section of boulder clay in excess of 50' in thickness, and all the way up Clapgate Beck (as far as Low Feldom) drift occurs on both sides of the valley obscuring the solid rock to a greater or lesser extent. It is very well seen from the road up Clapgate Bank, in the vicinity of which the valley sides up to 150' above the beck are plastered with moundy boulder clay, imparting the typical hummocky topography of drift-covered ground.

These valley deposits are so much better preserved than those found at higher levels that there can be little doubt, as Raistrick says, that they are of considerably later date, and that they were deposited by valley glaciers which existed long after the ice-sheet as a whole had gone. It is clear that the Swaledale glacier flowed the full length of the dale, and in this connection the record of a series of bore holes sunk near the centre of the valley in 1923 for a water supply for Catterick Camp is of interest. They were located about 1½ miles west of Richmond, near Lownethwaite Bridge, and proved up to 187' of loose material. About 170' of this is below the present river level, and the upper part of it was apparently boulder clay, while near the base were recorded blocks of siliceous limestone, evidently part of a pre-glacial landslip into the very deep gorge in which the Swale then flowed. So the drift covering the floor of the valley is seen to be very much thicker than the surface exposures would suggest, and the retreat of the Swaledale glacier from the Richmond area westwards in the direction of Reeth must have been continuous, because there is no sign of any morainic deposit downstream of the excellent terminal moraine at Ellerton. It was doubtless this fact that led Carvill Lewis to the conclusion that the glacier reached no further down the dale than that point.

The glacial deposits of Arkengarthdale contain no Lake District erratics (as was first noted by Goodchild), and the glacier which filled this valley must have been an integral part of the system evolved by the ice-sheet centred on Mallerstang. Much of the ice which flowed northwards over the watershed near Tan Hill must have later turned SE to flow down the dale, but Arkengarthdale Head was evidently a critical point as far as this stream was concerned. Large mounds of ill-sorted drift have been dumped in the region between Sleightholme and Cleasby Hill, and the ice must have been held up here for some time to have deposited all the morainic material which now forms Coney Seat Hill, Bow Hills, Redmire Hills, Ling Pulled Hill, Stoney Hill, Suet Set Hills and Seven Hills. The last mentioned, in particular, consists of a highly irregular and complex mound of rather angular drift. The drift boundary rises up to a height of 1400' on the western side of Cleasby Hill, but falls away both north and south. Evidently the ice stream piled up in this region, undecided in which direction to continue, until most of it was diverted down Arkengarthdale by the pressure of the Stainmore ice to the north. Some of it managed to get round the north side of Cleasby Hill, where it has left striations trending between 040° and 080° on the top of the Upper Coal Sill along White Crag. This stream bounded the Stainmore ice and kept the latter further north than would otherwise have been the case, but the glacial deposits of upper Arkengarthdale are so thick and extensive, and include so much grit from the vicinity of Tan Hill, that there is little doubt that most of the ice stream found its way down Arkengarthdale to rejoin the Swaledale ice at Reeth. The latter was much the stronger, however, and the ice from the north deposited an extensive terminal moraine which blocked the SE end of Arkengarthdale for a mile above Reeth. This has now been breached by Arkle Beck, which runs for some distance through a narrow gorge of boulder clay before emerging onto the flood plain of the Swale.

There were a series of lake systems in Swaledale associated with the retreat of the ice, which are now marked by overflow channels in varying degrees of preservation. These systems have been adequately described by Raistrick, and there are no further details of importance to add to his work. But a former glacial lake on the watershed between Arkengarthdale and Sleightholme Beck is worthy of mention. The site of this lake, which was about 1½ miles long, is now a broad flat peat-covered hollow running from Mud Beck across Adjustment Bottom and Rushy Moor Bottom to the head of Hound Beck at 1220' O.D. The Arkengarthdale glacier must have closed this area to the south, and melt waters were accumulated to form a lake. This overflowed over the watershed at its northern end, and a channel (now the site of Hound Beck) was rapidly cut into the shales beneath the Lower Coal Sill. This channel in turn fed another lake, the site of which straddles Sleightholme Beck immediately north of Sleightholme itself. This second lake drained northwards along the line of the present beck, a process which contributed largely to the cutting of the gorge through the Coal

A. Lower Swaledale, from the west. Richmond and the Vale of York are in the background. Solid rock is exposed in the wooded scars on either side of the dale, but drift (some 200' thick) now extends all the way across the floor of the valley.

B. The southern end of the Feldom lateral moraine (here some 60' high) from the north, with Swaledale and Catterick Camp beyond. Outwash sands and gravels form the gentle slope into drift-free ground on the right, contrasting strongly with the drift-covered hummocky ground to the left.

Sills north of Bog Scar.

(ii) Deposits of the Stainmore ice

(a) Moraines

One of the most striking features of the country west of Richmond and north of lower Swaledale is a ridge of morainic drift which runs along the south side of Barningham and Gayles Moors (near the watershed between Swaledale and the Gilling valley) to end abruptly on Richmond Out Moor. This ridge is up to 60' high, and presents a steep slope to the north and NE, but a much more gentle one on its other side (Plate 20B, p.207). There are many erratics of Shap granite (and a few from the Borrowdale Volcanic Series) along this moraine, but no far-travelled boulders have been found south or SW of it, from which it is clear that this is the highest lateral moraine left by the Stainmore ice. It was first recognised as such by Kendall and Wroot, who noted that it could be followed on the ordinary topographical map for part of its length, and Raistrick subsequently traced it to its western extremity, naming it the Feldom moraine after its most excellent development on Feldom Moor. In all, it is about 6 miles long, and makes a quite unmistakable feature. Raistrick mentions another moraine to the south of the Feldom moraine, which he says makes How Tallon Ridge. But this ridge is entirely solid, many exposures of the Main Limestone occurring along it, and there is no doubt that the Feldom moraine marks the maximum advancement of the Stainmore ice.

Outside the moraine, the drift is very patchy and exposures are good, in strong contrast to the ground inside the moraine which was overridden by the ice from the Lake District. Here, boulder clay is dominant, and exposures are relatively very poor. The rolling, sometimes hummocky, topography of the ground moraine is the dominant feature of the landscape, and features do not often have a solid foundation. But there are a series of ridges north of the Feldom moraine, and roughly parallel to it, which make features of very varying strength lower down the hillside. These ridges are frequently breached by small streams, sections in which show them to consist entirely of boulder clay, and the ridges clearly represent a series of lateral moraines deposited by the Stainmore ice during brief halts in the retreat stage. It is noticeable how much less well defined these moraines are than the one which runs across Feldom Moor, and the ice must have remained at its highest level for some considerable time to have produced such a striking deposit.

The highest of the retreat stage moraines runs across Scargill Moor at about 1050' O.D., some 250' below the Feldom moraine. It is breached by Scale Knoll and Woodclose Gills, which expose at least 60' of boulder clay. It cannot be followed across Hope and Scargill Becks, in the vicinity of which there is an unbroken and very thick deposit of drift, but north of the latter it is picked up again at the same height, and is followed westwards beneath Spanham as far as Eller Beck. The second moraine of this series can be traced from a point ¾ mile south of Gayles for 3½ miles, as far as Newsham Pasture (south of Barningham). The ridge is 150' high SW of Dalton, where it is surmounted by the road up Long Bank, and Dalton Beck provides a section of over 100' of boulder clay in the banks beneath the old fortress of Castle Steads. This moraine is probably continuous with the one which runs across Scargill Low Moor in the direction of Bowes, as far as Farewell Farm. An excellent section of this is afforded by Thwaite Beck as it turns through a right angle a mile NE of Spanham to cut straight through the moraine and expose 80' of boulder clay. Just east of this section, the road leading up to Stang makes an acute double bend to get over the strong feature formed by this moraine. To the north of this, The Rigg is a remnant of yet another moraine, but this can only be followed for about 2/3 mile. The drift cover in this region is very heavy, even between the moraines, and outcrops only occur in the bottoms of the deepest valleys. A bore-hole at White Close Hill (on the northern edge of the lowest moraine) went through 194' of boulder clay before reaching solid rock, showing that the drift cover ¼ mile south of the Greta extends below the level of the present-day river. So the pre-glacial valley of the Greta between Bowes and Brignall Banks must have been considerably different from the valley as it is today, modified by this vast thickness of boulder clay, and the river itself would have flowed south of its present position.

(b) Erratics

During the course of this survey, every exposed far-travelled erratic was mapped up to a distance of about 5 miles from the Feldom moraine, beyond which they become too common to need individual attention. By far the most numerous are those of Shap granite, the positions of over 100 of which have been entered on Plate IV (p.215). Their southern limit coincides exactly with the position of the Feldom moraine, which is considerably further south than the boundary drawn by Raistrick. The highest Shap erratics were found at the foot of Eel Hill, at 1340' O.D., near the western end of the moraine. Most of the boulders call for no particular comment, but the positions of the largest may be mentioned. There is one a mile north of Brignall Banks, near The Birks, the upper surface of which measures 8' x 7'. The rest of this boulder is embedded in drift, but it must be extremely large, and can scarcely weigh less than about 12 tons, assuming a minimum depth of 4'. On the south side of the Gilling valley large Shap erratics occur south of Gayles, some of which must well exceed 60 cubic feet. About 1½ miles west of Melsonby there is a boulder of shap granite in which the orthoclase phenocrysts bear well-developed rims of another feldspar, apparently plagioclase (with an appearance similar to that of rapakivi structure). There is an interesting occurrence of a Shap erratic in the yard of the old Paper Mill west of Richmond (mentioned by Raistrick), and the finding of a similar boulder in Sand Beck, due south of Richmond, makes it certain that the Stainmore ice must have crossed Swaledale at least a mile upstream from Richmond. There is no evidence of morainic deposits south of Richmond Out Moor, but the presence of the deep gorge of Swaledale was evidently no obstacle to the ice stream, which rode across it almost at right angles (as shown by Raistrick, p.398).

It is interesting to note that no boulders of Shap granite less than about a foot in diameter have been found. This rock is never present in gravels, and it can be supposed that due to the large phenocrysts which it contains, it is more easily crushed by the ice when it reaches a certain critical size (apparently a diameter of a foot) than other finer-grained rocks present in the drift. Grain size must, within reason, be as important a factor in this process as the actual hardness of the rocks, when the latter does not vary widely. Boulders below the critical size would then be preferentially reduced by crushing, and the absence of pebbles of Shap granite would thus be explained.

Erratics found in the deposits of the Stainmore ice include a large proportion of Carboniferous material which has evidently not travelled far, and the most common boulders are generally from the horizon over which the ice had recently travelled. But the power of transport was large, and often these local boulders reach 5' in diameter, and weigh over a ton. Apart from the Shap erratics, boulders of andesitic lavas and tuffs from the Borrowdale Volcanic Series are by no means uncommon, particularly well away from the edge of the glacier. They can be collected from the drift at the top of most large quarry sections, and it is significant that the furthest travelled erratics tend to be found towards the bottom of the drift in these quarries. This suggests that Pennine ice played a greater part during the later stages of glaciation, and that exposed boulders recognised as coming from the Lake District probably represent only a very small fraction of those which are present further down in the drift, and which have not yet been exposed. Boulders from the Whin Sill are found occasionally, and erratics from the Vale of Eden, to the west of Stainmore, have also been recorded. Carboniferous Basement Conglomerate is present in the drift overlying the Main Limestone in Forcett quarry, and a reddened slightly arenaceous limestone (probably Carboniferous) was found in fluvio-glacial gravels in St Trinians quarry, east of Richmond. A recent excavation into the side of the lateral moraine SW of Dalton, at the top of Long Bank, revealed a piece of Penrith sandstone together with several erratics of the Borrowdale Volcanic Series.

The matrix in which these boulders occur is, in general, a fairly uniformly grey-blue stiff clay. But east of the Great North Road (along the eastern side of Barton quarry and in the vicinity of

Plate 21

A. Fluvio-glacial sand and gravel in St Trinians quarry, Richmond. Foreset bedding in the lower sands is truncated by the overlying gravel.

B. The site of the Harker Moss glacial lake, with the overflow channel into Swaledale in the background. The Feldom moraine is immediately behind the photographer.

Middleton Tyas) the clay takes on a red-brown colour, presumably due to Triassic material which was taken up by the moving ice-sheet. The Trias outcrops beneath the drift a little way to the east of these localities, across the Scorton-Darlington-West Hartlepool fault, as was demonstrated by Fowler (1945) by means of sub-surface information. So at some time the direction of movement of the ice which crossed this part of the country must here have had a westerly component, to enable the red Triassic material to be carried across to the west side of the fault.

(c) Fluvio-glacial sands and gravels

A very extensive spread of sand and gravel occurs immediately to the east of Richmond, and has been worked in St Trinians quarry, a mile east of the town. This quarry exposes up to 70' of very strikingly current-bedded sand, in part ripple-marked, which encloses very variable but fairly well graded horizons of gravel (Plate 21A, p. 212). These are water-borne deposits, but conditions and rates of deposition were evidently liable to extremely rapid fluctuation. Occasional clay and silt bands represent periods during which the rate of deposition was at a minimum. The sand is remarkable for the fine particles of coal which occur in it sporadically, picking out the bedding, and coal must have been eroded in considerable quantities during this period. But there is no evidence to show where the outcrops might have been. The owners of this quarry had a bore-hole sunk in 1943 for a water supply, and this proved 9'8" of boulder clay between the base of the sand and the solid rock beneath. This in itself is not remarkable because the sands and gravels are clearly deposits from a melting ice-sheet. But up to 8' of true boulder clay also occur above the sands, which have been eroded and contorted as they were over-ridden during a readvance of the ice. Probably the readvance was only short-lived and on a small scale, not implying separate glacial periods. It is only necessary to visualise the retreat of the ice taking place in a somewhat more complex manner than had previously been supposed.

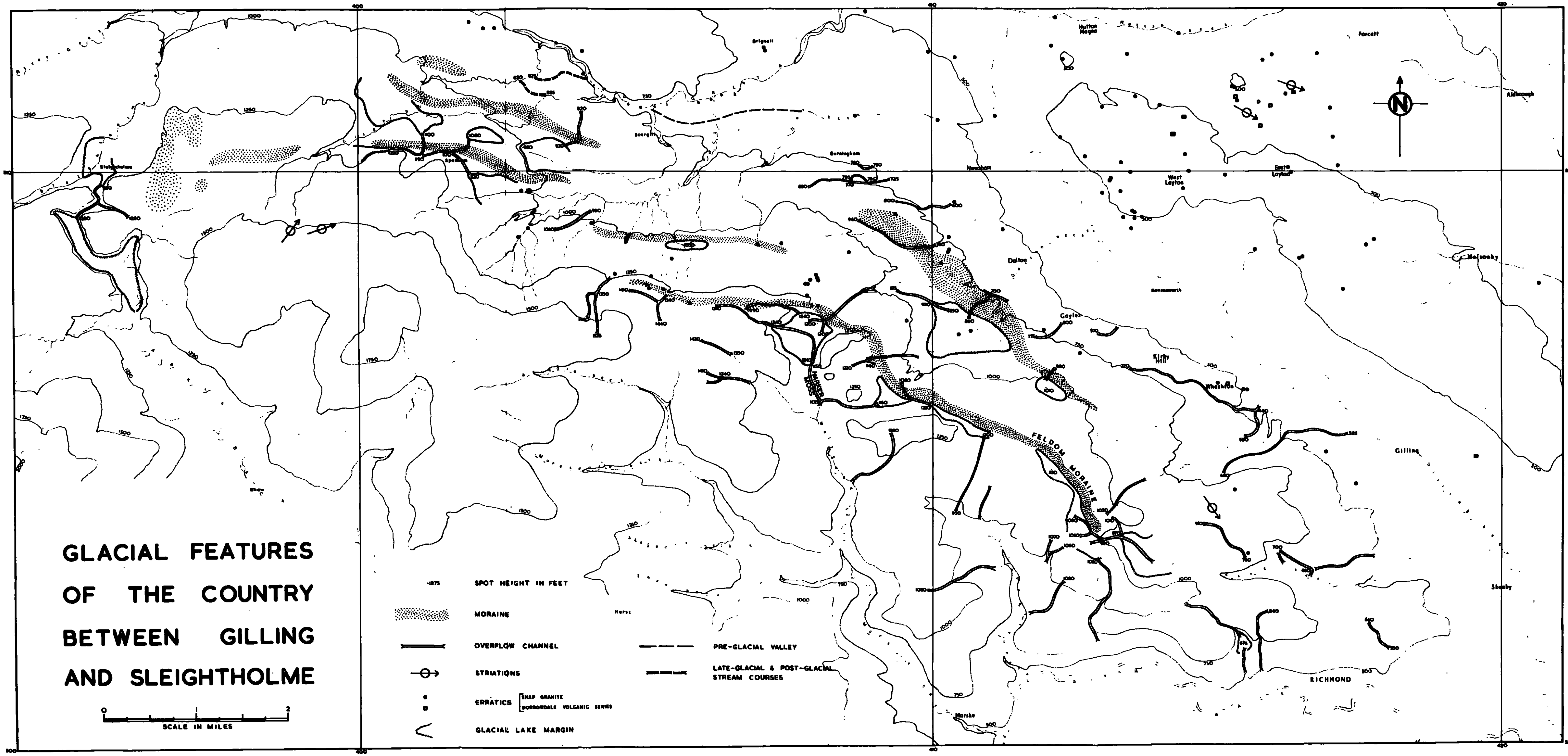
These fluvio-glacial deposits probably belong to the early stages of the retreat of the Stainmore ice. During, and probably for some time after, the period of maximum glaciation, the Stainmore ice must have blocked up the exit from Swaledale. But immediately this barrier was removed, a vast quantity of material that had accumulated behind it would have been free to find its way out of the gorge. As Swaledale opens out so suddenly onto the Vale of York immediately east of Richmond, it was only natural that this would be where much of the debris from the melting ice in Swaledale would come to rest. As first stated by Kendall and Wroot (p.535), the pre-glacial Swale flowed past Richmond north of its present position, through the hollow to the north of the market-place (where the drift cover must now be some 300' thick, from the evidence of the Lownethwaite Bridge bore-holes), and this old channel was blocked with boulder clay from the Stainmore ice. As this glacier retreated northwards, the water from the lake which had accumulated behind it first escaped round the southern margin of the ice, and began to cut a channel for itself into the solid rock (south of the present market-place), carrying with it much sand and gravel which had been deposited in the lake, and which must have greatly increased its erosive power. By the time the ice had gone, this new channel had already been cut to a lower level than that of the drift blocking the old channel (as was first recognised by Raistrick), with the result that the river has remained in solid rock to the present day as it flows past Richmond. North of the market-place, near the centre of the town, there must consequently lie buried a gorge which is over twice as deep as the well-known one through which the Swale now finds its way out onto the Vale of York. That the sands and gravels east of the town must have been deposited soon after the removal of the ice barrier is clear from the fact that they are found up to a height of 450' O.D., approximately equal to that of the top of the present gorge. So these highest deposits must have been emplaced before the river had cut an appreciable depth into the solid rock.

There are also small and local deposits of fluvio-glacial sands associated with the Feldom moraine. When the ice began to melt, sand was deposited in places on the outside of the moraine itself, evidently while the ice was still in position on the other side of the ridge. This has resulted in a very much more gentle slope on the south and SW side, especially in the vicinity of ice-edge drainage channels (a number of which are associated with this moraine), which is in striking contrast to the hummocky boulder-clay covered ground north and NE of the ridge (see Plate 20B, p.207). The clearest sand deposits of this type are on Feldom Moor, near the eastern end of the moraine.

(d) Glacial lakes and overflow channels

A well-marked series of ice-edge lakes were associated with the lateral moraines of the retreat stages of the Stainmore ice. These and their attendant overflow channels (as they are today) have all been entered on Plate IV (p. 215). The most important were those associated with the Feldom moraine, and an ice-edge drainage channel

PLATE IV



GLACIAL FEATURES OF THE COUNTRY BETWEEN GILLING AND SLEIGHTHOLME is now preserved along the outside of the western part of the moraine. This channel carried melt-waters eastwards from above the 1300' O.D. level, round the north side of Byers Hill, and into an ice-edge lake at 1240' O.D. situated some 2 miles south of Barningham. The site of this lake is now marked by a flat peat-covered partly marshy area rather over ½ mile across (Plate 21B, p.212). The only escape for the water in this lake was southwards, over the watershed, and an overflow channel was rapidly cut into the soft shales overlying the Underset Limestone. This channel, first recognised by Kendall and Wroot (p.536) and described by Raistrick (p.401), had the effect of temporarily carrying water from the Teesdale drainage system over the watershed into Swaledale, and the resulting erosion produced the now dry trough known as Harker Moss, which, in part, is 80' deep and 250 yards wide. At a later stage, the water from the ice-edge channel which fed this lake over-flowed round the south side of Byers Hill, and entered the lake from a point ¼ mile further south, cutting a V-shaped gorge some 40' deep. This later channel continued in use for as long as there was water to be carried away, which must have been for some time after the Harker Moss channel had become deep enough to drain the lake completely. This is seen from the fact that the lake deposits themselves have been channeled by the continuation of the later over-flow round the south side of Byers Hill, which can be followed directly into the Harker Moss channel as shown in Plate IV (p.215) At a still later date, after the recession of the ice, the head of Dous Gill worked back through the moraine from a northerly direction, and the site of the former lake is now drained both into Swaledale and into the Gilling valley. A mile to the SE, there was another small lake at 1160' O.D. at the head of Dalton Beck, the overflow from which ran westwards and cut a channel (now the dry Snaiza Gill) through the Main Limestone to join Harker Moss. The combined waters flowed south into the Swale, and helped to cut the gorge in which the diminutive Waitgate Gill now runs.

East of the lakelet at the head of Dalton Beck there were stretches of water which bordered the moraine for about 2 miles, and which can have been no more than ¼ mile wide. These drained over the watershed into Clapgate Gill through several channels, the highest of which starts at 1200' O.D. near Pin Hill. At the eastern end of this long thin series of lakes, at the point where the Feldom moraine now ends abruptly, a later channel at 1060' O.D. leads over to Hey Gill and Clapgate Beck, while another, at the same height, leads southwards across the moor to enter the Swale by Deepdale. After the retreat of the ice, the Feldom moraine was breached by channels at either end of this series of long thin lakes, the one at the eastern end leading water into a lake of the next stage at 970' O.D. on Aske Moor, at the head of Aske Beck. This lake in turn later drained by a channel at 910' O.D. near the Jockey Cap into the lower reaches of Aske Beck. The channel breaching the Feldom moraine at the western end in the mean time fed a large lake at 920' O.D. a mile SW of Dalton. This lake was subsequently drained into Dalton Beck after the retreat of the ice by a deep and steep channel breaching the moraine to the NW of the gorge cut by the present beck.

There were a number of ice-edge lakes associated with the moraines on Scargill Low Moor. West of Spanham, there was a lake at 1220' O.D. in the upper reaches of Eller Beck, the site of the eastern end of which is now a flat marshy peat-covered area lying between Spanham West Hill and Long Side. This lake drained eastwards along the outside of the moraine, and into another much larger lake at 1120' O.D. at the head of Stang Gill. The site of the NW corner of this lake is still preserved as a patch of flat peat-covered ground between ¼ and ½ mile SE of Spanham. After the retreat of the ice, the channel draining the Eller Beck lake broke through the moraine north of Spanham (along the line of the present Gregory Beck) and supplied water to a lower lake at 1080' O.D., which in turn drained into another lake at 980' O.D. bordering the lower moraine on Garnathwaite Pasture. Soon after this, the channel draining the Eller Beck lake broke through the higher moraine further west, between Spanham East and West Hills. This left the Gregory Beck channel dry, and the water was now carried into a lake at 1100' O.D. lower down Eller Beck which, however, probably drained eastwards into the two lower lakes fed by the same channel before the second breach. Finally, after the retreat of the ice from the lower moraine, the water from the Garnathwaite Pasture lake found its way northwards through the moraine into Thwaite Beck near its confluence with the Greta.

There are also a number of overflow channels which are not directly associated with moraines, but which must have been cut when the ice was in the vicinity. Of these, the dry valleys in Barningham Park are notable. A channel starts at 880' O.D., and runs eastwards, rapidly deepening, into the Park. It separates round Bleaberry Hill, which has been left as an outlier some 80' high, and the water evidently flowed alternately to the north and south of this hill. The southern channel was the last in use, and has been cut

Plate 22

A. Round Howe, Richmond from the north. This in-and-out channel was cut by the Swale (flowing from right to left) during a temporary blockage, probably by a lobe of ice from the north during the glacial retreat stage.

B. Brignall Banks, near Gill Beck Foot. The gorge here is perfectly V-shaped in section, and is clearly of comparatively recent origin. It is thought that this is a post-glacial re-excavation of a pre-glacial valley.

12' lower than that going round the north side, although the latter is still open. The dry valley then continues eastwards to die out in drift at 725' O.D. near the eastern boundary of the Park. On the north side of the Park, Adam Hill is another outlier some 60' high, isolated by an in-and-out channel. But the main channel to the north, of which this was temporarily a part, is no longer preserved. Adam Hill was probably formed in very much the same way as The Round Howe, west of Richmond (Plate 22A, p.218), which was cut by the Swale during a temporary blockage (presumably by ice) of the main channel to the north (a process which was first visualised by Kendall and Wroot).

Several other channels are also associated with the retreat of the ice from the Gilling valley. The longest of these, about 1¾ miles in length, starts at 720' O.D. on the hillside west of Kirby Hill, and runs eastwards through Whashton as far as the SW corner of Hartforth Wood at 440' O.D., probably feeding a lake beneath Whashton Hag. This channel would have been cut over a long period, and it is unlikely that the full length was ever in use at any one time because of the comparatively large vertical interval involved. The same is true of a channel starting at 680' O.D. near Whashton Springs and running NE through Gilling Wood and beneath Crabtree House to end near Gilling Beck at 325' O.D. It doubtless belongs to the same period as the Kirby Hill-Whashton channel, but again is unlikely to be a simple single-period channel, in contrast to many of those associated with the moraines. A well-defined deep dry valley runs from Bend Hagg at 660' O.D. in a SE direction through the NE corner of Richmond. This, as Raistrick noted, was the channel by which Aske Beck overflowed into the Swale when it was blocked by the glacier in the Gilling valley, and was probably cut during the time when the upper parts of the previously described channels were in use. Immediately the exit to Aske Beck was opened, this channel was no longer required, the lake subsided, and the water flowed into the Gilling valley and thence to the Swale by its present course.

(e) Striations

Striations made by the Stainmore ice have been observed on only one natural exposure, and these marks are evidently rapidly erased by weathering after the striated surface has been laid bare. This single locality is 400 yards NW of Aske Moor Farm, where the coarse top of the sandstone beneath the Underset Limestone bears striations trending 35° east of south. This direction is parallel to the trend of the Feldom moraine a short distance to the west. Many excellent striae are seen in quarry sections further north, however, and in Hulands quarry (east of Bowes) the Main Limestone is overlain by boulder clay up to 12' thick. This has striated the surface of the limestone, and shows the ice to have come from a direction 25° north of west. There are striations which run as much as 30° to either side of this average, but by far the largest number point away from the northern part of the Stainmore depression. Further striations are present on the surface of the Main Limestone in East Layton and Forcett quarries, where the drift (up to 25' thick) has also polished the top of the limestone. There are two separate sets of striations discernible here. One set trends in an average direction of 30° south of east, with individual striae between 5° and 55° south of east. The other set, which is quite separate, trends 15° north of east, showing that here the ice sheet must at one time have been heading in the direction of the mouth of the Tees. Kneeton Hall quarry (a mile north of Scotch Corner) has exposed a pavement of the Underset Limestone striated in a direction between 35° and 40° east of south, while Barton quarry (¾ mile to the NNE) shows the same limestone striated in a direction between 30° and 35° south of east. The ice stream must therefore, in this region, have flowed in a general south-easterly direction at least as far east as the present Great North Road before turning southwards to travel down the Vale of York.

(iii) Pre-glacial topography

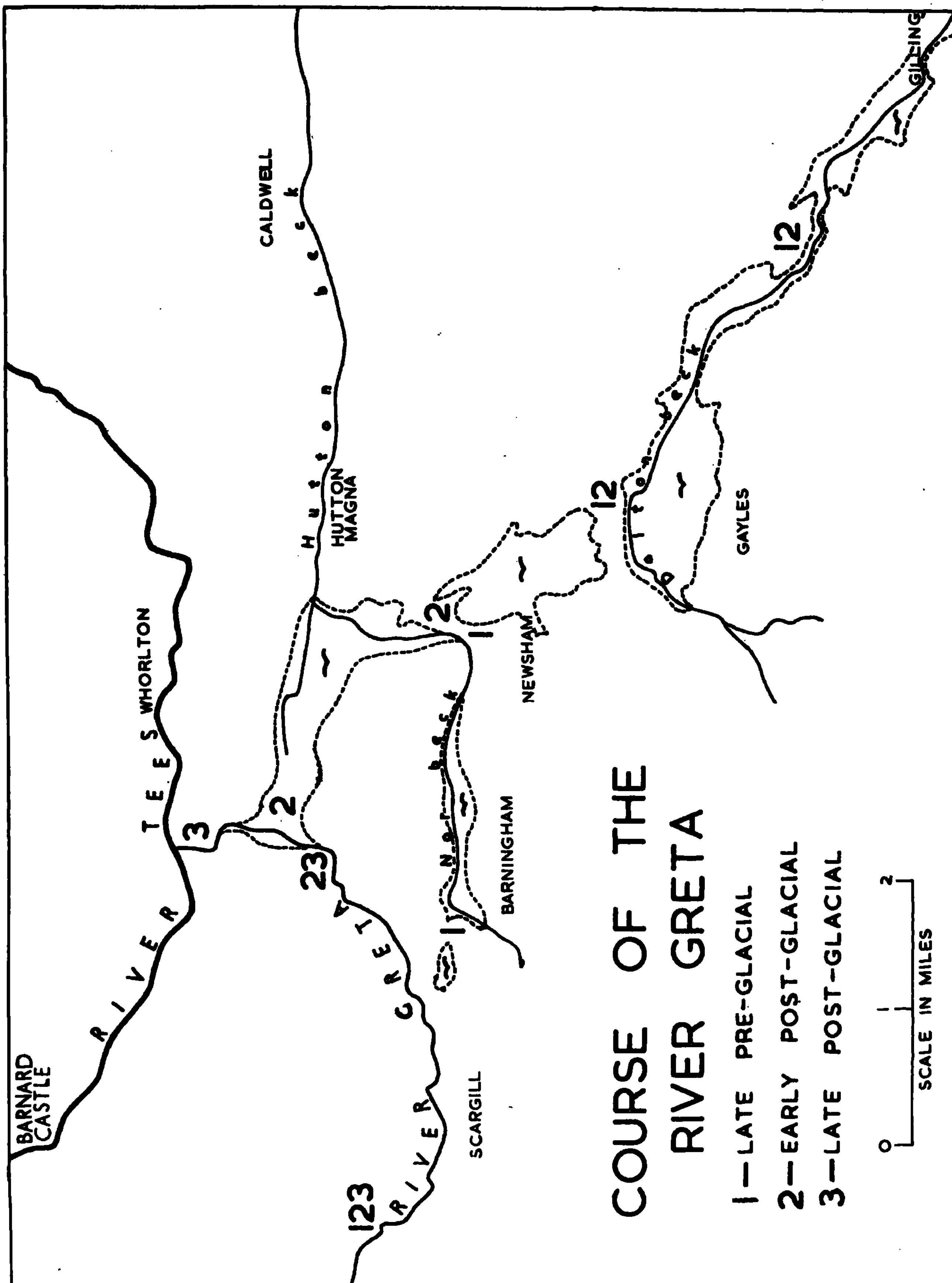
It is clear from the evidence provided by both Swaledale and the valley of the Greta that many of the pre-glacial rivers were flowing in valleys as deep as, and in some cases deeper than, those of the present day. So the period of rejuvenation which led to the formation of these deep valleys must date from a considerable time before the close of the Tertiary, and post-glacial erosion has been largely confined to the re-excavation of these valleys which had been filled to a greater or lesser extent by glacial deposits and pre-glacial landslips. Enormous spreads of drift have much modified the topography to the north and NE of the Feldom moraine, and east of Richmond it is not possible to tell anything of the pre-glacial topography. The pre-glacial Swale 1½ miles west of Richmond was already flowing at a level considerably below that at which the river now enters the Vale of York, and the drift deposits, well over 100' thick for the most part, everywhere obscure the solid rock except in the vicinity of Barton, Middleton Tyas and Moulton. Along Gatherley Moor, however, on the north side of the Gilling valley, the drift is penetrated by what must have been pre-glacial peaks, which now form hills of solid rock surrounded by drift. The most notable of these is Diddersley Hill (1½ miles WSW of Melsonby) which rises sharply some 70' out of the drift, and the pre-glacial topography must have been considerably smoothened by the boulder clay which is now banked round these former peaks. This smoothing effect due to deposition is probably the most important modification of the topography, and is undoubtedly far more marked than that due to actual erosion by the ice in this particular part of the Pennines.

(iv) <u>River diversions</u>

The post-glacial gorge of the Swale at Richmond has been described in section ii(c), and sub-surface information has shown that the pre-glacial course of the Greta between Bowes and Brignall Banks was to the south of its present position. There is, in addition, sufficient surface evidence to be able to reconstruct the various courses of the Greta downstream from the head of Brignall Banks, and these are shown in Fig. 11 (p.222).

The alluvial tract around Greta Bridge, onto which the gorge of Brignall Banks opens at its eastern end, has long attracted attention, but it was left to Phillips in 1836 to attempt the first geological explanation of it. He was under the impression that there was a fault running down Teesdale from near High Force, which continued SE down the Gilling valley, and that it was this fault (since shown to be non-existent here) which had caused the Tees to flow at one time down the Gilling valley. In this way he explained the extensive alluvial tract which now joins the Greta valley around Greta Bridge to the head of the Gilling valley. He also remarked on the fact that soon after receiving the water from Gilling Beck,

FIG. 11


COURSE OF THE RIVER GRETA
1—LATE PRE-GLACIAL
2—EARLY POST-GLACIAL
3—LATE POST-GLACIAL
SCALE IN MILES
0
1
2
BARNARD CASTLE
RIVER TEES
WHORLTON
CALDWELL
Hutton beck
HUTTON MAGNA
RIVER GRETA
SCARGILL
BARNINGHAM
Nor beck
NEWSHAM
GAYLES
GILLING
123
23
3
2
1
12

the Swale turns to run more or less in the line of the Gilling valley, but the Swale is here running on drift deposits well over 100' thick, and its present course doubtless bears little resemblance to that which it followed in pre-glacial times. In 1916, Fawcett published a paper on the development of the middle Tees and its tributaries, which included an assessment of the successive courses of the Greta. He states (p.314) that east of Bowes the original course of the Greta lay beneath Kilmond Scar, the site of which is now occupied by the diminutive Tutta Beck flowing eastwards to Greta Bridge. This conclusion was apparently based only on comparison of profiles and the fact that the Tutta runs in approximately the same line as that of the Greta west of Bowes. In mid-Tertiary times, soon after the eastward tilt of the peneplain surface, the Greta may have had such a course during the initial stages of erosion, but it is clear from the evidence of the White Close Hill bore-hole (p.209) that in later pre-glacial times the Greta was deeply entrenched at least ¾ mile south of Kilmond Scar in a gorge which was deeper than the present day valley.

For a distance of 1/3 mile, to the north and NW of Scargill, the south side of Brignall Banks is entirely cut in boulder clay, and east of this, in Gill Beck (500 yards south of its confluence with the Greta), solid exposures suddenly give way to a coarse conglomerate of boulders and pebbles from the drift, which have been partially cemented by tufa. These are evidently part of the infilling of a pre-glacial valley, and it appears that the pre-glacial Greta diverged from its present course near Scargill to flow ESE into the Gilling valley. The latter is a mature feature, and must, at some time prior to the ice age, have been cut by a river of considerable dimensions, as was realised by Phillips. But the field evidence points to this having been accomplished by the Greta rather than by the Tees. At some later date (but still in pre-glacial times) the Greta was diverted northwards into its present course as far as Greta Bridge, but then turned east and SE in a great loop to rejoin the Gilling valley near Newsham.

There is a patch of alluvium at 680' O.D. between Nor Beck and Brignall Banks, and Nor Beck itself flows through a stretch of alluvium which is too extensive to have been deposited by that little beck. It appears that the pre-glacial course of the Greta through Brignall Banks was blocked by boulder clay during the ice-age, and that during the retreat stage the Greta first took the approximate line of its original course between Scargill and Newsham, depositing those patches of alluvium shown in Fig. 11 (p.222). The Greta must have rapidly re-excavated its pre-glacial course, however (Plate 22B, p.218), and before long the line of least resistance was its former channel by way of Greta Bridge into the Gilling valley. This led to the deposition of a wide spread of alluvium on top of the glacial material which partly filled in the pre-glacial valley (see Fig. 11).

In comparatively recent times, the Greta has cut through the narrow divide between Greta Bridge and the Tees in a gorge some ½ mile in length, to join the Tees below Rokeby gorge, as described by Fawcett. The Gilling valley was thus deprived of most of its water, and the preservation of much of the alluvial tract across which the Greta flowed not very long ago was ensured.

Eller Beck has suffered two minor post-glacial diversions in its lower reaches. There is an abandoned course leading eastwards from Eller Beck into Thwaite Beck near Scargill Lodge, and another also runs eastwards from a point 230 yards further downstream, past Green Gill Farm into the Greta at In Bank Wood. This second and later course starts 25' above the present level of Eller Beck, and overhangs the Greta by some 30' at its eastern end, so there has been considerable erosion since the time when Eller Beck was diverted northwards into its present course to join the Greta some 300 yards above Rutherford Bridge.

(v) Post-glacial deposits

(a) Peat

There are two distinct types of peat within the area. Extensive hill peat covers much of the high moorland region, while a few relatively small pockets of low-level peat are to be found in depressions in the drift in the valley bottoms.

The hill peat, which is to be found mainly on and around the fell tops between Swaledale and the Gilling valley, is up to 10' thick in places, but has, for the most part, been cut up by erosion into haggs. These erosion channels cut down as far as the underlying impervious drift cover, and excellent sections of the peat are very common. The most constant feature of these exposures is a wood layer near the base of the peat (generally in the lowest 3'), which contains many well-preserved pieces of silver birch, and some of alder. Large trunks of oak are also found from time to time, and are in a sufficiently good state of preservation to be used for timber. This wood layer (the remains of an early post-glacial forest) has been found up to 1800' O.D. But it has been traced over much of the north of England up to heights considerably in excess of 2000' O.D., and not only must the forest have been very extensive, but the climate was then presumably somewhat milder than that of today. The upper parts of the peat are of a moorland type, and consist largely of sphagnum and heather. For the most part, the peat is developed over impervious drift cover, but is sometimes observed lying directly on sandstone and shale, as is the case, for instance, around Hoove. Peat is never developed on limestone, however, when there is no drift cover, because suitable conditions for its formation never prevailed due to the good drainage. The limestone horizons are thus often easily distinguished on the high ground by their grass cover, in direct contrast to the peat and heather cover of much of the rest of the ground. The peat is thickest on the highest ground, and becomes progressively thinner towards the 1000' level. Below this it is rarely present, except for the small areas of low-level peat in the valley bottoms.

One of the best developed patches of low-level peat is that which almost surrounds the ruins of Ravensworth Castle, in the Gilling valley. It is ¼ mile across, and occupies a flat, rather marshy area, filling a former hollow in the drift. The peat is at least 10' thick (and probably considerably more), and when the ground was less well-drained than it is now, it must have presented a formidable obstacle to unwelcome visitors to the Castle, which is built on a mound of drift. Other flat peat-covered areas are found on the sites of former glacial lakes, but these are mostly only erosion remnants, and date from a considerably earlier period than the true valley-bottom deposits. The latter commonly fill abandoned stream courses and minor hollows in the drift cover, and some are still in the process of formation.

(E) Alluvium

The alluvial deposits of the Swale above Richmond call for no particular comment, as they are the normal consequence of a river winding its way across a drift-covered valley floor. East of Richmond, however, where Swaledale opens out onto the Vale of York, the alluvial deposits assume considerable importance, and in the region of Catterick Bridge they extend for over ½ mile to the north of the river. There are numerous well sections in this area, which show the alluvium to be only a thin cover on top of gravel deposits (probably of fluvio-glacial origin) at least 50' thick. This alluvial spread, which assumes even larger proportions further out into the vale, is joined from the north by the deposits in the parallel becks running southwards through the outskirts of Middleton Tyas and Moulton, which clearly carried much more water during the glacial retreat stage than they do now.

The deposits of the River Greta include up to 3 terraces above the lowest alluvium upstream from the head of Brignall Banks. The top terrace is some 40' above present river level, but only small remnants are now left near Bowes. The lowest terrace, 15' above the alluvium on the average, is the best developed, and has been traced up Eller Beck (a south-bank tributary) for a little over 2 miles. Where the Greta leaves Brignall Banks, near Greta Bridge, a great spread of alluvium deposited by the Greta in early post-glacial times sweeps east and SE to join the Gilling valley near Newsham. This alluvial tract has an average width of nearly ½ mile between Greta Bridge and Ravensworth, and is penetrated by the tops of numerous little mounds of the underlying drift. Between Ravensworth and the confluence of Gilling Beck with the Swale, the alluvium makes a well-defined feature. But nowhere, except immediately downstream from Gilling, is it of similar dimensions to that at the head of the valley, where a marked decrease in the slope of what was then the Greta valley caused such extensive deposition.

Nor Beck (between Ladysmith Plantation and Newsham Lodge) runs across a stretch of alluvium and thin interbedded horizons of gravel which is ¼ mile across in places. Mill Hill is a mound of drift isolated by this deposit, which again seems too extensive to be attributed to the present beck, with its restricted drainage area. A further isolated and un-drained alluvial patch between North Wood and Coronation Plantation to the west gives the necessary clue to the method of deposition of this alluvium, which is attributed to the Greta in immediate post-glacial times (see p.223).

Numerous other becks, such as Gill, Thwaite, Marske, Dalton, Hutton and Barton Becks, have left alluvial deposits which have been mapped, but these are of relatively small extent and minor importance, being the straightforward result of normal erosion further upstream.

(c) Landslips

Apart from pre-glacial landslips, of which there is evidence from Swaledale (see p.204), there are numerous post-glacial slips which have had the effect of obscuring the solid rock for varying distances along the sides of some of the steeper valleys. These slips are not by any means confined to those places where the dip is down the slope; but in general, movement down the sides of steep valleys has apparently taken place along thin shale bands in the succession, aided by well-developed joint planes in the overlying beds. An important slip is that on the north side of Moresdale Gill, about 1/3 mile west of Kexwith, which has had the effect of presenting a double scar of the Main Limestone, the two being separated by a vertical interval of between 50' and 75'. The most extensive landslip is that along the NE side of Holgate Beck, between Kexwith and West House, where a vertical interval of 200' is completely obscured by slipped and jumbled material for a distance of ½ mile. Very extensive also are the slips on either side of Waitgate-Throstle Gill. The west side of the valley is obscured between Thringill Scar and the eastern end of Helwith Bank, while nothing solid is seen on the east side beneath the Marske Band for ½ mile along the southern part of Dickey Edge. There has also been much slipping between Telfit and Marske (particularly along Telfit Bank), where fallen material from the Richmond Chert Series near the top of the bank has for the most part obscured the underlying beds. On either side of Clapgate Beck, and also along Applegarth and Whitcliffe Scars, the same has happened and much material from the Richmond Chert Series making the top of the scars has fallen down and obscured nearly all the beds beneath the Main Limestone. The Main itself generally makes a sufficiently good scar of its own, however, to be able to stand out above the top of the slips. Along the north side of Swaledale between Clapgate Beck and Whitcliffe Wood, there is extensive drift cover which has also become involved in slipping, and it is difficult to tell what proportion of the obscuring material has slipped from above, and how much had been transported by ice from further up the valley before it, in turn, added to the confusion by moving down the hillside over pre-existing landslips.

CHAPTER 11

MINERAL DEPOSITS

(a) Coal

The lowest coal seam recorded from within the anticline is exposed once only, in Brignall Banks, 1000 yards SW of Brignall. It is no more than 1" thick, and comes 26' below the base of the 5 Yard Limestone, in a series of fresh-water shales and shaley sandstones. At the base of the scar exposing the 3 Yard Limestone in the Greta, south of Kilmond Scar, a foot of poor coal is seen 23' beneath the limestone, while in the Mount Pleasant bore the 3 Yard is directly underlain by 7" of good coal. Some 900 yards east of Brignall, the transgressive sandstone which cuts down into the shales overlying the 3 Yard Limestone is seen in the right bank of the Greta to contain Stigmaria and many thin irregular streaks of coal in its lowest few feet. But the best developed coal horizon is that associated with the sandstone underlying the Underset Limestone. It is well seen in the east bank of Rake Beck, 500 yards downstream from the bridge, where it is separated from the limestone by 25' of sandstone. The seam is 8" thick, of moderate quality, has been worked from a nearby shaft, and is unusual in that it overlies a shale. A coal which is no longer exposed, but which is said to be 7" thick, has been worked from a number of old shafts on Gayles Moor, 650 yards south of Pace's House, and it is very probable that this is the same seam as that seen in Rake Beck. There is also evidence of coal at the same horizon on Gatherley Moor, between Gilling and Melsonby, where traces are seen in the soil round the top of an old roadside quarry at the NW end of Quarry Hill. It is and it is definitely absent only ¼ mile further upstream. Along the east side of the Harker Moss overflow channel, traces of coal on an underclay immediately underly the Main Limestone in some places.

No coal seams are here exposed in the Coal Sills Group overlying the Main Limestone, although further north, on the Alston Block, workable coals are found at this horizon. Reading (1954) mentions an exposure on the south side of the Stainmore syncline, in the Greta valley, where a thin seam is seen at the top of the Lower Coal Sill. There is loose coal in the banks of Sleightholme Beck at this horizon for ¾ mile upstream from Sleightholme Farm and, although none could be found in situ, it is assumed that Reading's seam is also present here. But this is near to the edge of the Coal Sills delta, and coal cannot be expected further to the south-east. A coal seam within the Ten Fathom Grit has been worked on Hurst Pasture, by a level driven into the north bank of Roan Beck. This coal has also been much worked on the moor 1½ miles west of Hudswell, immediately to the south of lower Swaledale. The Ten Fathom Grit is here very poorly represented, but nevertheless the coal was probably of reasonably good quality, judging by the large number of old pits now to be found over its outcrop.

(b) <u>Lead and Barium</u>

Lead is present in the form of galena in a number of mineralised veins within the anticline. It is also found in replacement 'flats' in limestone, and the occurrences are similar to those of the Alston Block (Dunham, 1948) in that they are in the great majority of cases associated with the thick Main Limestone. The lowest horizon seen to be affected by lead mineralisation is the 3 Yard

Limestone, which is traversed by thin calcite veins containing galena in the Holgate Beck exposure immediately to the south of the Faggergill-Waitgate fault. The Underset Limestone is seen to bear a thin patchy film of galena on a joint surface in a swallow hole in the Byers Hill overflow channel, but the nearest fault to this locality is ¼ mile away to the west, and the mineral may, in this case, be authigenic. Lead has not been found along the north flank of the anticline, but the Main Limestone has been mineralised in a number of localities on the south side of the structure. These are associated with the much-worked veins of Arkengarthdale and upper Swaledale, but in this area, east of Arkengarthdale, the deposits are (for the most part) much less prolific than those further to the west.

The North Spanham fault has been worked for galena in Eller Beck Hush and Spanham Hush. The latter was first reached by means of a level driven southwards through Spanham East Hill, but subsequent working into the Main Limestone was from a deep shaft sunk at the eastern end of the hush. On Scargill High Moor, numerous small shafts have penetrated the Main Chert to work two mineralised veins of small throw to the south of Eller Beck Hush. There are remains of lead workings 2/3 mile ENE of Arndale Hill, at the western end of a WNW-ESE fault. Pieces of Main Limestone which have been brought up from the old shafts are rich in galena, and there is a higher proportion of lead in these tips than in any of the others examined during the course of this survey.

The old Stang mine yielded much lead from the Main Limestone along Stang and Black Veins, which are branching cross-veins from the Faggergill-Waitgate fault, the latter having been worked at intervals along most of its length. ½ mile south of Stang mine, Windegg Level and Alcock Hush proved rich deposits of galena along this major fault, and further east there are remains of old workings with traces of galena at Moresdale Head, on Moresdale Ridge and near Waitgate. The old Faggergill Mine proved extensive deposits of galena, and much material from the Main Limestone has been brought out from levels at Faggergill Head and Seavy Hole. Exposures are unusually good along the sides of the Faggergill Valley, and there is no evidence of any faulting within ½ mile of this mine. So it may be assumed that metasomatic replacement of the limestone has taken place along the line of a vein with little or no throw.

A fault which runs across the north side of Pattison Plain to join the Waitgate fault near Holgate Beck is mineralised at its eastern end to the north and NE of the outlier of Sail How, and old shafts have yielded galena from both the Richmond Chert Series and the underlying Main Limestone. But the richest deposits of galena in the area were found to the south and SW of this, around Hurst. The Marske fault has been worked most of the way between Hurst and High Green House, where it has been called Wallnook Vein, but most of the lead was obtained from Queen's Level, which penetrated the Main Limestone far into the hillside. Lead has been worked intermittently for at least 1900 years in the Hurst district, and there are remains there of many different types of mining. Some of the old bell-pits are quite spectacular in size. Both Wallnook Vein and Shaw Vein to the east were worked from Prys Level, which was cut in a westerly direction from Shaw Beck into the Richmond Chert Series. Along and beyond Shaw Vein rich galena deposits were proved near the top of the Main Limestone, and these were worked as recently as 1937.

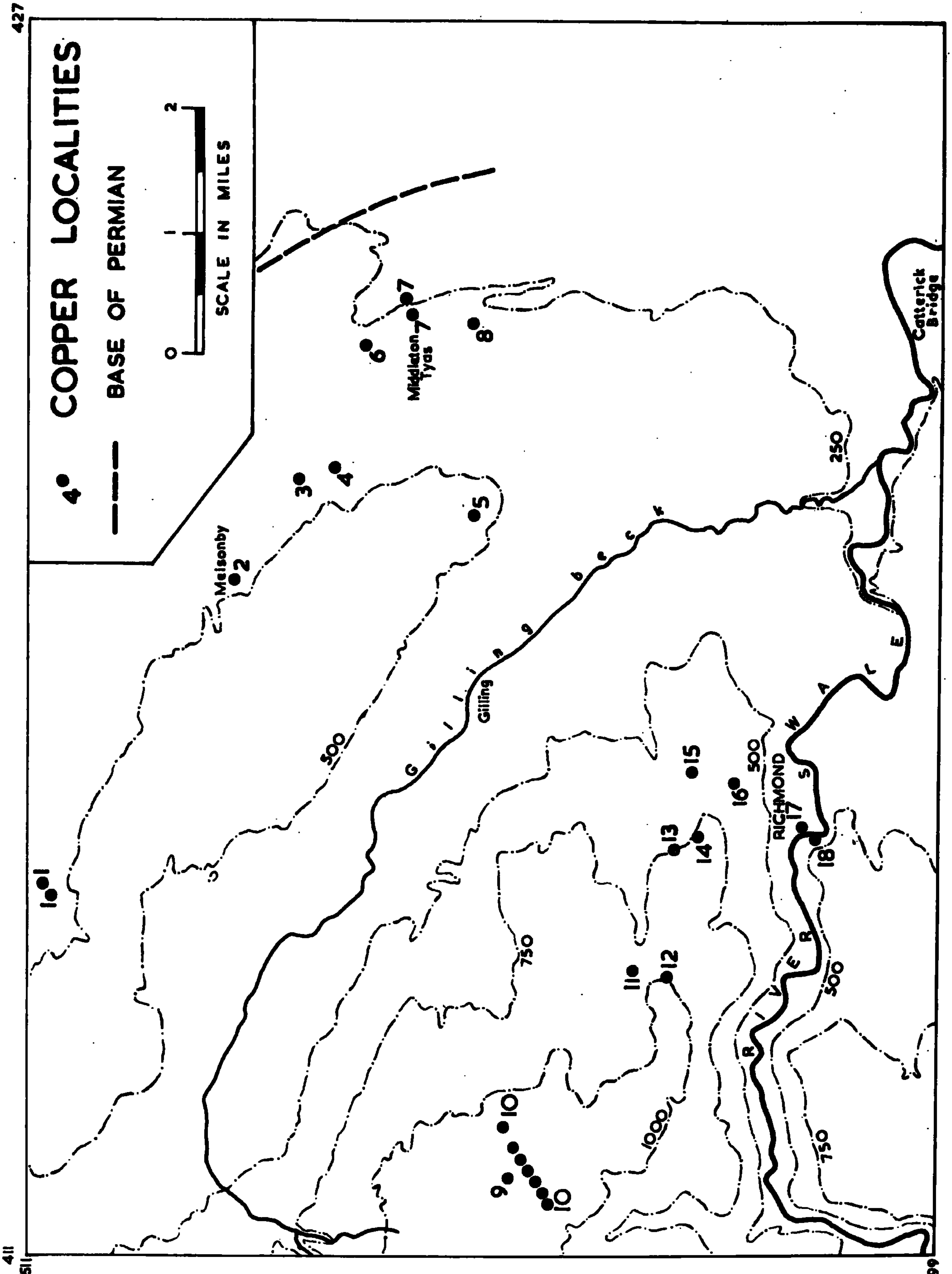
The eastward continuation of Shaw Vein has also proved to be richly metalliferous, and has been worked by means of shafts along the north side of Skelton Moor. Galena is plentiful in the tips from these old shafts, and again has come from the underlying Main Limestone. On the south side of Skelton Moor, shallow workings into the upper part of the Richmond Chert Series along Moss Mire Vein (a cross-vein to the Marske fault) have produced galena in only moderate quantities.

To the east of Marske Beck, galena has been obtained from shafts along Orgate Vein, on the south side of Marske Moor, while 1/3 mile north of this, in a small quarry in the Richmond Chert Series on the north side of Limekiln Hill, galena is present in very small quantities on joint surfaces, and may be authigenic. On the west side of Feldom Moor there have been extensive workings in replacement 'flats' in the Main Limestone to the south and SE of the remains of Low Feldom, which are presumably associated with a vein of little or no throw. The fault which runs from Clapgate Beck towards Low Feldom has been tried for lead at various points along its course, but it cannot have yielded more than small amounts, as there is now no sign of galena in the tips from the old shafts. On the other hand, the Feldom fault, which crosses this one at Daleflat Spring and runs off towards Whashton in an easterly and NE direction, has been much worked on Feldom Moor from many old bell-pits, and galena is moderately plentiful in the tips for about ¼ mile on either side of Feldom Lane. Some 400 yards to the north of the fault, on the east side of Feldom Lane, the Main Limestone has been worked from many shallow pits in another small area of 'flats' replacement.

There is a small NE-SW fault in the Whashton Springs area which shows no sign of mineralisation, but which was continued NE by the Primary Survey as far as the old Lead Mill in Smelt Mill Beck. This was evidently on the supposition that the mill had smelted lead obtained locally. But the drift cover is very heavy in this region, there being no exposures in or near this beck, and in fact the ore which was used in this old mill was brought along Jagger Lane from the Hurst district, some 7 miles away. Applegarth Vein, at the western end of Whitcliffe Scar, has been worked for galena. It has a throw of 4' to the NE, and must have kept a number of men busy for some time, judging by the quantity of tailings (including galena and barytes) thrown over the edge of the scar. In Hurgill quarry, on the NW outskirts of Richmond, galena occurs on joint surfaces in an impure crinoidal limestone of the Richmond Chert Series far from any faulting, and again is probably authigenic. Finally, the Bend Hagg fault has been worked along the north side of Pilmoor Hill and around Bend Hagg itself. The workings are, for the most part, overgrown, but dolomitised Main Limestone is still visible in the latter locality. Although no galena was seen there, it is probable that the workings were for lead, which can only have been present in small quantities.

Barium, in the form of barytes, is present in a number of fault zones and is often (but by no means always) associated with deposits of galena. To the west of Arkengarthdale it is commonly associated with witherite, and sometimes with baryto-calcite, and it appears that much of the barytes is secondary after witherite in the oxidation zone, where it is porous and in strong contrast to the coarse platey barytes which is primary in the deeper workings (Dunham and Dines, 1945). To the east of Arkengarthdale, however, witherite has only been recorded from a single locality on the north side of the anticline, and no baryto-calcite was found. Barytes is present as a gangue mineral in many of the old lead mines of the Hurst region, but it is apparently very subordinate to calcite. One of the shafts on Orgate Vein, north of Marske, has brought up a limestone breccia which is cemented by barytes, and along the Feldom fault most of the old tips yield barytes in fair quantity, associated with galena in the Main Limestone. But undoubtedly the richest deposits of barytes occur in East Layton quarry, on the north flank of the anticline, where there is no trace of galena. Here the Main Limestone is affected by two relatively minor NE-SW faults which have associated limestone breccias up to 2' in width along much of their exposed length. The cementing material in these breccias is mainly barytes, which occurs in interlocking white tabular crystals up to 4 cms in length, and which is most probably primary. Witherite (the only recorded locality for this area) and calcite are present as subordinate constituents. This occurrence is consistent with those on the Alston Block, where barytes is the most persistent gangue mineral around the edge of the ore-field (Dunham, 1948, p.94). In this connection it may be mentioned that fluorite (which occurs in quantity in the region surrounded by the barytes zone on the Alston Block) has not been recorded from the present area. Small deposits of fluorite are, however, present in some of the upper Swaledale mines, particularly in the deeper workings, and this suggests that if the mineralisation process was similar to that of the Alston Block (and there seems no reason to suppose that it was not), then the

FIG. 12



COPPER LOCALITIES
BASE OF PERMIAN
SCALE IN MILES
0
1
2
Melsonby
Middleton Tyas
Catterick Bridge
Gilling
GILLING BECK
RICHMOND
RIVER SWALE
250
500
750
1000
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
427
411
511
499

southern part of the Northern Pennine Orefield has not been denuded (with respect to the mineral zones) to such a depth as has the northern part.

(c) Copper.

Copper-bearing minerals have been recorded from 18 localities within the area, the positions of which are shown on Fig. 12 (p.237). In at least five of these localities the deposits were large enough to have been worked, but they are (for the most part) very small, and in some cases mere traces are present. Malachite and azurite, the commonest of these minerals, are so brightly coloured that they are readily seen even when they are present in only minute quantities.

These copper localities fall into two distinct geographical groups which run approximately along the watersheds to the north and south of the Gilling valley. The northern group is the more varied and interesting from the mineralogical point of view, but the deposits appear to be of the same order of magnitude in both groups.

Details of individual localities are as follows:-

1. East Layton quarry. The northern part of the quarry shows only malachite in small quantities on joint surfaces, but the southern part contains considerable deposits. Malachite is common throughout the Main Limestone here, particularly on joint surfaces, where it is sometimes accompanied by azurite and occasionally chalcopyrite. Mineralisation has mainly taken place, however, along the two NE-SW faults crossing the south side of the quarry. The south-easterly of the two, with a throw of some 9' to the NW, carries widespread but small specks of chalcopyrite (surrounded by secondary malachite) enclosed in barytes, which cements the fault breccia. Occasional cavities in this breccia contain small

clusters of radiating fibrous malachite. The other fault, with a throw in the same direction of at least 20', occupies a zone some 20' wide in parts of the quarry. Within this zone, bornite nodules about 1" in diameter are common in a thin shaley sandstone immediately underlying the Main Limestone, and are rather rare in a sandy shale some 18" beneath the limestone base. Near the SW corner of the quarry, a temporary exposure of a cavity in the fault zone revealed a small quantity of chalcanthite, together with malachite and a little azurite, on sandstone some 10' below the limestone. Chalcanthite is rare in Britain, due to its high solubility, and this is the first recorded occurrence of the mineral in the north of England. The Main Limestone in the fault zone contains abundant massive chalcopyrite (partially altered to goethite) and a little covellite, the former being generally coated with secondary malachite.

2. Old roadside quarry 250 yards south of Melsonby cross-roads. The Underset Limestone bears traces of chalcopyrite and malachite on joint surfaces. A very small fault in the quarry face is not thought to have any connection with the occurrences.
3. Old Copper Mine, Low Merrybent. No records are available from here, except that the ore was worked near a N-S fault with an easterly throw of 60'. The shaft is sealed off, and an examination of the old tips (nearly overgrown) yielded no copper-bearing minerals other than malachite.
4. Kneeton Hall Old quarry. A shaft at the western end of the quarry, and an adit at its NW corner, have both worked small deposits of chalcocite and chalcopyrite, associated with which are secondary malachite and azurite. The workings have proved a fault with a

throw of 45' to the ESE, which carries a little galena. This is the most westerly of the recorded localities for chalcocite, and at the same time the most easterly one for chalcopyrite.
Several old shafts some 200 yards west of Kneeton Hall have yielded Underset Limestone bearing a little chalcopyrite and malachite.

5. Old quarry beside Sedbury Park East Drive. A trace of malachite was recorded from the gannister immediately underlying the Main Limestone. This locality is within 100 yards of the Sedbury fault.
6. Small wood 300 yards north of Five Hills, Middleton Tyas. A small inlier of sandstone beneath the Underset Limestone bears traces of malachite. There is no evidence for faulting within 1/3 mile.
7. Many localities in and around Leyberry Plantation, Middleton Tyas. The only traces of copper now visible are in the form of malachite and azurite around former workings in the Underset Limestone.
But about 2 centuries ago there was in Middleton Tyas a flourishing industry which has been described by Raistrick (1936). It appears that the copper was discovered just before 1750, and was worked between 1752 and about 1770 by both Cornish and Derbyshire miners. The ore was probably mostly chalcocite, which occurred in very irregular masses, often in cavities more or less filled with 'ferruginous sand'. Raistrick mentions the occasional findings of lumps of native copper. Bricks of slag from the smelting mill are still to be found in the walls in parts of the village. Two WNW-ESE faults have been mapped across Middleton Tyas, but it appears that, although the copper ore may have been in some way associated with them, it did not by any means always

occur along these faults.

8. Black Scar quarry, Middleton Tyas. The Underset Limestone bears traces of malachite, sometimes with azurite, at all levels throughout the quarry, but particularly on bedding planes and joint surfaces. Chalcocite is also present as nodules in the limestone, but more commonly in pockets between joint surfaces or along shaley partings in the limestone. At the north end of the quarry a vertical slab of chalcocite up to 1" thick, nearly a square foot in area, and partially altered to malachite, was found in a joint gap filled with brown clay. This may well be similar to those ore bodies in cavities filled with 'ferruginous sand' which were worked in the 18th century. Deans (1951) has collected chalcocite from this locality which can be seen (in polished section) to contain native copper. There is no evidence of faulting within ¼ mile of Black Scar quarry.

9. Feldom Moor. Traces of chalcopyrite with malachite are present in the Main Limestone where it has been worked for lead by numerous small shallow pits some 300 yards north of the Feldom fault.

10. Feldom fault. Many old bell-pits are located along the fault for a distance of ¾ mile, between points 200 yards NE of East Feldom and 500 yards NW of Buddle House. The tips from these old shafts contain plenty of galena, and it was evidently mainly for this that the old workings were sunk. But there is also much chalcopyrite in the Main Limestone brought up along the fault zone, and this has been partially altered to goethite, the copper from the change having gone into malachite and azurite. Secondary barytes (later than the chalcopyrite) is often stained green by malachite, and the formation of some of it may have been due to

the sulphuric acid released during the alteration of the chalcopyrite. It might have been expected that covellite would mark an intermediate stage in the alteration of chalcopyrite to goethite, but this mineral was not recorded. The most easterly shaft in this set of workings has yielded some rather coarse sandstone (from a few feet below the base of the Main Limestone) which is impregnated with malachite, presumably secondary after chalcopyrite in the overlying limestone. Much of this malachite is in small interstitial specks, but some rosettes of radial fibres occur up to a centimetre in diameter.

11. Coalsgarth Vein. Traces of azurite and malachite occur on joint surfaces in the Main Limestone along the line of this small SE-throwing fault. There was an old shaft on the vein at the foot of the limestone feature, but it is not known for what purpose it was sunk, and it seems unlikely that it met with any success.

12. Beacon Hill quarry. Traces of malachite and azurite occur on joint surfaces in the Main Limestone. The south Beacon Hill fault runs within 50 yards of the quarry.

13. Gingerfield quarry. Malachite is present in very small quantities in dolomitised and veined Main Limestone, within a few yards of a small NE-SW fault.

14. Old quarry on the north side of Richmond Race Course. Traces of malachite and azurite occur in the Main Limestone some 200 yards south of the western part of the Bend Hagg fault.

15. Bend Hagg quarry. Malachite and azurite are found on joint surfaces in the Main Limestone just south of the Bend Hagg fault.

16. Quarry behind the Infectious Diseases Hospital, Richmond. Thin films of goethite containing small unaltered patches of chalcopyrite

and coated with malachite occur on joint surfaces in a coarse crinoidal limestone of the Richmond Chert Series. The nearest fault is nearly ½ mile away.

17. Temple Grounds, Richmond. Four levels for copper have been driven into the base of the Richmond Chert Series on the left bank of the Swale, 100 yards west of The Temple. It is unknown what results were achieved, and only traces of malachite are now to be found.

18. Old Copper Mines, Billy Bank Wood, Richmond. Two levels have been driven into the lower part of the Richmond Chert Series on the right bank of the Swale, the southerly one being along the line of the northern and major branch of the Richmond fault. Both levels are now closed, but it is known that they proved sufficient deposits (probably of chalcopyrite) to enable work to continue for a number of years. Malachite and azurite can be collected in small quantities from around the entrances to the old levels.

Three striking features emerge about these copper deposits. The first is their topographical location, roughly along the water-sheds to the north and south of the Gilling valley, and at elevations progressively increasing towards the WNW. The second is that many of the deposits seem to be associated either directly or indirectly with lines of faulting, but that some of them are so far removed from faults as to suggest that their origin may not necessarily be connected with the faults at all. Thirdly, the primary deposit is chalcopyrite over most of the area, but this is replaced in the most easterly localities by chalcocite. It is pointed out by Deans (1951 and personal communication) that these facts can be largely explained by supposing that the copper minerals originated in the overlying Permian, which at one time must have been no great distance above these Carboniferous rocks. Of the beds under consideration, those along the eastern parts of the watersheds north and south of the Gilling valley must clearly have been nearest to the Permian unconformity, and as has been seen, this (with but one exception) is precisely where the copper minerals are to be found. The exception is the old copper mine in Temple Grounds and Billy Bank Wood, Richmond (localities 17 and 18). Here it may be supposed that due to the magnitude of the Richmond fault (with which the deposits are associated), and also because of the dolomitisation of limestones which has taken place along it, the descending mineralising solutions, offered a relatively easy channel, were able to penetrate to a greater depth than was the case elsewhere. It must also be supposed that west of East Layton quarry (locality 1) and Feldom Moor (localities 9 and 10), the Permian rocks were too high for the copper minerals to have percolated as far down as the present ground level.

It is well known that the Permian is unusually rich in copper minerals, and Deans has collected fossils which have been completely replaced by chalcocite. The process which is visualised for the transport of these minerals is merely one of descending ground waters, it being an established fact that copper minerals are among the most susceptible to this process (Lindgren, 1933, p.832). They are also easily precipitated minerals, and they can often be shown to have replaced primary pyrite. Chalcocite commonly replaces not only pyrite but both chalcopyrite and galena as well, and in this instance it would appear that the higher chalcocite zone (which can only have been a short distance beneath the Permian unconformity) is one of secondary enrichment from a more widespread chalcopyrite zone, which may itself have been due to replacement of primary sulphides. Native copper is not common in zones of secondary enrichment as it is soluble in H_2SO_4, but Deans has found it associated with chalcocite. In the oxidation zone it is more usual for it to be formed by way of cuprite (Cu_2O), but chalcocite may sometimes alter direct to native copper. It is significant that of the present chalcocite deposits, the one which was evidently the richest (around Middleton Tyas, locality 7) was also the one which must have been closest to the overlying Permian. The fact that in some places, notably along the Feldom fault (locality 10), the copper minerals are associated with galena should only be taken as showing that it was along the faults (some of which happened to carry lead deposits) that the mineralising solutions tended to circulate most easily. Deans has found chalcocite replacing galena, a well-known reaction in secondary copper enrichment zones, which lends further support to his view that although the lead came up from below, the copper probably came down from above.

(d) <u>Petroleum.</u>

It has long been known that the limestones of the Yoredale Series are often bituminous, a fact which is betrayed by their smell on being struck. Beds of Lower Carboniferous age have yielded oil in useful quantities in several localities in Derbyshire, and a bore-hole at Norton, Co. Durham, produced a little oil and much H_2S from alternating Yoredale shales and sandstones underlying the Permian (Tate, 1892, p.489). Petroleum is frequently present in Coal Measure shales (sometimes in commercial quantities) and it cannot be certain that the oil from Norton had not originated in the Coal

Measures. But the fact that oil is known to be present in Lower Carboniferous rocks of the North of England led to a particularly close investigation of the beds exposed along the axis of the Middleton Tyas-Sleightholme anticline. This structure is very well suited to the accumulation of oil deposits, particularly as it incorporates a number of subsidiary domes along its axis. The largest of these, the Gilling dome, is clearly the most likely place for oil (if available) to accumulate, and the lowest bed to outcrop round the dome is the Simonstone Limestone, in the lower part of the Middle Limestone Group. This limestone, when struck, gives off a smell of bitumen which is particularly strong even for a Yoredale limestone, and samples of the rock were crushed and subjected to treatment with carbon tetrachloride. The resulting brown discolouration proved that oil as such is present in the limestone. Although it contains only a very small quantity at the moment, this fact suggests that the Simonstone Limestone may here, at one time, have acted as a reservoir rock for the accumulation of oil. The breaching by erosion of this horizon at the centre of the Gilling dome would have allowed nearly all the oil that was then present to have flowed to waste, leaving only the present small quantity behind to serve as evidence of the former accumulation. It is equally possible, of course, that this limestone never contained any more oil than it does now, but the chance is there, and suitably porous sandstones and limestones further down in the series beneath the Simonstone may also have acted as reservoir rocks. If this has been the case, the oil will still be there, and for this reason it follows that the possibilities of striking oil in the Gilling dome are not remote. A trial in the centre of this subsidiary structure, near Crabtree

Farm on the south side of the Gilling valley, should prove to be of considerable interest.

APPENDIX I

FAUNAL LISTS

Numbers refer to fossil localities, which are listed at the end of this appendix.

(a) Simonstone cyclothem

Archaediscus karreri Brady, 1, 2.
Endothyra sp., 1.
——— ammonoides Brady, 2.
——— bowmani Phillips, 2.
Howchinia bradyana (Howchin), 1, 2.
Tetrataxis decurrens (Brady), 2.
——— palaeotrochus (Ehrenberg), 2.
Textularia gibbosa d'Orbigny, 2.
Clisiophyllum sp., 1.
Dibunophyllum bipartitum konincki (Edwards and Haime), 1.
Crinoid ossicles, 1 (to 3 mm), 2 (to 18 mm).
Annelid tubes up to 1 cm. in diam., 3a.
Indet. brachiopods, 1, 2.
Fenestrellina sp., 2.
Penniretepora sp., 2.
Polypora sp., 2.

(b) Middle cyclothem.

Archaediscus karreri Brady, 3b.
Endothyra ammonoides Brady, 3b
——— bowmani Phillips, 3b.
Howchinia bradyana (Howchin), 3b.
Tetrataxis decurrens (Brady), 3b.
——— palaeotrochus (Ehrenberg), 3b.
Textularia gibbosa d'Orbigny, 3b.
Trochammina sp., 3b.
Chaetetes depressus (Fleming), 4.
Clisiophyllum cf. keyserlingi M'Coy, 3b.
Diphyphyllum sp., 3b.
Koninckophyllum echinatum (Thomson), 3b.
Lithostrotion junceum (Fleming), 3b.
——— m'coyanum Edwards and Haime, 5.
Crinoid ossicles, 7 (to 21 mm).
Smooth annelid trails, 8.
Eione sp. Tate, 8.
Brachythyris decora (Phillips), 3b.
Productus (Dictyoclostus) cf. muricatus Phillips, 3b.
——— (Echinoconchus) punctatus (Martin), 6.
——— (Gigantoproductus) giganteus (Martin) group, 3b, 6.
——— (———) latissimus J. Sowerby group, 3b.
——— (Linoproductus) hemisphericus J. Sowerby, 3b.
Spirifer striatus (Martin) group, 3b.
Rhombopora sp., 3b.

(c) 5 Yard cyclothem.

Indet. plants, 24.
Archaediscus karreri Brady, 14, 15.
Endothyra ammonoides Brady, 15.
——— bowmani Phillips, 10, 14, 15.
Howchinia bradyana (Howchin), 10.
Tetrataxis decurrens (Brady), 15.
Textularia gibbosa d'Orbigny, 16.
Syringopora sp., 13.
Crinoid ossicles, 21 (to 17 mm), 22 (to 7 mm).
Brachythyris sp. (young shell), 18, 19.
Leptaena analoga (Phillips), 9.
Orthis (Rhipidomella) michelini (Léveillé), 11.
Productus sp., 9.
——— (Dictyoclostus) cf. insculptus Muir-Wood, 20.
——— (———) pinguis Muir-Wood, 9.
——— (———) semireticulatus (Martin), 9.
——— (Gigantoproductus) giganteus (Martin) group, 23.
——— (Productus) cf. redesdalensis Muir-Wood, 9.
Spiriferina insculpta (Phillips), 12.
Fenestrellina sp., 22.
Penniretepora sp., 12.
Polypora sp., 12.
Rhombopora sp., 17, 22.

(d) 3 Yard cyclothem.

Stigmaria, 34.
Indet. plants, 35, 36.
Archaediscus karreri Brady, 25.
Endothyra ammonoides Brady, 25, 29, 30.
——— bowmani Phillips, 25, 27, 29, 30, 31, 32.
Howchinia bradyana (Howchin), 25, 26.
Tetrataxis sp., 29.
Textularia gibbosa d'Orbigny, 25, 29, 31, 32.
Diphyphyllum lateseptatum (M'Coy), 27.
Crinoid ossicles, 28 (to 8 mm.).
Productus sp., 27.
———(Productus) redesdalensis Muir-Wood, 35.
Schellwienella rotundata I. Thomas, 33.
Spirifer sp., 33, 37.
Cycloceras sp., 28.
Sanguinolites plicatus M'Coy, 36.

(e) Underset cyclothem.

Indet. plants, 56.
Archaediscus karreri Brady, 41.
Howchinia bradyana (Howchin), 41.
Saccamminopsis fusuliniformis (M'Coy) (= Saccammina carteri Brady), 38.
Tetrataxis decurrens (Brady), 42.
Textularia gibbosa d'Orbigny, 42.
?Hyalostelia sp., 40.

Peronella sp. (spicules), 54.
Aulophyllum fungites (Fleming), 39.
Canibia sp., 45.
Dibunophyllum bipartitum bipartitum (M'Coy), 38.
——— ——— cf. craigianum (Thomson), 40.
Zaphrentis sp., 43.
Crinoid ossicles, 56 (to 10 mm.), 40.
Ureocrinus bockschii (Geinitz) 45.
Brachythyris decora (Phillips), 46.
Chonetes hardrensis Phillips, 56, 57.
Lingula quadrata Eichwald, 47.
——— squamiformis Phillips, 48, 56.
Orthotetid, 46.
Productus sp., 40, 47, 49, 59, 60, 61.
——— (Dictyoclostus) cf. insculptus Muir-Wood, 56.
——— (———) muricatus Phillips, 57.
——— (Echinoconchus) elegans M'Coy, 44, 50.
——— (———) punctatus (Martin), 40.
——— (Eomarginifera) sp., 56.
——— (———) lobatus J. Sowerby, 57.
——— (Gigantoproductus) latissimus J. Sowerby group, 40, 46.
——— (Plicatifera) plicatilis J. Sowerby, 56.
——— (Productus) concinnus J. Sowerby, 56, 57.
——— (———) productus (Martin) group, 59.
——— (———) redesdalensis Muir-Wood, 56, 57.
Rhipidomella aff. carbonaria (Swallow), 56.
Schizophoria resupinata (Martin), 57.
Smooth Spiriferid, indet., 40.
Spirifer, sp., 40, 49, 51, 56.
Fenestrellina sp., 56, 57, 59.
Aviculopecten sp., 56.
Leiopteria cf. laminosa (Phillips), 46.
Nucula oblonga M'Coy, 56.
Posidonia membranacea (M'Coy), ?55, 58.
Posidoniella laevis (Brown), 56.
——— minor (Brown), 56.
Pseudamusium sublobatum (Phillips), 56.
Syncyclonema cf. sowerbyi (M'Coy), 55.
Bucaniopsis decussatus (Flemming) group, 56.
Euphemites urei (Fleming), 56.
?Glabrocingulum sp., 53.
Straparolus sp., 56.
?Worthenia sp., 52.
Orthocone nantiloid, 56.
Stroboceras sulcatum (J. de C. Sowerby), 56.
Ostracods, 53.
Crushing tooth of Petalodus, 48.

(f) Main cyclothem.

Calcareous algae, 68, 73, 77, 79.
Indet. plants, 81.
Organism "α", 63.
Archaediscus karreri Brady, 63.

Endothyra ammonoides Brady, 62.
——— bowmani Phillips, 62, 64, 67, 68.
Tetrataxis decurrens (Brady), 62, 64.
Textularia gibbosa d'Orbigny, 64, 67, 69.
Trochammina pusilla (Geinitz), 62.
Hyalostelia sp, (body spicules), 73.
Aulophyllum fungites (Fleming), 74.
Chaetetes depressus (Fleming), 70, 71, 72.
Dibunophyllum bipartitum craigianum (Thomson), 65.
——— ——— konincki (Edwards and Haime), 65, 66.
Diphyphyllum lateseptatum (M'Coy), 62.
Lonsdaleia floriformis cf. laticlavia Smith, 72.
Zaphrentis delanouei Edwards and Haime group, 80.
Archaeocidaris (Echinocrinus) sp. (spine), 80.
Crinoid ossicles, many localities (to 7 mm.).
Annelid tubes (to 2 mm. diam.), 84.
Eione sp. Tate, 87.
Serpulites longissimus, 82.
Spirorbis sp., 81.
Athyris sp., 77.
Camarotoechia pleurodon (Phillips), 80.
Crurithyris sp., 80.
Lingula quadrata Eichwald, 81.
——— squamiformis Phillips, 81, 82.
Productus sp., 84, 85, 86.
——— (Dictyoclostus) semireticulatus (Martin) group, 65.
——— (Echinoconchus) sp., 78.
——— (———) elegans M'Coy, 71.
——— (Eomarginifera) sp., 80, 85.
——— (———) longispinus J. Sowerby, 83.
——— (Productus) sp., 80.
Pugnax pugnus (Martin), 76.
Schellwienella rotundata I. Thomas, 84.
Spirifer bisulcatus J. de C. Sowerby, 81.
Fenestrellina sp., 63.
Rhabdomeson sp., 63.
Rhombopora sp., 63.
Aviculopecten sp., 81.
Myalina verneuilii (M'Coy), 81.
Nuculana attenuata (Fleming), 80.
Nuculopsis gibbosa (Fleming), 80, 81.
Pseudamusium ellipticum (Phillips), 80.
Sanguinolites cf. abdenensis R. Etheridge jun., 80.
——— cf. ovalis Hind, 82.
Solenomya primaeva (Phillips), 82.
Syncyclonema sowerbyi (M'Coy), 80.
Bucaniopsis sp., 80.
Euphemites urei (Fleming), 80.
Glabrocingulum cf. beggi E.G. Thomas, 80.
Hesperiella thomsoni de Koninck, 80.
Macrochilina sp., 80.
Straparolus sp., 80.
Zygopleura sp., 80.
Orthocone nautiloid, 82, 83.
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INDEX OF FOSSIL LOCALITIES

Six figure numbers are National Grid references.

Simonstone Limestone.

1. Crabtree quarry, 163054.

Gillingwood Limestone.

2. Small quarry in feature, 250 yards WNW of Long Acres quarry, 178044.

Sandstone beneath Middle Limestone.

3a. Long Acres quarry, 181043.

Middle Limestone.

3b. Long Acres quarry, 181043.
4. On feature, 300 yards N of High Scales, 163049.
5. From wall, 400 yards NE of High Scales, 166049.
6. Small quarry at foot of Lythe Wood, 168073.

Sandstone beneath 5 Yard Limestone.

7. Mill Scar, Brignall Banks, 044113.
8. Gill Beck, 062111.

5 Yard Limestone.

9. Whashton Springs quarry, 152047.
10. Old quarry 270 yards ENE of Gilling Reservoir, 190059.
11. Eller Beck, 028116.
12. 150 yards W of Moorcock Hall, on feature, 066098.
13. 150 yards SW of Moorcock Hall, in gully, 066097.
14. 620 yards W of Sturdy House, in little beck, 132053.
15. Beck SE of Gayles, at 725' O.D., 127069.
16. Holgate Beck, immediately S of main fault, 063043.
17. Base of Whitcliffe Wood, small quarry, 143012.
18. North bank of Greta, 500 yards ENE of Gillbeck Foot, 066115.
19. South bank of Greta, SW side of Mill Scar fault, 045110
20. Quarry at 540' O.D. off Forcett Lane, 178069.
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26. Punchard Gill, ¼ mile WSW of Punchard House, 968047.
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28. As 22.
29. Scotchman's Stone, Brignall Banks, 081124.
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34. Beck 60 yards E of Bowes Sewage Works, 001133.
35. North bank of Greta, in gully S of Stone Bridge, 008132.
36. Wycliffe B.H., 122, 134.
37. East bank of Holgate Beck, 500 yards NW of Holgate, 064041.

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38. Quarry 400 yards E of Browson Bank, 128102.
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40. North end of Black Scar quarry, Middleton Tyas, 231052.
41. Telfit Bank, 400 yards SW of Telfit, at 950' O.D., 084024.
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43. Telfit Bank, 200 yards SSW of 41, at 950' O.D., 083022.
44. Kexwith Beck, 250 yards N of Kexwith, 053053.
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47. West bank of Waitgate Gill, below Thringill Hill, at 990' O.D., 083040.
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50. South bank of gill NW of Rake Gate, 079057.
51. In gill, 220 yards NW of 50, 076058.
52. Clapgate Beck, beneath bridge, 112017.
53. East bank of Waitgate Gill, 90 yards W of Waitgate, 085046.
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58. North bank of Greta at Gilmonby Bridge, 995133.
59. North bank of Greta S of Bowes, 993133.
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65. Eller Beck, 100 yards S of hush, 991102.
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71. From wall, 50 yards NW of Daleflat Spring, 108041.
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73. Shaw Beck, 100 yards SE of The Green Dragon Inn, 053027.
74. Top of bank, 130 yards WSW of Waitgate Barn, 088054.
75. Quarry 470 yards WSW of Limekiln Hill, 098023.
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77. Ovening Nick, Faggergill, 982070.
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98. East bank of Waitgate Gill, above Buzzard Scar, at 1050' O.D., 087042.
99. South bank of Shaw Beck, at 850' O.D., 450 yards WSW of Helwith, 071028.

100. From wall at top of bank, SE of Clapgate Scar, 119025.
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107. Arndale Beck, 1200 yards upstream from sheepfold, 038064.
108. South bank of Marske Beck, at 750' O.D., 500 yards ESE of Helwith, 079028.
109. Scar in N bank of Feldom Gill, 350 yards WSW of Low Feldom, 109037.
110. Dry gill 450 yards ESE of 101, 104039.
111. High Band, 600 yards NNE of Cocker Hill, 045075.
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113. In grain at 1710' O.D., 380 yards SW of 84, 012074.
114. In Swale, 110 yards W of Red House Farm, 185995.
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116. South bank of Shaw Beck at 900' O.D., 100 yards W of Prys Level, 065025.
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118. Gully 100 yards NE of Round Hill, 005083.
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120. 240 yards SSE of 117, 054025.
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APPENDIX II

RECORDS OF BORE-HOLES

1. WYCLIFFE BORE

Record of a bore for a water supply for Wycliffe Hall, sunk between Wycliffe and Hutton Magna by J.T. Hymas, Burton Leonard, Harrogate, 1953.

Core examined by A.J. Wells, October-December 1953. Locality, 350 yards north of St Mary's R.C. Church, Hutton Magna, National Grid reference 122134. Height, 460' above O.D.

	Thickness	Depth
1. Glacial drift. Top 18 ft contains large boulders up to 4 ft in diameter, mostly of local Yoredale beds, mainly limestone, and some sandstone. Erratics also brought up included a Shap granite, 2 Borrowdale volcanics and a coarse pebbly grit. Below 18 ft mainly clay with cobbles.	76 ft	76 ft
2. Shale, dark grey, soft and very uniform. Top 20 ft unfossiliferous apart from one Lingula. Poorly fossiliferous generally, apart from thin bands where fossils are relatively common. These contain mainly fragments of Productids, also Rhynchonellids, orthocone Nautiloids and 2 trilobites. No marked tendency for any preferential direction of parting, and bedding only rarely apparent. A few horizons show a very rude vertical hexagonal jointing. Very scattered ironstone nodules up to 1½" by 6", but rarely more than 1" by 3". Part of a much larger septarian nodule came up 30 ft from the base, below which no further fossil bands occurred, only very scattered and sometimes pyritised Productids and Rhynchonellids, mostly fragmentary. Parts of slickensided surfaces were occasionally seen here. Two smaller septarian nodules (1½" by 4") 8-10 ft above the base, and rough vertical jointing is more common in the lower 20 ft. Most of this part of the core was broken during drilling, and depths are only approximate.	94	170

		Thickness	Depth
3.	Top of MAIN Limestone. Shaley limestone with fine shell fragments and some bryozoa, also small crinoid ossicles.	1'6"	171'6"
4.	Grey lst (2') on shaley lst (4") on grey lst (2'6")	4'10"	176'4"
5.	Slightly calcareous shale with scattered Rhynchonellids and Productid spines.	10"	177'2"
6.	Grey lst with small crinoid ossicles (3') on slightly calcareous shale with scattered Rhynchonellids (7").	3'7"	180'9"
7.	Grey crinoidal lst, traces of ?chalcopyrite on vertical parting (1'8") on slightly calcareous shale with scattered Rhynchonellids and some vague slightly pyritic markings on bedding planes (3").	1'11"	182'8"
8.	Grey crinoidal limestone with many irregular argillaceous streaks, which become less frequent in the lower 6 ft. They are essentially similar to those seen in the Main lst in Forcett quarry.	38'	220'8"
9.	Grey non-streaky crinoidal lst, containing a small cavity lined with little curved dolomite crystals.	2'	222'8"
10.	Bottom of MAIN limestone. Brownish-grey lst with small crinoid ossicles.	4'2"	226'10"
11.	Dark slightly calcareous shale, many shells, fragmentary and some pyritised towards top, but lower part has a number of whole specimens, mainly Productids.	5"	227'3"
12.	Dark slightly sandy unfossiliferous shale, considerable mica, some pyrite.	1'	228'3"
13.	Dark shale with many pyritised spiny Productids and some crinoid ossicles.	3"	228'6"
14.	Dark micaceous sandy shale, unfossiliferous, many very thin and very irregular bright coal streaks, especially in upper 4", many small carbonised wood fragments.	1'6"	230'

		Thickness	Depth
15.	Grey rather fine-grained micaceous sandstone with many thin and irregular sandy shale streaks. Unfossiliferous except for unidentifiable plant remains near base, where a thin coal streak also occurs. Mica flakes are both brown and white, and get progressively smaller downwards.	2'10"	232'10"
16.	Rapidly alternating sandy shale and shaley sandstone, small mica flakes and scattered plant remains.	3'3"	236'1"
17.	Slightly sandy shale, very small mica flakes, scattered plant remains and some small pyrite nodules.	1'8"	237'9"
18.	Shale, occasional slightly sandy bands with small mica flakes. Many small pyrite nodules, and scattered plant stems.	4'3"	242'
19.	Light grey medium-grained sandstone with a few white mica flakes and a few irregular shaley streaks.	4'6"	246'6"
20.	Thinly bedded and rapidly alternating sst and sandy shale bands, current-bedded. Considerable mica on bedding planes.	2'6"	249'
21.	Light grey current-bedded medium-grained sandstone, with very thin micaceous shaley streaks picking out bedding.	3'	252'
22.	Rapidly alternating sandy shale and shaley sandstone bands, current-bedded, micaceous and very scattered small pyrite nodules.	3'	255'
23.	Rapidly alternating sandy shale and shaley sandstone bands, some mica on sandy beds, 3 Productids from shaley band a foot above the base. Very scattered small pyrite nodules.	4'	259'
24.	Shale with thin sandy shale bands, a number of very small ironstone nodules and a few scattered small pyrite nodules. Unfossiliferous.	1'3"	260'3"
25.	Grey shale, small ironstone nodules and some small pyrite nodules, poorly fossiliferous, very occasional sometimes partially pyritised Productids and small Lamellibranchs. Occasional thin slightly sandy beds with very small mica flakes and no		

		Thickness	Depth
	fossils. A few short lengths of very small crinoid ossicles. Single bedding plane 9'1" from top crowded with partially pyritised Productids.	10'	270'3"
26.	Grey shale, nodules less frequent but larger (to 2" by 3") than 25, and very knobbly. No pyrite nodules. 5 ft down a slightly sandy horizon 3" thick contains a number of Productids. 6 ft down a small piece of plant was found adjacent to a Productid. 11'-12' down some nodules assume a roughly horizontal cylindrical shape.	13'	283'3"
27.	Grey slightly sandy shale with small mica flakes, fairly common plant remains, occasional small Lamellibranchs, rare Productids, some with spines pyritised, and a few small ironstone nodules.	7'	290'3"
28.	As 27, except that only plants are found, apart from one small Productid and two small Lamellibranchs.	5'	295'3"
29.	Shale, very slightly sandy. Two gasteropods 2' down, very rare very small crinoid ossicles in short lengths, plant remains continue right through but become rather scarce in lower 3'.	6'	301'3"
30.	Dark grey shale with very occasional thin slightly sandy bands. Many small ironstone nodules and rare plant remains in upper 10 ft. Also very rare short lengths of very small crinoid ossicles.		
31.	Dark shale with common small ironstone nodules. Two plant fragments 4 ft down, a Chonetes 8½ ft down, a very small Productid 10 ft down, a ?gasteropod 11'3" down. Ironstone nodules tend to be sausage-shaped in parts, disc-shaped in others, often spherical, but always small, becoming rather less common in the bottom 6 ft. A small pyrite nodule a foot from base.	29'3"	346'
32.	Dark shale with no nodules.	1'6"	347'6"
33.	Mudstone, very difficult to split in a particular direction. A small Productid 6" down, several below 350 ft. Probable lateral equivalent of the Underset Chert.	7'6"	355'

		Thickness	Depth
34.	Shale, a tendency to split across the bedding. A Lingula a foot down, 2 Chonetes and an orthocone Nautiloid 4' down.	7'6"	362'6"
35.	Dark shale with fine shell debris, crinoid ossicles (some with pentagonal canals) and a few orthocone Nautiloids	2'	364'6"
36.	Shale.	6"	365'
37.	UNDERSET Limestone. Greyish-brown crinoidal limestone, argillaceous streaks in upper 10", crinoidal debris decreasing to become only scattered towards base. Some Productids.	18'	383'
38.	Slightly pyritic shale, probably slightly calcareous, with many crinoid ossicles.	1"	383'1"
39.	Gannister with many roots.	3'	386'1"
40.	Hard grey fine-grained sandstone, with white mica and some roots.	2'8"	388'9"
41.	Sandy shale, variable mica, scattered pyrite nodules, many plants.	3'1"	391'10"
42.	Pale grey medium-grained thickly-bedded sandstone, much white mica on bedding planes.	3'2"	395'
43.	Pale grey sandstone with many very thin partings of micaceous sandy shale.	9'6"	404'6"
44.	Sandy micaceous shale, with occasional bands of shaley sandstone. Scattered plant remains.	9'	413'6"
45.	Slightly sandy shale, very small mica flakes, unfoss.	7'	420'6"
46.	Sandy shale with plant remains.	6"	421'
47.	Slightly sandy shale, very scattered plant remains.	4'6"	425'6"
48.	Very pale medium-grained hard sandstone, with a few very thin micaceous sandy shale partings which increase in number towards the base.	5'6"	431'
49.	Rapidly alternating pale sst and micaceous sandy shale bands, scattered plants in latter. Sst predominates in upper part but is very subordinate towards base.	4'	435'

	Thickness	Depth
50. Sandy shale, abundant plant remains, part of a fairly large ironstone nodule 3 ft down.	3'6"	438'6"
51. Alternating sandy shale and micaceous shaley sandstone, several bands of hard pale sandstone, bedding poor, plant remains in the more shaley bands.	4'6"	443'
52. Slightly sandy shale, very scattered plant remains. Fragments of small Lamellibranchs and a small Productid from 18" down. Many plants in bottom 3".	2'6"	445'6"
53. Pale hard sandstone with thin sandy shale partings, with much white mica. One shaley parting is penetrated by sand-filled "burrows".	3'6"	449'
54. Sandy shale with several sandstone bands towards base. Scattered plants.	3'	452'
55. Sandstone with very many thin and poorly bedded sandy shale partings. Much white and brown mica and carbonaceous matter on partings, apparently unfossiliferous.	6'	458'

Both the Main and Underset Limestones were completely dry in this bore. An adequate domestic supply was obtained from the alternating non-marine sandstones and shales beneath the Underset Limestone, but an analysis of this water, by Richardson and Jaffe of Bradford, showed it to be of an unusual type. Details of the analysis are as follows:-

	Parts per million
Total solids	680
Chloride	29
Permanent hardness	Nil
Temporary hardness	4
Lead, Zinc, Copper	Nil
Iron	0.24
Ammonia	0.52
Alkalinity	514

The high alkalinity of this water is due mostly to sodium bicarbonate, with some sodium carbonate, the pH value being 8.8.

Sodium bicarbonate is one of the characteristic essential constituents of juvenile waters (Gautier, 1910), and it may be that the water tapped by this bore at the modest depth of 450' (and whose hardness is almost nil) is related to that which is depositing barium minerals in some of the deeper mine-workings in the Durham coalfield. It would appear that this Durham water may, in some way, be connected with the source of mineralisation of the Alston Block, and therefore be juvenile in part. It is of interest to find another occurrence of possibly juvenile water on the Askrigg Block.

2. NEWTON MORRELL BORE

Record of a bore for a water supply for South Farm, Newton Morrell, sunk by J.T. Hymas, 1954-5.

Core examined by A.J. Wells between November 1954 and January 1955. Locality, 50 yards south of South Farm, Newton Morrell, National Grid reference 237093. Height 240' above O.D.

	Thickness	Depth
1. Glacial drift. Top 70' is normal boulder clay. Red marl between 70' and 78'. Clay with limestone boulders between 78' and 88'. Shale and clay below 88'	135'	135'
2. PERMIAN. Yellow dolomitic limestone cementing angular fragments, mainly of purple sandstone with some chert, of all sizes up to 3" in length. Number of fragments decreases downwards, and near the base beds of pure dolomite over 1' thick occur.	48'	183'
3. L. CARBONIFEROUS (Middle Limestone Group). Yellowish-purple sandstone, abundant white mica.	2'	185'
4. Shale, mainly dark and poorly fossiliferous. Slightly sandy with very small white mica flakes and irregular reddened patches towards the top.	14'	199'
5. Dark shale, horizons of small flattened crinoid ossicles.	6'	205'

	Thickness	Depth
6. Calcareous shale with thin irregular shaley limestone bands, abundant flattened crinoid ossicles. Traces of malachite in lower part.	13'	218'
7. Pale grey crinoidal UNDERSET Limestone	8'	226'
8. Hard blue-grey slightly argillaceous crinoidal limestone	26'	252'
9. Hard grey gannister with roots and cherty streaks.	1'	253'

Normal hard water was obtained in adequate quantity for domestic purposes from the Underset Limestone.

3. MOUNT PLEASANT BORE

Record of a bore for a water supply for Barnard Castle, sunk in 1951, given here for comparison with the record of the Wycliffe Bore.

Core examined by Dr. G.A.L. Johnson. Locality, ½ mile NNW of Boldron, National Grid reference, 033151. Height, 770' above O.D.

	Thickness	Depth
1. Boulder clay, sandy clay and stones	79'	79'
2. Coarse uniform light-brown grit	43'	122'
3. Banded sandy shale with plants (8') on finely laminated blue shale with plants (29'6")	37'6"	159'6"
4. Soft dark shale	25'6"	185'
5. Believed limestone and shale bands (core broken)	7'	192'
6. MAIN Limestone. Some algal mottling in upper parts, indication of current bedding at various horizons. Rather unfossiliferous, except for small crinoid ossicles throughout. Few corals and brachiopods at base. Apparently slightly dolomitic about 4' from base.	48'	240'

		Thickness	Depth
7.	Very dark soft shale, rich in brachiopods, Fenestrellina and a few Lamellibranchs. Little crinoid debris and a few small corals	2"	240'2"
8.	Rather sandy micaceous shale with scattered shells (4") on thin patchy coal on strong sandy micaceous seat-earth with many roots (18")	1'10"	242'
9.	Micaceous sandy shale (1'6") on fine light sandstone (1'9")	3'3"	245'3"
10.	Hard speckled sandstone (2') on fine light unevenly bedded sandstone with shaley bands (5')	7'	252'3"
11.	Shale with shells and fish scales passing down to sandy micaceous shale with plant fragments.	2'	254'3"
12.	White current-bedded sandstone (1'6") on sandy micaceous shale (3")	1'9"	256'
13.	White sandstone with a parting of dark papery shale with fish scales	2'3"	258'3"
14.	Alternations of dark micaceous shale with plants, and sandstone	16'9"	275'
15.	Sandstone, with shaley bands, worm tracks and marine shells	8'	283'
16.	Dark shale with small ironstone nodules, and fossiliferous bands with many Productids and some Lamellibranchs, also scattered plants	37'	320
17.	Very hard Underset Chert (4') on hard blue fossiliferous argillaceous limey chert (3'3")	7'3"	327'3"
18.	Hard dark calcareous shale, extensive scattered fauna, including rare plant fragments and trilobite fragments	3'9"	331'
19.	Hard blue argillaceous limestone (1'6") on fossiliferous black calcareous shale (6") on black non-crinoidal very fine-grained argillaceous limestone.	21'	352'
20.	Black shale with scattered fauna	5'6"	357'6"
21.	Black shale, very pyritic, with highest P_2 goniatites (Rayner, 1953)	3'6"	361'

		Thickness	Depth
22.	Black unfossiliferous shale (2'6") on black shale with many shells	4'	365'
23.	UNDERSET Limestone, grey and buff, crinoidal, with 9" of limestone conglomerate at 383'.	25'	390'
24.	Hard dark very fossiliferous shale (3") on 1½" coal on shaley seat-earth (2") on light sandy seat-earth with roots (3'5")	4'	394'
25.	Light gannister (1'6") on alternating sandstones and shales with plants.	17'3"	412'9"
26.	Alternating shales and sandstones, scattered plants, rich Lingula band 5'6" from top	67'3"	480'
27.	Shale, non-micaceous, scattered ironstone nodules, plant horizons in upper part, with a 2" slightly calcareous fine sandstone at 514'	48'6"	528'6"
28.	Dark shale, with ironstone nodules and bands of marine fossils	11'6"	540'
29.	Top of 3 YARD Limestone, dark, crinoidal, with a few productids	6'	546'
30.	Dark wavy-bedded shale, a few plants and impersistent coal bands	1'	547'
31.	Dark shale, many bryozoa in upper 6", very pyritic below	2'6"	549'6"
32.	Dark hard calcareous shale, passing down to muddy limestone with a few crinoid and shell fragments, base of the 3 YARD Limestone	3'	552'6"
33.	Good coal (7") on dark sandy seat-earth with roots (4") on very hard shaley limestone with many productids (10") on hard dark pyritic shale (3")	2'	554'6"
34.	Sandstone, calcareous with shells at top	8'6"	563'
35.	Dark shale with plants (1'3") on fine hard sandstone (1'3") on hard fine grey sandy limestone (1')	3'6"	566'6"
36.	Alternating shale and sandstone bands	3'6"	570'
37.	Fine light sandstone, with much white mica on partings	15'	585'
38.	Dark pyritic shale	6"	585'6"

	Thickness	Depth
39. Grey crinoidal limestone, taken to be the 5 YARD LIMESTONE	6'6"	592'

LIST OF WORKS TO WHICH REFERENCE IS MADE

BUTTERFIELD, J.A. 1939. A Petrological Study of some Yoredale Sandstones. Trans. Leeds Geol. Assoc., v, 264-284.

CARRUTHERS, R.G. 1938. Alston Moor to Botany and Tan Hill: an adventure in Stratigraphy. Proc. Yorks. Geol. Soc., xxiii, 236-253.

CLARKE, F.W. 1924. The Data of Geochemistry. U.S. Geol. Surv. Bull. 770, Washington.

CORRENS, C.W. 1951. Zur Geochemie der Diagenese. I. Das Verhalten von $CaCO_3$ und SiO_2. Geochimica et Cosmochimica Acta, I, 49-54.

DAKYNS, J.R. et al. 1890. The Geology of the country around Ingleborough. Mem. Geol. Surv., London.

——————— 1891. The Geology of the country around Mallerstang. Mem. Geol. Surv., London.

DAVIS, A.G. 1951. Howchinia bradyana (Howchin) and its distribution in the Lower Carboniferous of England. Proc. Geol. Assoc., 62, 248-253.

DEANS, T. 1951. Notes on the copper deposits of Middleton Tyas and Richmond. Notice No. 74, Min. Soc., dated May 28th, 1951.

DUNHAM, K.C. 1933. Structural features of the Alston Block. Geol. Mag., lxx, 241-254.

——————— 1948. Geology of the Northern Pennine Orefield, volume I, Tyne to Stainmore. Mem. Geol. Surv., London.

——————— 1950. Lower Carboniferous Sedimentation in the Northern Pennines (England). Rept. XVIII Int. Geol. Congress, Pt. IV, 46-63.

——————— and DINES, H.G. 1945. Barium minerals in England and Wales. Geol. Surv. Wartime Pamphlet No.46.

——————— et al. 1948. Dickite and collophane in the Magnesian Limestone of Durham. Min. Mag., xxviii, 338-342.

FAWCETT, C.B. 1916. The Middle Tees and its Tributaries: a study in River Development. Geog. Journ., 48, 310-325.

FOLK, R.L. and WEAVER, C.E. 1952. A study of the texture and composition of chert. Amer. Journ. Science, 250, 498-510.

FORSTER, W. 1809. A treatise on a Section of the Strata from Newcastle-on-Tyne to the mountain of Cross Fell, in Cumberland, Alston.

FOWLER, A. 1944. A Deep Bore in the Cleveland Hills. Geol. Mag., lxxxi, 193-206, 254-265.

——— 1945. Evidence for a new major fault in North East England. Geol. Mag., lxxxii, 245-250.

GAUTIER, A. 1910. Caractères differéntiels des eaux de source d'origine superficielle ou météorique et des eaux d'origine centrale ou ignée. Comptes Rendus Acad. Sci., Paris, 150, 436-441.

GILLIGAN, A. 1920. The Petrography of the Millstone Grit of Yorkshire. Q.J.G.S., lxxv, 251-294.

GILPIN, W. 1786. Observations on the Mountains and Lakes of Cumberland and Westmorland, Vol. II. London.

GOODCHILD, J.G. 1875. Glacial Phenomena of the Vale of Eden. Q.J.G.S., xxxi, 55-99.

HINDE, G.J. 1888. British Fossil Sponges, Vol. 1. Mon. Pal. Soc., London.

HUDSON, R.G.S. 1924. On the rhythmic succession of the Yoredale Series in Wensleydale. Proc. Yorks. Geol. Soc., xx, 125-135.

——— 1929. A Carboniferous Lagoon Deposit with Sponges. Proc. Yorks. Geol. Soc., xxi, 181-196.

——— 1938. Part of 'The Geology of the Country around Harrogate'. Proc. Geol. Assoc., xlix, 295-330.

——— 1941. The Mirk Fell Beds (Namurian, E_2) of Tan Hill, Yorkshire. Proc. Yorks. Geol. Soc., xxiv, 259-289.

KENDALL, P.F. 1911. The Geology of the Districts around Settle and Harrogate. Proc. Geol. Assoc., xxii, 27-60.

——— and WROOT, A.E. 1924. The Geology of Yorkshire. 2 vols. Privately printed.

LEWIS, H.C. 1894. Glacial geology of Great Britain and Ireland.

LINDGREN, W. 1933. Mineral Deposits. 4th edition. McGraw-Hill, New York.

MARR, J.E. 1910. In 'Geology in the Field'. Jubilee volume of Geol. Assoc., London.

——— 1921. On the rigidity of North-West Yorkshire. The Naturalist, 63-72.

METEOROLOGICAL OFFICE. 1952. Climatological Atlas of the British Isles. H.M.S.O., London.

MILLER, A.A. and TURNER, J.S. 1931. The Lower Carboniferous succession along the Dent Fault, and the Yoredale Beds of the Shap district, Proc. Geol. Assoc., xlii, 1-28.

MILLER, H. 1887. The Geology of the Country around Otterburn and Elsdon. Mem. Geol. Surv., London.

PARKER, J.M. 1942. Regional systematic jointing in slightly deformed sedimentary rocks. Bull. Geol. Soc. America, liii, 381-408.

PHILLIPS, J. 1836. Illustrations of the Geology of Yorkshire, Part II - The Mountain Limestone District. London.

RAISTRICK, A. 1926. The Glaciation of Wensleydale, Swaledale, and adjoining parts of the Pennines. Proc. Yorks. Geol. Soc., xx, 366-410.

__________ 1936. The Copper Deposits of Middleton Tyas, N. Yorks. The Naturalist, 111-115.

RANKAMA, K. and SAHAMA, Th.G. 1950. Geochemistry. The University of Chicago Press.

RAYNER, D.H. 1953. The Lower Carboniferous rocks in the north of England: a review. Proc. Yorks. Geol. Soc., xxviii, pt. 4.

READING, H.G. 1954. Stratigraphy and Structure of the syncline of Stainmore. Thesis submitted for the degree of Doctor of Philosophy in the University of Durham.

ROWELL, A.J. 1953. The Upper Limestone Group and Millstone Grit of the Stainmore Outlier and the Askrigg Block from Tan Hill to Swarth Fell. Thesis submitted for the degree of Doctor of Philosophy in the University of Leeds.

SARGENT, H.C. 1923. Massive chert formations of North Flintshire. Geol. Mag., lx, 168-183.

__________ 1929. Further studies in chert. Geol. Mag., lxvi, 399-413.

TARR, W.A. 1917. Origin of the Chert in the Burlington Limestone. Amer. Journ. Science, xliv, 436.

TATE, T. 1892. Borings for Salt and Coal in the Tees district. Q.J.G.S., xlviii, 488-495.

TIDDEMAN, R.H. 1872. Evidences of an ice-sheet in North Lancashire. Q.J.G.S., xxvii, 471.

TROTTER, F.M. 1929. The Tertiary Uplift and resultant drainage of the Alston Block and adjacent areas. Proc. Yorks. Geol. Soc., xxi, 161-180.

——————— 1952. Sedimentation facies in the Namurian of North-Western England and adjoining areas. Liverpool Manch. Geol. Journ., i, 77-102.

——————— and HOLLINGWORTH, S.E. 1928. The Alston Block. Geol. Mag., lxv, 433-448.

TURNER, J.S. 1935. Structural Geology of Stainmore, Westmorland, and notes on the late Variscan Tectonics of the North of England. Proc. Geol. Assoc., xlvi, 121-151.

VERSEY, H.C. 1927. Post-Carboniferous Movements in the Northumbrian Fault Block. Proc. Yorks. Geol. Soc., xxi, 1-16.

WAGGER, L.R. 1931. Jointing in the Great Scar Limestone of Craven, and its relation to the tectonics of the area. Q.J.G.S., lxxxvii, 392-424.

WINCHELL, A.N. 1951. Elements of Optical Mineralogy, 4th edition. Part II, Descriptions of Minerals. Wiley.

WOOLACOTT, D. 1923. A boring at Roddymoor Colliery, Near Crook, Co. Durham. Geol. Mag., lx, 50.

WROOST, V. 1936. Vorgange der Kieselung an Beispiel des Feuerstein der Kreide. Abh. Sencken. nuturf. Ges., 432, 1-68.

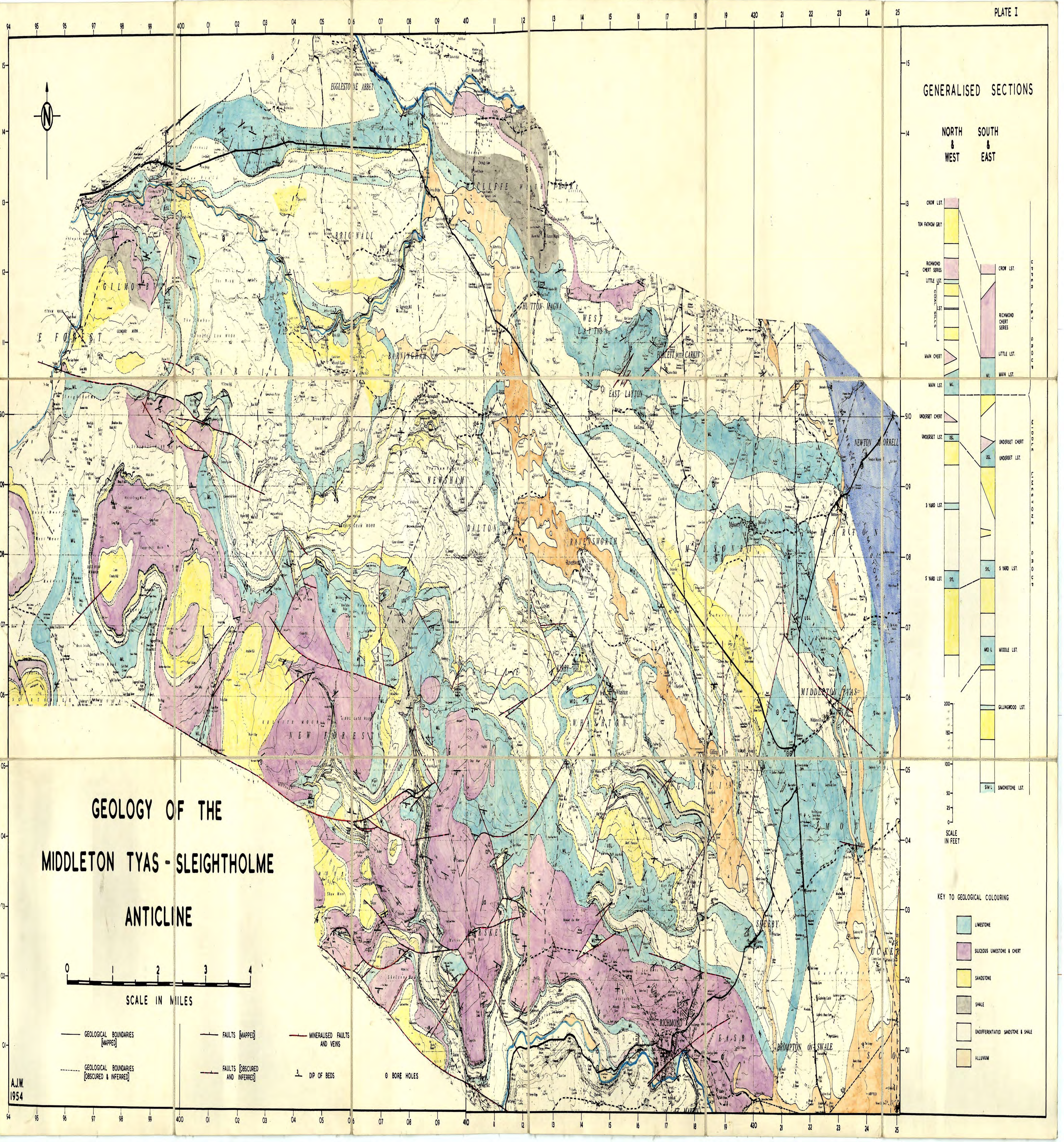
PLATE I
GEOLOGY OF THE
MIDDLETON TYAS - SLEIGHTHOLME
ANTICLINE
GENERALISED SECTIONS
NORTH & WEST
SOUTH & EAST
CROW LST.
TEN FATHOM GRIT
RICHMOND CHERT SERIES
LITTLE LST.
MAIN CHERT
MAIN LST.
UNDERSET CHERT
UNDERSET LST.
3 YARD LST.
5 YARD LST.
MIDDLE LST.
GILLINGWOOD LST.
SIMONSTONE LST.
UPPER LST. GROUP
MIDDLE LIMESTONE GROUP
SCALE IN FEET
KEY TO GEOLOGICAL COLOURING
LIMESTONE
SILICEOUS LIMESTONE & CHERT
SANDSTONE
SHALE
UNDIFFERENTIATED SANDSTONE & SHALE
ALLUVIUM
SCALE IN MILES
0 1 2 3 4
GEOLOGICAL BOUNDARIES (MAPPED)
GEOLOGICAL BOUNDARIES (OBSCURED & INFERRED)
FAULTS (MAPPED)
FAULTS (OBSCURED AND INFERRED)
MINERALISED FAULTS AND VEINS
DIP OF BEDS
BORE HOLES
A.J.W.
1954
EGGLESTONE ABBEY
ROKEBY
BRIGNALL
BARNINGHAM
HUTTON MAGNA
WEST LAYTON
EAST LAYTON
NEWSHAM
DALTON
RAVENSWORTH
NEWTON MORRELL
MIDDLETON TYAS
WHASHTON
NEW FOREST
SKEEBY
RICHMOND
BROMPTON ON SWALE